Distributional Effects of a Nonlinear Price Scheme in Public Utilities

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Abstract

Nonlinear pricing schemes are the primary instruments that policymakers use to ensure access to public utilities for low-income households while penalizing high-income households for overconsumption. In this paper, I evaluate the effectiveness of these pricing schemes and introduce a novel methodology to analyze their impact on the distribution of consumption and welfare in public utilities, with a specific focus on the case of water utilities in Bogotá, Colombia. To achieve this, I employ a combination of reduced-form and structural model techniques, leveraging Bogotá's unique context, where households have historically encountered diverse pricing schemes, including the introduction of additional nonlinear elements in the pricing scheme through a 2012 policy change. Notably, the results reveal that the nonlinear pricing scheme exhibits regressive characteristics, benefiting wealthier households with higher consumption levels and more significant welfare gains. Furthermore, the evidence suggests that income effects, driven by changes in the virtual incomes of households, are the primary driving force behind these outcomes. These findings underscore the necessity for an alternative approach to achieving more significant equity in the distribution of benefits within public utilities.

1 Introduction

Pricing schemes in public utilities significantly influence households, directly impacting their access to vital services such as water and electricity. Typically, policymakers design these systems with a primary aim: to ensure the equitable allocation of these essential services. One prevalent approach to achieving this equity is subsidizing consumption portions, often called Increasing Block Tariffs (IBT), frequently resulting in non-linear household pricing schedules. This subsidy strategy primarily aims to secure access for lower-income households. However, it is worth noting that these subsidies sometimes extend to affluent households as well, raising questions about the effectiveness of this method in achieving fair distribution. While subsidies are intended to promote fairness, their broader impact on service distribution may not always align with this objective.

With this in mind, I examine how different pricing methods affect water usage in Bogotá, Colombia. Specifically, I aim to understand how these pricing methods impact the amount of water households use and how they affect household welfare. To achieve this, I propose implementing a semi-parametric model for water consumption, especially when faced with non-linear budget constraints. My methodology integrates a hybrid approach, combining reduced-form and structural methods to estimate this model effectively.

My approach capitalizes on a pivotal moment in the trajectory of water pricing—a policy shift that introduced a free water policy. This policy alteration introduces additional nonlinearities by reducing prices for initial consumption levels. The response of households to this policy shift provides valuable information for estimating the model's parameters. Furthermore, it allows me to simulate how households react to various pricing schemes, including linear pricing. Through these simulations, I gained insights into their effects on welfare and consumption, offering a better understanding of the impact of different pricing strategies. Based on this analysis, I propose a pricing strategy that utilizes household information and yields more favorable results than other pricing schemes.

Previous efforts to estimate demand systems within the realm of non-linear budget constraints have traditionally focused on specific domains, such as analyzing the effects of tax scheme adjustments on labor supply, as evidenced by e.g. Burtless & Hausman (1978), Hausman (1985), Blomquist & Newey (2002) and Blomquist et al. (2021). Similarly, prior research has employed either reduced-form or structural methodologies to investigate how demand reacts to changes in tariff structures, particularly within the contexts of electricity (Terza, 1986; Herriges & King, 1994; Reiss & White, 2005) and water (Hewitt & Hanemann, 1995; Pint, 1999; Olmstead et al., 2007; Olmstead & Stavins, 2009). However, this body of literature has often neglected to explore the broader implications of pricing schemes on the distribution of welfare and consumption.

This paper aims to fill this gap in the existing literature by introducing a flexible model that is easily estimable and capable of accommodating variations in pricing schemes while allowing for the inclusion of income effects. This model serves as a valuable instrument for estimating the impact of pricing schemes on welfare and consumption within public utilities and builds on the works of earlier research, such as Szabo (2015), which scrutinized changes in an Increasing Block Tariff (IBT) scheme coupled with a free water policy in South Africa, and McRae (2015), which examined how an IBT tariff scheme for energy provision could potentially impede infrastructure development and service enhancement. Additionally, the methodology proposed in this paper can be seamlessly adapted to settings where households use the average price and not the marginal price when optimizing, as exemplified in works like Ito (2014) and Shaffer (2020). Ultimately, as Borenstein (2012) suggested, the findings presented here challenge prevailing about the reveal that non-linear tariffs, such as those found in electricity, may have limited impacts on wealth redistribution but can result in substantial welfare losses compared to direct transfers to households.

The subsequent sections of this paper follow this structure: In Section 2, I explore the institutional framework underpinning the case study of water utilities in Bogotá, Colombia. In this city, a single firm provides water and sanitation services to households and commercial establishments. This regulated entity enforces a fixed fee to recuperate the expenses of ensuring uninterrupted water availability. Remarkably, all households with service access must pay this fixed fee, regardless of their consumption level.

Furthermore, the pricing system incorporates a solidarity mechanism that implements cross-subsidies, adjusting the marginal price in relation to consumption levels. The regulatory body employs a socioeconomic stratification tool, classifying properties into six categories known as "strata," with the lowest-income group designated as "stratum one" and the most affluent as "stratum six." Leveraging this stratification, the regulator assigns each household a distinct tariff structure. The lower-strata tariff schedules adopt an IBT approach, featuring discounts for initial consumption units and charging the total price for subsequent units.

In Section 3, I exploit the introduction of the free water policy and use the differences-in-differences (DID) method to evaluate the effects on consumption. Additionally, I employ a change-in-changes model (CIC) (Athey & Imbens, 2006), which, in contrast to the traditional DID, allows me to recover the quantile treatment effects. I find reduced-form evidence of households responding to variations in the tariff scheme and recovering the distributional impact on water consumption when it was introduced. This exercise demonstrates that the tariff scheme affects households' water consumption; specifically, the free water policy increases the amount of water households consume. Furthermore, the introduction of nonlinearity in the tariff scheme significantly impacts households that consume large quantities of water. These findings are even more pronounced when I introduce covariates; the effect on the lower consumption quantiles becomes zero, and on the larger quantiles, the effect is positive and increasing.

The theoretical details of the demand model for water consumption are developed in Section 4. The model is a semi-parametric demand specification allowing for nonlinearity in the demand function and budget sets. This model enable me to estimate the demand and income elasticity for water when there are income effects. To accomplish this, in Section 5, I estimate the model's parameters. I use the estimates obtained from the CIC model in an Indirect Inference procedure, following a similar approach to that used by Allen et al. (2014) in their model of demand for mortgages or Shaffer (2020) in his model of demand for energy utilities. Using these parameters, in Section 6, I conduct counterfactual simulations to estimate the equivalent variation as a measure of household welfare when the tariff scheme changes to a constant tariff for water consumption. The counterfactual exercise allows me to identify the households most affected by the change in the tariff scheme. Additionally, I perform a counterfactual simulation where the subsidies are directly transferred to the households rather than the household's total consumption. The previous exercise enabled me to evaluate an alternative scheme and determine if it represents a better option for poor households. Finally, Section 7 concludes.

2 The Water Utility Service in Bogotá, Colombia

In this section, I provide an overview of the institutional background of the water utilities service in Bogotá, Colombia. The national regulator determines the tariff schedule for the water service, which includes both water consumption and sanitation. The regulator considers the limits established by Law 142 of 1994 for subsidies and household contributions. This law outlines three fundamental principles that guide the choice of tariffs. First is the principle of economic efficiency, which requires marginal prices to approximate those of a perfectly competitive market. Practically, any quantity of provided water that is not subsidized should be priced at a marginal cost. Second is the principle of redistribution, where higher strata tariffs subsidize lower strata tariffs. Lastly, the third principle is financial sustainability, ensuring that tariffs contribute to covering operational costs.

The tariff schedule in Bogotá before 2012 was structured as follows: households in stratum one, two, and three receive a subsidy that covers the fixed fee, along with approximately 70%, 40%, and 14%, respectively, of the first 40 Kl of consumption. Beyond this threshold, these households pay the total price for each additional consumption unit, representing the variable costs. Strata five and six households pay 224% and 274%, respectively, of the fixed fee, and they are charged 155% and 165% of the marginal costs for all additional consumption. Stratum four households are unique in that they cover the entire cost, paying both the fixed fee and the variable costs for their whole usage (100%).

This study focus exclusively on strata one, two, and four, as they are the strata that experienced a change in their IBT scheme in 2012 for the first two, while the latter has a tariff equal to the marginal cost.

In response to the 2010 directive from the United Nations General Assembly and the Colombian Constitutional Court orders, the mayor of Bogotá took action through decrees 485 of 2011 and 064 of 2012. These decrees stipulated that households within strata one and two must receive a guaranteed bi-monthly allocation of 12 cubic meters (Kl) of water for free consumption. The responsibility for covering the cost of these allocated kiloliters falls upon the city administration. The primary objective of this decree is to ensure a dignified standard of living that fulfills the basic needs of households in these strata.

Alongside water consumption charges, households are billed for a fixed fee and a variable price for sanitation services, all included in a single bill. The calculation of the sanitation service fee is based on the household's total water consumption. This tariff structure mirrors the pattern of subsidies and additional charges in the water service, except for the free water policy. Essentially, households are billed for the combined water consumption and sanitation cost and fixed fees for each kiloliter of consumption. These charges are invoiced to households on a bi-monthly basis. These tariffs undergo yearly adjustments based on the previous year's values, with increases limited to the inflation rate—figure 1 summarizes the stratum one and two tariff schedules.

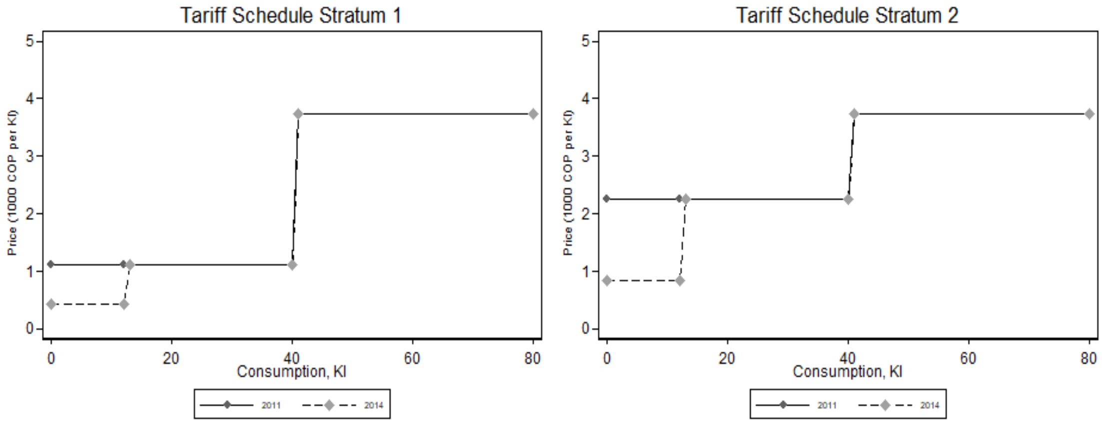

Figure 1: Tariff Schedule for stratum one to 2 for water

The notable change in the tariff schedules occurred in 2012, introducing a free allocation of 12 kiloliters (6 kiloliters per month, billed bi-monthly) for households in strata one and two. For strata four, the tariff matches that of strata one and two, but only after consuming 40 kiloliters of water.

3 Effects of the Pricing Scheme on Consumption

This section aims to study the effect of a change in the pricing scheme on the distribution of water consumption. To do this, I evaluate the introduction of more nonlinearities in the price schedule of a group of households in Bogotá.

The main objective of the empirical exercises in this section is to measure the responsiveness of the households concerning the policy changes; I follow the approach from Allen et al. (2014). To do this, I consider the introduction of the free water policy as an intervention (I_i) that changes the price scheme of the households in strata one and two; in that way, using the potential outcomes setting I have that

$$w_i = I_i \pi^I(\eta_i, T_i) + (1 - I_i)\pi^N(\eta_i, T_i), \tag{1}$$

where w_i denotes the water consumption of household i depending on whether it is treated or not. $\pi^I(\eta_i, T_i)$ and $\pi^N(\eta_i, T_i)$ are the consumption functions in the case of being strata one or two and being part of the strata that don't receive the benefits of the free water policy, T_i is a before/after indicator, and finally η_i correspond to the unobserved attributes of the households.

The approach that I follow will aim to characterize the counterfactual distribution of the water consumption of the households without the free water policy, given that they belong to the treated group (strata one and two), using the control group information that was not affected by this policy (stratum four). In the following subsections, I will provide information on the data that will be used and the identification strategy used.

3.1 Data

I use a unique data set of households in Bogotá. This data set consists of repeated cross-sections of households in Bogotá, which uses information from two sources: data on water consumption and survey data that provides expenditure and socioeconomic information for the years 2011 and 2014 for strata one to three, which are the ones that have an IBT tariff scheme for water consumption, and strata four which has a linear tariff equal to the marginal cost of providing water.

The first source of information is the multipurpose survey of the city of Bogotá for 2011 and 2014. This survey evaluates the results of city-level policies and has information about socioeconomic variables. These surveys are random samples of the city's households; the sampling is done so that they are representative at the strata level and are repeated cross-sections.

The variables constructed from the survey information are total expenditures per household as a measure of income and variables that could affect water consumption like the number of rooms in the household, if the household has a washing machine, if the household has a water tank, the number of toilets, the number of people living in the household, the average education in years of the household, etc. The reason for not using the income variable directly is that there is evidence of sub-report in the survey (Gallego et al., 2014).

The second source of information in the dataset consists of the billing information of the households of Bogotá available in the surveys, which has data on the bi-monthly water consumption (in Kl) for the billing periods of 2011 and 2014. There are cases of more than one household per bill (i.e., two apartments inside one house) where it is impossible to disaggregate the consumption information per household. Those households were discarded from the analysis.

The data shows variations in the tariff scheme between the strata and the years since the tariff scheme changed. The local government implemented the most crucial change in 2012, following the General Assembly of the United Nations Organization of 2010, which determined that access to drinking water is a basic human right and fundamental for individual development.

In Colombia, the Constitutional Court has been issuing orders to ensure citizens' access to water as a fundamental right when it is used for human consumption. The Constitutional Court has indicated that the state must guarantee access, mainly when there are conditions of vulnerability.[1] Consequently, Bogotá implemented a free water policy for the first 12 Kl of bimonthly consumption in 2012 for strata one and two, which gives variation between years in the lower strata.

Following the literature (Szabo, 2015), observations with more than 100 Kl of water and 0 Kl of water consumption were discarded since this indicate possible damages in the supply network; this corresponded to 30 observations only. Summary statistics of the variables of interest and covariates are provided in Table 1.

The mean consumption is 19.05 Kl of water with a standard deviation of 12.27, which means there is huge variability in the water consumption in my

[1] See the following directives from the Constitutional Court of Colombia: T-381 of 2009, T-546 2009, T-614 of 2010, T-055 of 2011 and T-092 of 2011

Table 1: Summary statistics

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
Water Consumption (Kl)	8,039	19.05	12.27	1	99
Expenditures (1000 pesos)	8,039	5,265	5,220	40.49	84,916
Nuber of persons	8,039	3.297	1.707	1	19
Garden	8,039	0.390	0.488	0	1
Age head of household	8,039	49.94	14.78	17	100
Number of Rooms	8,039	3.730	1.309	1	15
Average Years Education	8,039	3.922	2.389	0	10
Number of Toilets	8,039	1.678	0.803	0	7
Washing machine	8,039	0.847	0.360	0	1
Laundry	8,039	0.924	0.266	0	1
Water Tank	8,039	0.449	0.497	0	1

sample. Figure 2 shows the kernel distribution of the water consumption by strata in 2011 and 2014. The graphs for 2011 show no bunching evidence around the kinks where the marginal price changes (40 Kl for 2011). In both periods, most households consumed below 40 kl of water, indicating that most households consumed in the first segments of the price schedule. This pattern didn't change between 2011 and 2014, even with the introduction of the free water policy.

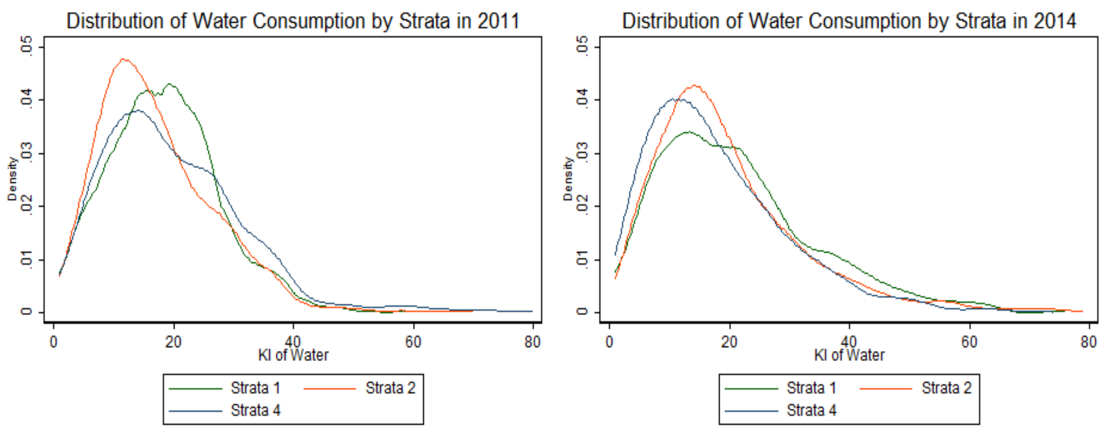

Figure 2: Distribution of Consumption of Water

Concerning the total expenditure, the mean is 5.265.000 COP, and the variance is 5.220.000, which means there is a lot of heterogeneity in my sample. Figure 3 shows the kernel density of the expenditures in 2011 and 2014 in Colombian

Pesos (COP) of 2011. All the strata show a high level of heterogeneity, as they have a very high standard deviation. There is also evidence of a high concentration of households between 2 and 10 million COP of expenditures, given that twice the monthly minimum wage in 2011 was one million COP.

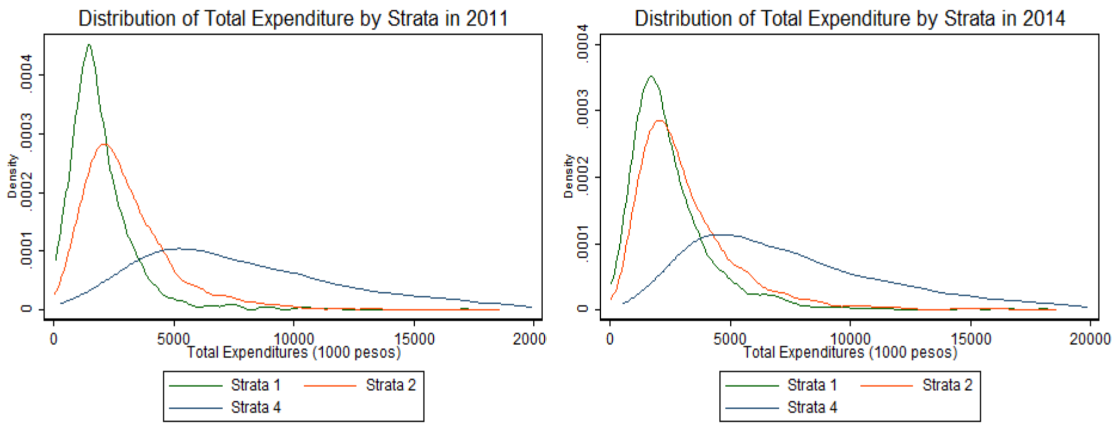

Figure 3: Distribution Expenditures

The mean of the variables by strata one to two and in comparison with strata four are provided in Table 2. The table shows differences in the variables between the strata, especially concerning expenditures, where the mean of stratum four is four times that of stratum one.

Table 2: Variables by stratum

VARIABLES	(1) Stratum one	(2) Stratum two	(3) Stratum four
Water Consumption (Kl)	20.41	19.00	19.87
Expenditures (1000 pesos)	2,387	3,228	8,621
Number of Rooms	3.325	3.668	3.923
Garden	0.944	0.937	0.903
Laundry	0.508	0.487	0.242
Washing Machine	0.672	0.804	0.947
Water Tank	0.204	0.317	0.678
Number of Toilets	1.248	1.359	2.194
Number of People	3.951	3.753	2.569
Age Head of Household	49.23	49.84	50.24
Average Years Education	2.563	2.926	5.512

Concerning the covariates, it shows that the use of water appliances is more common in the higher strata, except for the laundry variable. This variable indicates if the household has a particular place where they do laundry by hand. This suggests that the higher strata substituted it with washing machines.

One variable of interest for this paper is the number of people in the household. The mean is decreasing between strata, and since the mean of the expenditures increases with the strata, this seems to indicate that there is a negative correlation that I will exploit in the counterfactual exercises.

3.2 Preliminary Estimates

In this section[2], I summarize the main effects of introducing the free water policy on water consumption. The strategy that I follow is as follows. First, I measure the average treatment effect on water consumption using two different methods: the first one is a traditional linear DID approach, and the second one is using a CIC approach.

The linear DID model is estimated by least squares regression

$$w_i = \alpha_0 + \alpha_1 I_i + \alpha_2 T_i + \alpha_3 I_i T_i + X_i' \beta + \eta_i, \tag{2}$$

where w_i is the water consumption, I_i is an indicator variable that indicates if the free water policy affected the household (if it belongs to strata one or two), and T_i is an indicator variable that is one if the observation belongs to the post-treatment period. In this specification, α_3 is the ATT of the policy.

The CIC estimator (Athey & Imbens, 2006) allows me to recover heterogeneous treatment effects, which means that it allows me to determine if there are different responses inside the strata to a change in the nonlinearity of the tariff schedule. Regarding the selection of treated and control stratum for this analysis, I have to take into account that both strata one and two have non-

[2]In Appendix A, there are the robustness checks of the results of this section using stratum three

linear prices in water, and stratum four has a flat rate equal to the marginal cost; therefore, strata one and two form the treated group and strata four is the control group.[3] Also, the sum of strata one, two, and four households is close to 70% of the city.

The CIC estimator works like the traditional Differences in Differences model but replaces the values of the expected outcomes with the results' full quantile function. The model recovers the counterfactual distribution of the outcome.

The CIC takes the outcome, water consumption, of a quantile q from the pre-treatment treated group. Then, it finds the quantile, q', in the pre-treatment control group distribution where it would fit the pre-treatment period in the treatment group. Then, it computes the distance to the quantile in the counterfactual where the untreated group is treated.

The CIC model has two essential assumptions that need to be satisfied: the first one is that the functions $\pi^I(\eta_i, T_i)$ and $\pi^N(\eta_i, T_i)$ from equation (1) should be monotonically increasing in η_i. And the second one is that the distribution of η_i within groups must be time-invariant. In other words, the distribution of the unobservable characteristics determining the preference for water must be the same over time.

The second assumption is problematic to verify with the data since I do not have two pre-treatment periods to do a placebo test, as the literature suggests (Melly & Santangelo, 2015). Instead, to validate this assumption, I argue that the groups' composition did not change much over time. In the sample, only 6% of the households recently changed where they live, and approximately 73% of the households have lived in the same place for more than five years; this indicates that the composition of the treatment and control groups did not change significantly over time. Additionally, using the information on the average monthly consumption provided by the regulator, as Figure 4 shows, I can

[3] A similar approach could be made using strata one and two as the treated group and stratum three; even if strata three has an IBT scheme, it was not affected by introducing the free water policy. The results of all the exercises found in this section with stratum three as control can be found in the appendix.

verify that the treated and control groups seem to have a similar co-movement before the implementation of the free water policy and after the implementation of the policy, there is no evidence of any about change in the trends different than the one given by the introduction of the policy.

Finally, it is possible to include covariates that can affect the preferences for water consumption in the CIC model. The approach that I used to adjust for covariates was to apply the CIC estimator to the residuals of a least square regression of the water consumption against the covariates with the effects of the dummy variables of treatment and period added in (Athey & Imbens, 2006).

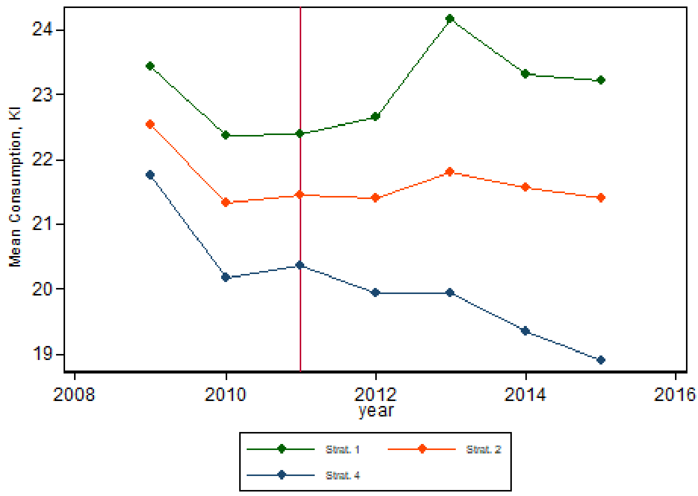

Figure 4: Mean of consumption over time. Source: Comisión de Regulación de Agua Potable y Saneamiento Básico (CRA)

Athey & Imbens (2006) showed that the distribution of the counterfactual of water consumption of the treated households could be recovered from the observed empirical distributions in the following way:

$$\hat{F}^{C}_{1,1}(w_i) = \hat{F}_{1,0}(\hat{F}^{-1}_{0,0}(\hat{F}_{0,1}(w_i))), \tag{3}$$

where $\hat{F}_{I,T}$ is the empirical distribution of the group I at period T, and the superscript C indicates that is the counterfactual distribution. With this, I can obtain the quantile treatment effect for the quantile q with the next equation:

$$\Delta(q) = \hat{F}_{1,1}^{-1}(q) - \hat{F}_{1,1}^{C-1}(q),$$

The following subsections will show the results of these empirical exercises.

3.2.1 Quantile impact of the free water policy

In Table 3, I show the average treatment effect of introducing the free water policy in Bogotá, Colombia. The results are presented with and without covariates. The first two columns give the results when stratum one is the treated group, stratum four is the control group, and columns three and four present the results when stratum two is the treated group. The standard errors of the final estimates are corrected by bootstrapping the sample 1000 times.

Table 3: ATE of the introduction of the free water policy

	Stratum one		stratum two	
	Without Covariates	With Covariates	Without Covariates	With Covariates
DID				
Free Water Policy ATT	4.698***	3.472***	4.584***	3.325***
	(0.964)	(0.830)	(0.584)	(0.529)
Observations	4064	4064	7186	7186
R2	0.007	0.290	0.010	0.200
CIC				
Free Water Policy ATT	5.313***	3.493***	5.047***	3.216***
	(0.859)	(0.809)	(0.526)	(0.469)
Observations	4064	4064	7186	7186

Note: Standard errors obtained by bootstrapping 1000 times. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$

The results for stratum one, presented in the first two columns, show that the impact of the introduction of the free water shows that with the introduction of the covariates, the point estimates are lower between one and two Kl of water. Also, the average estimate estimated with CIC is higher before introducing covariates in around one kl of water than the DID estimates. Still, once these variables are introduced, the average impact is very similar between the two methodologies, with the difference only in decimals.

Something similar is presented for stratum two; the estimates of the average impact are higher before introducing the covariates between one and two Kl of water. The CIC estimates are higher before introducing the covariates, but the result is very similar between the methodologies after presenting these variables.

The point estimates of the average treatment effect, in terms of magnitude, correspond to around 40 to 25 percent of the standard deviation of the water consumption in my sample. This is not a small effect, meaning the free water policy considerably affected the average household in strata one and two. This can be explained by the free water policy, which lowers the prices of low-consumption and high-consumption households in the first consumption segments.

On the other hand, the results between strata one and two are very similar. This comparison is surprising since if stratum one's households are the poorest, this policy affects this group more. This can be explained as, even if the prices in stratum one are way lower than the ones in stratum two, the absolute change in the price in the first segment was the same; this seems to indicate that the total income effect is more critical than the substitution effect.

An approach to analyzing the heterogeneous treatment effects is necessary to understand this result better. I will address this issue in the following subsection.

3.2.2 Distributional impact of the free water policy

In this subsection, I estimate the impact of introducing the free water policy on the distribution of water consumption. To do this, I use the CIC estimator to recover the counterfactual distribution of water consumption of strata one and two in the post-treatment period.

In Figure 5 is plotted the observed (blue line) and counterfactual empirical distributions (red line) for the households in stratum one in 2014. The dashed lines correspond to the 95 percent confidence interval of the counterfactual distribution. The graph on the right is the estimation without covariates, and the left is the estimation with these variables.

Without covariates, the counterfactual distribution is stochastically dominated by the observed distribution; this suggests that all the households in stratum one consume more water after introducing the free water policy. In addition, the higher consumption quantiles benefit more from this policy since the distance between the curves seems to increase with the quantiles.

With the covariates, this pattern seems to be more notorious since the first quantiles of consumption seem not to have any difference between the observed and counterfactual empirical distribution, which means that the effects of the policy for the lower quantiles were null. This also may indicate that a pure substitution effect did not ride the impact on consumption of the price change, since the prices were changed for all the households, but by the income effect.

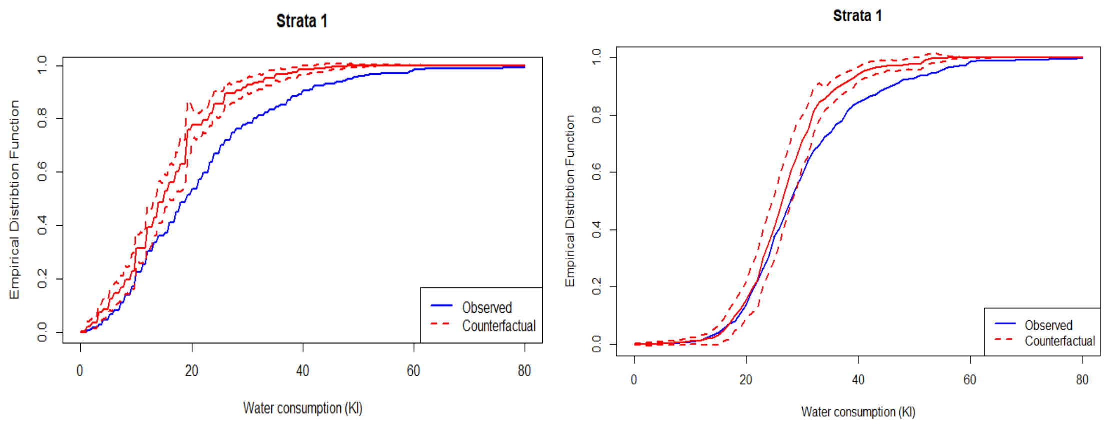

Figure 5: Empirical distribution of water consumption of stratum one in 2014 with and without free water policy

Table 4 shows the CIC estimates when 2011 is the pre-treatment, 2014 is the post-treatment, and the treated group is stratum one, and it also shows the Kolmogorov-Smirnoff (KS) statistic. This test measures the differences between the observed and counterfactual empirical distributions, where the null hypothesis is that the observed data and the counterfactual data were drawn from the same continuous distribution. The statistic shows that the null is quickly rejected.

In all the estimators, the impact of the free water policy is positive and increasing in the quantiles of water consumption. The results indicate that a policy that exacerbates the nonlinearity of the tariff schedules has a higher impact on households with high consumption levels; quantile 75, for example, has an effect of around 7 and 11 Kl of water, which corresponds to between 58 percent and 91 percent of the standard deviation of water consumption in my sample.

In contrast, those with low consumption levels where the effect of the policy is minor (3 Kl of water) or null. These results, at first view. With the addition of covariates, the outcomes seem to not change that much across the quantiles, which means there is the possibility that the household characteristics explain some of the impacts on the first quantiles.

In the second column in Table 4 is the observed water consumption in Kl. This indicates that the only stratum of households where the free water policy changed the marginal price they face is below the quantile 25, and these households are the ones that have low quantile effects or zero. This means that for the quantile treatment effects for households above quantile 25, the substitution effect is zero, and all the changes in consumption are a product of their income effects.

In Figure 6, the observed (blue line) and counterfactual empirical distributions (red line) are plotted for the households in stratum two in 2014. The dashed lines correspond to the 95 percent confidence interval of the counterfactual distribution. The graph on the right is the estimation without covariates, and the left is the estimation with these variables.

Without covariates, the patterns found in stratum one repeat; the observed distribution stochastically dominates the counterfactual distribution. This means all the households in stratum two consume more water after introducing the free

Table 4: QTE on water consumption of the free water policy for stratum one

		Baseline			With covariates		
		Est.	95% CI		Est.	95% CI	
Quantile effects	W						
q5	5	2	0.293	3.707	-0.351	-2.994	2.293
q10	7	2	0.132	3.868	1.011	-0.942	2.963
q25	11	1	-0.948	2.948	0.655	-0.931	2.241
q50	17	4	1.581	6.419	1.526	0.101	2.951
q75	26	8	5.215	10.785	4.855	2.517	7.193
q90	37	12	7.479	16.521	10.06	6.204	13.915
q95	46	14	8.43	19.37	15.07	9.964	20.175
Tests							
KS		0.233***			0.166***		

Notes: Confidence intervals were calculated by bootstrapping 1,000 times. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$

water policy. Also, the higher consumption quantiles benefit more from this policy.

With the covariates, it's more notorious than in stratum one that the first quantiles of consumption seem not to have any difference between the observed and counterfactual empirical distribution, which means that the effects of the policy for the lower quantiles were null.

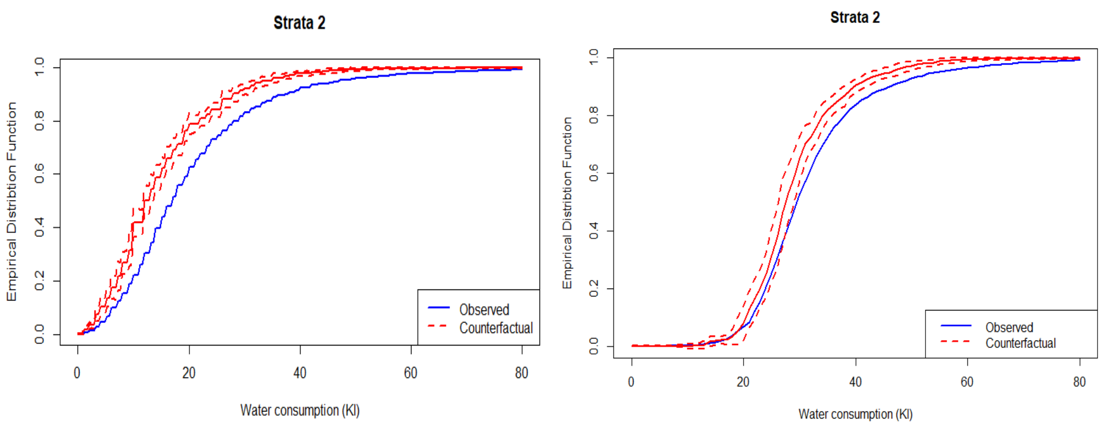

Figure 6: Empirical distribution of water consumption of stratum two in 2014 with and without free water policy

Table 5 shows the changes in the changes estimator when 2011 is the pre-treatment, 2014 is the post-treatment, and the treated group is stratum two. The KS test shows that two different continuous distributions generate the counterfactual and observed data since the test's null hypothesis is quickly rejected.

Table 5: QTE on water consumption of the free water policy for Stratum two

		Baseline			With covariates		
		Est.	95% CI		Est.	95% CI	
Quantile effects	W						
q5	5	2	1.020	2.980	-0.035	-1.590	1.519
q10	7	3	1.505	4.495	1.223	0.106	2.340
q25	12	3	1.516	4.484	0.800	-0.158	1.758
q50	19	5	3.545	6.455	2.209	1.349	3.069
q75	26	7	5.088	8.912	3.403	2.278	4.529
q90	36	9	5.942	12.058	7.156	4.414	9.899
q95	42	12	7.638	16.362	9.661	4.485	14.837
Tests							
KS		0.194***			0.131***		

Notes: Confidence intervals were calculated by bootstrapping 1,000 times. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$

Table 5 shows that the policy has an increasing impact on water consumption across the percentiles; the effect of the lower quantiles without covariates is seven times larger, and with covariates, it is 15 vs zero. Still, as in the results from stratum one, with the addition of covariates, the impact across the quantiles seems to indicate that much of this heterogeneity is explained by the household characteristics. Like in stratum one, the second column shows the households below the quantile 25 of consumption. The households with an extensive and significant effect are the ones where the marginal price they face is entirely unaffected by the free water policy, which means that their substitution effects are zero, and income effects cause all the change.

The results obtained in this section seem to indicate a need for a model that allows for income effects to explain the patterns in the impact of the free water policy on consumption; I will handle this in the next section.

4 A Demand Model for Public Utilities

In this section, I develop a model in which households demand a public utility good, explicitly focusing on water consumption. Each household operates under a unique pricing scheme, determined by their stratum and the respective year. The households decide how much of their available budget to allocate towards water consumption and how much to a numeraire good.

The model considers the budget set's nonlinearity resulting from the nonlinear pricing scheme. In this paper, I explore cases where the budget set is convex due to the IBT pricing scheme, as this is the prevailing scenario in Bogotá, Colombia.

To maintain brevity, the primary text delves into the case where households have a three-piece IBT pricing scheme. However, it's important to note that the model can be easily adapted to other scenarios. Finally, the model does not impose a specific functional form on the relationship between demand, prices, and income. Nonetheless, in the concluding part of this section, I analyze two particular cases that connect the model with existing literature.

4.1 Model

The model I employ is constructed within the framework proposed by Burtless & Hausman (1978) and Szabo (2015). It considers a household in a general setting facing a piecewise increasing linear budget constraint. In this context, I assume that all households in Bogotá, Colombia, are categorized into strata, and each household consumes both water and a numeraire good. Let w_{ist} represent the water consumption for household i, strata s, and year t, and let c_{ist} denote the numeraire good. The utility function for the household is as follows:

$$U(c_{ist}, w_{ist}) \tag{4}$$

I assume that the household utility is strictly quasi-concave and increasing in both goods. The price scheme is $P_{st}(w)$. It is piecewise linear with three segments, denoted as $j \in \{1, 2, 3\}$, where segment j has a marginal price P_{jst} between the kinks of consumption denoted as ℓ_{kst} where $k \in \{1, 2\}$, notice that the segments and kinks depend of s and t, this is because the elements of the price scheme change across time and strata:

$$P_{st}(w) = \begin{cases} P_{1st} & \text{if } w \in [0, \ell_{1st}] \\ P_{2st} & \text{if } w \in (\ell_{1st}, \ell_{2st}] \\ P_{3st} & \text{if } w \in (\ell_{2st}, \infty) \end{cases} \tag{5}$$

Now, let

$$w_{ist} = w^*(P_{st}, y_{ist}, X_{ist}, \eta_{ist})$$

be the demand function for water consumption, where P_{st} are a vector of marginal prices and y_{ist} is a vector of virtual incomes(the household income plus the benefits from the different marginal prices of the price scheme), and X_{ist} a vector of covariates that influence the demand for water consumption.

In this model, η_{ist} is an error term that accounts for an intrinsic taste for water not captured by the household's marginal prices, virtual income, or covariates. This error has a distribution F_{η_s}that I assume to be invariant in time; in addition, I assume that the demand function is increasing in η_{ist}. Finally, I assume that η_{ist} is independent of P_{st}, y_{ist} and X_{ist}.

Then, the optimal demand function of the household is obtained as a solution to the following problem:

$$w^*_{ist} = w^*(P_{st}, y_{ist}, \eta_{ist}) = \underset{w}{\operatorname{argmax}}\, U(y_{ist} - M_{st}(w), w, \eta_{ist}) \tag{6}$$

where, $M_{st}(w) = M(w, P_{st}) = \int_0^w P_{st}(u)du$ is the total expenditure on water.

Except for the kinks, I assume that the ideal demand in segment j is

$$w^*_{jist}(P_{jst}, y_{jist}, X_{ist}, \eta_{ist}) = \pi(P_{jst}, y_{jist}(P_{st}), X_{ist}) + \eta_{ist}, \tag{7}$$

for some function π. Where y_{jist} is the virtual income of the household of segment j. This ideal demand represents the demand that the model predicts if the marginal price and virtual income don't change in the price scheme.

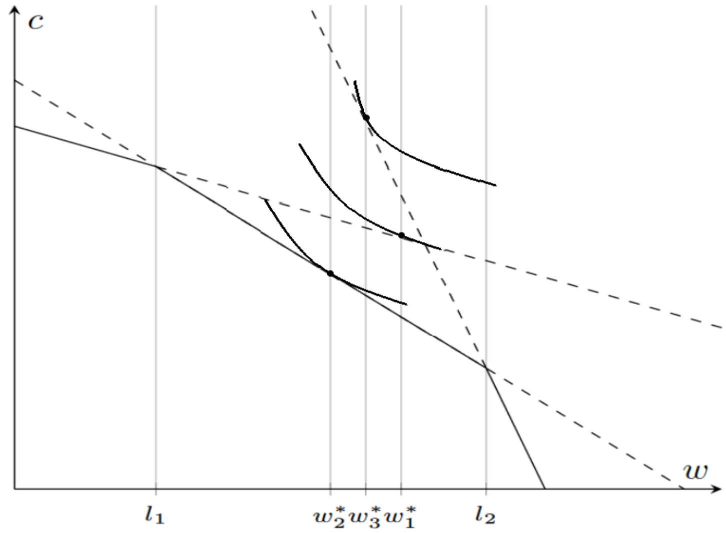

Figure 7: Example of a household problem

For illustration, consider the scenario depicted in Figure 7, which represents a specific household belonging to strata s and period t. To enhance clarity, we omit the subscripts for strata and price in this discussion. In this case, the household faces a three-piece linear budget constraint, resulting in three ideal demand points. For instance, the ideal demand for water utilities at the marginal price and virtual income within the first segment is w_1^*. It's worth noting that this ideal demand may not necessarily be achievable. In this specific case, the only feasible option for this household is represented by w_2^*. Consequently, this household's optimal demand for water utilities is w_2^*.

Then, the total demand of household i in period t and strata s is the feasible ideal demand that maximizes the household utility, including the cases where this is equal to the kink points. This formulation can be written as:

$$w_{ist}(P_{st}, y_{ist}, X_{ist}, \eta_{ist}) = \begin{cases} \pi(P_{1st}, y_{1ist}, X_{ist}) + \eta_{ist} & \text{if } \pi(P_{1st}, y_{1ist}, X_{ist}) + \eta_{ist} < \ell_{1s} \\ \ell_{1s} & \text{if } \pi(P_{2st}, y_{2ist}, X_{ist}) + \eta_{ist} \leq \ell_{1s} \leq \pi(P_{1st}, y_{1ist}, X_{ist}) + \eta_{ist} \\ \pi(P_{2st}, y_{2ist}, X_{ist}) + \eta_{ist} & \text{if } \ell_{1s} < \pi(P_{2st}, y_{2ist}, X_{ist}) + \eta_{ist} < \ell_{2s} \\ \ell_{2s} & \text{if } \pi(P_{3st}, y_{3ist}, X_{ist}) + \eta_{ist} \leq \ell_{2s} \leq \pi(P_{2st}, y_{2ist}, X_{ist}) + \eta_{ist} \\ \pi(P_{3st}, y_{3ist}, X_{ist}) + \eta_{ist} & \text{if } \ell_{2s} < \pi(P_{3st}, y_{3ist}, X_{ist}) + \eta_{ist} \end{cases} \tag{8}$$

Now, consider the case of a change in the price schedule; the difference in the ideal demand is:

$$\Delta(w^*_{jist}) = w^*_{jist}(P_{jst}, y_{jist}, X_{ist}, \eta_{ist}) - w^*_{jist}(P'_{jst}, y'_{jist}, X_{ist}, \eta_{ist})$$

The second part of this equation considers the change in the segment's marginal price and the change in virtual income when the price schedules change.

Note that the function π is not specified at any point, and it provides flexibility for income effects since the virtual income takes into account the changes in all segments of the price schedule. This allows me to match the predictions obtained from the CIC model. Based on the existing literature on the labor supply of Saez (2010) and Chetty (2012), an alternative approach is to assume a quasilinear utility function. This assumption predicts that households in the higher quantiles of consumption have zero effects from a change in the price at lower levels of consumption. This is because income effects in this model are null, and the substitution effects do not change, as the marginal price of the higher levels doesn't change. However, this contradicts the findings from the reduced form.

Furthermore, the π function serves as a bridge to previous demand models with budget sets, such as those discussed in Burtless & Hausman (1978) and Szabo (2015). Assuming a linear function for π would lead to the exact specification as in these authors' models. I will analyze these cases in the following subsections.

4.2 Example: π is linear

Consider the case where the function $\pi()$ is linear; this means that the ideal demand function takes the following form

$$w^*_{jist} = \alpha P_{jst} + \gamma y_{jist} + X'_{ist}\beta + \eta_{ist}, \tag{9}$$

For this demand function, Hausman (1981) showed that using Roy identity, an indirect utility function exists that represents this kind of preference. The indirect utility function is the following one

$$V(P_{jst}, y_{jist}) = e^{-\gamma P_{jst}} \left(y_{jist} + \frac{\alpha}{\gamma} P_{jst} + \frac{\alpha}{\gamma^2} + \frac{X'_{ist}\beta + \eta_{ist}}{\gamma} \right), \tag{10}$$

This indirect utility function is homogeneous of degree zero in prices and income. If $\alpha \leq 0$, and $\gamma \geq 0$ it is decreasing in prices and increasing in revenue, and finally, if $\gamma w^*_{jist} + \alpha \leq 0$ is quasi-concave, which means that it is a valid indirect utility function product of utility maximization.

This parametric form of the utility function links my setting with the previous literature on demand estimation with non-linear budget sets (Burtless & Hausman, 1978; Szabo, 2015; McRae, 2015), since this is the utility function generally used. Still, since I want to use a more general demand function for my paper, I use this specification as a baseline for my analysis.

4.3 Example: A more general demand specification

Now consider the case where the π has the following form.

$$\pi(P_{jst}, y_{jist}, X_{ist}) = f(P_{jst}, y_{jist}) + X'_{ist}\beta,$$

This means that the ideal demand function is

$$w^*_{jist} = f(P_{jst}, y_{jist}) + X'_{ist}\beta + \eta_{ist},$$

where $f(P_{jst}, y_{jist})$ doesn't have a parametric form. An easy way to approximate $f(P_{jst}, y_{jist})$ is to use a local polynomial estimator or a kernel estimator.

One particular case of interest is when a local polynomial of the second degree is used; in this case, the ideal demand function has the following form:

$$w^*_{jist} = \alpha_0 + \alpha_1 y_{jist} + \alpha_2 P_{jst} + \alpha_3 y^2_{jist} + \alpha_4 P^2_{jst} + \alpha_5 y_{jist} P_{jst} + X'_{ist}\beta + \eta_{ist}, \quad (11)$$

For this specification of the ideal demand Hausman (1981) showed that an indirect utility function can be derived using Roy's identity and has the following form

$$V(P_{jst}, y_{jist}) = \frac{h_{jist} W_{1ist} - W'_{1ist}}{W'_{2ist} - h_{jist} W_{2ist}}, \quad (12)$$

where $h_{jist} = -\alpha_3 y_{jist} + (\alpha_5/2)(\alpha 1 + \alpha_5 P_{jst})^2$ and where W_{1ist} and W_{2ist} are functions of the α and $X'_{ist}\beta$. This means that even with a more general framework, it is possible to find an indirect utility function that can be used for my analysis.

5 Model Estimation

In this section, I estimate the parameters of the model of demand for water consumption. I calculate the case parameters for this exercise where π is linear and when π takes a more general form using a second-degree polynomial.

With this in mind, the model parameters to estimate include the parameters for expenditures and price for the linear case and the parameters of the second-degree polynomial to evaluate the function f non-parametrically. It also has the vector β of the covariates. And finally, the parameters related to the distributions of the errors η_{ist}.

I use an indirect inference estimator that minimizes the distance between the CIC estimates obtained from the data and the CIC estimates obtained from simulated data obtained from the model.

The estimation procedure is the following. First, I draw the parameters' values. Second, with these parameters, I use them to draw random values of η_{ist}

using their parametric distribution. Third, I use this η_{ist} and equation (8) to simulate the values of w_{ist}. Fourth, I calculate the CIC of this simulated data. Fifth, I calculate the distance from the CIC obtained from the data concerning the CIC obtained from the simulated one. Finally, I adjust the parameters and repeat until convergence.

For the estimation, I assume that the distribution η_{ist} is Gumbel and normalized with mean zero; this is to match the distributions of the water consumption that are skewed to the right and have a fat left tail. And I only use strata two and four. This is to reduce the computational time to get the estimates.

The estimator is obtained from the next GMM procedure:

$$J = \min_{\theta}(M(\theta) - \hat{M}(\theta))'\Omega^{-1}(M(\theta) - \hat{M}(\theta)), \tag{13}$$

where $M(\theta)$ denotes the vector of CIC estimates, which means the distributional effects of the introduction of the free water policy at seven percentiles $(q_{10}, q_{25}, q_{50}, q_{75}, q_{90})$ the average treatment effect, and the conditional mean of the treated, no treated in the post and pre-treatment.

$\hat{M}(\theta)$ is the corresponding distributional effects of the free water policy 100 simulated independent draws η_{ist}. Finally, Ω is the optimal weighted matrix estimated using a two-stage estimation procedure.

The results of the estimation procedure are in Table 6; the standard errors are in parenthesis and were obtained by bootstrapping the sample 1000 times. In the linear demand case, the parameter related to the marginal price is negative and significant. In contrast, the one related to the expenditures is positive and important: the expected relations. The σ_2 and σ_4 represent the scale parameter of the Gumbel distribution for η_{ist} for stratum two and stratum four. This shows that the distribution is different between the strata.

For the quadratic specification, the estimated function f is shown in Figure 8; it shows an increasing relationship concerning the expenditures and a decreasing

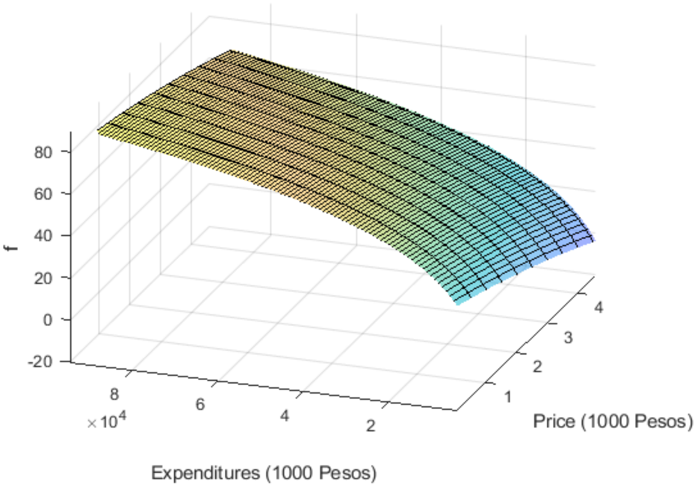

Figure 8: Estimated function f

one concerning the marginal price. The σ_2 and σ_4 parameters that are the scale parameters of the distributions of η_{ist} are closer, but still, they are different, which means that the distribution for stratum two and four are different.

5.1 Price and Income Elasticities

The price elasticity under this tariff scheme is defined as the percentage change in consumption resulting from an increment of one percent in each price block. For each observation, I use the following formula to compute the price elasticity:

$$\epsilon_{ist} = \frac{\hat{w}_{ist}(1.01 \times P_{st}, ...) - \hat{w}_{ist}(P_{st}, ...)}{0.01} \frac{1}{\hat{w}_{ist}(P_{st}, ...)}, \tag{14}$$

where $\hat{w}_{ist}$ is the predicted water consumption. Income elasticities are calculated similarly by increasing total expenditure by one percent.

The price elasticities and income elasticities by the consumption group of the linear specification are shown in Table 7, and the standard errors are reported and calculated using Bootstrap. The price elasticity obtained with this model indicates that households change their water consumption when the price

Table 6: Model parameters

	Linear	Quadratic
Price	-2.117	
	(0.003)	
Expenditures	0.001	
	(0.000)	
Number of persons	1.669	-1.314
	(0.001)	(0.047)
Garden	-9.906	3.273
	(0.000)	(0.006)
Age head of household	7.943	0.074
	(0.001)	(0.022)
Number of rooms	-2.067	-8.975
	(0.000)	(0.028)
Average Years Education	-0.918	-7.231
	(0.001)	(0.073)
Nuber of Toilets	7.131	7.916
	(0.001)	(0.051)
Washing Machine	3.417	1.173
	(0.005)	(0.050)
Laundy	0.012	0.074
	(0.001)	(0.009)
Water Tank	-0.151	-0.872
	(0.007)	(0.051)
σ_2	10.723	5.487
	(0.001)	(0.067)
σ_4	6.992	6.729
	(1.500)	(0.042)
Constant	-2.879	
	(0.000)	

Standard errors in parenthesis obtained by bootstrapping the sample 100 times.

changes, with an average price elasticity of -0.257. I found that, on average, the price elasticity of strata two and four is very similar, even if the one for stratum four is not significantly different from zero.

Comparing the price elasticities to the ones found previously for water utilities, the range between -0.4 and -0.2 is smaller compared to what other papers found before for developing countries; the range of the elasticities that Szabo (2015) found is around -1.2 to -0.9, while other studies (Olmstead et al., 2007; Nauges & van den Berg, 2009) found elasticities in the range that I found in my data.

Also, on average, the first quantile price elasticities are not significantly different from zero; this is because the model captures the lower effect of the change in prices that the low-consumption household has in my data. Price elasticities are affected by income and substitution effects, and the reduced form showed that the income effects are the main force affecting water consumption with price changes. In the first segment of consumption, it is small.

Something similar happens with the income elasticities for the linear model, which are only significant in the higher quantiles; in the first quantiles, the model captures the no effect found in the reduced form results. The average income elasticity range is around 0.2 to 0.3 and is only significantly different from zero in the higher consumption quantiles.

Table 7: Elasticities Linear Specification

	Price Elasticities					Income Elasticities				
	All	q20	q40	q60	q80	All	q20	q40	q60	q80
All	-0.257	-0.240	-0.390	-0.270	-0.206	0.169	-0.250	0.331	0.258	0.228
	(0.150)	(0.741)	(0.005)	(0.003)	(0.002)	(0.193)	(0.930)	(0.007)	(0.006)	(0.005)
Stratum two	-0.240	-0.491	-0.238	-0.186	-0.151	0.189	0.365	0.177	0.143	0.124
	(0.017)	(0.091)	(0.002)	(0.001)	(0.001)	(0.012)	(0.057)	(0.003)	(0.003)	(0.003)
Stratum four	-0.279	0.306	-0.737	-0.453	-0.313	0.144	-1.198	0.613	0.499	0.434
	(0.349)	(1.719)	(0.005)	(0.002)	(0.001)	(0.415)	(1.996)	(0.011)	(0.009)	(0.008)

Standard errors in parenthesis and obtained by bootstrapping the sample 1000 times.

The linear model also predicts a more or less constant change across the distribution of water consumption, and also that water consumption is an inelastic good, which is not what I found in the reduced form results, where the change in consumption with the change of the price scheme was big and significant concerning the standard deviation of water consumption in the sample. This can be explained by the constant rate of income effects that this specification predicts.

This contrasts with the results in the more general specification approximated by a quadratic function. In this case, the Price elasticities are around -1.1 and -9 and seem greater once the consumption exceeds the quantile 20 of water consumption. The model captures the null change in the first quantile but also explains the high response of the high quantiles at water.

Table 8: Elasticities Quadratic Specification

	Price Elasticities					Income Elasticities				
	All	q20	q40	q60	q80	All	q20	q40	q60	q80
All	-0.955	-0.948	-1.159	-1.143	-0.888	0.541	0.496	0.565	0.629	0.550
	(0.322)	(1.590)	(0.020)	(0.010)	(0.008)	(0.136)	(0.692)	(0.011)	(0.007)	(0.005)
Stratum two	-0.805	-1.061	-0.930	-0.886	-0.697	0.446	0.461	0.469	0.493	0.445
	(0.019)	(0.091)	(0.008)	(0.003)	(0.002)	(0.007)	(0.031)	(0.007)	(0.006)	(0.005)
Stratum four	-1.140	1.722	-3.527	-1.875	-1.243	0.658	-0.623	1.644	0.991	0.738
	(0.758)	(3.582)	(0.032)	(0.011)	(0.006)	(0.312)	(1.499)	(0.016)	(0.006)	(0.004)

Standard errors in parenthesis and obtained by bootstrapping the sample 1000 times.

6 Effects on Welfare

In this section, I use the model and the estimators I obtained to calculate the welfare gains from the non-linear pricing schemes; in particular, I calculate the welfare gains from the IBT, the welfare gains from the free-water policy, and an alternative pricing scheme.

To calculate the welfare gains, I use the implications of the previously estimated cases. This allow me to recover the equivalent variation when the pricing schemes change. The procedure to get the equivalent variation is explained in the following subsection, and the results are in the next.

6.1 Welfare changes with a non-linear price scheme

To calculate the welfare effects of a non-linear price scheme, I follow the method proposed by Hausman (1981),Reiss & White (2005), and Ruijs (2009). They calculate the welfare changes by using the definition of the demand function and indirect utility functions to obtain the expenditure function. Then, they calculate the welfare effects of the difference in the price scheme.

To calculate the equivalent variation with a non-linear budget constraint, I need to consider all the cases depending on what part of the budget constraint the estimated consumption is. First, let's define the indirect utility function as $V(p,y)$ and the expenditure function obtained from this as $e(p,u)$. Ruijs (2009) showed that for a budget constrain with multiple segments, the equivalent variation for each household is going to be:

$$EV(P_{st}, P'_{st}, y_0) = \left[e(P_{jst}, u') - \sum_{k=1}^{j-1} (P_{k+1st} - P_{kst}) \ell_{ks} \right] - y_0, \tag{15}$$

, where P'_{st} is the new pricing scheme, y_0 is the initial income in the first segment, and u' indicates the indirect utility of the new water consumption obtained at the new prices. The equivalent variations are then used in a linear budget constraint adjusted for the amount of subsidies received for the nonlinearities in the budget set.

When the predicted consumption is in a kink ℓ_{kst}, Ruijs (2009) show that the equivalent variation, if the predicted demand is at the kink k and comparing it with a segment j is going to be the next one:

$$EV(P_{st}, P'_{st}, y_0) = \left[e(\bar{P}_{jst}, u') - (\bar{P}_{jst} - P_{jst})\ell_{kst} - \sum_{k=1}^{j-1} (P_{k+1st} - P_{kst}) \ell_{kst} \right] - y_0, \tag{16}$$

where $\bar{P}_{jst}$ is a price at which the predicted demand is going to be equal to the king ℓ_{kst}.

In the following subsections, I evaluate two counterfactual exercises using the equivalent variation formula to recover the welfare gains from the IBT and other pricing schedules.

6.2 Welfare gains from the IBT

In this section, I evaluate the gains in welfare from the IBT pricing scheme for stratum two. To do that, I simulate the consumers' water consumption when they have a linear tariff, and the tariff equals the marginal cost to provide 1 Kl of water to the household. Then, I calculate the equivalent variation for each household and evaluate the relationship concerning their total expenditures; the objective is to identify which households are the ones that are getting more gains from this policy and answer the question of whether the richest ones are the ones doing better.

I aim to do this exercise using both specifications in my model. In this paper, only the results with the linear specification are presented.

With this in mind, I see if there is a relationship between the equivalent variation and expenditure. To do this, I identify the deciles of expenditure in the sample and plot the equivalent variation for these deciles in each stratum, and in 2011 and 2014, the results of this exercise are in Figure 9.

The equivalent variations, the blue line in the figures, seem to have a positive relationship. The households in the higher deciles of expenditure are the most impacted by the tariff change. The reason for this is that the households in the higher deciles of expenditure are the ones with high water consumption, and they are the ones that receive more subsidies before the change in the tariffs. In addition, the Equivalent variation from 2011 is lower in each decile than the ones obtained in 2014 because of the additional free water policy in the first

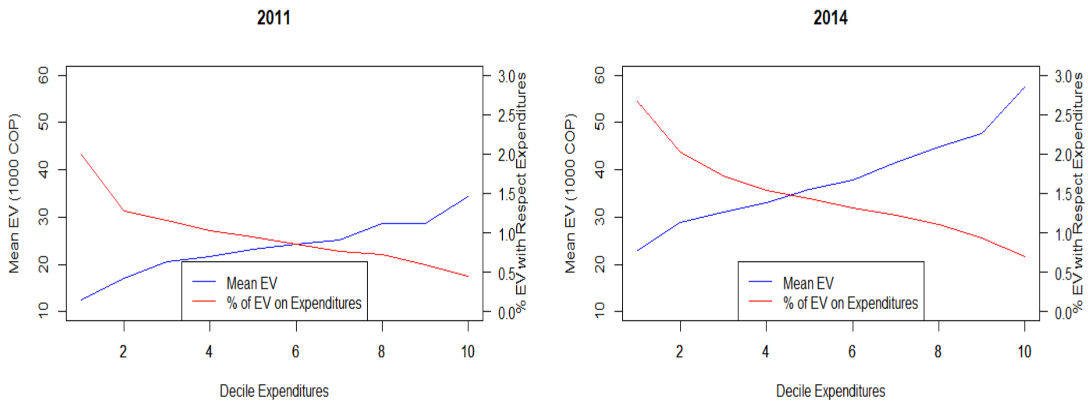

Figure 9: Mean equivalent variation per deciles of total expenditures of the IBT compared to a linear price scheme without subsidies.

consumption segments.

In absolute terms, the results indicate that the IBT benefits households in stratum two the most in the higher expenditure deciles, being in 2011 around 10 thousand Colombian pesos on average for the poor households and 30 thousand Colombian pesos on average for the richest ones, and in 2014 around 20 thousand on average for the poorest ones and on average close to 60 thousand for the richest ones. Still, if I compare how considerable the equivalent variation is concerning the total expenditure of the households, I obtain the opposite relationship. The red line in Figure 9 indicates the percentage of the welfare gains in the total expenditures.

This means welfare gains are more critical for lower-expense households than higher-expense ones. In 2011, the welfare gains for the poorest households were around 2% and for the richest ones around 0.5%. The results show that in 2014, the welfare gains were around 3% of the poorest households' total expenditures, while for the richest ones, it was around 0.5%.

This counterfactual also measures the amount of welfare transfer from the government to the households because the linear pricing I'm using to compare to the IBT is a price equal to the marginal cost of providing an extra Kl of water for the household. The government arcs pay any deviation of the cost, filled with the overprice paid by strata five and six and public funds. This means that most of the transfers from the government to the households are going to the wealthiest households inside stratum two, which makes the IBT a nonprogressive policy.

6.3 Welfare gains from the Free Water Policy

In this section, I analyze the welfare gains of the free water policy. To do this, I changed the price schedule of stratum two to the one they had before introducing the free water policy. This means that the first 12 Kl of water has a marginal price equal to the marginal price of the segment between 12 and 40 Kl of water. This counterfactual's objective is to obtain each household's welfare in stratum two and see their relationship concerning the total expenditures.

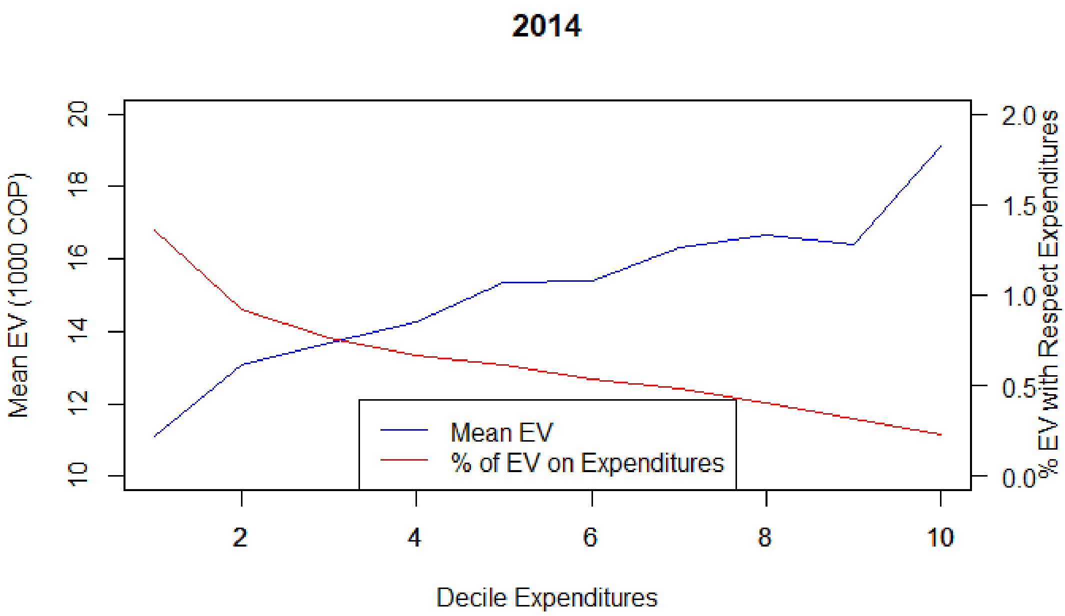

Figure 10: Mean equivalent variation of the free water policy compared to an IBT without free water policy

The mean equivalent variation per total expenditures decile is the blue line in

Figure 10. The results indicate that changing a tariff scheme with an additional subsidy in the first consumption segments affects the households in the lower deciles, with the mean equivalent variation of the poor households around 11 thousand pesos and around 19 thousand pesos for the richest ones. Considering that the local government assumes the costs of this policy, this result implies that the free water policy is regressive, giving more benefits to the wealthiest households than the poorest ones.

The proportion of welfare gains in their total expenditures shows that the free water policy is still more important for poor households; it represents around 1.5% of expenditures in the lower decile and around 0.2% in the higher decile.

The main takeaway from these two counterfactuals is that the non-linear price scheme is that even though there is evidence of being regressive, giving more benefits to households that don't need that amount of welfare gains, there is also evidence that it is essential for the poorest households, for this reason, it is crucial to design a better price schedule. This concern is going to be treated in the next two counterfactuals.

6.4 Direct transfer to the households

In this section, I evaluate the welfare gains from directly transferring the subsidies related to the free water policy to the households in stratum two in 2014. To do that, I simulate the consumers' water consumption with and without a direct transfer and with a linear tariff equal to the marginal cost to provide 1 Kl of water to the household. This exercise aims to compare the results with those in section 6.2.

The reasoning behind this exercise is that, given the evidence that the households are changing their consumption only through the change in their virtual income, it would be more efficient for the policymaker to directly transfer the subsidies and avoid the distortions created by the non-linear price scheme. The results of calculating the equivalent variation for each household and the posterior evaluation of the relationship concerning their total expenditures are in Figure 11.

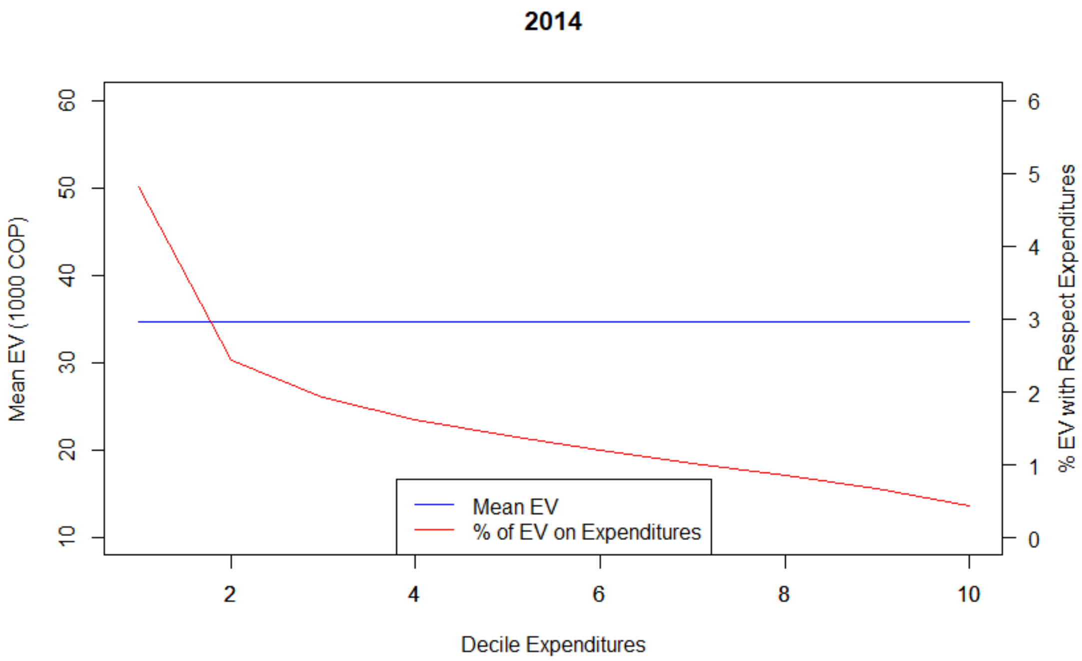

Figure 11: Mean equivalent variation per deciles of total expenditures of a direct transfer of the subsidies of the free water policy compared to a linear price scheme without subsidies

In Figure 11, the mean equivalent variation is constant because the linear model predicts a constant change in the consumption of water utilities and of the numeraire good. The constant effect is more progressive than the IBT; when I compare the results concerning the one in Section 6.2, the welfare gains of the poorest households with a direct transfer are higher, and for the richest ones, they are lower.

The proportion of the welfare gains concerning their total expenditures shows that the direct transfer represents around 5% of their total expenditure for the lower decile, and for the higher one, it is around 0.4% for the higher decile; this means that this kind of policy it is also progressive in relative terms concerning the total expenditure. These results indicate that if one intends to reduce inequality in the provision of water utilities, a direct transfer is more effective than using non-linear prices.

7 Concluding Remarks

In this paper, I quantify the effects of the distribution of consumption and welfare of a non-linear price scheme on water in Bogotá, Colombia. In the first part of my paper, I used a policy change that added a subsidy on the first level of consumption for some households to evaluate the causal effect on consumption by adding more nonlinearities in the price schedule. The results showed that after the policy change, the households, on average, increased the amount of water they consumed; still, the quantile treatment effects were higher for the wealthiest households than for the poorest ones.

The increasing effect concerning the consumption quantiles suggested that most of the change in consumption is related to income effects. The evidence for this is that the marginal cost that the households in the higher consumption quantiles face didn't change before and after the policy was introduced, which means that the substitution effects were null and that all the change is ridden by the shift in income created by the subsidies in the first levels of consumption.

In the second part of my paper, I use a model that rationalizes the results obtained in the first part. I use a model that allows for non-linear budget constraints and income effects to do this. To estimate the parameters of my model, I use an indirect inference approach, using the results obtained in the first part to get the structural parameters of my model. Once I obtained the model parameters, I used them to measure the welfare gains of the non-linear price schedule compared to a linear one. I find that the households that are getting more benefits s are the wealthiest ones. Still, at the same time, I found that the amount of welfare gains over the total expenditure is higher in the poorest households.

This section's main result shows the non-linear pricing scheme's regressiveness. Considering that almost all the costs related to this kind of policy are government-funded, it is concerning that the majority of welfare transfers made by the government go to the wealthiest households. Still, the evidence of the importance of these welfare gains on the poorest households indicates that the subsidies in the pricing scheme are necessary. Still, the design should be done differently to fix the regressive aspects.

This paper is a methodological contribution to the literature on evaluating pricing schemes in public utilities. Current work doesn't consider the importance of income effects on the demand for public utilities. My paper shows that this kind of treatment can be highly restrictive when it is not taken into account that introducing subsidies affects the income of the households, which affects the final demand.

These results are also very policy-relevant. This kind of price scheme is widely used worldwide for different public utilities. The evidence of this policy's regressiveness and the importance of subsidies for poor households suggest the importance of a better price scheme design.

I plan to extend this paper as follows. At present, I have only focused on households that don't make mistakes when choosing the quantity of water they consume. I plan to address this in the following ways: The first is to allow for optimization errors in the demand; the distribution of water consumption is smooth and doesn't have evidence of bunching in the kinks where the marginal price changes; my model predicts this kind of behavior, for this reason, the most natural extension is to add this kind of errors.

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A Robustness check: Result of free water policy on stratum three

In this section, I will evaluate the effects of the free water policy on stratum three, that is, the group of households with an IBT type of tariff scheme that wasn't affected by the free water policy. Their tariff scheme was unaffected between the two periods. Then, it is expected that there will not be any effect of the policy on this group of households or change in their consumption. If this is true, this will indicate that the change in strata one and two is the result of the change in the tariff scheme and not other variables that could affect the water consumption of the households.

Then, for the exercises performed in this section, the control group will be stratum four, the treated group will be stratum three, the pre-treatment period will be 2011, and the post-treatment will be 2014.

In Table 9, there are the upshots for the ATT of the free water policy for stratum three; the first rows have the results using a linear Differences in Differences (DID) model, and the last ones have the ATT calculated using the Changes in Changes (CIC) model. The DID results show that there is no effect of the policy on stratum 3, with and without covariates. The same kind of results are obtained with the CIC model.

Table 9: ATT of the introduction of the free water policy

	Stratum three	
	Without Covariates	With Covariates
DID		
Free Water Policy ATT	1.622	0.542
	(0.542)	(0.478)
Observations	9504	9504
R2	0.007	0.227
CIC		
Free Water Policy ATT	2.087	0.526
	(2.471)	(0.471)
Observations	9504	9504

Note: Standard errors obtained by bootstrapping 1000 times. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$

The results of the QTE with the CIC model are in Table 10; QTE is never significative with and without covariates; this means that the counterfactual distribution for stratum 3 is not different at any point than the observed one. This suggest that for all the group of households at stratum 3 there is not effect of the free water policy.

Table 10: QTE on water consumption of the free water policy for stratum three

	Baseline			With covariates		
	Est.	95% CI		Est.	95% CI	
Quantile effects						
q5	1	0.317	1.682	-0.984	-2.393	0.424
q10	2	-0.078	4.078	0.025	-1.011	1.062
q25	1	-0.650	2.650	-0.123	-0.745	0.499
q50	2	-0.506	4.506	0.330	-0.437	1.099
q75	4	-0.970	8.970	1.024	-0.299	2.347
q90	4	-0.550	8.550	1.406	-0.346	3.158
q95	3	-1.101	7.101	3.595	-0.579	7.770

Notes: Confidence intervals were calculated by bootstrapping 1,000 times. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$

B Robustness check: Stratum 3 as control group

This section presents the results for strata one and two of the effects of the change in tariff scheme using stratum three as the control group. The idea is to use a different control group and show that the results don't change significantly from the ones in the main text.

In Table 11 are the results for the ATT of the free water policy using stratum three as the control group. The ATT is around 2 to 3 Kl of water, which is not that different from the results from the main text, especially since the results with covariates are very close to the ones using stratum four as the control group.

Table 11: ATT of the introduction of the free water policy

	Stratum one		stratum two	
	Without Covariates	With Covariates	Without Covariates	With Covariates
DID				
Free Water Policy ATT	3.075***	3.558***	2.961***	2.704***
	(0.892)	(0.816)	(0.493)	(0.455)
Observations	4064	4064	7186	7186
R2	0.003	0.179	0.005	0.156
CIC				
Free Water Policy ATT	3.566***	3.649***	3.467***	2.797***
	(0.827)	(0.862)	(0.511)	(0.438)
Observations	7146	7146	10268	10268

Note: Standard errors obtained by bootstrapping 1000 times. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$

Table 12 shows the QTE results for stratum one using as control group stratum three. The results maintain the increasing QTE with respect to the quantile of consumption, being close to zero and not significative to the first quantiles while being significative for the higher consumption quantiles, as the results use stratum four as the control group.

Table 12: QTE on water consumption of the free water policy for stratum one

		Baseline			With covariates		
		Est.	95% CI		Est.	95% CI	
Quantile effects	W						
q5	5	2	0.270	3.729	1.462	-0.836	3.762
q10	7	1	-0.711	2.711	1.190	-0.279	2.660
q25	11	0	-1.744	1.744	1.586	0.218	2.954
q50	17	2	-0.440	4.440	1.886	0.245	3.526
q75	26	5	2.490	7.509	4.943	2.190	7.697
q90	37	10	5.897	14.102	10.291	5.610	14.973
q95	46	11	5.261	16.538	10.839	3.683	17.996

Notes: Confidence intervals were calculated by bootstrapping 1,000 times. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$

Table 13 shows the QTE results for stratum two using as control group stratum three. The results are similar as the ones in stratum one, it maintains the increasing QTE with respect to the quantile of consumption. They are close to zero and insignificant to the first quantiles while being significant for the higher consumption quantiles, as the results use stratum four as the control group.

Table 13: QTE on water consumption of the free water policy for stratum two

		Baseline			With covariates		
		Est.	95% CI		Est.	95% CI	
Quantile effects	W						
q5	5	1	-0.229	2.229	1.411	-0.192	3.015
q10	7	2	0.413	3.587	1.138	0.194	2.082
q25	11	2	0.896	3.104	1.251	0.505	1.997
q50	17	3	1.465	4.535	1.972	1.348	2.596
q75	26	4	2.110	5.890	2.671	1.438	3.904
q90	37	7	3.896	10.104	5.878	3.415	8.341
q95	46	9	5.428	12.572	6.534	2.318	10.750

Notes: Confidence intervals were calculated by bootstrapping 1,000 times. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$