The Water Vital Minimum: Analyzing the Bogotá Free Water Policy

Gallego, J; Oviedo, J; Rojas, M; Sepúlveda, C.

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Abstract

(Szabo, 2015) analyzes the effects of a free water allowance in South Africa equal to the World Health Organization's recommended minimum. The author demonstrates that the free allowance acts as a lump-sum subsidy without significantly affecting water consumption. Furthermore, it is shown that it is possible to reallocate the current subsidy to form an optimal tariff without needing a free allowance. In this study, we revisit Szabo's analysis using data from Bogotá, Colombia, where a similar policy was implemented. First, employing the methodology proposed by the author, we successfully replicate the original results on consumption, revealing a minimal impact. Second, we reexamine the calculation of the price elasticities for water, identifying lower price elasticities. Third, we replicate the exercise of creating an optimal tariff that increases social welfare.

1 Introduction

The provision of water utilities plays an essential role for policymakers, and this is because access to clean water significantly impacts health, education, and economic outcomes. This paper aims to build on the existing literature by conducting a wider replication of the study by Szabo (2015), which evaluated the effects of a free water policy in South Africa. Specifically, the objective is to evaluate the impact of a similar policy implemented in Bogotá, Colombia, in 2012.

This study evaluates the effectiveness of a policy intended to improve water utility provision for populations where water costs may represent a significant burden for households. According to Szabo's findings, consumers tend to respond strongly to fluctuations in water prices, exhibiting a price elasticity of -0.98, suggesting that price-based policy instruments can effectively alter water consumption. However, Szabo's counterfactual analysis in South Africa showed that removing the free water policy led to minimal changes in consumption. Still, it significantly increased household water expenditure by 81.6%, indicating that such policies may function more like lump-sum cash transfers than consumption incentives.

This paper will use an adjusted methodological framework based on the one developed by Szabo (2015). The final goal is to provide an analysis that replicates the original findings and identifies the unique impacts of Bogotá's policy environment on water consumption and welfare. For this reason, this paper will determine whether the results from the original paper hold true under a different context (a different country) and explore potential improvements to the local policy that could improve household welfare while maintaining or increasing the financial sustainability of water provision.

The policy discussed in this paper resulted from South Africa and Colombia's commitment to comply with the Millennium Summit recommendations to reduce the population without access to water by 2015. This led to the implementation of a policy in both countries that modified the pricing scheme for some groups of households, making the first 6 Kl of water for monthly consumption completely free, referred to as a vital minimum. Before implementing this policy, both countries utilized a tariff scheme known as standard block tariffs with multiple tiers. This scheme divides total consumption into blocks, each with a different marginal price. Generally, lower consumption blocks have lower marginal prices to subsidize the poorest consumers, considered lower-level consumption users. In comparison, higher consumption blocks have a marginal price closer to or higher than the marginal cost (Banerjee et al., 2010). The free water policy introduced a consumption block at a lower marginal cost.

In Bogotá, Colombia, water service tariffs are regulated by Law 142 of 1994, which sets subsidy and tariff limits for households based on a variable that acts as a proxy for income known as stratum. Stratum one is supposed to be for the poorest households, and stratum six for the richest. The tariffs have two components: one for consumption and another related to sanitation services, linked to the amount of water households consume. Before 2012, strata one, two, and three received subsidies for the first 40 Kl of bimonthly water consumption, with subsidies of about 70%, 40%, and 14% of the marginal price, respectively. After consuming 40 Kl, they paid a tariff equal to the marginal cost of providing and sanitizing an extra Kl of water. With the introduction of the free water policy in 2012, strata one and two received an additional subsidy, reducing the consumption part of the tariff to zero for the first 12 Kl of bimonthly water consumption while maintaining the exact structure of subsidies after 12 Kl. Higher strata, precisely five and six, had a linear price scheme with 155% and 165% surcharges, respectively, while stratum four always pays a tariff equal to the marginal cost.

Moreover, in Colombia, the division by stratum is not a perfect proxy for income; each stratum has significant income heterogeneity. Some wealthier households fall into lower strata, while some poorer households are in higher strata. This intra-stratum heterogeneity, as noted by Gallego et al. (2014), challenges the effectiveness of the tariff system, as it does not always accurately reflect households' financial capabilities. Therefore, this paper aims to evaluate the effectiveness of the new subsidy for strata one and two. It is essential to clarify that the Szabo methodology is designed to deal with South Africa's price schedule, where this more complex pricing scheme does not follow the standard incremental pattern of the marginal costs of the consumption blocks. Still, this will not represent a problem since the methodology can be easily modified to accommodate the Colombian case.

Szabo's methodology builds on methodologies traditionally used to estimate demand systems under non-linear budget constraints generated by the non-linearity of the tariff schemes. The seminal papers developed in Burtless & Hausman (1978) and Hausman (1985) aimed to study how changes in non-linear tax schemes affect labor supply. This approach has since been adapted and applied in other areas, especially in demand estimation of public utilities, like residential electricity demand (Reiss & White, 2005; McRae, 2015) and residential water consumption (Hewitt & Hanemann, 1995; Pint, 1999; Olmstead et al., 2007; Olmstead & Stavins, 2009).

The data that is used in this paper for the replication exercise is explained in detail in Section 2; the source of this dataset came from the multipurpose survey of the city of Bogotá; this is a repeated cross-section data set of households in Bogotá, Colombia for strata one to four for the years of 2011 and 2014, strata five and six are excluded from the analysis given the lack of reliability of the collection of data for these group of households. The dataset includes information on water consumption, detailed household expenditures, and socioeconomic data for 2011 and 2014. This information is complemented with administrative data related to the tariffs each household faced during this period.

Section 3 explores the details of the structural model and its estimation, based on the model proposed by Szabo (2015) and modified to fit the Colombian case. The results of this model are presented in Section 4. Generally, the model's performance is acceptable, predicting a mean water consumption of the lower strata close to the observed. However, for stratum 4, the fit is not particularly good since the predicted consumption is lower than the observed one. Additionally, the model's year-to-year performance is not perfect; the predicted mean consumption for the lower strata in 2011 is higher than observed, while 2014 the relationship is reversed.

Regarding price elasticities, contrary to the results found by Szabo (2015), the obtained price elasticities range between -0.02 and -0.07, indicating that households are less responsive to price changes than those observed in the original South African data. However, the counterfactual results of eliminating the free water policy are consistent with those in the original paper. The elimination of the free water policy resulted in a minimal change in consumption but a big change in the expenditures in the water of the households affected by the policy, around 64% increase, which gives evidence that this kind of policy is working as a lump sum transfer and not changing the incentives of the households to consume water.

An optimal tariff scheme calculation is proposed, contrasting with the cases explored by Szabo (2015). In this paper, the goal is to find the optimal marginal prices that maximize welfare while ensuring that households, on average, consume at least the desirable 12 Kl as recommended by the Millennium Summit and that the price schedule at least covers the cost of providing this amount of water. The results indicate that a price schedule meeting these conditions is achievable, giving room for improvement to the local policy. Finally, Section 5 concludes.

2 Data

The data used in this paper comes from two sources. The first source is the multipurpose survey of the city of Bogotá for 2011 and 2014 for households in strata one to four. This survey was created to evaluate the results of the district-level policies of the city of Bogotá. It has information regarding socioeconomic and urban environment variables. Within the variables of interest, it has an essential component of expenses and income, water expenditure, and socioeconomic variables relevant to water consumption. Additionally, the information available in the survey covers August and November. Finally, if more than one household shared the water expenditure, those households were discarded as it was impossible to disaggregate the consumption information per household.

The second source is administrative data from the unique water provider in Bogotá. The main information obtained from this source is the tariff schemes for each stratum for the years 2011 and 2014.

The set of variables constructed from the multipurpose survey includes total expenditures per household as a measure of income. The reason for not using the income variable directly is that there is evidence of underreporting in the survey (Gallego et al., 2014). Additionally, other variables obtained from this survey is a set of covariates that could affect water consumption: the number of rooms in the household, if they have a washing machine, if they have a water tank, the number of toilets, the number of people living in the household, the average education of the household between others. The water consumption is recovered from the household water expenditure using the administrative information.

Summary statistics by stratum are provided in Table 1. There is evidence of heterogeneity inside the stratum, especially in the total expenditures; even if the mean of expenditures increases with the stratum, the standard deviation is big in all of these groups. Additionally, if we consider that the minimum wage of two months in 2011 was one million COP, the percentile 10 and percentile 90 indicate that most of the sample is concentrated between 2 and 10 million in expenditures.

Regarding water consumption, Table 1 provides summary statistics of the consumption by stratum. We can see the mean doesn't change between strata and that the standard deviation is very high but very similar across strata; this indicates a lot of heterogeneity in the consumption of water in Bogotá, with the majority of households consuming less than 40 Kl of water.

Table 1: Summary Statistics by Stratum

	N	mean	sd	p10	p90
Stratum 1					
Water Consumption (Kl/Bimonth)	853	19.93	11.52	7	35
Total Expenditures (1000 COP)	853	2,380	2,215	789.6	4,160
Number of Rooms	853	3.322	1.243	2	5
Laundry	853	0.671	0.470	0	1
Garden	853	0.508	0.500	0	1
Washing Machine	853	0.671	0.470	0	1
Water Tank	853	0.204	0.403	0	1
Number of Toilets	853	1.249	0.507	1	2
Number of People	853	3.940	1.914	2	6
Age Head of Household	853	49.26	13.35	32	68
Average Years of Education	853	2.562	1.204	1.333	4
Stratum 2					
Water Consumption (Kl/Bimonth)	3,975	18.67	11.97	6	33
Total Expenditures (1000 COP)	3,975	3,215	2,476	1,170	5,782
Number of Rooms	3,975	3.667	1.242	2	5
Laundry	3,975	0.804	0.397	0	1
Garden	3,975	0.487	0.500	0	1
Washing Machine	3,975	0.804	0.397	0	1
Water Tank	3,975	0.317	0.465	0	1
Number of Toilets	3,975	1.359	0.592	1	2
Number of People	3,975	3.752	1.737	2	6
Age Head of Household	3,975	49.83	13.87	32	69
Average Years of Education	3,975	2.926	1.430	1.500	4.500
Stratum 3					
Water Consumption (Kl/Bimonth)	6,293	18.63	12.32	6	33
Total Expenditures (1000 COP)	6,293	5,202	3,820	1,714	9,727
Number of Rooms	6,293	3.976	1.226	3	5
Laundry	6,293	0.917	0.275	1	1
Garden	6,293	0.410	0.492	0	1
Washing Machine	6,293	0.917	0.275	1	1
Water Tank	6,293	0.597	0.490	0	1
Number of Toilets	6,293	1.709	0.723	1	3
Number of People	6,293	3.195	1.532	1	5
Age Head of Household	6,293	51.58	15.36	32	73
Average Years of Education	6,293	4.099	2.113	1.800	7.500
Stratum 4					
Water Consumption (Kl/Bimonth)	3,211	19.29	12.81	6	35
Total Expenditures (1000 COP)	3,211	8,570	6,403	3,050	15,564
Number of Rooms	3,211	3.915	1.373	2	5
Laundry	3,211	0.947	0.224	1	1
Garden	3,211	0.239	0.427	0	1
Washing Machine	3,211	0.947	0.224	1	1
Water Tank	3,211	0.677	0.468	0	1
Number of Toilets	3,211	2.188	0.823	1	3
Number of People	3,211	2.563	1.298	1	4
Age Head of Household	3,211	50.25	16.17	29	72
Average Years of Education	3,211	5.516	2.667	2.333	9.333

The tariff schedule for each stratum in 2011 and 2014 are obtained from administrative data in Figure 1. For Stratum one to three, the marginal price of the first consumption levels is until 40 Kl; the marginal price is lower than the marginal cost, which means that the lower quantities are subsidized for these groups of households.

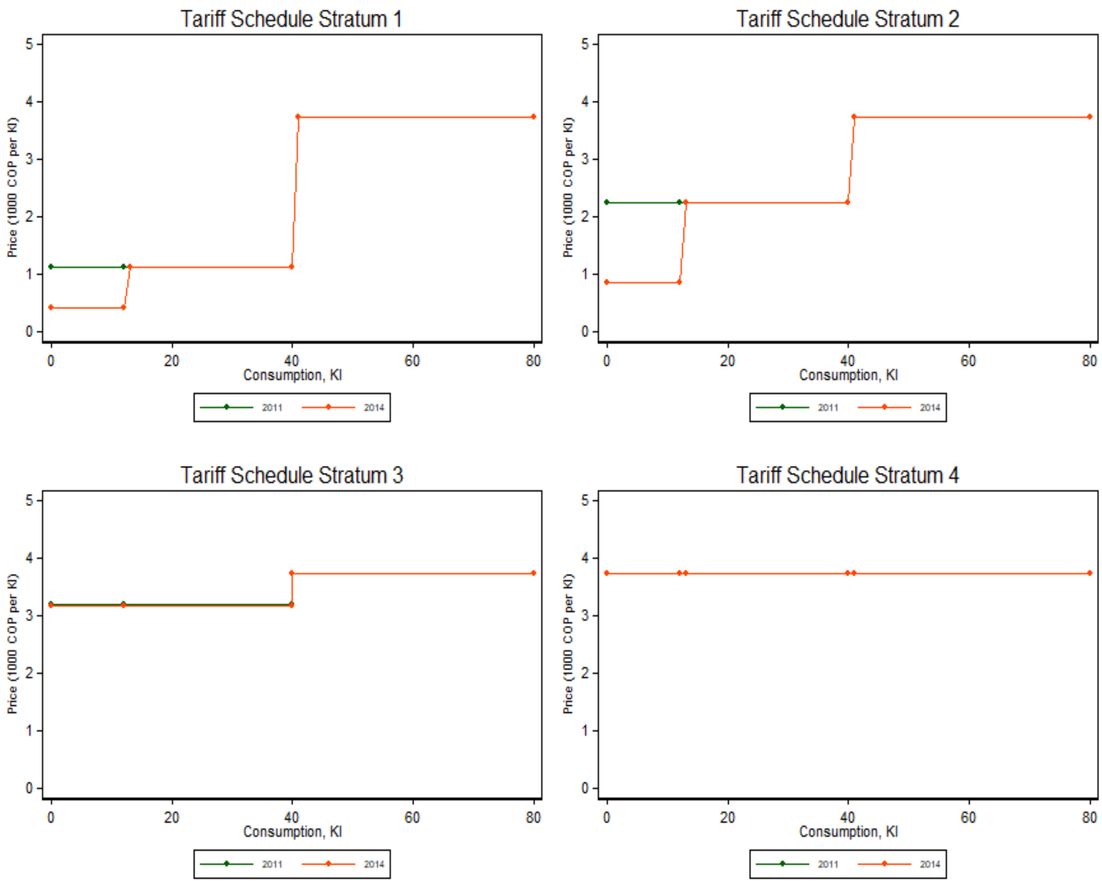

Figure 1: Tariff Schedule for stratum one to four

Strata one and two are the household groups with the lower marginal price at the first level of consumption. The main difference between 2011 and 2014 was the introduction of the free water policy, which modified the tariff schedule by adding an additional block of consumption with a lower marginal price. The marginal price of this first block, which corresponds to the first 12 Kl of water bimonthly, is not zero since the marginal price includes two components: consumption and sanitation. Then, after the introduction of the policy, the price for sanitation is maintained, but the consumption part is not. The consumption after 40 Kl of water for both groups is charged at a marginal price equal to the marginal cost.

The tariff schedule for strata three and four didn't change between 2011 and 2014. Stratum three has a two-piece-wise linear tariff scheme with a subsidized marginal price for the first 40 Kl of water and a marginal price equal to the marginal cost afterward. Stratum four has a linear tariff scheme with a marginal price equal to the marginal cost.

The following section describes the structural model that will be used with this data to obtain the main results of this paper.

3 Structural Model

This section describes the model estimated to obtain the primary results of this paper. The model is based on the one proposed by Szabo (2015), which consists of a demand model with non-linear budget sets, building on the work of Burtless & Hausman (1978); Hausman (1985); Reiss & White (2005). The starting point of the model is a utility function initially proposed by Hausman (1985) that, adjusted to the case of study, is the following:

$$U(w_{ist}, c_{ist}) = \frac{\gamma w_{ist} + \beta}{\gamma^2} \exp(\gamma \frac{\gamma c_{ist} - q_{ist} + X_{ist}\delta + \eta_{it}}{\gamma w_{ist} + \beta}), \tag{1}$$

where w_{ist} indicates the water consumption of household i at stratum s and period t, c_{ist} is a numeraire good, X_{ist} is a vector of covariates of the household that can affect their consumption of water and that where described in the previous section, and η_{it} is a shock that recovers the non-observable characteristics that can affect the preferences for water of the household.

For this utility function to be concave, it can be shown that $\gamma w_{ist} + \beta < 0$, this condition is considered at the hour of the estimation. Still, when this condition is true, and in the case of having a linear budget constraint given the prices P and income y_{ist}, the Marshallian demand for water can be obtained and is the following one:

$$\hat{w}_{ist} = X_{ist}\delta + \beta P + \gamma y_{ist} + \eta_{it}. \tag{2}$$

From the utility function and the Marshallian demand, the indirect utility function is:

$$V(P, y_{ist}) = exp(-\gamma P)(y_{ist} + \frac{\beta}{\gamma}P + \frac{\beta}{\gamma^2} + \frac{\delta X_{ist} + \eta_{it}}{\gamma}). \tag{3}$$

To use this result in the case of a non-linear budget constraint, it is necessary to define the price schedule that a household faces. As an example, the price schedule of a household with a three-piecewise linear tariff scheme is the following:

$$P(w_{ist}) = \begin{cases} P_1 & \text{if } q_{ist} \in [0, Q_1] \\ P_2 & \text{if } q_{ist} \in (Q_1, Q_2] \\ P_3 & \text{if } q_{ist} \in (Q_2, \infty), \end{cases} \tag{4}$$

where P_k indicates the marginal price at segment $k \in \{1, 2, 3\}$, and Q_l is the kink point where the marginal price changes with $l \in \{1, 2\}$. In contrast to the case of South Africa, in Bogotá, the marginal prices of the price schedule follow an ascending pattern $P_1 < P_2 < P_3$, which means that the budget constraint is convex, which indicates that if the utility function is concave, then there is a unique solution to the household problem by finding the Marshallian demand at each segment of the budget constraint and check the feasibility of each one.

The econometric consumer for water can be expressed in the following way:

$$w_{ist}(P, y_{ist}, X_{ist}, \eta_{it}) = \begin{cases} X_{ist}\delta + \beta P_1 + \gamma y_{ist1} + \eta_{it} + \epsilon_{it} & \text{if } X_{ist}\delta + \beta P_1 + \gamma y_{ist1} + \eta_{it} < Q_1 \\ Q_1 + \epsilon_{it} & \text{if } X_{ist}\delta + \beta P_2 + \gamma y_{ist2} + \eta_{it} \leq Q_1 \leq X_{ist}\delta + \beta P_1 + \gamma y_{ist1} + \eta_{it} \\ X_{ist}\delta + \beta P_2 + \gamma y_{ist2} + \eta_{it} + \epsilon_{it} & \text{if } Q_1 < X_{ist}\delta + \beta P_2 + \gamma y_{ist2} + \eta_{it} < Q_2 \\ Q_2 + \epsilon_{it} & \text{if } X_{ist}\delta + \beta P_3 + \gamma y_{ist3} + \eta_{it} \leq Q_2 \leq X_{ist}\delta + \beta P_2 + \gamma y_{ist2} + \eta_{it} \\ X_{ist}\delta + \beta P_3 + \gamma y_{ist3} + \eta_{it} + \epsilon_{it} & \text{if } Q_2 < X_{ist}\delta + \beta P_3 + \gamma y_{ist3} + \eta_{it}, \end{cases} \tag{5}$$

where, $y_{istk} = y_{ist} - M(Q_{k-1}) + P_k Q_{k-1}$ is the virtual income at segment k with $M(Q_{k-1})$ be the total expenditure until kink Q_{k-1}. The demand specification is a simpler case of the one proposed in Szabo (2015), which means that the result from Proposition 1 is still applicable, so once the distributions of η_{it} and ϵ_{it}, the distribution of water consumption can be written down in terms of the parameters and the observed data and the model can be estimated using Maximum Likelihood. The details of the estimation procedure are in the following subsection.

3.1 Estimation

Szabo (2015) assumes that the distributions of ϵ_{it} and η_{it} are parametric. It is necessary to first define a random variable $v_{it} = \epsilon_{it} + \eta_{it}$, and, assume that ϵ_{it} is independent of η_{ist}. First, if assuming that ϵ_i is distributed $N(0, \sigma_\epsilon)$, and that the distribution of η_{ist}, is $N(0, \sigma_\eta)$. The probability of observing water consumption w_{ist} for household i in strata s and period t when faced with a three-piecewise linear budget constraint is:

$$\begin{aligned} Pr(w_{ist}) = & Pr(v_{ist} = w_{ist} - (X_{ist}\delta + \beta P_1 + \gamma y_{ist1}), \quad \eta_{ist} < Q_1 - (X_{ist}\delta + \beta P_1 + \gamma y_{ist1})) \\ & + Pr(v_{ist} = w_{ist} - (X_{ist}\delta + \beta P_2 + \gamma y_{ist2}), \quad Q_1 - (X_{ist}\delta + \beta P_2 + \gamma y_{ist2}) < \eta_{ist} < Q_2 - (X_{ist}\delta + \beta P_2 + \gamma y_{ist2})) \\ & + Pr(v_{ist} = w_{ist} - (X_{ist}\delta + \beta P_3 + \gamma y_{ist3}), \quad Q_2 - (X_{ist}\delta + \beta P_3 + \gamma y_{ist3} < \eta_{ist})) \\ & + Pr(\epsilon_{ist} = w_{ist} - Q_1, \quad Q_1 - (X_{ist}\delta + \beta P_1 + \gamma y_{ist1}) < \eta_{ist} < Q_1 - (X_{ist}\delta + \beta P_2 + \gamma y_{ist2})) \\ & + Pr(\epsilon_{ist} = w_{ist} - Q_2, \quad Q_2 - ((X_{ist}\delta + \beta P_2 + \gamma y_{ist2})) < \eta_{ist} < Q_2 - (X_{ist}\delta + \beta P_3 + \gamma y_{ist3})), \end{aligned} \tag{6}$$

where Equation 6 is the sum of the probabilities of water consumption w_{ist} to be done in each segment k plus the probabilities of consume at the kinks Q_l.

Still, additional restrictions need to be applied to the distribution of η_{it} to ensure that the utility function is concave and has a unique solution to the household problem. It is enough to guarantee that for each segment k, the condition $\gamma w_{ist} + \beta < 0$ is to be satisfied. Szabo (2015) imposed a truncation value for the distribution of η_{it} that is sufficient to satisfy each segment's condition and ensure the utility function's concavity. The truncation value, $\bar{\eta}_{it}$ is defined as:

$$\eta_{it} < \min_k(-(\alpha + \gamma y_{istk} + \beta P_k + \delta X_{ist})) - \frac{\alpha}{\gamma} = \bar{\eta}_i, \tag{7}$$

then, the distribution of η_{it} is truncated normal with mean zero, standard deviation σ_η and truncation value $\bar{\eta}_{it}$. With this, it is possible to recover the distribution of water consumption through the parameters and the observable data. The model is estimated using maximum likelihood maximizing the function resulting from multiplying the probability of consuming w_{ist} of each household i in period t and taking ln.

The set of parameters to estimate are the following ones: the vector of coefficients δ of the covariates, γ, β, and the standard deviations σ_ϵ and σ_η. The starting values for the parameters not related to the distributions of the shocks are obtained doing the instrumental variables exercise of Olmstead & Stavins (2009) as Szabo (2015) suggested in her paper, for the standard deviations starting values are the estimated ones in her paper. Since the budget constraints are convex, the optimization algorithm is more straightforward than the one used with the South African data and is the following one:

1. Start from the starting values.
2. Calculate for each segment k the virtual income y_{istk}, $\bar{w}_{istk} = X_{ist}\delta + \beta P_k + \gamma y_{istk}$ and $\bar{\eta}$.
3. Check if $\bar{w}_{istk}$ is feasible comparing them with the kink points Q_l as in Equation 5. If $\bar{w}_{istk}$ is not feasible, replace the probability of being in that

segment with zero.

4. Do the same with the kink points.
5. Calculate the probability of each household's feasible segment or kink point, take natural logarithms, and add them.
6. Choose new estimates to maximize this function from the previous step and iterate until convergence.

Once the optimal estimates are found, let $\bar{w}_{istk} = X_{ist}\delta + \beta P_k + \gamma y_{istk}$, $L_k = Q_{k-1} - \bar{2}_{istk}$ and $H_k = Q_k - \bar{w}_{istk}$, and let $l_k = Q_k - \bar{w}_{istk}$ and $h_k = Q_k - \bar{w}_{istk}$, then the expected consumption for each household can be calculated using the following formula:

$$
\begin{aligned}
E(w_{ist}(P, y_{ist})) = &\bar{w}_{ist1} - E(\eta|\eta \in (-\infty, H_1])F_\eta(H_1) \\
&+ \bar{w}_{ist2} + E(\eta|\eta \in [L_2, H_2])(F_\eta(L_2) - F_\eta(H_2)) \\
&+ \bar{w}_{ist3} + E(\eta|\eta \in [L_3, \infty)F_\eta(L_3) \\
&+ Q_1(F_\eta(l_1) - F_\eta(h_1)) \\
&+ Q_2(F_\eta(l_2) - F_\eta(h_2)).
\end{aligned}
\tag{8}
$$

This formula is used to calculate the price elasticities and counterfactuals. In particular, the price elasticities are calculated for each household using the expected consumption when the marginal prices of all the segments have an increment of 1% in the following way:

$$
\epsilon_{ist} = \frac{E(w_{ist}(1.01 \times P, y_{ist})) - E(w_{ist}(P, y_{ist}))}{0.01} \frac{1}{E(w_{ist}(P, y_{ist}))}. \tag{9}
$$

The estimation results, price elasticities calculation, and counterfactuals can be found in the next section.

4 Structural Model Results

The following subsections provide the results of the maximum likelihood estimation, the calculation of price elasticities, the results from the counterfactual exercise, and the calculation of optimal tariffs. Additionally, the particularities of each exercise's procedure and the corresponding analysis will be added.

4.1 Model estimation and performance

This section contains the estimation results, the marginal effect of the variables and covariates, and the model performance. The estimation procedure is simplified concerning the one that (Szabo, 2015) has since there are no convexities in the budget sets of the households. The Maximum Likelihood results are in Table 2 in the second column. The standard errors in the third column were calculated using the formula $H^{-1}(s's)H^{-1}$ where H is the hessian of the likelihood function and s is the total likelihood score of each household, both of this objects where that are computed numerically.

The price estimate (β) is negative and significant, and the expenditure estimate (γ) is positive and significant; compared with the estimates of the original paper, β is smaller; in the case of South Africa, the is -1.139, while in this case is -0.420. This means that price is a less important variable in determining household water consumption in Colombia. Regarding γ, the value of the estimator is as close as the one in the original paper of income. The covariates are all significant and had the expected sign, being all positive but the average years of education of the household.

Regarding the estimates for the standard deviation of the household heterogeneity η and the optimization error ϵ, the individual heterogeneity is small and insignificant, while the optimization error is large. This suggests that the covariates and expenditures explain the majority of the household water consumption heterogeneity. Also, this estimate is way smaller than the one found in South

Africa since the set of covariates is not the same as the one used in the original paper; this suggests that the covariates used here have better explanatory power. On the other hand, the distribution of optimization error, ϵ, is very close to the one in the original paper.

Additionally, in Table 2 in the fourth column, there are the marginal effects of the variables used in the estimation. This was calculated by calculating the expected consumption when each variable changed by one unit. In the Price and Expenditure cases, a change in one unit represents an increment of 1000 COP. The standard deviation of these marginal effects is in the fight column, and the calculation was made by bootstrapping 100 samples of the total sample size.

The marginal effects of the price and income seem to indicate that the water consumption of the households is not as responsive to changes in the price as they are to changes in the income; an increment of 1000 COP in the price is relatively lower than a change in the income, given that the mean expenditures of a household in Stratum 1, that is the group of household with the lower mean, is 2,380 1000 COP, and the higher marginal price that the households in my sample pay is lower than 4 1000 COP. The price elasticities in the following subsection will explore this in more detail.

Table 2: Maximum Likelihood Estimates and Marginal Effects

Variable	Parameter	se	Marginal Effect	se
Price (β)	-0.420	0.000	-0.428	0.009
Expenditures (γ)	0.0003	0.000	0.009	0.010
Number of Rooms	0.081	0.000	0.071	0.010
Laundry	1.504	0.001	1.508	0.010
Garden	0.760	0.001	0.749	0.009
Washing Machine	0.655	0.001	0.495	0.160
Water Tank	0.436	0.001	0.425	0.009
Number of Toilets	2.311	0.002	2.297	0.010
Number of People	2.348	0.001	2.333	0.010
Age Head of Household	0.055	0.000	0.045	0.009
Average Years of Education	-0.168	0.000	-0.177	0.009
σ_η	0.0002	0.0002	-	-
σ_ϵ	9.320	0.090	-	-
Constant	1.832	0.003	-	-

Robust standard errors in third column. Standard errors on fifth column obtained from 100 bootstrapped samples of the size of the full sample.

The statistics related to the model performance are in Table 3. The total sample's predicted water consumption mean is very close to the actual mean, with an average error of 0.429 Kl of water. Still, going into more detail, the mean difference between the observed versus the predicted one with the model for strata one and four is higher than the one of the total sample, being the mean difference around one Kl of water, which means that there is an overestimation in the consumption for these group of households.

Table 3: Model Performance

	Actual Mean (Kl)	Predicted Mean (Kl)	Mean Difference	N
All	18.865	18.437	0.429	14332
Stratum 1	19.930	18.996	0.933	853
Stratum 2	18.666	18.707	-0.042	3975
Stratum 3	18.629	18.325	0.304	6293
Stratum 4	19.293	18.171	1.122	3211
Year=2011				
Stratum 1	18.512	19.329	-0.817	430
Stratum 2	17.375	18.711	-1.336	2106
Stratum 3	18.734	18.541	0.193	3245
Stratum 4	20.252	18.971	1.281	1535
Year=2014				
Stratum 1	21.371	18.658	2.713	423
Stratum 2	20.120	18.703	1.417	1869
Stratum 3	18.518	18.096	0.422	3048
Stratum 4	18.414	17.438	0.976	1676

Predicted mean obtained calculating the expected consumption at household level with the estimated parameters. The mean difference is obtained from the difference between the observed and expected consumption.

When analyzing the model performance each year, the fit gets worse, overestimating the strata 1 and 2 in 2011 for between 0.8 and 1.4 Kl in the mean and underestimating the mean of these strata in 2014 for more than 1 Kl of water consumption. These may indicate that the model is not capturing the change in water consumption that resulted from the free water policy and is a possible reason for the results obtained in the counterfactual exercise in the Szabo (2015) and this paper.

4.2 Price elasticities

The price elasticities by consumption group are in Table 4. The values are very low in absolute value compared to the ones calculated by Szabo (2015) for South African households [1]. While the price elasticities for the households in Bogotá are between -0.05 and -0.14, in South Africa, the price elasticities are close to -1. In contrast to one of the main results from the original paper, the price results from Bogotá indicate that households are not responsive to price changes, and price-oriented policy instruments will not affect households' consumption meaningfully.

Table 4: Price elasticities by consumption group

		Consumption Group			
	All	1-12 Kl	12-20 Kl	20-40 Kl	40-100 Kl
All	-0.079	-0.110	-0.071	-0.062	-0.059
	(0.006)	(0.021)	(0.000)	(0.000)	(0.001)
Stratum 1	-0.026	-0.029	-0.026	-0.023	-0.023
	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)
Stratum 2	-0.076	-0.140	-0.052	-0.047	-0.048
	(0.024)	(0.074)	(0.000)	(0.000)	(0.001)
Stratum 3	-0.080	-0.095	-0.078	-0.068	-0.066
	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)
Stratum 4	-0.096	-0.122	-0.095	-0.079	-0.067
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Washing Machine	-0.080	-0.115	-0.072	-0.062	-0.058
	(0.008)	(0.027)	(0.000)	(0.000)	(0.001)
Less than 2 people	-0.081	-0.113	-0.072	-0.063	-0.061
	(0.007)	(0.023)	(0.000)	(0.000)	(0.001)

Standard errors in parenthesis obtained from 1000 bootstrapped samples.

The price elasticities increase with stratum, being four times higher for stratum four than the ones in stratum one, which means that the stratum that the policy focuses on is less responsive to price. Even if the consumption group between one to 12 Kl of water that are the ones that are the one that is going to be directly affected by the change in the marginal price of the free water policy, has higher price elasticities, the price elasticities are low in absolute value; then this seems to indicate that the model will predict a low quantity change of the

[1] There is a possible error in the author's code. The author didn't use the expected consumption without the change in prices when calculating the price elasticity but used the contribution of each household to the likelihood function. Given this, it is possible that the author overestimated the price elasticities

water consumption.

Table 5: Price elasticities by expenditure group

		Expenditure Group				
	All	0-20p	20-40p	40-60p	60-80p	80-100p
All	-0.079	-0.066	-0.102	-0.076	-0.078	-0.073
	(0.006)	(0.001)	(0.032)	(0.001)	(0.001)	(0.000)
Stratum 1	-0.026	-0.027	-0.024	-0.023	-0.023	-0.023
	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)
Stratum 2	-0.076	-0.056	-0.130	-0.049	-0.047	-0.046
	(0.024)	(0.000)	(0.080)	(0.000)	(0.001)	(0.001)
Stratum 3	-0.080	-0.094	-0.085	-0.081	-0.075	-0.067
	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Stratum 4	-0.096	-0.117	-0.113	-0.112	-0.103	-0.081
	(0.001)	(0.003)	(0.002)	(0.002)	(0.001)	(0.001)
Washing Machine	-0.080	-0.067	-0.107	-0.075	-0.076	-0.072
	(0.008)	(0.001)	(0.036)	(0.001)	(0.001)	(0.000)
Less than 2 people	-0.081	-0.066	-0.105	-0.077	-0.081	-0.077
	(0.007)	(0.001)	(0.034)	(0.001)	(0.001)	(0.001)

Standard errors in parenthesis obtained from 1000 bootstrapped samples.

The low price elasticities in absolute value are maintained under the different covariates. The households with washing machines also have low price elasticities similar to those of the total sample. The same is true for households with less than two people. The price elasticities are higher in the low consumption group but still low in absolute value, and they got even lower with the higher consumption group.

In Table 5, there are the price elasticities by expenditure group, where each group is the group of households between every 20 percentiles of expenditure. The price elasticities are low in absolute value and very similar to the ones found in the consumption group; the price elasticities are always low in absolute value in the lower stratum, and in the low expenditure groups, they are always low, which means that there is not an expenditure group where the households are responsive to changes in price, especially at low strata.

The results of the counterfactual exercise, a change in the price schedule will complement the results from this subsection, are in the following subsection.

4.3 Counterfactual exercise: No free water

To evaluate the free water policy, the counterfactual exercises consist of obtaining the expected consumption of the households affected by the free water policy and changing their tariff schedule to the same one they had in 2011. Using the ML estimates, the predicted consumption with these prices is compared with the expected consumption with the observed ones. Table 6 has the the results of this procedure.

The results for the total sample of strata one and two in 2014 are in the second column of Table 6. The mean expected water consumption of the sample without the additional subsidy in the first 12 Kl of water is 18.6 Kl, which is 0.5% lower than the mean expected consumption with the free water policy. The change in consumption is low, as is expected by the low price elasticities in absolute value that the model predicts. Still, concerning the water expenditure, the mean of the case without a free water policy is way higher than the case with the free water policy, being 64.5% higher. These results are consistent with the ones of the South African case, with negligible change in consumption and a significant shift in expenditure; this supports the affirmation that this policy is working as a lump-sum transfer to the income of the households and not as an incentive to increase the consumption of the households.

Table 6: Results of Counterfactual No Free Water

	All	Stratum 1	Stratum 2
Consumption(Kl/Bimonth)			
With Free Water	18.695	18.658	18.703
Without Free Water	18.600	18.637	18.591
Change(%)	-0.508	-0.112	-0.597
Water Expenditure (1000 COP/Bimonth)			
With Free Water	23.024	12.649	25.372
Without Free Water	37.896	20.920	41.738
Change(%)	64.593	65.386	64.504

The third and fourth of Table 6 have the results for strata one and two. As the price elasticities for stratum one are lower in absolute value than the ones of stratum two, the change of consumption is lower; the change is 0.112%, while for stratum two, the change is 0.597% lower. The change in water expenditures is very close between the two strata, around 64 to 65% higher, being a lump sum transfer for both groups of households.

4.4 Optimal tariff scheme

In this subsection, optimal tariffs for strata one and two are calculated; the way to obtain these tariffs is to define the planner problem. Since there is a random shock in the demand function, the social welfare function will also be a random variable (Szabo, 2015), then the social planer objective function be the following expected social welfare function.

$$\begin{aligned} SW_{ist} &= E\left[\sum_{i=1}^{n} U(w_{ist}, c_{ist})\right] \\ &= \sum_{i=1}^{n}\left[\int_{-\inf}^{\bar{\eta}_{it}} U(w_{ist}(P, y_{ist}, \eta_{it}), y_{ist} - M(w_{ist}(P, y_{ist}, \eta_{it}))dF(\eta_{it})\right], \end{aligned} \tag{10}$$

where $M(w_{ist}(P, y_{ist}, \eta_{it})$ is the total expenditure in water at that level of water consumption. $F(\eta_{it})$ is truncated normal with truncated value $\bar{\eta}_{it}$. The social planner will maximize equation 10, and two different sets of restrictions are imposed, different from the ones that (Szabo, 2015) impose in her paper.

The first restriction is that the total expected consumption in the aggregate is at least 12 Kl of water, the desired vital minimum. Let the restriction be

$$\sum_{i=1}^{n_{st}} E\left[w_{ist}(P, y_{ist}, \eta_{it})\right] \geq 12 \times n_{st} \tag{11}$$

where n_{st} is the number of households at period t and stratum s. Given the restriction, the social planner optimizes the social welfare function, choosing the marginal prices of the same blocks of consumption as the observed one. Also, it is imposed that the tariff scheme is of the increasing block tariff type.

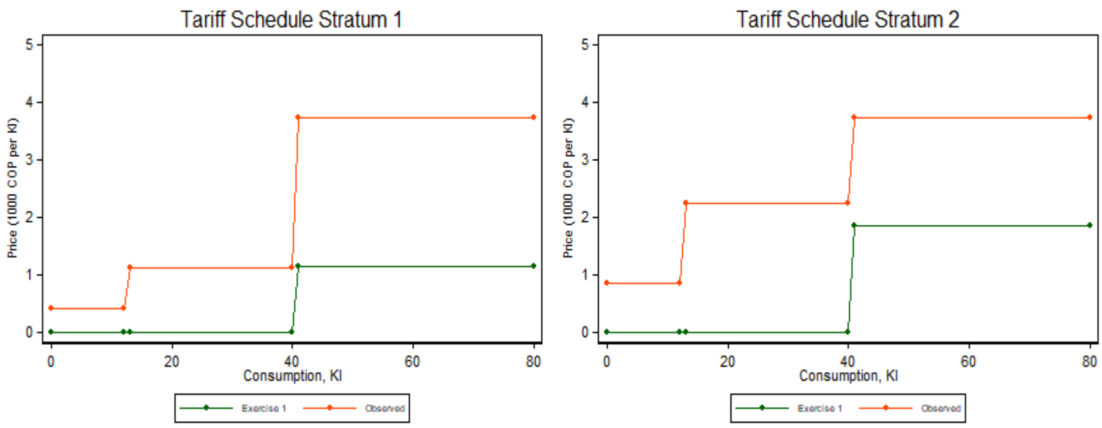

Figure 2: Observed tariff schedule vs. Optimal tariff schedule of exercise 1

The result from this optimization is in Figure 2; the left panel has the observed tariff schedule with the free water policy, the optimal tariff scheme for stratum one, and the right one with stratum two. The resulting optimal tariff maximizes social welfare and guarantees that the expected aggregate consumption is at least the vital minimum; the marginal prices should be way lower than the observed ones.

The main reason for this is that since the price elasticities are that low in absolute value, to create an incentive for the low-consumption households to consume more water, the marginal price of the lower blocks of consumption should be reduced significantly, also increasing the available income to spend in the numeraire good.

This pattern is the same for both strata, only being different the marginal price after 40 Kl of water; stratum two is a little bit higher because of two main reasons; the first one is that, in general, stratum two has more income to spare, and the second one is that the price elasticity is higher in absolute value for this group of households, the change in the marginal price doesn't need to be as extreme to generate a shift in consumption. This indicates that to maximize social welfare and guarantee the vital minimum, the observed tariff schedule can be improved if the objective is to use price-oriented policy tools.

The second exercise adds an additional restriction to the optimization. The objective is to guarantee at least a revenue to the utility firm that allows it to recover the marginal cost of the free water policy then the restriction is:

$$\sum_{i=1}^{n_{st}} E\left[\int_{-inf}^{w_{ist}} P(w)dw\right] \geq 12 \times n_{st} \times MC \tag{12}$$

where MC is the marginal cost of providing an additional Kl of water. This exercise aims to find the optimal tariff schedule that guarantees that, in the aggregate, the households consume 12 Kl of water and that this 12 Kl of water doesn't represent a burden to the budget of the public utility provider.

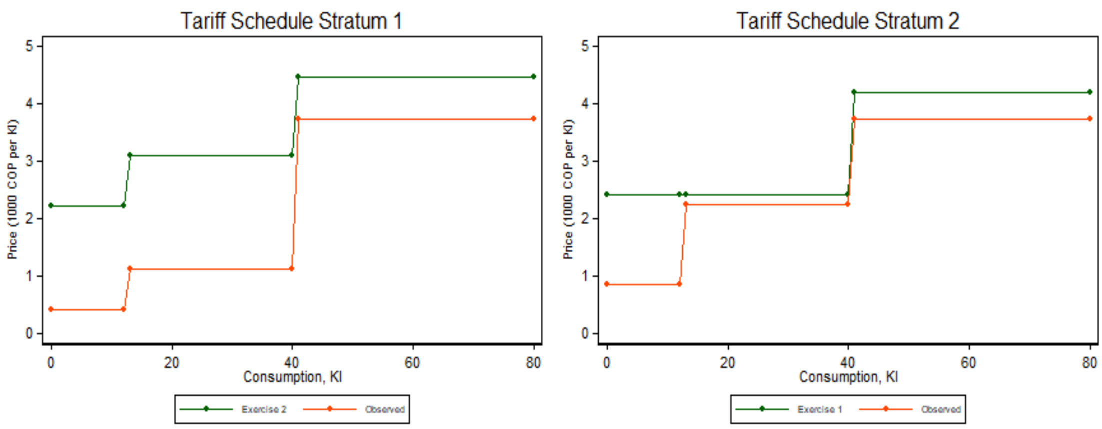

Figure 3: Observed tariff schedule vs. Optimal tariff schedule of exercise 2

In Table 3, there are the results of the second exercise, in contrast to the first one, the optimal tariff schedule that maximizes the social welfare and that guarantees that in the aggregate, the expected consumption is at least larger than the vital minimum and that at least recover the cost of those, has the characteristic that all the marginal prices are higher than the observed ones for both strata. The results indicate that to recover the cost of the vital minimum; the optimal tariffs need to be way higher than the ones observed. This also occurs because the price elasticities are low in absolute value, which means that even increasing the price not cause the change in water consumption to be that high.

The welfare analysis of the tariff schemes from these two exercises will be analyzed in the following subsection.

4.4.1 Compensated variation calculation of the optimal tariff

In this section, an analysis of the welfare gains of the optimal tariff schemes is obtained from both exercises of optimal tariffs. The measure of monetary welfare that is used is the compensated variation, the change of the household income that equates to the baseline utility under the observed tariff scheme, and the expected utility under the optimal tariff scheme. A negative compensated variation indicates that the households are better under the optimal tariff scheme than the observed prices. In contrast, the opposite, a positive compensated variation, means that the household is better under the baseline case.

Table 7: Compensated variation Stratum 1

	Stratum 1		
	Exercise 1	Exercise 2	N
Compensating variation (1000 COP)			
Mean/Median	2.7/2.1	-2.8/-2.1	423
Consumption(Kl)			
Mean	19.109	17.844	
25p	15.498	14.194	
50p	18.771	17.468	
75p	21.867	20.564	
Actual consumption (Kl)			
Mean	18.658		
25p	15.028		
50p	18.301		
75p	21.398		

In Table 7, there are the calculations of the welfare gains for stratum one under both exercises. The optimal tariffs under exercise one are lower than the ones in the baseline. This means that it is cheaper to consume more water, as shown in the table, and more income is available to consume the numeraire, so it is not surprising that the compensating variation in the mean and median are negative. In 2, the households are always worse; having a tariff scheme that recovers the cost has a toll on welfare and water consumption.

Table 8: Compensated variation Stratum 2

	Stratum 2		
	Exercise 1	Exercise 2	N
Compensating variation (1000 COP)			
Mean/Median	3.3/2.6	-3.4/-2.7	1869
Consumption(Kl)			
Mean	19.533	18.516	
25p	16.254	15.236	
50p	19.269	18.251	
75p	22.192	21.175	
Actual consumption (Kl)			
Mean	18.703		
25p	15.326		
50p	18.341		
75p	21.266		

The results under both exercises for stratum two are in Table 8. The results are very similar to the ones of stratum one. This means that the compensating variation under exercise one is negative for all the households in this stratum. This means they are better under the optimal tariff schedule because of the lower marginal price and more income available to consume the numeraire. In exercise 2, as with stratum one, the marginal prices are higher than those observed in stratum two in 2014. Therefore, the compensated variation is positive, meaning the households are worse under these optimal tariffs.

5 Concluding Remarks

This paper replicates the methodology of (Szabo, 2015) to evaluate the effects of the free water policy in Bogotá, Colombia. To do this, the demand model developed by the author is used, adjusting it to the particular case of Colombia. The model is used to calculate the price elasticities, the counterfactual exercise, and to find the optimal tariff scheme that guarantees that the household in the aggregate consumes 12 Kl of water.

The estimates from the model's estimation are very similar to the ones from the original paper. The main takeaway from this part seems to be that the heterogeneity of households' water consumption is explained in most cases by the covariates and especially by the heterogeneity of expenditures, which is the measure of income used in this project.

Another takeaway from this part is that the model predicts the mean water consumption of all the samples but is deficient in predicting the mean consumption of the low-stratum households. It overestimates the consumption before the implementation of the free water policy and underestimates the expected water consumption after the policy's implementation. This raises concerns about how effective this model evaluates the policy, given that it is missing the mark in the main sub-samples of interest.

The price elasticities obtained in this paper are very different from those calculated by Szabo (2015); in Colombia, the price elasticities are very low in absolute value, while in South Africa, they are closer to one in absolute value. The Bogotá elasticities make more sense, given the size of the price estimate and the marginal effect. The consequence of these price elasticities is that they highlight the ineffectiveness of price-oriented policies in generating incentives to change water consumption in water utilities, as it was evident in the counterfactual exercise.

The results from the counterfactual exercise show that the effect of the free water policy in Bogotá is similar to that in South Africa. Szabo (2015) finds that the impact of the policy on consumption was low and that the policy worked as a lump sum transfer to the poorest households. This is the same case for the Colombian case; the change in consumption is between -0.5% to -0.1%, while the change in the water expenditure is between 64 to 65%, suggesting this policy's lump sum transfer nature.

The optimal tariff exercises were designed to find the schedules that guarantee the 12 Kl of water consumption bimonthly in the aggregate. The first exercise showed that there is an alternative price schedule that achieves this goal and improves social welfare. Still, given that households are not price-responsive regarding their water consumption, the initial marginal prices are nearly zero. The second exercise has the additional restriction that the price schedule needs to guarantee that the public utility provider recovers the marginal cost of the first 12 Kl of water. The resulting tariff schedule has marginal prices that are always higher than the observed ones; in this case, the households are always worse, which means that the free water policy is ineffective and burdens the public utility's budget.

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