Residential water price regulation: does equity matter? A case study in Granada (Spain)

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Abstract

In this paper we have used Latent Class Models to estimate residential water demands identifying several groups of consumers with different levels of water consumption and price elasticities. This paper introduces two different welfare functions to maximize social welfare: the utilitarian welfare function and the weighted utilitarian social welfare function. The proposed Increasing Block Tariff achieves the objectives of equity and water conservation while maintaining the revenue levels obtained by the water utility in 2011. Our analysis exploits data on residential water demand and consumers' preferences in the city of Granada, Spain.

JEL-Classification: Q21, Q23 and Q25
Keywords: water demand, water pricing, panel data, household microdata, latent class analysis.

1. Introduction

Water management is becoming a key issue as water is an increasingly scarce resource. This is of special importance in the South of Spain where they are regularly affected by water availability problems. These problems can be assesed by developing demand-side policies such as pricing.

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The Dublin Statement on Water and Sustainable Development (WMO, 1992) stated that "water has an economic value in all its competing uses and should be recognized as an economic good", therefore the pricing system must represent that value in order to avoid a wasteful use of water. Moreover, the Dublin Principles also set out that all human beings must have access to water at an affordable price. Water affordability has been emphasized also in the UN's Economic and Social Council (UN, 2002) and more recently, the study on water OECD (2009) has highlighted the importance of well-designed tariffs that allow poor and vulnerable groups have access to affordable water. However, there is a clear trade-off between equity and efficiency, as social prices could lead to significant inefficiencies.

Water pricing must be implemented fulfilling multidimensional requirements, that is, it is crucial that pricing achieves sustainability, equity and efficiency in use and full cost recovery (Boland and Whittington, 2000).

The assessment of water management is thus becoming an increasingly relevant area of research. To carry out such an assessment, the design of optimal tariffs in the residential water sector and the welfare effects linked to price reforms have been receiving increasing attention in recent years. Renzetti (1992) evaluated the efficiency gains from modifying the water pricing system in Vancouver, Canada, showing that a seasonally differenciated pricing based on a Ramsey framework (Ramsey, 1927) could lead to a welfare improvement. Rietveld et al. (2000) estimated household water demand in Indonesia to study the welfare consequences of a shift to uniform pricing, finding that the equity gains are not large and, therefore, they recommended measures such as giving low-income consumers access to water to improve equity. Similarly, Hajispyrou et al. (2002) analysed residential water demand in Cyprus and they found that switching from the existing increasing block pricing system to a uniform marginal cost pricing system would avoid the actual deadweight loss. Castro-Rodríguez et al. (2002) designed optimal two-part tariffs for the city of Vigo, Spain, which did not reduce current revenue levels and did not increase current consumption levels and allowed them to evaluate the equity of the existing increasing block pricing system. Garcia and Reynaud (2004) evaluated the pricing of water utilities in France and proposed a marginal-cost pricing. García-Valiñas (2005) analysed welfare effects of reforming water price systems in three Spanish cities, proposing two-part tariffs based on Ramsey (1927) and Feldstein (1972) optimal pricing schemes. Porcher (2013) proposed a shift to Coasian tariffs for French water utilities, however the efficiency gains obtained were not large.

Increasing block tariffs (IBT) have been often proposed as a useful pricing system for achieving a balance between efficiency and equity (Bithas, 2008). However, it is worthy to note that most of the papers in this literature propose two-part tariffs with a constant unit price, whilst the number of studies that have designed optimal block tariffs and their welfare effects is certainly small. Ruijs (2009) proposed several water tariffs and then the effects of the switch to the proposed tariffs, resulting in a zero welfare effect for the median consumer and budget neutral for the water utility were analysed. Meran and Hirschhausen (2009) compared a modified Coasian tariff and a progressively increasing block tariff focusing on the effects for low-income groups by using data from Bangladesh.Diakité et al. (2009) designed a nonlinear social tariff for residential water in Côte d'Ivoire, considering both efficiency and equity aims. The tariff entails a fixed fee for the first block of the tariff that satisfies a basic level of water consumption, and a nonlinear pricing rule for higher water volumes.

Nevertheless, none of those studies have considered heterogeneous demands in the design of optimal block-pricing and addressing the unobserved heterogeneity is crucial when analysing the effect of changes in residential water prices, as water demand functions rely on unobservable different preferences.

In this paper we implement a Latent Class Analysis to model the heterogeneity of water demand functions in a population. This technique allows us to identify a finite number of consumer "classes" within which individuals respond in a relatively similar way to the drivers of demand. Unlike other techniques, such as Cluster Analysis, which permit the identification of different groups in two stages, this methodology is a one-stage technique. Since it is a data-driven methodology, there is no need to have prior knowledge about these classes; the consumers demand and the probability of membership of a particular group are estimated simultaneously.

Latent Class Models (LCM) have attracted increased attention lately to control for unobserved heterogeneity and several studies have used this methodology to analyse demand in other research areas such as health economics (Deb and Trivedi, 2002; d' Uva, 2006; Ayyagari et al., 2013; Hyppolite and Trivedi, 2012), cultural economics (Boter et al., 2005; Fernandez-Blanco et al., 2009; Grisolía and Willis, 2012) or transport (Hensher and Greene, 2003; Shen et al., 2006; Shen, 2010; Hess et al., 2011; Greene and Hensher, 2013). Pérez-Urdiales et al. (2013) implemented latent class models to estimate heterogeneous water demand functions and define consumers groups with similar preferences. However, as far as we are aware, heterogeneous water demands estimated using Latent Class Models have not been used to design an optimal block pricing system.

Our application exploits a panel dataset from Granada (Spain), which contains information on bimonthly water consumption and prices for the period 2009-2011, as well as on socioeconomic variables and self-reported water conservation habits for 2011, which can be useful to control for individual heterogeneity. Four different residential water consumer profiles are identified. Once the water demand function is estimated by using LCM, two different welfare functions are considered to design alternative block tariff systems using the information obtained from the previous estimation. Finally, we examine the impact on social welfare of a change in the water tariff and the change in total bill for different levels of water consumption.

The paper has the following structure. In Section 2, the tariff structure in the city of Granada is described, paying special attention to the water tariff in 2011. Section 3 focuses on the estimation of water demand, presenting the econometric model, the data and the estimation results. Section 4 demonstrates the welfare maximising problem for two different welfare functions and presents the results from the simulation experiment and a comparison between the existing tariff and the simulated tariffs while Section 5 concludes summarizing the main results.

2. Residential Water Tariffs in Granada

The water pricing structure in Granada, as in most of the cities in Spain, is based on increasing block prices (IBP). In this case, the tariff[1]also includes a fixed water service fee that must be paid regardless of the level of use and a set of increasing block prices. The fixed component of the tariff includes a water supply fee, a sewage collection fee, and a treatment fee and, from 2009 to 2010, a drought surcharge. Additionally, in 2011 a water tax collected on behalf of the Regional Government was incorporated to the tariff.

As can be seen in Table 1, the price structure in Granada remained unchanged between 2009 and 2010, but in 2011 the size of the price blocks was altered.

Table 1: Evolution of the size of pricing blocks

Blocks	2009-2010	2011
Block 1	0-8 m^3	0-2 m^3
Block 2	8-10 m^3	2-10 m^3
Block 3	10-16 m^3	10-18 m^3
Block 4	16-30 m^3	>18 m^3
Block 5	>30 m^3	-

As water is becoming more and more scarce in the South of Spain, water supply managers are using price as a water conservation tool. As stated above, Granada experienced a change in the price structure that resulted in a decrease in average water consumption, but also an increase in the average total bill (Table 2).

Table 2: Evolution of the average total bill and the average quantity of water consumed

Blocks	2009	2010	2011
Water consumed (m^3)	15.4939	16.0069	15.2579
Total bill (€)	44.3969	45.0625	49.1680

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[1] The tariff also includes discounts to those who are unemployed, retired, or have a certain minimum number of dependants.

3. The estimation of heterogeneous water demand

This section is devoted to the estimation of the residential water demand as a prior step to the design of optimal social pricing systems. First, the econometric model is presented, followed by a data description and finally, the results are presented.

3.1. Methodology

From a methodological point of view, latent class models are proposed to identify different groups of consumers with similar preferences using observable variables and self-reported data from the survey.

In a latent class model, we assume that the sample of individuals is drawn from a population that is a finite mixture of C distint subpopulations (Cameron and Trivedi, 2005) such that:

$$f(y_i|\theta;\pi) = \sum_{j=1}^{C} \pi_j f_j(y_i|\theta) \qquad i = 1, ..., n \tag{1}$$

where π_j is the probability of choice j of individual i ($\sum_{j=1}^{C} \pi_j = 1$ and $\pi_j \geq 0 \;\; j = 1, ..., C$). The membership probabilities (π_j) are considered constant[2] across observations and are estimated simultaneously with the other parameters.

The mixture density in the normal mixture for individual i, i=1,...n is given by the following:

$$f(y_i|\theta;\pi) = \sum_{j=1}^{C} \pi_j \frac{1}{\sqrt{2\pi\sigma_j^2}} exp(-\frac{1}{2\sigma_j^2}(y_i - x_i\beta_j^2)) \tag{2}$$

Therefore, in order to choose among the different models, one must assess ex post their performance. Although there is no a priori need to sort individuals among classes, a key choice the researcher must make involves the number of the classes to consider. Models based on different numbers of classes will result in different degrees of goodness of fit. In order to evaluate the models, we use two different information criteria: the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC).

Once the model is estimated, we use the parameter estimates to compute the posterior probabilities of belonging to each latent class:

$$Pr[y_i \epsilon c|x_i; y_i; \theta] = \frac{\pi_c f_c(y_i|x_i;\theta_c)}{\sum_{j=1}^{C} \pi_j f_j(y_i|x_i;\theta_j)} \qquad c = 1, ..., C \tag{3}$$

Latent class models have two main advantages with respect to other techniques such as Cluster Analysis, which permits the identification of different

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[2] Membership probabilities can be further parameterized as a function of covariates using, for example, a logit function. However, if separating information is not available, extension of the model may be fraught with identification problems (Deb and Trivedi, 2002)

groups in two stages. First, unlike other two-stage techniques that feature an exogenous or *ad hoc* selection of the membership, this approach allows a data-determined and probabilistic assignment of the consumers across the groups, which avoids arbitrariness and sample selection bias. Additionally, mixture models can account not only for intercept but also slope heterogeneity across different groups of consumers, which represents an improvement over other techniques such as fixed effects and random effects models that only capture individual-specific effects in the constant term.

Latent class model estimation simultaneously models the demand function and classifies individuals into different consumers groups.

3.2. Data description

Our dataset comprises an unbalanced panel consisting of bimonthly observations corresponding to 1,465 households in the city of Granada for the period 2009-2011. The data come from two sources. The first source of information consists of water consumption and water tariffs data on a random and representative sample of urban households in the city of Granada, provided by EMASAGRA, the company in charge of water supply and sewage collection in Granada. The second one is a 2011 survey of these households, who were questioned about socioeconomic characteristics (occupation, household size), housing characteristics (size, equipment), attitudes towards the environment, and conservation habits.Table 3 shows some descriptive statistics for the variables included in the demand model. The variables used in our demand specification were:

1. Water consumption (explained variable): Household water consumption per two-month billing period, in cubic meters.

2. Price ($MagcP_{t-1}$ and *difference*): in order to correct for the bias associated with the simultaneous determination of price and the block of consumption, we include an instrumental marginal price in the demand function. That is, we perform a modification of the approach in Billings (1982), whereby we generate a constant marginal price and a difference variable by regressing the current amounts of the individual consumers' bills (TB_i) against their respective water quantities (Q_i) separately for each year and discount type but also for each neighborhood, i.e. we use a grouping approach (Grafton et al., 2011), since we expect that consumers within the same neighborhood may have a similar perception of the price, yielding:
$$TB_i = \alpha + \beta Q_i + u_i \tag{4}$$
where u_i is the residual term.
This instrumental marginal price is the slope of the estimated function and the Nordin-difference variable is the intercept. Therefore, by construction, the instrumental price allows for some variation across individuals and time. Once these variables are constructed, we select the one-period lagged marginal price. Since prices change every year, the one-period lagged price captures this change in the second two-month period every year.

3. Income (*highincome*). Household income was recorded as an ordered categorical variable, with households belonging to one of the following intervals (in Euros/month): [0-1100]; [1101-1800]; [1801-2700]; [2701-3500]; [3501-$+\infty$]. It would not be appropriate to use the interval categories as if they were values of a continuous variable. Usually, one would construct a set of five binary indicators of income level and introduce four in the model. However, because we did not seem to have enough sample variability to estimate all four corresponding parameters, we simplify our original income variable into a binary indicator of relatively higher income. In particular, we create a binary variable that identifies the richer households (those falling in the two highest income categories).

4. Household composition (*members*). Household size, defined as the number of members living in the household, is expected to be positively associated with water demand. According to Barberán et al. (2000), an increase in water consumption is frequently less than proportional to an increase in the number of members living in the household or population, therefore scales economies in water demand should be expected.

5. Ownership (*owner*). An indicator of home ownership is included as homeowners are expected to have more incentives than tenants to make investments in water-saving devices in the property as shown by Grafton et al. (2011).

6. Water conservation habits (*habits*). Following Beaumais et al. (2010), a water habit index was constructed by calculating the mean score on the answers related to the values of water use/conservation habits that were asked in the survey (possible answers were 1 = yes or 0 = no).

7. Seasonal effect (*summer*). In order to capture a seasonal effect, we include a binary indicator that takes value 1 for summer months (defined as May throught August) and 0 otherwise.

Table 3: Summary statistics

Variable	N	Mean	Std. Dev	Min	Max
water consumption	21050	15.5793	8.9574	1	64
difference	21050	0.4436	1.2555	-22.6907	29.5233
highincome	21050	0.1910	0.3931	0	1
MagcP_{t-1}	21050	1.2407	0.1539	0.1974	2.2842
members	21050	2.6813	1.2139	1	9
owner	21050	0.7468	0.4349	0	1
habits	21050	0.6156	0.1610	0	1
summer	21050	0.3493	0.4768	0	1

3.3. Results

As stated in the methodology section, to select the model with the number of classes that fits best the data, we estimated several latent class models increasing the number of classes and investigated the performance of the resulting likelihood-based model selection criteria, such as the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC).

These two information criteria are reported in Table 4 and show that the Latent Class Model is a more accurate specification than the OLS model, which forces all consumers to respond to the same pattern in terms of their water demand.

The selection criteria yield different recommendations. The BIC suggests that the 4-class model fits the distribution better, but the AIC suggests that the 5-class model is best. Since the difference in terms of likelihood-based criteria is relatively small and one additional class represents only 2.92% of the population, we chose the 4-class model as the most accurate for capturing consumer heterogeneity. The results confirm that household heterogeneity is important in the estimation of residential water demand in Granada.

Table 4: Selection criteria for several models

Model	Log likelihood	Degrees of freedom	Akaike information criterion	Bayesian information criterion
single class	-75211.39	8	150438.8	150502.4
2-class	-73753.8	19	147545.6	147696.7
3-class	-73435.42	29	146928.8	147159.5
4-class	-73277.05	39	146632.1	146942.3
5-class	-73236.48	49	146571	146960.7

Next, in Table 5, we present the results of the selected demand model. Most of the coefficients are significant and have the expected signs, however, the coefficients vary from one class to another indicating that individual heterogeneity is affecting both the intercept and the slope parameters, as confirmed by the likelihood-based criteria seen above.

Table 5: Estimated water demand models

	Class 1	Class 2	Class 3	Class 4
constant	3.3397*** (3.23)	11.1803*** (7.23)	20.3255*** (6.61)	49.8855*** (4.97)
$MagcP_{t-1}$	-0.1105 (-0.18)	-2.1280*** (-3.51)	-4.6404*** (-4.99)	-16.6101*** (-3.28)
difference	-0.0580 (-0.73)	-0.0597 (-0.67)	-0.3839*** (-3.07)	-0.1237 (-0.64)
highincome	0.1597 (0.67)	0.0370 (0.12)	-1.3386** (-2.22)	-4.8381*** (-4.17)
members	0.1250 (0.7)	1.5571*** (4.3)	2.6029*** (16.73)	2.1320*** (5.74)
owner	-0.2189 (-1.15)	0.4249*** (1.44)	-0.8548 (-1.49)	-2.7448*** (-3.35)
habits	1.6558*** (3.3)	-2.3487** (-3.09)	-3.0235*** (-4.19)	-3.7427** (-1.98)
summer	1.1867*** (5.47)	1.3280*** (7.3)	1.4292 *** (3.86)	0.5822 (0.74)
observations	21050	21050	21050	21050
Mean posterior probability	0.1087	0.5149	0.3208	0.0556
Average water consumed (m^3/2-month)	3.7490	11.6169	22.1688	37.3570

Robust t-statistics are in parentheses

* Significant at 10% level.

** Significant at 5% level.

*** Significant at 1% level.

Price elasticities are computed from the estimates. As can be seen in Table 6, we find that for the first class price has no significant impact on residential water demand. The first class is the one with the lowest average water consumption, thus, we can consider that this class represents the group of households consuming the basic amount of water that is not sensitive to changes in prices. In contrast, for the other classes, price is significant but the price elasticities are different among the classes, being the fourht class (i.e., the class with the highest average water consumption), the one with the most elastic water demand.

Table 6: Price elasticities of demand

Classes	Price elasticity
1st class	-0.0512
2nd class	-0.2614*
3rd class	-0.2717***
4th class	-0.5590***

4. Nonlinear pricing and welfare

In this section, the three approaches followed for designing an optimal social pricing system are presented.

In order to address this problem, an ethical criteria derived from the Utilitarian theory is employed and two different welfare functions are used: the standard utilitarian social welfare and the weighted utilitarian social welfare.

4.1. The standard utilitarian social welfare function

In utilitarianism and hence, welfare economics, social welfare is computed as an aggregation of individual utilities (Perman et al., 2011) and each individual in the society is treated equally, regardless of their level of utility, that is, one extra level of utility of an individual consuming below the basic amount of water does not have a greater value than one extra level of utility of an individual consuming an extremely high amount of water.

Considering a society consisting of the four groups of individuals that have been identified in Section 3.3, four inverse demand functions can be specified:

$$pi(xi) = \alpha_i - \beta_i x_i \qquad i = 1, ..., 4 \tag{5}$$

where x_i is the quantity consumed and p_i is the price.

The additive utilitarian social welfare function is determined by a function of the form:

$$W = U_1 + U_2 + U_3 + U_4 \tag{6}$$

Formally, using the welfare function (6) and substituting by the four inverse demand functions, the first alternative price scheme is obtained from the following optimization problem:

$$
\begin{aligned}
\underset{p_1,p_2,p_3,p_4}{\text{maximize}} \quad \mathrm{W^U} = {} & CS_1 - A + CS_2 - A + CS_3 - A + CS_4 - A = \\
& \int_0^{X_1} (\alpha_1 - \beta_1 x - p_1)dx - A + \\
& \int_0^{X_2} (\alpha_2 - \beta_2 x - p_2)dx + (p_2 - p_1)X_1 - A + \\
& \int_0^{X_3} (\alpha_3 - \beta_3 x - p_3)dx + (p_3 - p_2)X_2 + (p_2 - p_1)X_1 - A + \\
& \int_0^{x_4} (\alpha_4 - \beta_4 x - p_4)dx + (p_4 - p_3)X_3 + (p_3 - p_2)X_2 + \\
& (p_2 - p_1)X_1 - A = \alpha_1 X_1 - \beta_1 X_1^2/2 - p_1 X_1 - A + \alpha_2 X_2 - \\
& \beta_2 X_2^2/2 - p_2 X_2 + (p_2 - p_1)X_1 - A + \alpha_3 X_3 - \beta_3 X_3^2/2 - \\
& p_3 X_3 + (p_3 - p_2)X_2 + (p_2 - p_1)X_1 - A + (\alpha_4 - p_4)^2/2\beta_4 + \\
& (p_4 - p_3)X_3 + (p_3 - p_2)X_2 + (p_2 - p_1)X_1 - A
\end{aligned}
\tag{7}
$$

subject to

$$
\begin{aligned}
& \pi_1(p_1\bar{x_1} + A) + \pi_2(p_2(\bar{x_2} - X_1) + A) + \pi_3(p_3(\bar{x_3} - X_2) + p_2(X_2 - X_1) + \\
& p_1 X_1 + A) + \pi_4(p_4(\alpha_4 - p_4)/\beta_4 - X_3) + p_3(X_3 - X_2) + p_2(X_2 - X1) + \\
& p_1 X_1 + A) >= \overline{TR}
\end{aligned}
\tag{8}
$$

where p_1,p_2, p_3 and p_4 are the per unit prices in the first, the second, the third and the fourth block respectively; X_1, X_2 and X_3 are the kink points[3]; x_4 is the water demand for consumers in the fourth block when the price is p_4 and is defined as $(\alpha_4 - p_4)/\beta_4$; π_1, π_2, π_3 and π_4 represent the probabilities of belonging to each class that have been previously estimated in the Latent Class Model; A is the fixed charge and $\overline{TR}$ is the total revenue obtained by the water utility in 2011[4].

As we do not have information about the costs, following Castro-Rodríguez et al. (2002),we assume that the water utility was covering costs in 2011. Therefore, we maximize the welfare of consumers, subject to the maintenance of the water utility's revenue levels.

4.2. The weighted utilitarian social welfare function

The previous social welfare function may not be egalitarian since utilitarianism does not carry any assumption about the relative position of a consumer in the society. However, water is a scarce natural resource and high levels of water consumption may reduce social welfare in the long-run.

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[3] The kink points are set by rounding up the average water consumption in each class to the upper integer

[4] The same notation will be used for the weighted utilitarian social welfare function

Therefore, social welfare can be defined as a weighted sum of individual utilites

$$W^U = w_1U_1 + w_2U_2 + w_3U_3 + w_4U_4 \tag{9}$$

w_1, w_2, w_3 and w_4 being the weights that reflect the relative social value of increases in water consumption (Schulz, 2008). These weights satisfy the non-negativity constraint and sum up to one. In this special case, the optimization problem is formulated as follows:

$$\begin{aligned}\underset{p_1,p_2,p_3,p_4,w_1,w_2,w_3}{\text{maximize}} \quad & \mathrm{W^U} = w_1(\alpha_1X_1 - \beta_1X_1^2/2 - p_1X_1 - A)+ \\ & w_2(\alpha_2X_2 - \beta_2X_2^2/2 - p_2X_2 + (p_2 - p_1)X_1 - A)+ \\ & w_3(\alpha_3X_3 - \beta_3X_3^2/2 - p_3X_3 + (p_3 - p_2)X_2+ \\ & (p_2 - p_1)X_1 - A) + w_4((\alpha_4 - p_4)^2/2\beta_4 + (p_4 - p_3)X_3+ \\ & (p_3 - p_2)X_2 + (p_2 - p_1)X_1 - A)\end{aligned} \tag{10}$$

being equation (8) the budget constraint.

4.3. Implementation

In this section we present the optimal solutions in the two welfare approaches defined in sections 4.1 and 4.2. Next, we compare the existing water tariff in 2011 and the two simulated water tariffs to evaluate the changes in social welfare.

Table 7 and Figure 1 present the bounds and the block prices of the three tariffs.

4.3.1. Tariff 1

Tariff 1 is the actual water tariff in Granada in 2011, with an increasing-block structure, as explained in section 2.

4.3.2. Tariff 2

Tariff 2 consists of 4 blocks that are obtained from the maximization of the Utilitarian social welfare function described in section 4.1. As seen in Table 7, increasing prices are not obvious when the Utilitarian social welfare function is used. A similar result was found by Schulz (2008).

4.3.3. Tariff 3

This tariff is calculated by including different distributional weights for each consumer surplus in the social welfare function as stated in section 4.2 and it also consists of 4 blocks. As detailed above, households pay only a fixed fee for water consumption levels up to 4 m^3/2-month period. This result is in line with Diakité et al. (2009) who implemented only a fixed fee for the lowest consumption block in the simulated water tariffs. The second block ranges from

4m^3/2-month period to 12 m^3/2-month period and its unit rate is 1.6079€. The third block corresponds to volumes between 12m^3/2-month period and 22m^3/2-month period and it has a unit price of 3.4067€. Finally, for the fourth block, that is, beyond 22m^3/2-month period, the marginal price is 5.3533 €. Regarding the weights that reflect the relative social values of increases in the water use, the weights obtained from the optimization problem are similar to those imposed in a Rawlsian social welfare function. The weight for the group with low water consumption tends to unity whereas the weights for the remaining classes tend to zero. Adapting the Rawlsian social welfare function to this specific case, the water utility's welfare maximization problem is pruned to maximize the consumer surplus of the households with a basic level of water use.

Table 7: Actual and proposed water tariffs

Block size	€/ m^3	Block size	€/ m^3	Block size	€/ m^3
Tariff 1		Tariff 2		Tariff 3	
(water tariff in 2011)		(Utilitarian)		(Weighted Utilitarian)	
0-2	0.9731	0-4	0	0-4	0
2-10	1.3536	4-12	3.4220	4-12	1.6079
10-18	2.3534	12-22	0.1812	12-22	3.4067
>18	3.4347	>22	0.1050	>22	5.3533

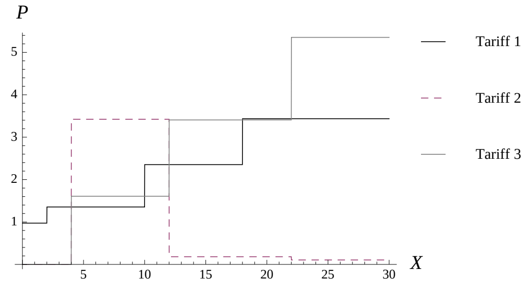

Figure 1: Water tariffs

4.3.4. Welfare Analysis

In order to evaluate changes in social welfare, we perform a modification of the approach in Diakité et al. (2009). First, we analyse consumer welfare from the consumer surplus for a representative household (see appendix).

Table 8 presents the welfare measures computed for each tariff and the percentages of welfare change associated with the switch from Tariff 1, i.e. , the existing tariff to Tariff 2 and 3. The tariff with the highest consumer surplus is

Table 8: Welfare changes for a representative household

Tariff	Consumer surplus	Welfare loss	Welfare change (%)
Tariff 1	115.616	-	-
Tariff 2	140.043	-24.427	21.13%
Tariff 3	120.031	-4.415	3.82%

Tariff 2, that is, the one obtained using and utilitarian social welfare function. As explained before, this social welfare function does not reflect te society's judgement of the relative worth of each household's utility, therefore it treats individuals equally regardless of their level of water consumption.

The consumer surplus obtained from Tariff 2, that is, using a weighted utilitarian social welfare function, is also higher than the one obtained from Tariff 1. Moreover, the percentage of welfare change is in the range of the ones obtained by Garcia and Reynaud (2004) and Diakité et al. (2009).

Finally, total bills for different levels of water consumption for each tariff are presented in Table 9. Total bill is computed as the quantity of water consumed by the correspondent unit price plus the fixed fee, that remains unchanged across tariffs. As expected, the switch from the existing tariff to Tariff 2 harms households consuming from 7 m^3/2-month period to 16 m^3/2-month period of water, whereas the total bill for those households consuming beyond 16 m^3/2-month period becomes extremely low.

The introduction of Tariff 3 implies a reduction in total bill for those households consuming from 1 m^3/2-month period to 16 m^3/2-month period. However, this simulated water tariff penalizes high levels of water consumption discouraging wasteful or unreasonable use of water. Therefore, the introduction of Tariff 3 does not suppose an improvement for all households, but it implies an efficiency improvement.

Table 9: Total Bill for different levels of water consumption

m^3	Total bill (€) Tariff 1	Total bill (€) Tariff 2	Total bill (€) Tariff 3
1	5.0110	4.0379	4.0379
2	5.9841	4.0379	4.0379
3	7.3377	4.0379	4.0379
4	8.6913	4.0379	4.0379
5	10.0449	7.4599	5.6458
6	11.3985	10.8819	7.2537
7	12.7521	14.3039	8.8616
8	14.1057	17.7259	10.4695
9	15.4593	21.1479	12.0774
10	16.8129	24.5699	13.6853
11	19.1663	27.9919	15.2932
12	21.5197	31.4139	16.9011
13	23.8731	31.5951	20.3078
14	26.2265	31.7763	23.7145
15	28.5799	31.9575	27.1212
16	30.9333	32.1387	30.5279
17	33.2867	32.3199	33.9346
18	35.6401	32.5011	37.3413
19	39.0748	32.6823	40.7480
20	42.5095	32.8635	44.1547
21	45.9442	33.0447	47.5614
22	49.3789	33.2259	50.9681
23	52.8136	33.3309	56.3214
24	56.2483	33.4359	61.6747
25	59.6830	33.5409	67.0280
26	63.1177	33.6459	72.3813
27	66.5524	33.7509	77.7346

5. Conclusion

In this paper we have used Latent Class Models to estimate residential water demands identifying several groups of consumers with different levels of water consumption and, consequently, different responses to changes in prices. This more accurate information has allowed us to maximize social welfare using a utilitarian social welfare function and a weighted utilitarian social welfare function, distinguishing groups of consumers.

Our results show that Increasing Block Prices are not obvious when the utilitarian social welfare function is used, as this social welfare function treats individuals equally regardles of their level of water consumption,i.e., is indifferent to the distribution of satisfaction between households. However, by using the weighted utilitarian social welfare function, we obtained a progressive tariff if the weights are similar to those used with a Rawlsian social welfare function, i.e., when the maximization problem is pruned to maximize the consumer surplus for the group with a basic level of water consumption.

The main implication of our study is that a better and more flexible pricing system can be achieved by classifying households in different groups. By using the weighted utilitarian social welfare function, we have proposed an Increasing Block Tariff that achieves the goals of equity, water conservation and full cost recovery. The first block in this tariff is a ”social” block in which households pay only a fixed fee for the first cubic meters of water that are mainly for essential uses, i.e., those households with lower incomes. The prices for the remaining blocks are higher, penalizing a wasteful or unreasonable use of water. Finally, this form of cross-subsidization also allows the water utility to break-even.

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Appendix

A representative household of type θ that faces a tariff system such as $\widetilde{p} = (b, p_i)_{i=1,\dots,b}$ where b is the number of blocks and p_i is the unit price in block i. Formally, the consumer surplus of the representative household is defined as:

$$U(p,\theta) = \sum_{i=1}^{b} \pi_i \int_{p_i}^{p_{i+1}} q(p_i,\theta,z) + \pi_b \int_{p_b}^{\infty} q(p_i,\theta,z) \tag{11}$$

where $q(p_i,\theta,z)$ is the demand function for each block and π_i is the proportion of households in a given block, i.e., households consuming up to block i. For the existing tariff, the proportion of households in a block is observed from the data and, for the proposed tariffs, they are defined as the probability of belonging to a certain class, obtained from the estimation of the residential water demand.

The Consumer Surplus variation is given by the difference of the consumer surplus for the existing tariff and the simulated.