ESTIMATING THE DEMAND FOR RESIDENTIAL WATER IN A STONE-GEARY FORM INCLUDING A PRICE PERCEPTION VARIABLE[1]

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Abstract. W*e investigate which water price specification should be included in an econometric analysis of residential water demand derived from a Stone-Geary utility function. Using a non nested model specification developed by Davidson and McKinnon (1981), we develop a general residential water demand function which includes a price perception parameter. Thus, the residential water demand estimation allows to identify the price to which the consumer actually responds. Using a detailed survey data concerning the French overseas territory of Réunion characterized by an increasing block rate schedule, the perceived price parameter is estimated to be 1.97 and is statistically different from zero. We conclude that households perceive a price of water that is generally lower than its actual marginal price. This conclusion emphasizes the relevance of a marginal price information policy to promote water saving.*

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1. INTRODUCTION

To promote efficient water use, water authorities need to know what price variable consumers are responding to. Indeed, a large empirical literature aims at obtaining consistent values of price elasticity of demand to analyze the relevance of a pricing policy to manage water consumption. Two important issues have been addressed in the literature, concerning the functional form of the demand function and the water price specification, as pointed out in the recent surveys available in the literature (Arbuès et al (2003), Dalhuisen et al (2003), Worthington and Hoffman (2008), Nauges and Whittington (2010)).

First, most of the earlier studies in water demand have chosen simplicity, using linear or double-log specifications. But recently, since Gaudin et al. (2001) and Martinez-Espineira and Nauges (2004), a few articles have derived the water demand function using a Stone-Geary utility function (see Dharmaratna and Harris (2010) and Madhoo (2009)). The main attractive feature of such a specification is that it allows total residential water consumption to be broken down into two constituent parts. The first is the incompressible part, which may be interpreted as a minimum required water consumption which covers essential needs. This part thus provides an estimate of the portion of water that may not be responsive to price, and may also be useful in designing a social pricing of water. The second component of total water consumption is the variable part which depends on income and price levels. And, water pricing policies can only influence the variable part of water consumption, in the short-run.

Second, the water tariff structure is often complex with increasing or decreasing block rates and fixed charges. Therefore, one important issue in the literature is to provide an adequate specification of the price variable in residential water demand models. The discussion generally focuses on the adequacy of using the average or the marginal price. A perfectly informed consumer should react to marginal price (in addition to Nordin's difference variable). But in case of price illusion or incomplete information, the consumer can react to other price indicator as the average price.

To date, the determination of the price variable to which consumers respond has been tackled as an empirical issue. Howe and Linaweaver (1967) were the first to discuss and compare average and marginal prices for water demand analysis. In a first approximation, the price providing the best fit is presumed to be the price perceived by consumers (see Foster and

Beattie (1981)). Ruijs et al. (2008) provide a recent study comparing the use of average versus marginal prices in water demand modeling.

Next, to our knowledge, two other empirical methodologies have been implemented to explicitly compare price variables. Opaluch (1982) was the first to devise a test of whether consumers respond to marginal or average price in a linear demand for residential water when faced with block rates. Unfortunately, this test can lead to the rejection of both water price assumptions by preventing one from discriminating between these two price definitions, as occured in the study of Ruijs et al. (2008) for example. The second test was suggested by Shin (1985) to analyze residential electricity demand of households faced with a declining block rate schedule. The test is based on a specification of the electricity price perception, which is a weighted geometric average of marginal and average prices, to be introduced in a double-log demand specification. Using this methodology, Nieswiadomy and Molina (1991) and Binet et al. (2012) analyzed the perception price issue in a residential water demand with a log-log specification. But, to the best of our knowledge, no one has developed a price perception model for residential water demand in a Stone-Geary form.

This paper first intends to contribute to the literature on empirical residential water by providing a generalization of the procedure developed by Opaluch (1982) using a non nested test developed by Davidson and Mc Kinnon (1981, 2004). This general specification is based on a linear combination of two residential water demand specifications, using average and marginal prices. Thus, the relevant price perception specification can be identified by estimating and testing the value of the price perception parameter which also is a nesting parameter. The perceived price specification is superior to existing models which use marginal or average price, because it allows consistent estimations under any behavioral hypothesis.

The second originality of this paper is to introduce one perception price parameter in a residential water demand derived from a Stone-Geary utility function. And, following the translating method developed by Pollack and Wales (1981), one way to propose a better empirical specification and to reduce unexplained variation in consumption behavior is to postulate that the parameter measuring the minimum required water consumption is a function of the characteristics of the household. This specification thus also provides one useful tool for a social pricing of water. Indeed, the estimated minimum required water consumption helps to choose the length and the determinants of a first consumption block covering essential needs, with a low unit price.

Third, we use a unique micro data set collected on an island where the use of water resources has become a source of increasing controversy. Our sample contains 449 useful water bills (between 1 and 3 water bills per household) collected from a household survey in the French overseas territory of Réunion. We have time unbalanced panel data as residential water consumption is observed for durations and periods of time that change across the surveyed household.

Using GMM estimator that accounts for both endogeneity of the price variable, and non linear coefficients, our main finding is that the perceived price parameter is different from zero and equal to 1.97. We conclude that consumers react to a price which turns out to be smaller than the price paid in the case of perfect information, namely the marginal price. The conclusions that we draw from this empirical study also have innovative implications for policy analysis. In the case of imperfect information and increasing block rates, an effective water saving policy can consist in improving consumer's price information, i.e. by providing households information about the marginal price they pay on their water bill.

Finally, using our econometric results, we assess by simulation the magnitude of the impact of such an information pricing policy on water conservation. Our simulation shows that if households set their water demand according to marginal price instead of perceived price, then average water consumption would decline substantially.

This paper proceeds as follows. In section 2, the model specification is presented. Section 3 describes the data used in our empirical application. Section 4 examines and discusses the empirical results. Section 5 concludes by outlining recommendations intended to improve the information provided to households on the cost of water, thereby allowing them to rationally respond to pricing policies aiming to promote household water saving behavior.

2. WATER DEMAND SPECIFICATION

First, we describe the pricing modeling. We then present the water demand specification and describe the translating method.

2.1 Pricing model in the literature

On Réunion island, as in numerous other locations, the pricing of residential water consists of several increasing consumption blocks (between 1 and 4 depending on the municipality considered). In the literature, generally two different measures of water price can be used in the demand function for such a good subject to a block pricing structure.

If consumers are well informed, they will respond to marginal price. To simplify the presentation, consider a block rate schedule consisting of two consumption blocks with increasing prices π_1 and π_2 and a fixed charge F. The consumer's budget constraint can be written as follows:

(1) $F + \pi_1 q + p_x X = Y,$

if the consumer's actual water consumption, denoted by q, is located in consumption block 1 and as:

(2) $F + \pi_1 b_1 + \pi_2 (q - b_1) + p_x X = Y,$

if q is located in consumption block 2, with b_1 the highest consumption level in block 1. p_x and X are respectively a price index and the corresponding consumption of other private goods, while Y is the household income.

According to Nordin (1976), in both cases the budget constraint can be rewritten as a standard budget constraint of the form:

(3) $\pi q + p_x X = Y - F + D$

with

(4) $D = \begin{cases} 0, \text{ if } 0 \le q \le b_1 \\ (\pi_2 - \pi_1) b_1 > 0, \text{ if } q > b_1 \end{cases}$

and π is the "marginal price" of water, namely: either π_1 if $0 \le q \le b_1$ or π_2 if $q > b_1$. This formalization can be easily generalized to the case of a multi block rate schedule as we will see in subsection 2.2.

Formula (3) claims that a perfectly informed water consumer should react not only to marginal price, but also to changes in intra-marginal prices through an income increase measured by Nordin's difference variable *D*, expressing the refunding to which the consumer is entitled whether he had paid his entire water consumption at the marginal price.

However, consumers may not be aware of the block pricing structure as this information often is not available in the water bill. And even if it the case, it may be costly for consumers to determine the actual rate they pay for one additional unit consumed. Therefore, most consumers might not respond to marginal price. Under this hypothesis, in many studies, authors suppose that consumers may respond to average price, which can be identified from typical water bills. Average price can be expressed as:

$$(5)\ \bar{\pi} = \frac{\pi_1 b_1 + \pi_2 (q - b_1)}{q}$$

if we suppose the fixed part influences water consumption through an income effect. Indeed, as discussed by Taylor et al. (2004), the fixed charges are subtracted from the total bill to compute the average price to prevent bias in the estimated price elasticity

(5) can be rewritten as:

$$(6)\ \bar{\pi} = \pi_2 + \frac{(\pi_1 - \pi_2) b_1}{q} = \pi_2 - \frac{D}{q}$$
.

Therefore, $\bar{\pi} < \pi_2$ when Nordin's $D > 0$.

To test the two alternative measures of price (average or marginal prices), Opaluch (1982) employed the decomposed measure of average price (6) in a linear residential water demand function, and allowed separate coefficients to be estimated on each of the component, namely c_1 and c_2. The corresponding demand specification can be expressed as:

$$(7)\quad q = c_0 + c_1 \pi_2 + c_2 [\frac{(\pi_1 - \pi_2) b_1}{q}] + c_3 (y - (\pi_1 - \pi_2) b_1) + X\beta + \varepsilon$$

Where c_0, c_1, c_2, c_3 are coefficients to be estimated.

Thus, Opaluch (1982) developed the two following tests:

Test 1	*Test* 2
$\mathrm{H}_0 : c_2 = 0$	$\mathrm{H}_0 : c_1 = c_2$
$H_1 : c_2 \neq 0$	$H_1 : c_1 \neq c_2$

Therefore, if the null hypothesis of test 1 is not rejected while that of test 2 is rejected, the data are consistent with consumer reaction to marginal price. Or, if the null hypothesis of test 2 is not rejected while that of test 1 is rejected, thus consumers appear to react to average price. Unfortunately, if both hypotheses are rejected, we observe indeterminancy by preventing one from discriminating between these two price specifications.

To solve such an indeterminancy, we propose to generalize Opaluch's specification using an additional *k* parameter, in a water demand function derived from a Stone-Geary form.

2.2 Residential water specification in a Stone-Geary form

a) *Stone-Geary form*

We specify the consumer's utility function in the following Stone-Geary form: $U(q,x) = \beta \ln(q - m_q) + (1-\beta)\ln(x - m_x)$.

The assumptions of this function are strong separability, the adding-up restriction, positive marginal budget share β and $q > m_q$ *and* $x > m_x$.

m_x is often considered as a subsistence level of consumption. m_q can be regarded as a minimum required water consumption. Then, residential water demand function is derived from the following program $MAX\ U(q,x)$ subject to $Y = p_q \mathrm{q} + p_x \mathrm{X}$:

$$(8) \quad \mathrm{q} = m_q + \beta \frac{(Y - p_q m_q - p_x m_x)}{p_q}$$

(8) can be rewritten as:

$$(9) \quad \mathrm{p_q q} = p_q m_q + \beta(Y - p_q m_q - p_x m_x)$$

where p_q is the residential water price variable perceived by consumer (marginal or perception price).

This specification is a (simplified) linear expenditure system (LES) if we consider only two goods (water consumption and other consumption goods). This specification has the advantage of being compatible with theory while explicitly modelling a minimum level of consumption, irrespective of the price of the consumed good or the consumer's income. The consumer first purchases the minimum level of each good, and the left-over income then is allocated in a fixed proportion β to the demand for residential water. Since a part of residential water consumption covers essential needs, the LES specification is particularly well suited to account for this feature.

In the general case (with n substitutes goods), the LES is a system in which expenditures on individual commodities can be expressed as *n* linear functions of income and prices. However, at the empirical level, we estimate a system of n-1 equations. Then, as we only consider two goods here, and considering the adding-up restriction, we simply have to estimate the residential water demand function. As we are only interested in the demand for water consumption, and without spatial variation for p_x, we suppose that the minimal value of other consumption goods can be incorporated in parameter γ:

$$(10) \qquad \mathrm{q} = m_q + \beta \frac{(Y - p_q m_q - \gamma)}{\mathrm{p_q}}$$

In the literature, to our knowledge four other recent articles have used such a specification to analyze residential water consumption, Dharmaratna and Harris (2010), Madhoo (2009), Martinez-Espineira and Nauges (2004) and Gaudin et al (2001) using marginal or average prices.

b) Generalization of Opaluch's test

If we suppose residential water consumption is in block *j*, $b_{j-1} < q < b_j$, the specification can be expressed as

$$(11) \qquad \bar{\pi}_{\mathrm{j}}\mathrm{q} = \bar{\pi}_{\mathrm{j}} m_q + \beta\,(Y - F - \bar{\pi}_{\mathrm{j}} m_q - \gamma)$$

if we consider average price $\bar{\pi}_{\mathrm{j}} = \pi_j - \frac{D_j}{q}$ or:

(12) $\pi_j q = \pi_j m_q + \beta(Y - F + D_j - \pi_j m_q - \gamma)$ if we retain the marginal price π_j, with $b_0 = 0 < b_1 < ... < b_j$ and $D_j = \sum_{l=2}^{j} (\pi_l - \pi_{l-1}) b_{l-1}$ the Nordin's difference variable.

Following Davidson and Mc Kinnon (1981, 2004), we can build a more general model using a linear combination of (11) and (12):

(13) $k\overline{\pi}_j q + (1-k)\pi_j q = \pi_j^* q$

where k is a nesting parameter and

(14) $\pi_j^* = k\overline{\pi}_j + (1-k)\pi_j$.

According to (14), we see that the perception price can be rewritten as:

(15) $\pi_j^* = \pi_j - k\dfrac{D_j}{q}$.

k is the price perception parameter as it directly measures the degree of price perception: facing a complex tariff schedule, the consumer may have a partial knowledge of it, and the perception price may include one fraction only of the difference variable. More precisely, as shown in (14), the perception price is a weighted average of marginal and average prices.

Finally, introducing (11) and (12) in (13), we obtain the following econometric specification to be estimated:

(16) $\pi_j^* q = \pi_j^* m_q + \beta(Y - F + (1-k)D_j - \pi_j^* m_q - \gamma) + \varepsilon$

where ε is the error term.

If k is equal to zero, we conclude that consumers respond to marginal price π_j whereas if k is equal to one, they respond to average price $\overline{\pi}_j$. And according to (15), we see that $\overline{\pi}_j < \pi_j^* < \pi_j$ if $0 < k < 1$, that $\pi_j^* > \pi_j$ if $k < 0$ and $\pi_j^* < \overline{\pi}_j$ if $k > 1$.

The income elasticity of demand may be written as: $E(q/Y_m) = \dfrac{\beta}{\omega}$ with $\omega = \dfrac{p_q q}{Y}$.

In addition, price elasticity is:

$$E(q/\pi_j^*) = \frac{-\beta(Y-F)}{\pi_j^* q} = -1 + (1-\beta)\frac{m_q}{q} \text{ for perception price } \pi_j^*.$$

or $E(q/\pi_j) = \frac{-\beta(Y - F + D_j - \pi_j b_{j-1})}{\pi_j q}$ for marginal price π_j.

Thus, the income elasticity is always positive since the marginal budget share β is positive. Furthermore, as $0 < \beta < 1$, price elasticity is greater than -1 and the demand is inelastic.

2.3 Translating method

Pollack and Wales (1981) developed the translating method in a demand specification to allow subsistence parameters to depend on demographic variables. Using a Stone-Geary form, Martinez-Espineira and Nauges (2004) and Gaudin et al (2001) also implemented this method, assuming parameter m_q to be a linear function of exogeneous variables that have been showed to be of significance to estimate the demand for residential water.

The introduction of variables to explain the minimum required water consumption is a good tool for a proposal for social pricing of water in Réunion, i.e. to build a first consumption block with a low unit price. Indeed, The minimum required water consumption covers essential needs, thus includes within-home uses (drinking, showers and bathing, washing and other cleaning uses) which depends on the size of the family. The threshold may also include a part of outside of the home uses, linked with the presence of the garden. Therefore, m_q can be defined by the following system of equations (17-19):

(17) $\mathrm{m_q} = \alpha_1 N_c + \alpha_2$ Garden

The presence of a garden is defined as a dichotomous variable that takes the value of one if the family has a garden, zero otherwise. The presence of a garden is an important factor as 77% of households leave in a house with a garden in Réunion against 30% in metropolitan France, in 2004. We would have liked to use data giving the size of the garden to improve our specification, but our data set gives only information on the presence or not of a garden.

Following Binet et al. (2012), the size of the population of water users can be differentiated by distinguishing the number of childs from the number of adults *NA*:

(18) $\mathrm{N_c} = NA + \delta_1$ CHILD

If we consider the needs of daily life, intended for the whole of the family, we expect that the water consumption will increase with the household size. But, we expect a lower impact of an additional child.

Climate conditions can determine the amount of lawn and garden watering. As a great proportion of households has a vegetable garden, equation (19) enable us to include these climatic effects on consumption:

(19) $\alpha_2 = \alpha_{20} + \alpha_{21}$ Weather

The weather variable is measured as the percentage of non rainy days over the billing period.

$\alpha_1, \alpha_{20}, \alpha_{21}, \delta_1$ are the parameters to be estimated (with β, γ *and k)*. Equations (17-19) are substituted in the water demand function (16) to obtain one equation with non linearity in parameters.

3. HOUSEHOLD SURVEY ON REUNION ISLAND

The analysis is based on a unique survey dataset covering the entire territory of Réunion island. We first offer a description of the survey and then introduce the data selected for empirical analysis.

3.1 Household survey

Réunion, a French overseas territory lying in the Indian Ocean, is 70 km long and 50 km wide, with the population in 2004 estimated to be approximately 700,000 inhabitants. In 2004, a great part of the population was quite young (40% are under 40 years old). Furthermore, the population growth rate and the unemployment rate (about 30%) are both high. The climate is rather humid and tropical. The rainy season (from December to April) follows the dry season (from May to November). Rainfall differs considerably according to the geographical location: the northeast of the island receives about 70% of the total rainfall. Urban development mainly occurs in the northwest of the island, where the weather is dry. Lastly, household use of water in 2004 appears quite high, as the daily water consumption level on

Réunion, computed with aggregate data, is 269 litres per inhabitant compared to an average of 150 litres on mainland France, Coutelier and Le Jeannic (2007).

Water therefore has become the source of increasing controversy on Réunion because supply is failing to meet demand in many areas, especially in the western part of the island. In this context, the *Regional Directorate for the Environment* (DIREN) was given the important job of setting up an overall water management system based on a law passed in 1992 intended to secure the future provision of water on Réunion. The long term objective of the water management plan is to reduce water consumption by 30% over 20 years (or about 1.32% per year).

This paper analyzes the data of a survey sample performed on Réunion on behalf of the *Regional Directorate for the Environment*. The objective of the survey was to identify the reasons for the comparative over-consumption of water by island inhabitants compared to those on mainland France. The stratified random survey was financed by DIREN and conducted in 2004 on a sample of households living on Réunion. The survey was designed as a proportionate stratified random survey according to municipalities, on a sample of 2,000 households representing 1% of the total household population of Réunion. The questionnaire included 25 questions concerning:

- Household socio-economic characteristics (sex, family head age and occupation, family income and size, number of working adults and children, and if they are property owners or tenants).
- Housing characteristics (detached house or flat, age, number of rooms, altitude).
- Water consumption equipment (swimming pool, washing machine, dishwasher, garden ownership).
- Consumption habits (washing frequency, business activity at home to verify that only domestic users are targeted).

Carried out by telephone, this first step survey was followed by a mailing to 1000 volunteer households intended to collect information on the volume of water consumption displayed on the last three bills that they had received (covering one year). Unfortunately, this second step survey provided 173 reliable responses supplying us with 449 useful water bills. Since the billing period varies across municipalities, consumption data were converted to a daily consumption per household (in litres). Corresponding daily weather indicators as precipitation, temperature were taken from Meteo France Agency.

3.2 Description of the variables

a) Price of water

Data on rates and on the length of consumption blocks were available from DIREN. The block rate schedule varies across municipalities (between 1 and 4 consumption blocks). When the fixed portion of the bill is removed, the average variable price includes only the portion which varies with consumption.

b) Household income

The DIREN survey recorded household income level[2] as an ordered qualitative variable, namely as belonging to one of the following five income intervals (in Euros per month): [0;750], [750;1500], [1500;3000], [3000;4500] and [4500; $+\infty$].

Unfortunately, this income information is not relevant to estimate the income elasticity of the water demand specification. Therefore, we used a quantitative estimate of the household income levels developed by Carlevaro et al. (2007). These estimates are based on an econometric model describing the observed qualitative information on household income according to an ordered polychotomous econometric model, where the unobserved household income level is specified as a latent variable. This unobserved variable is assumed to be distributed, within the household population, according to a log-normal random variable. Furthermore, the household income distribution is influenced by some household income indicators, recorded by the DIREN survey, to characterize the household standard of living. Finally, an individual income level estimate for each household of the DIREN sample is obtained by computing an estimate of the mean square error predictor of this latent variable, namely its expected value given all the available information at hand, including the income interval the household declared to belong to.

c) Climate variables

The impact of climate on residential water use can be measured in different ways. In the

[2] Households were asked to include all their income sources, including wages, welfare benefits, property revenues,…

literature, precipitation and temperature often are assumed to influence residential water demand. Binet et al. (2012) provided some evidence that households respond to whether it rains or not rather than to the total amount of rainfall. More precisely, we choose to use the percentage of non rainy days over the billing period, with the expectation that demand for garden water will be higher when the percentage of non rainy days is high.

We used daily observations recorded by Meteo France Agency (about one hundred stations set up on Réunion). These geographical distributed observations allowed us to compute the number of days without rainfall for each bill collected according to the observations recorded at the closest weather station.

d) Equipments and other variables collected

We tested other explanatory variables, particular those measuring billing frequency, housing characteristics, consumption habits and the presence of a swimming-pool, dishwasher or washing machine. However, the parameters associated with all these variables turned out to be highly not significant, probably due to the absence of information other than presence or absence. As variables such as appliance stocks are particularly useful in analyses of long term reactions to a price shock, which was not the focus of our study, we did not address this issue.

The set of available variables measured in 2004 and summary statistics for all variables are displayed in Table 1:

Table 1. Data set description, 449 water bills in 2004

Description of variables	Mean	Min	Max
Daily water consumption per household (litres)	675	102	5204
Monthly household income (Euros)	2096	426	7374
Average price of water without fixed charges (Euros per litre)	0.00089	0.000010	0.00218
Marginal price of water (Euros per litre)	0.00118	0.00013	0.00346
Household number of children	0.91	0	4
Household number of working adults	0.98	0	3
Household number of non-working adults	1.29	0	5

Share of days without rainfall (%)	58	0	100
Share of fixed charges in total income (%)	0.22	0.01	1.86
Share of water bill in total income (%)	2.8	0.19	30.6
Monthly Nordin's D (Euros)	5.4	0	87.48

In our sample, average residential water consumption is 675 litres per household per day (which correspond to 253 litres per capita on average). Coutelier and Le Jeannic (2007) confirm the pertinence of our estimates as they measured water consumption to be 269 litres per inhabitant on Réunion, which is similar to the highest consumption levels in the OECD. For example, the average daily per capita water use in the UE-15 countries ranges from 115 litres in Belgium to 265 litres in Spain, EWA (2002). On Réunion, per capita residential water consumption also is about 60% greater than in mainland France, on average. Water bills furthermore account for 2.8% of household income, on average, and up to 30% for the poorest consumers.

Distinctive features such as lifestyle (a high proportion of households live in a house with a garden) and climate may help explain these high water consumption levels. Water prices also are very low on Réunion (around one Euro per m^3 in average). To conclude, the fixed charges represent a small part of household income, equal to 0.22% on average.

4. EMPIRICAL RESULTS

The estimation strategy is described in section 4.1, and empirical results are reported and discussed in section 4.2.

4.1 Estimation method

One problem which must be addressed with multipart tariff pricing is simultaneity because consumers select the quantity of water and the price simultaneously. As an application of the the Breush-Pagan test also revealed the presence of heteroscedasticity, we chose to implement a GMM (Generalized Method of Moments) estimator, using an appropriate set of instruments, in order to deal with both econometric issues. Heteroskedasticity-robust standard errors estimates of parameter estimates were computed.

In the spirit of Hausman and Wise (1976), prices associated with fixed levels of consumption (the three first quartiles of the water consumption distribution) are used as instruments for marginal and average prices. Instrumental variables must satisfy two requirements. They must be correlated with the endogenous variable and be uncorrelated with the error term. We use the Bound et al. (1995) test to select relevant instruments and we perform the Hansen test of overidentifying restrictions to choose valid instruments.

4.2 Results

Empirical results obtained for specification (16) are listed in Table 2:

Table 2. Estimation results obtained with GMM estimator

Specification	***Perception price***
Coefficient estimates	*Value (probability)*
β (marginal budget share)	0.001** (0.015)
α_1 (adult)	98*** (0.00)
α_{20} (garden, common effect)	0
α_{21} (garden with weather effect)	340*** (0.000)
δ_1 (child)	0.80* (0.067)
K (perception price parameter)	1.97*** (0.000)
γ	0
Overidentifying restrictions test (p-value)	0.178
Adjusted R²	0.78
Number of observations	449
Mean value of minimal water consumption	451 (84%)

*Significance level: *** for 1%, ** for 5% and * for 10%.*

Insignificant values of parameters α_{20} and γ obtained in preliminary estimations finally have been set equal to 0. Similarly, in Gaudin et al. (2001), the value of the consumption of other private goods is fixed to be $\gamma = 0$ to obtain consistent estimates.

The minimum required residential water consumption $\hat{m}_q$ can be computed for each bill using estimates parameters and equations (17-19). Finally, average value corresponding to 84 percent of total per household consumption is obtained. We conclude that a dominant part of residential water consumption will not be sensitive to a price increase, in the short run.

To delve further into the interpretation of the incompressible per household water consumption, we give the expression of the minimum required water consumption:

$$(20)\ \hat{m}_q = 98\,\text{NA} + 80\,\text{child} + 340\,\text{weather} * \text{garden}$$

Results reveal the expected signs for all significant explanatory variables. We observe a positive and significant impact of household size on the minimum water consumption: an increase of one adult will result in an increase of 98 liters per day. Next, one additional child will generate an increase of around 80 liters per day in household water consumption. Therefore, 98 liters per day per adult could be the threshold to specify the length of a first consumption block covering essential needs, with a low unit price. The threshold is around three times larger than the essential needs estimated to be 5 m^3 a month for a five persons family, i.e. 33 liters per day and per capita (World Health Organization). Furthermore, we can use equation (20) to propose a first block length depending on the family size and climate conditions.

Whatever the specification considered, the presence of a garden has a positive impact upon water consumption. It generates an increase of 167 liters per day in the family at the sample mean.

One point of interest is the value of price perception parameter. The perception price parameter estimate is equal to 1.97. The coefficient is significantly different from zero (the value for which perceived price is equal to marginal price), reflecting a perceived price not only less than the marginal price but also less than the average price. This indicates that Réunion households highly underestimate the price of water. This result is in accordance with Binet et al. (2012) who have previously estimated a perception price parameter equal to 1.53 using the Shin's methodology in a log-log specification. As a consequence, increasing the billing information of Réunion households on the actual marginal price of water they pay may noticeably reduce their consumption of water and therefore contribute to a sustainable use of this scare resource of the island

To gain a better insight on the effectiveness of such an information policy on residential water saving, we simulate the impact of the presence of marginal price information on the bill on water consumption. We compare simulated water consumption levels obtained through estimated equation (16), by assuming that consumers respond to a perceived price defined by a perception price parameter k=1.97, to consumption levels obtained by assuming that consumers respond to marginal price (k=0). Using water bills in at least in the second consumption block (Nordin's D positive), our simulations show that the household sample average water consumption level would decrease from 623 to 576 liters per household per day. These simulated results correspond to a drop in residential water consumption of 7%, in average. Using the same dataset and Shin's price perception methodology in a double-log specification, Binet et al. (2012) showed that if the survey households set their water demand according to marginal price instead of perceived price, then their average water consumption would decline from 16%. This gap is not surprising as the functional form we have retained suppose than a great part of water consumption (more than 80%) will not be sensitive to a price variation.

Therefore, we conclude that the use of clear marginal price information as a water conservation policy could be advocated, in order to significantly reduce residential water consumption on Réunion.

We turn now to the distributions of income and price elasticities obtained, which are described in the following table:

Table 4. Income and price elasticities of demand estimated with the perception price specification.

	Perception price specification	
Price-elasticity	*Mean*	*-0.15*
	Min	*-0.78*
	Max	*-0.014*
Income-elasticity	*Mean*	*0.15*
	Min	*0.013*
	Max	*0.78*

The price elasticities derived from the linear expenditure system must be greater than -1, and the income elasticities must be positive, by construction. Therefore all estimated values suit these constraints.

Price elasticities vary from -0.014 to -0.78, with a mean value equals to -0.15 (respectively from 0.013 to 0.78 for the income elasticity). Indeed, the specification reports lower values of income and price elasticities than the range of estimates reported in the literature. According to Dalhuisen et al (2003), in their meta-analysis, the distribution of price elasticities has a sample mean of -0.41 and a median of -0.35. And the distribution of income elasticities has a mean of 0.43 and a median of 0.41. Those results can be explained by the low price perception by consumers on Réunion. Indeed, Gaudin (2006) showed that billing price information increases the value of water price elasticity.

5 CONCLUSION

The concern in this paper is with empirical investigation of the household's perception of the price of water under an increasing block rate schedule. We assume that residential water consumers are not well-informed about the marginal price at which a rational consumer should respond. To estimate unbiased values for the coefficients of residential water demand derived from a Stone-Geary form, we construct a perceived price variable as a weighted average of marginal and average prices. The weight plays the role of a price perception parameter leading to one of these two prices depending on whether its value is 0 or 1. Thus, the relevant price perception specification can be identified by estimating and testing the value of the price perception parameter within an econometric specification of residential water demand. Using a unique sample of water bills collected from a household survey on the French overseas territory of Réunion, our main findings are twofold.

First, we show that a dominant part of consumption can’t be reduced in the short term by a pricing policy. Indeed, residential water consumption includes a minimum consumption level which covers outdoor uses of water and essential needs. Our estimates show that 98 liters per day per adult could be the threshold to specify the length of a first consumption block covering essential needs, with a low unit price.

Second, results suggest that the perceived price to which consumers respond is less than the marginal price. This indicates that Réunion households underestimate the price of water. Therefore, the addition of marginal price information on the bill alongside the quantity consumed could be an effective simple device to help reduce water consumption.

Using our model estimate, we assess by simulation the magnitude of the impact of such an information pricing policy on water conservation. Our simulation shows that if the survey households set their water demand according to marginal price instead of perceived price, then their average water consumption would decline from 623 to 576 litres per household per day, on average. As the block rates schedules remain the same, the distributional effects of such a clearer price policy are negligible compared to those resulting from a traditional pricing policy. The welfare and distribution effects of changes in block price systems are evaluated by Ruijs (2009) for example. We conclude that the use of clearer information on marginal prices should be considered in conservation policy as it should lead to lower water bills for all the consumers who reduce water consumption.

To conclude, future analyses based on spatial econometrics could provide more insights into residential water demand behaviour. Indeed, according to Ramachandran and Johnston (2011), outside of the economics literature, it is well established that households landscaping are often influenced by latent spatial correlation, e.g to water lawns, leading to a dependency of households decisions to those of neighbours (mimicking effects).

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