Residential water demand estimation in a tropical island using household data.

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Abstract

This paper analyzes the data of a survey sampling performed in the French island La Réunion, on behalf of the Regional Directorate for the Environment (DIREN), in order to explain the average water over-consumption of the island inhabitants with respect to that of metropolitan France.We divide our data set into two sub-groups with different income level. Finally, we find that only low income familly can reduce their water consumption by increasing intramarginal prices through an income effect.

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1 Introduction

This paper analyzes the data of a survey sampling performed in the French island La Réunion, on behalf of the Regional Directorate for the Environment (DIREN). We try to explain the average water over-consumption of the island inhabitants with respect to that of metropolitan France by estimating the water demand function.

In La Reunion, water consumption level, computed with municipal aggregate data, seems to be excessive: with 250 liter by day per inhabitant in this tropical island against an average level of 150l in France. Furthermore, in this French overseas 'département', water has become the source of increasing controversy, as supplies fail to meet demand in many areas, especially in the west part of the island. Therefore, an household survey is necessary to analyze the water consumption of households.

This paper is an original contribution to the literature on residential water demand estimation. Firstly it is based on a detailed survey data. In the literature, estimation of residential water demand at the micro level are rather few, see for example Hanké and de Maré (1982), Jones and Morris (1984), Nieswiadomy and Molina (1989), Schneider and Whitlatch (1991), Hewitt and Hanemann (1995), and Maresca et al (1997) in France. Secondly, we focus on the part played by the pricing of water services structure to control demand. Our specification explicitly incorporates the complexity of water pricing. We show that pricing structure plays a crucial part, but indirectly *via* an income effect.

The following two sections deals with those questions. The next section explains the data setup, after which the results of estimating two water demand functions using a sample of 173 families from all the 24 localities in La Reunion taken in 2004 are presented and discussed. Some conclusions are drawn in a final section.

2 The household survey in La Reunion

We retain a stratified sampling of 2000 households according to municipalities, i.e. 1% of the total household population

The questionnaire includes 25 questions concerning:

- Socio economic characteristics (sex, householder age and occupation, family income and size, number of working people and child, and if they are tenants or property owners)
- Housing characteristics (individual family house or apartment, age, number of rooms and altitude)
- Water consumption equipment (swimming pool, washing machine, dishwasher, garden or vegetable garden ownership).
- Consumption habits (washing frequency, business activity at home)
- Questions to collect the six last water bills, over one year, later by post..

Finally, we collected useful water bills from 173 households. But billing period are different (various months between 1998 and 2002) and only from 1 to 3 water bills per household recording actual water consumption.

Corresponding daily weather indicators as precipitation, temperature and evapotranspiration are taken from 'Météo France' services. Unfortunately, evapotranspiration data are incomplete.

3 Microeconometric specification of daily household water consumption

Two simple regression models are compared in order to study the strength of empirical results. The first one is linear, and the alternative one is a loglog approximation of the first one with $\ln(1-\frac{D}{I-F}) = -\frac{D}{I-F}$:

$$q_i^d = c + \alpha_r(I_i - F_i) + \alpha_d D_i + \alpha_p p_i + \alpha_w W_i + \beta X_i + \epsilon_i$$

$$\ln q_i^d = c + \alpha_i \ln(I_i - F_i) + \alpha_d \frac{D_i}{I_i - F_i} + \alpha_p \ln p_i + \beta \ln X_i + \epsilon_i$$

q_i^d measures daily consumption per inhabitant, p is the marginal price.

The pricing of water is a mixture of fixed and variable elements. The fixed part is measured by F.The tariff consists of different consumption blocks with increasing marginal prices denoted p_i with each successive block. Therefore, two of the usual questions with multipart rate schedules are how to take into account the effect of changes in intramarginal rates, and whether marginal or average prices should be used to estimate the demand function. The solution for the first problem has been solved by Taylor (1975), then Nordin (1976). Otherwise, in accordance with the standard demand theory, a perfectly informed utility maximizing consumer should react to marginal price.

When a consumer belongs to the second consumption block, the corresponding budget constraint can be written:

$I_i \geqslant FP + p_1 k_1 + p_2(q_i - k_{1)} + \overline{pq}$.

with I_i, the income level of individual household i, $p_1$and p_2 respectively the first and the second block price. $k_1$is the highest consumption level in block 1, $\overline{p}$ and $\overline{q}$ are respectively an index price and the corresponding consumption level for other private goods. Finally, the appropriate income measure is $I' = I - FP + (p_2 - p_1)k_1$.Water consumption locally depends on the price of the marginal block (here p_2), and other variables (here FP, k_1) are likely to influence resident water consumption *via* an income effect. Formally, the household resident behaves as if he pays all the water consumption at price p_2, then we repay him the excess amount of money paid that is to say $(p_2 - p_1)k_1$. $(p_2 - p_1)k_1$ can be considered as a virtual repayment.

In absolute value, the last term corresponds to the difference variable called D proposed by Nordin (1976) which is defined as the difference between the total bill and what the user would have paid if all units were charged at the marginal price. More precisely, $D = -(p_2 - p_1)k_1$=$(p_1 - p_2)k_1$.

In La Reunion, the number of blocks depends on the municipality. It can vary from 2 to 4 blocks:

- When the consumer belongs to block 1, $D = 0$.
- When the consumer belongs to block 2, $D = (p_1 - p_2)k_1$
- When the consumer belongs to block 3, $D = (p_1 - p_3)k_1 + (p_2 - p_3)k_2$
- When the consumer belongs to block 4, $D = (p_1 - p_4)k_1 + (p_2 - p_4)k_2 + (p_3 - p_4)k_3$

Therefore, in each municipality, total effect of changes in the intramarginal prices via this income effect can be analyzed. When p_1 raises, it is af if the virtual repayment decreases, and then, water consumption also decreases in every case. When p_2 raises, the repayment increases in block 2 and decreases in blocks 3 and 4. Therefore, total water consumption is indeterminate.On the contrary, if we only increase the price of the last municipal block, for instance p_4,total consumption always increases.

In our study, the income measure is total family money income relate to family size using the Oxford scale, in order to compute an income per consumption unit. Even if household size should positively influence water consumption, the presence of economies of scale in the use of water weakens this effect. So, we decide to use an income proxy. To obtain it, we divide total available income $I-F$ by 1 for the first adult, plus 0,7 for other adult, plus 0,5 for each child.

W_i denotes the weather variable. In the literature, climatic effects have been modelized in different ways, using precipitation measure, temperature or even evapotranspiration. As Martiñez-Espiñeiras (2002), the annual number of rainy days is preferred here to the amount of rain to explain outside water uses. Furthermore, to avoid the colinarity problem, a global indicator which multiply the annual number of dry days by the temperature over the consumption period seems to be the relevant measure in estimating the demand function..

X includes the following exogenous variables influencing household water consumption Preliminary estimations have shown that demand is more responsive to age, number of working people, the presence or not of a garden. Other variables, in particular those measuring frequency of billings, housing characteristics or consumption habits, are insignificant, probably owing to their imperfect measure. But as usual, variables as the stock of appliances especially help to analyze long run reactions to a shock price. But that question reaches beyond the scope of this article.

4 Econometric techniques and results

The simultaneity problem occurs when there is correlation between the error term and any of the explanatory variables or an error in measuring any of those variables. When this condition is not met, an econometric model is estimated using an instrumental variable estimator because OLS estimates are unbiased and inconsistent. In our study, the simultaneity problem is, at least, twofold relevant:

- With multipart block rates, prices are endogenously determinate by the consumer along with quantity demanded.
- Traditionally, individuals do not reveal their real income.

Usual tests have been implemented, first to check that instrument variables are strongly correlated with the marginal price, second to be sure that instrumental variables are uncorrelated with the error term. But we were foiled in our attempt to instrument income, due to the lack of good instruments in our data set. Furthermore, marginal prices for 100 $\mathrm{m}^3, 300m^3$, and $500\mathrm{m}^3 are$ chosen to instrument the marginal price.

Another problem in estimation is related to possible heterogeneity of consumer behaviors as regards water consumption. Chow tests clearly prove that water consumption behaviors are sensitive to income level. An iterative procedure finally leads to consider two different groups, the richer ones whose income per consumption unit is less than 900 euros, and the poorest whose income is greater than 899 euros.

The following tables give econometric results obtained with the two different specifications, first considering all individuals, second distinguishing the poorest from the richest families:

Table 1: Regression results for the linear model

regressors	total	I<900	I>899
constant	0.02	-0,13	0,39
	(0,15)	(-1,23)	(1,18)
$I - F$	$0{,}17.10^{-4}$	$0{,}21.10^{-3}$ **	$-0{,}61.10^{-4}$
	(0,71)	(2,24)	(-1,32)
p	-0,08	-0,07	-0,02
	(-1,08)	(-1,20)	(-0,16)
W	$0{,}21.10^{-4}$*	$0{,}25.10^{-4}$ ***	$0{,}31.10^{-4}$
	(1,63)	(2,72)	(1,29)
D	$-0{,}28.10^{-2}$ ***	$-0{,}12.10^{-2}$ **	$-0{,}36.10^{-2}$ ***
	(-4,86)	(-2,25)	(-4,02)
age	$0{,}34.10^{-2}$*	$0{,}19.10^{-2}$	$0{,}74.10^{-3}$
	(1,72)	(1,46)	(0,17)
$work$	-0,069	-0,01	-0,18***
	(-2,43)	(-0,56)	(-3,08)
$garden$	0,11**	0,11***	0,18*
	(2,04)	(2,80)	(1,71)
R^2	0,32	0,29	0,43
$numb.obs$	154	80	74
$het\ stat$			
$Student\ stat$	—	1,78	—

Table 2: Regression results for the log log model

regressors	total	I<900	I>899
constant	-7,90***	-9,53***	-5,46***
	(-5,46)	(-4,30)	(-2,49)
$\ln\,(I-F)$	0,25***	0,44***	$0,11$
	(3,91)	(2,75)	(0,73)
$\ln\,p$	-0,09	-0,17	-0,04
	(-0,56)	(-0,84)	(-0,17)
$\ln\,W$	0,31**	0,38*	0,28
	(2,26)	(1,90)	(1,47)
$\frac{D}{I-F}$	$-2,85***$	-2,32**	$-13,34***$
	(-2,92)	(-2,35)	(-3,51)
$\ln\,age$	$0,42***$	0,39*	0,17
	(2,19)	(1,70)	(0,49)
$\ln\,work$	-0,32***	-0,09	-0,68***
	(-2,86)	(-0,68)	(-3,73)
garden	0,42***	0,44***	0,44**
	(3,54)	(2,94)	(2,39)
R^2	0,3	0,28	0,47
numb.obs	154	80	74
het stat	—		—
Student stat	2,67***	1,91	

* (respectively **, ***) means a significant level at the 10% (respectively 5%, 1%). The White statistic is computed to check homoscedasticity.

Elasticity values show that the choice of specification does not greatly affect the results.

As in most studies, water demand is rather inelastic as the marginal price p is never significant. Several explanations can explain this results:

- Lack of consumer information about the marginal price.
- Except for dietary need, with mineral water, water has no substitutes for most uses.

However, if we consider low income households, prices can play a crucial role to bring down total water consumption, indirectly *via* an income effect, by reducing intramarginal prices. It follows that coefficients of income α_i and the intramarginal premium α_d must be significant. Furthermore, if the econometric model is well-specified, the two coefficients should roughly be the same in absolute value but with opposite sign. This theoretical expectation have been tested successfully here, unlike most previous empirical applications, Arbuès and all (2003), Bachrach and Vaughan (1994). The corresponding Student statistic, appearing in the last column of results tables, is often lower than the corresponding critical value at the 5% level. But, this price policy will never affect well-off households water consumption. However, note that with the log log specification, this condition is not fulfilled. But income heterogeneity probably weakens this result.

Results show that more working people would mean less water use. In other words, it seems that, spending more time at home could increase water uses. This result is important to explain the huge consumption level observed in La Réunion, where there are 30% of unemployed people who probably spend much time at home, especially in there garden. In this way, this result can be combined with the significant positive effect of the presence of a garden.

In our study, unlike most studies in the literature, age exerts a positive influence on water consumption. This result appear only with the log log specification and concern households with an low income level. Therefore, it seems to be a rather small effect, specific to this overseas 'département'. This conclusion is confirmed by the typology realized. Maybe, this result appears because retired people tend to spend much time at home and do more gardening.

In every case, the presence of a garden positively influences water consumption, which reflects that outdoor usage is preponderant to explain water use.

We observe differences in estimated: coefficients according to income level: weather, income and the number of working people do not influence water habits for the richer families. Their consumption cannot be cut down easily They probably water their garden whatever the weather. Furthermore, their water consumption is independent of price and income variations.

5 Conclusion

This paper analyzes the data of a survey sampling performed in the French island La Réunion, on behalf of the Regional Directorate for the Environment (DIREN), in order to explain the average water over-consumption of the island inhabitants with respect to that of metropolitan France.We divide our data set into two sub-groups with different income level. Finally, we found that income, the tariff structure with the Nordin indicator, the weather index, and households characteristics as age, the number of working people, as the presence of a garden are the main determinants of low income residential consumption in La Réunion island. In other words, we show that pricing structure plays a crucial part to control water demand, but indirectly *via* an income effect. Formally, the household resident behaves as if he pays all the water consumption at the marginal price, then we repay him the excess amount of money paid that is to say which can be considered as a virtual repayment. More precisely, increasing the price of the first consumption block will always reduce total water consumption. Furthermore, increasing the price of the last municipal block, will always increase total consumption. When other marginal price is increased, the effect on total water consumption is indeterminate.

In every case, the presence of a garden positively influences water consumption, which reflects that outdoor usage is preponderant to explain water use. Information campaign, devoted to watch water use for gardening seems to be the second policy to conduct.

One line of future research would deal with the water demand functional form. A more flexible functional form based on a Stone-Geary utility function, which accounts for a minimum water consumption level, a subsistence level, could be used.

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