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Efficiency, perceived prices, and household water demand: A stochastic frontier analysis for the Spanish city of Gijón

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Abstract:

In the current context of pressure on available water resources, sustainable patterns of water consumption emerge as an important matter of concern. In this sense, efficient consumption is usually understood as the optimal usage of the available resources. Thus, we study households' efficiency levels by considering a stochastic frontier analysis of the demand for water services using a representative sample of a northern city in Spain. Besides, efficient consumption habits require a costly acquisition of accurate information, whether in terms of prices or the effective demand of a given resource. Thus, we also study the impact of several determinants on the efficiency levels of water demand, as in Hung et al. (2017). These range from the deviations between perceived and real prices to social characteristics such as the average age of households or their degree of environmental awareness. We find strong evidence in favor of higher efficiency levels among more informed households which also commit themselves to the environment. The relevance of this research to the current state of the empirical literature is twofold: first, it expands the number of scarce analyses on stochastic frontiers of residential water demand; second, it contributes to a better understanding of the importance of accurate information on optimal decisions of consumers. Moreover, we use a novel and exclusive database for a representative sample of households in the city of Gijón (Spain) between 2017 and 2021, where we combine real data on water prices and consumption with consumer perceptions obtained from a survey.

1. INTRODUCTION

Water resources are under pressure in several areas in the world, where scarcity and quality problems are progressively increasing (UNESCO, UN-Water, 2020). The Goals proposed by the 2030 Agenda for Sustainable Development (UN, 2015) are aimed at ensuring access and quality of water resources to the entire population, promoting an efficient water use. Moreover, the 2030 Agenda is fostering to take urgent action to fight against climate change and its impacts.

In this context, the development of strategies for an efficient management of water resources is required, especially in areas with high levels of water stress. In this respect, Spain is considered as a water stressed country according to its water use index (Taušová, 2022), since its water consumption is over the 20% of its long-term annual average of available water.

Several institutions are keen of improving the efficiency of existing water infrastructure but also promoting water resource use efficiency thought the implementation of several water-demand side policies (EEA, 2012; UN-Water, 2021). Pricing and non-pricing tools are proposed to get efficient water consumption levels. Nevertheless, a previous assessment of water demands efficiency is necessary, in order to identify the best policy instrument to rationalize water consumption.

Water tariffs are a significant tool for addressing an efficient water management. However, the complexity of those tariffs could dilute its potential impacts when it comes to reducing water consumption (Binet et al., 2014; Brent y Ward, 2019). This complexity is especially significant in Spain, where plenty of non-linear and special tariffs are applied (García-Valiñas and Arbués, 2021). Thus, water price and consumption perceptions could be far from the actual prices, generating some distortions when adopting consumption decisions.

Although households and economic activities put pressure on water resources, there are plenty of studies focused on the water use efficiency of economic activities but the literature assessing the efficiency of residential water consumption is still scarce (Pérez-Urdiales, 2015; Hung, 2017). This research looks to deal this shortcoming, by evaluating the efficiency of households' water consumption using an original microdata base. Moreover, the determinants of residential water use efficiency will be assessed, by deepening in the role of information on water prices and consumption.

The outline of the paper is as follows. First section presents a brief literature review on previous studies analysing residential water use efficiency though frontier analysis. Next, the methodology proposed in this research is shown, with special attention to frontier demand functions. Data set and variables are described in the next section, while section 5 is displaying the main results. Finally, the paper concludes with a summary of the main findings and public policy implications.

2. LITERATURE REVIEW

2.1. Residential water demand

Since there already exists an important number of exhaustive surveys on empirical studies regarding households' water demand (Espey et al., 1997; Arbués et al., 2003; Worthington and Hoffman, 2008; Nauges and Whittington, 2010; Reynaud, 2015; Reynaud and Romano, 2018; García-Valiñas and Suárez-Fernández, 2022), the present subsection will cover their major conclusions as well as the most recent studies focused on the use of frontier analysis in the residential water sector.

According to previous literature, the impact of household income on water consumption is expected to be positive, while a negative relationship between prices and water consumption has been estimated. However, both income and price elasticities of demand lower than one (Arbués et al., 2003; Worthington and Hoffman, 2008; Nauges and Whittington, 2010; Reynaud, 2015; García-Valiñas and Suárez-Fernández, 2022). This will confirm water as a necessity good, with a diminishing relative weight on household expenditure as income increases, and a demand quite insensitive to changes in water prices.

García-Valiñas and Suárez-Fernández (2022) indicate that there are several groups of variables that have an impact on residential water use. First of all, households' characteristics and housing equipment are significant determinants of residential water use. Among others, household size and composition, education or the type of dwelling are some of those outstanding features. Secondly, some environmental factors such as climatic variables or water quality are considered as key-drivers of water demand. Third, attitudinal and psychological issues are also significant determinants of residential water use. Finally, some policy tools have been deeply analyzed when modelling residential water demand, including both pricing and non-pricing instruments (water efficient technologies, educational campaigns, etc).

Although there is a very large number of studies estimating residential water demand, the literature focused on modelling residential water demand efficiency are still scarce. Pérez-Urdiales (2016) estimated a Smooth-Coefficient stochastic frontier model using a sample of households in the city of Granada (Spain). She found that those households equipped with water efficient technologies and having recently renovated the house pipelines were more efficient in the use of water. Hung et al. (2017), estimated several stochastic frontier models under different error distribution to analyse the potential water savings in Taiwan. They concluded that smaller and richer households, with higher proportion of aged members and living in big houses registered higher efficiency levels in the use of water.

To conclude this section, it has to be stressed that some papers have found that households have significant shortcomings related to both water consumption and prices information (Binet et al. 2014; Brent and Ward, 2019, García-Valiñas et al., 2021). These information gaps could lead in the adoption of non-optimal decisions in terms of water consumption. However and as far as we know, no paper has tested the impact of information deficiencies on the residential water consumption efficiency.

3. METHODOLOGY

3.1. The Stone-Geary demand function with imperfect perception on water prices and consumption

Since it is a quite popular functional form in previous literature, we will focus on the Stone-Geary specification of households' water demand (e.g., Gaudin et al. 2001; Martínez-Espiñeira and Nauges 2004; Madhoo 2009; Garcia-Valiñas et al. 2010; Dharmaratna and Harris 2012; Clarke et al. 2017; Hung et al., 2017; Roibás et al., 2018). The advantages of this function are the following (Dharmaratna and Harris, 2012): i) it allows for positive consumption independent of prices and disposable income (that is, subsistence consumption); ii) it allows for non-constant price and income elasticities. However, in the context of price and quantity misperceptions, an inefficiency term arises that must be considered in the standard Stone-Geary water demand of households.

To that end, assume the head of a household faces the collective utility function

$$U(x, \tilde{w}) = x^{1-\alpha}(\tilde{w} - \gamma)^{\alpha} \qquad (1)$$

where, $0 < \alpha < 1$ and $x \in R_{+}$ is a composite of other goods and services than water. Since we assume that inefficient water demand implies an excess in its consumption, we follow Wichman (2017) and the quantity of perceived water consumption is $\tilde{w} = \phi w$, with $\phi \in (0,1]$ as the "quantity underperception parameter", and $w > \gamma/\phi$ as real water consumption, where $\gamma \geq 0$ is the parameter of subsistence water demand.

Considering a three-block increasing rate schedule (Binet et al., 2014), the maximization problem of a perfectly rational and informed individual is subject to (assume that x is the numeraire good)

$$I = x + F + p_1 b_1 + p_2 b_2 + p_3(w - b_1 - b_2) \qquad (2)$$

where, $I \in R_{+}$ is the household's disposable income, $F \in R_{+}$ as the real fixed rate, and $p_s \in R_{+}$ as the marginal price of consumption block "s", and b_s as the maximum threshold level of water consumption in block "s". The three-block increasing rate schedule implies $p_3 > p_2 > p_1 > 0$. Following Nordin (1976), equation (2) can be rewritten into

$$I_D = pw \tag{3}$$

where $I_D = I - x - F + D$ is the household income disposable for water consumption. The income effect captured in the Nordin's difference variable equals

$$D = \begin{cases} 0 & if\ w \leq b_1 \\ (p_2 - p_1)b_1 & if\ b_1 < w \leq b_1 + b_2 \\ (p_3 - p_1)b_1 + (p_3 - p_2)b_2 & if\ w > b_1 + b_2 \end{cases} \tag{4}$$

while marginal prices equal

$$p = \begin{cases} p_1 & if\ w \leq b_1 \\ p_2 & if\ b_1 < w \leq b_1 + b_2 \\ p_3 & if\ w > b_1 + b_2 \end{cases} \tag{5}$$

Similar to (3), the budgetary constraint with price and quantity misperceptions (Sexton, 2015; Whichman, 2017) can be read as

$$\tilde{I}_{\mathrm{D}} = \tilde{p}\tilde{w} \tag{6}$$

where $\tilde{I}_D = I - x - \tilde{F} + \widetilde{D}(\widetilde{p}_s, \widetilde{b}_s, \widetilde{w})$ is the perceived disposable household income for water consumption, $\tilde{F} = \rho F$ perceived fixed charges on water consumption, with $\rho \in (0,1]$ as the "fixed rate underperception parameter", and $\tilde{p}_s = \theta_s p_s$ is the perceived marginal price of the s block of perceived water consumption $\tilde{b}_s$, with $\theta_s \in (0,1]$ as the "price underperception parameter".

Maximizing (1), subject to (6), with respect to $\tilde{w}$, yields the following Stone-Geary demand function with price and quantity underperception biases

$$w = (1-\alpha)\gamma + \alpha\frac{I_D}{p} + (1-\alpha)\left(\frac{1-\phi}{\phi}\right)\gamma + \alpha\frac{(\tilde{I}_{\mathrm{D}} - \phi\theta I_D)}{\phi\,\tilde{p}} \tag{7}$$

Hence, (7) provides a theoretical justification for the estimation of residential water demand considering the inclusion of an inefficiency term containing price and quantity underperception biases, $(1-\alpha)\left(\frac{1-\phi}{\phi}\right)\gamma + \alpha\frac{(\tilde{I}_{\mathrm{D}} - \phi\theta I_D)}{\phi\,\tilde{p}}$.

3.2. Stochastic frontier analysis of the Stone-Geary demand function with perception bias

For estimation purposes, (7) can be rearranged into a stochastic frontier model (Aigner et al., 1977; Meeusen and van den Broeck, 1977) for water demand (Hung et al., 2017)

$$w = \sum_{j}^{K} \beta_j x_j + \alpha \frac{I_x}{p} + u \ + v \qquad (8)$$

where, following Gaudin et al. (2001), the subsistence parameter can be decomposed into a linear combination of K exogenous and constant household's characteristics, $\gamma = \frac{1}{1-\alpha}\sum_{j}^{K} \beta_j x_j$. Additionally, $v \sim iid\ N(0, \sigma_v^2)$ is the idiosyncratic error, and $u \sim iid\ N^{+}(\mu_u, \sigma_u^2)$ is the inefficiency term, which its expected value can be modelled as a function of H exogenous regressors z_s (Kumbhakar, Ghosh and McGuckin, 1991; Huang and Liu, 1994; Battese and Coelli, 1995)

$$\mu_u = E(u) = \delta_0 + \sum_{s}^{H} \delta_s z_s \qquad (9)$$

where z_s seeks to capture the vector of price and quantity underperception parameters (ρ, ϕ, θ) of (7). Contrary to Hung et al. (2017), we do not restrict ourselves to the sole estimation of the inefficiency effects on the mean of u. As it is common in stochastic frontier analyses, we also study of the impact of these H exogenous regressors on the variance term of u (Caudill et al., 1995; Hadri, 1999), that is

$$\sigma_u^2 = Var(u) = exp\left(\lambda_0 + \sum_{s}^{H} \lambda_s z_s\right) \qquad (10)$$

Due to likely problems of endogeneity associated with marginal prices, we consider the control function approach for the estimations (Amsler et al., 2016). This method produces numerical results identical to those of 2SLS but produces a heteroskedasticity-robust Hausman test for exogeneity (Woolridge, 2015) and allows to estimate stochastic frontiers easily by including the predicted control function $\hat{v}$ as an additional regressor. This method has been previously considered in the context of water demand estimations by Pérez-Urdiales et al. (2016).

To summarize, we consider five stochastic frontier specifications, corrected by potential endogeneity, which change according to the assumptions on the probability distribution function followed by the inefficiency term u: the classic half-normal zero-truncated stochastic frontier model with $u \sim iid\ N^{+}(0, \sigma_u^2)$ (SF_HN_CF, M1), the half-normal zero-truncated stochastic frontier with heteroskedastic inefficiency term, thus $u \sim iid\ N^{+}(0, \sigma_u^2(\lambda z))$ (SF_HN_CF_HK, M2), the random positive-truncated stochastic frontier model with $u \sim iid\ N^{+}(\mu_u, \sigma_u^2)$ (SF_TN_CF, M3), the positive-truncated stochastic frontier model with heteroskedastic inefficiency term, thus $u \sim iid\ N^{+}\left(\mu_u, \sigma_u^2(\lambda z)\right)$ (SF_TN_CF_HK, M4), and the positive-truncated stochastic frontier model with exogenous regressors in the inefficiency term, thus $u \sim iid\ N^{+}\left(\mu_u(\delta z), \sigma_u^2\right)$ (SF_TN_CF_IE, M5). To do so, we consider the *sfcross* STATA package for estimation of stochastic frontiers of water demand.

4. DATA AND VARIABLES

The database used in this study is one of its main contributions (see Tables 1 and 2 for a comprehensive description of variables and their summary statistics). Information regarding real bimonthly water consumption and its marginal prices was obtained from the water supplier in Gijón (the public company of EMA). It spans 1068 different households[1] with individual water meters, for 29 periods between 2017 and the first 8 months of 2021. However, not all households present the same number of observations across time due to contract start/ending date. Therefore, we have an unbalanced panel data of 24,402 observations.

Meteorological data were provided by the State Meteorological Agency (AEMET). Household socioeconomic and home characteristics were obtained from a survey conducted in Gijón between December 2020 and April 2021. Due to the pandemics, the survey was conducted by a mixed collection system, sending a letter with a questionnaire to households. According to the latest municipal census[2], Gijón counted with 26% of ageing population, then mail and online submissions were considered to avoid losing a representative share of Gijón's population.

Water consumption and household income are considered in daily terms to control for the effect of changes in the size of billing periods. Billing periods range between 58 and 61 days, with mean of 59.60 days. Water consumption ranges between 0 and 449 cubic meters, with mean of 17.29 cubic meters and standard deviation of 17.36 cubic meters. Daily water consumption (w) ranges between 0 and 7.483 cubic meters per day, with average consumption of 0.289 cubic meters (see Table 2).

Regarding net household income, respondents make a choice from six different intervals of monthly net household income, starting from 0-500€ to 2701-3700€. To obtain a non-categorical variable of corrected household income (disposable income after fixed charges on water consumption and the Nordin's difference - see Subsection 3.1-), we consider the mean of each income interval. Household

[1] 6,800 households were contacted, but the response rate was lower than 30%. Moreover, some households were purged due to excessive missing values or strange consumption levels (these were consulted with the EMA before taking a final decision).
[2] For further information, check https://observa.gijon.es/pages/inicio

Table 1 Description of variables

Variable	Name	Definition
w	Daily water consumption	Bimonthly water consumption divided by the number of days at each billing period (m^3/day)
P_w	Marginal price	Marginal price of the last block of water consumption reached (€/m^3)
I	Corrected daily household income	Bimonthly household income discounted from water fixed charges, corrected by Nordin's difference and divided by the number of days at each billing period (€/day)
hsize	Household size	Number of individuals residing in the surveyed household
largehsize	Large household size	Dummy variable: 1 if household size is larger than 4
p_65	Share of seniors	Proportion of household members older than 65 (%)
p_fem	Share of females	Proportion of household female members (%)
p_work	Share of employed	Proportion of household employed and self-employed members (%)
surf	Residence surface	Residence surface area (m2)
old_house	Old house	Dummy variable: 1 if residence is over 40 years old
gard	Garden ownership	Dummy variable: 1 if residence has a garden
pool	Swimming pool ownership	Dummy variable: 1 if residence has a swimming pool
eff_k	Efficient appliances index	Index: 0.5 if residence has a water/energy-efficient dishwasher or washing machine / 1 if residence has both
eff_devices	Water-saving devices index	Index: average number of affirmative answers on the ownership of water-saving devices (taps, shower, toilet, water pressure)
avt	Average temperature	Mean of average daily temperatures registered at each billing period (ºC)
avhum	Average humidity levels	Mean of average daily relative humidity registered at each billing period (%)
avrain	Average rainfall	Mean of accumulated daily rainfall registered at each billing period (dm)
Covid	Covid period	Dummy variable: 1 if billing period is between the second billing period of 2020 and the third billing period of 2021
wathabit	Self-reported water use habits index	Index: average number of affirmative answers on the adoption of water-saving habits (see text)
P_w_under	Underperception bias on marginal prices	Dummy variable: 1 if respondent declares a marginal price lower with respect to the real marginal price
w_under	Underperception bias on water consumption	Dummy variable: 1 if respondent declares a water consumption lower with respect to the real consumption
bill_under	Underperception bias on water bill	Dummy variable: 1 if respondent declares a water bill lower with respect to the real bill
P_w_unk	Ignorance of marginal prices	Dummy variable: 1 if respondent does not estimate a marginal price
w_unk	Ignorance of water consumption	Dummy variable: 1 if respondent does not estimate a level of water consumption
bill_unk	Ignorance of water bill	Dummy variable: 1 if respondent does not estimate a water bill

Table 2 Main statistics

Variable	Mean	SD	Min	Max
w	0.289	0.29	0	7.483
P_w	1.034	0.173	0.415	1.599
I	69.015	39.937	7.91	199.87
hsize	2.414	1.076	1	6
largehsize	0.032	0.178	0	1
p_65	0.307	0.42	0	1
p_fem	0.539	0.287	0	1
p_work	0.422	0.374	0	1
surf	106.896	75.928	30	711
old_house	0.5	0.5	0	1
gard	0.226	0.418	0	1
pool	0.042	0.201	0	1
eff_k	0.535	0.424	0	1
eff_devices	0.203	0.246	0	1
avt	15.262	3.419	9.217	21.071
avhum	75.918	2.661	71.369	85.214
avrain	30.096	19.692	1.143	103.197
Covid	0.34	0.474	0	1
wathabit	0.656	0.135	0	1
P_w_under	0.190	0.392	0	1
w_under	0.116	0.321	0	1
bill_under	0.111	0.314	0	1
P_w_unk	0.039	0.194	0	1
w_unk	0.670	0.470	0	1
bill_unk	0.261	0.439	0	1

income ranges between 250 and 5800€, with mean of 2073.31€ and standard deviation of 1194.57€.

Fixed charges range between 7.52 and 33.50€, with mean 16.63€ and mode 16.92€. These are a combination of a service fee for the maintenance and reparation of the water supply network, increasing with the water meter size, and a constant water sanitation regional tax, aimed to foster efficient water consumption and fund the preservation of water resources in the Principality of Asturias (Garcia-Valiñas and Arbues, 2021). Marginal prices (P_w) follow a three-block increasing structure, raising with cubic meters of water consumption. Average marginal prices equal 1.034€, and most households are located in the first block of consumption for the entire period (almost 90% of the observations).

Given the variable part of the water sanitation regional tax creates a super progressive structure, the Nordin's difference is more sensitive to changes between blocks of consumption, and price misperceptions penalize consumer's welfare to a larger extent. More precisely, the Nordin's difference ranges between 0 and 15.137€, with mean 0.894€ and standard deviation 2.904€. After considering billing days, fixed charges and the Nordin's difference, corrected daily household income (*I*) ranges between 7.91€ and 199.87€, with an average of 69€ per day and household (more than two minimum wages according to the Spanish legislation[3]).

Average household size (*hsize*) is 2.4, and almost 60% of households have two or less members. Furthermore, only 35 households (*largehsize*) have five or six members (3% of the sample). The share of members over 65 years (*p_65*) presents an average value of 30.7% (see Table 2), which is close to the share of elder people in Gijón (25.9%)[4]. Additionally, the share of female members (*p_fem*) is also representative of the population of Gijón (54%), with an average of 53.9% females per household, and less than half of the members of each household (42.2%) tends to be employed or self-employed (*p_work*). Therefore, we have a sample composed of small households, not excessively aged (members under 18 years represent less than 11% of the sample), balanced in terms of gender, and with more than half of the members not working.

Considering housing characteristics, Table 2 shows that households reside, on average, in large houses (106.89 m^2), with minimum and maximum sizes (*surf*) of 30 and 711 m^2. Moreover, half of the sample resides in old houses (*old_house*), with more than 40 years old, while less than a quarter owns a garden (*gard*), and less than 5% are equipped with a swimming pool (*pool*).

Since practically the entire sample owns a washing machine (99%), and almost two thirds of them a dishwasher (62.55%), we prefer to focus on quality, instead of quantity, of household capital stock. To summarize the available information on efficient household capital stock, and maintain the highest degrees of freedom, we construct two indices for water-saving appliances and water-saving devices. The first one (*eff_k*) takes the values 0 when there are no water-saving/energy-efficient[5] washing machines or dishwashers; 0.5 when there is just one water-saving/energy-efficient appliance; and 1 when both appliances are efficient. The second one (*eff_devices*) takes the values 0 when there are no water-saving devices installed in the house, and $\sum \mathrm{Dev_i} / 4$ where $\mathrm{Dev_i}$ is a dummy variable which takes the value of 1 when the i water-saving device is installed (i: efficient taps, efficient showers, efficient toilets, water pressure reducer). When *eff_devices* equals 1, the household owns all types of water-saving devices. According to Table 2, we expect that a randomly chosen household will present at least one efficient household appliance (44% of households own an efficient dishwasher and 67% an efficient washing machine), and about one efficient device (the most frequent efficient device is the double-flush toilet, with 48% of the sample, while general water pressure reducers are the least frequent, with 6% of the sample).

Since the COVID-19 pandemic captures one third of the sample (see the mean of *Covid* in Table 2), we include a dummy variable to control for the effect of

[3] https://www.lamoncloa.gob.es/lang/en/gobierno/councilministers/Paginas/2022/20220222_council.aspx
[4] Demographics of Gijón are available on https://observa.gijon.es/pages/inicio/
[5] A, A+, A++, A+++ rating.

curfews and movement restrictions on water consumption. We expect that people spending more time at home will lead to increases in residential water consumption.

Regarding the inefficiency determinants, we construct a self-reported water habits index (*wathabit*) which equals $\sum \mathrm{Hab_i} /13$, where $\mathrm{Hab_i}$ is a dummy variable which takes the value of 1 when the i water habit is implemented[6]. According to data, most of the sample declare to have rather good water habits (75% of the surveyed households declare to adopt at least 7 out of 13 efficient water habits), where the most popular habits are (with more than 90% of households answering positively): defrosting food in advance without making use of water, loading completely up the washing machine and the dishwasher, turning off the tap while brushing the teeth, and taking showers instead of baths. On the contrary, the least frequent habits are water recycling and filling the sink before washing dishes, with less than 20% of households declaring these habits.

Looking at marginal prices, quantity and bill misperceptions (*P_w_under, w_under, bill_under*) we construct two dummy variables. These take the value of zero when the respondent chooses a numerical value equal or superior to the actual values registered in terms of marginal prices, paid bill and quantity consumed. That is, those who have perfect information or overestimate the aforementioned variables are expected to not increase inefficient water consumption constrained to other information and cognitive biases. According to our data, there is a low percentage of households underestimating marginal prices, consumption levels and water bills (19%, 11.6% and 11.1% respectively). While the first and last ones are a result of generally overestimated marginal prices (more than 74% and 62% of the selected sample respectively), the second one is a consequence of respondents not estimating their consumption levels of water (more than 67% households).

To enrich our analysis, we also consider the ignorance of respondents on marginal prices, water consumption and water bill (*P_w_unk*, *w_unk*, *bill_unk*). Contrary to the previous misperception variables, our theoretical framework cannot presume how the ignorance bias will work on household decisions. For instance, previous works have found that provision of better information for water consumers tends to raise water demand (Whichman, 2017; Brent and Ward, 2019). Therefore, declaring lack of knowledge on information associated with water consumption does not necessarily imply that respondents do not have an unconscious bias towards under or overperception of their consumption levels or marginal prices, which leads to inefficient levels of demand. According to our data, while there is a significant number of respondents who do not dare to estimate their water bills and consumption levels, most households have provided an estimation of the

[6] Water habits are: water recycling, cooling water by keeping it bottled in the fridge, turning the tap off while soaping hands, defrosting food in advance without making use of water, filling the sink before washing dishes, loading completely up the washing machine and the dishwasher, reducing the water volume by partially closing the shut-off valve, not using the toilet for waste disposal, making use of the partial-flush system on the toilet tank, turning off the tap while brushing the teeth, taking showers instead of baths, turning off the shower while soaping themselves up, not washing cars with residential water.

marginal prices they have faced (more than 96% of the sample). These differences in the response rate are likely a consequence of the construction of the questionnaire and should not be attributed to a salience bias towards marginal prices: while bill payment and water consumption must be answered with a specific figure guessed by the respondent, marginal prices are chosen from six possible intervals ranging from *less than 1€* to *more than 2€*, including the possibility of answering *I don't know*.

Since we only have an answer for each household for the entire span of time, we must assume these answers are rather constant throughout time. This assumption is not too strong, given that water bills represent a limited share on household income (1.2% for the average household in our sample). Therefore, the costs associated with collecting information may not overcome the expected gains in terms of efficient consumption, and rational inattention remains as the optimal strategy (Sims, 2003; DellaVigna, 2009; Sexton, 2015). Furthermore, water bills are received two months after consumption decisions are taken, and estimation errors are likely to prevail since agents do not receive "timely and organized feedback" (Thaler, 1986).

5. RESULTS

This section presents the estimations of models, the comparison between them, the likely determinants of inefficient water demand, as well as the estimated elasticities and water waste levels.

5.1. Estimation of residential water demand considering water waste

Table 3 shows the estimates of the Stone-Geary frontier demand function; Table 4 presents the estimated impacts of exogenous regressors on water waste, and Table 5 exhibits estimated average income and price elasticities, as well as subsistence, efficient and waste levels of water consumption. We control for the likely endogeneity associated with corrected daily income divided by marginal prices (I/P_w) by considering the control function procedure (Amsler et al., 2016). Inspired in the "Hausman instruments" (Hausman and Leonard, 2002; Hausman and Ros, 2013), the chosen instruments are the 2-year lag of average corrected daily income divided by marginal prices ($mean\_area\_L12\_Iday/P_w$) and a time trend for each billing period (t) (see Table A1 in the Appendix).

Besides, LR tests are carried out to choose among the different nested specifications that we consider, as well as the Akaike's Information Criterion (AIC) for selection of non-nested models (Table A2 in the Appendix shows the estimates for all models). According to LR tests, stochastic frontier specifications M4 and M5, with a positive truncated-normal distribution of the inefficiency term

Table 3 Parameter estimates of daily water stochastic frontier demand

Variable / Model	SF_TN_CF_HK (M4)
Intercept	0.0352
	(0.80)
I/P_w	0.00133***
	(6.10)
hsize	0.0347***
	(13.45)
p_65	-0.00105
	(-0.25)
p_fem	0.0203***
	(5.03)
p_work	-0.0503***
	(-7.11)
surf	0.000275***
	(8.44)
old_house	0.0528***
	(20.46)
gard	0.0206***
	(4.76)
pool	0.0100
	(1.30)
eff_k	-0.00923**
	(-2.94)
eff_devices	-0.0351***
	(-6.25)
avt	0.000821
	(1.93)
avhum	-0.00177**
	(-2.79)
avrain	0.0000357
	(0.83)
Covid	0.0125***
	(5.77)
$\hat{v}$	-0.00158***
	(-7.20)
λ	
σ_u^2	
σ_v^2	0.07139***
	(68.17)
μ	-127.024***
	(-10.56)
Observations	14441
Log likelihood	7424.4

Notes: *t* statistics in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

and exogenous inefficiency determinants, are the best ones at fitting data[7]. Furthermore, since the AIC Difference of M5 with respect to M4 ($\Delta_5 = AIC_5 - AIC_4$) equals 18.6, the level of empirical support of model 5 is *essentially none* (Burnham and Anderson, 2002). Therefore, our further analysis will be focused on model M4.

According to the estimations for the SF_TN_CF_HK model (see Table 3), we observe that water demand increases with income and decreases with marginal prices, as the theory predicts. Continuing with other socio-economic determinants, the household size (*hsize*) seems to increase daily water demand as expected (Schleich and Hillenbrand, 2009; García-Valiñas et al., 2010; Binet et al., 2014; Pérez-Urdiales et al., 2016; Hoyos and Artabe, 2017; Hung et al., 2017; Roibás et al., 2019).

Furthermore, gender (*p_fem*) and employment (*p_work*) status also prove to be relevant variables at explaining household water consumption patterns. More precisely, an increase in the percentage of female-declared members leads to increases in water demand, as in Mu et al. (1990) and Reynaud (2015), while households with more employed members tend to present lower figures of water consumption, as in Binet et al. (2014). Since this specification already controls for water waste, and the number and quality of home efficient devices are also considered, our results points towards women having higher preferences over water consumption on average. On the other hand, given that we also control the changes in work patterns through the COVID-19 dummy variable, the explanation behind lower consumption among employed people is that they spend less time at home on average (Binet et al., 2014).

Regarding housing characteristics, we find that houses with larger surfaces (*surf*) present higher levels of water consumption, as in Pint (1999), Renwick and Green (2000), Hajispyrou et al. (2002), Grafton et al. (2011) and Hung et al. (2017). Due to more likely leakages (Nauges and Thomas, 2000), we find that older houses (*old_house*) are also associated to higher water consumption. This result is found in Nauges and Thomas (2000) and Garcia and Reynaud (2004). As it is common in previous works, the ownership of a garden (*gard*) is significant and leads to increases in domestic water demand (Agthe and Billings, 1987; Rizaiza, 1991; García-Valiñas et al., 2013; Binet et al., 2014; Jayarathna et al., 2017). Moreover, we find that specific water-saving equipment measured by the index of efficient dishwashers and water machines (*eff_k*), and the installment of efficient devices in taps or flushes (*eff_devices*), is significant and presents the expected negative sign as in previous works (Renwick and Green, 2000; García-Valiñas et al., 2013; Pérez-Urdiales et al., 2016; Rathnayaka et al., 2017).

[7]LR(M5vsM1)=7073.82***(p=0.000); LR(M5vsM2)=5013.20***(p=0.000); LR(M5vsM3)= 1202.12***(p=0.000); LR(M4vsM1)=7092.48***(p=0.000); LR(M4vsM2)=5031.86***(p=0.000); LR(M4vsM3)=1220.78***(p=0.000).

Table 4 Estimates on determinants of water waste

Variable / Model	SF_TN_CF_HK (M4)
	$\boldsymbol{Var(u)}$
Intercept	2.820***
	(25.73)
I/hsize	0.0000795***
	(8.34)
largehsize	0.427***
	(8.14)
wathabit	-0.433***
	(-6.54)
P_w_under	0.0606*
	(2.36)
w_under	0.156***
	(4.79)
bill_under	0.770***
	(27.00)
P_w_unk	0.169**
	(3.22)
w_unk	0.0315
	(1.24)
bill_unk	0.294***
	(12.71)

Notes: *t* statistics in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Ending with environmental factors, we find that only average humidity levels (*avhum*) are significant at explaining differences in domestic water demand. More precisely, we observe that drier bimonthly periods lead to higher levels of water consumption, most likely due to more intensive garden-water needs, as in Rinaudo et al. (2012). Finally, the COVID-19 period (*Covid*) has significantly increased water demand across households on average, a consequence of people spending more time at home due to curfews and other mobility restrictions.

Table 4 shows the parameter estimates for the likely determinants of inefficient water demand or water waste. As commented in the methodology section, we argue that inefficient water demand responds to different sources such as coordination or "agency" problems due to households' size (similar to firms, as in Williamson (1967))[8], cognitive biases and imperfect information (Kahneman, Strong and Goemans, 2015; Brent and Ward, 2019; García-Valiñas et al., 2021).

We first find that households with higher per capita income (*I/hsize*) are more inefficient, then richer households seem to present a laxer attitude towards water saving, probably due to the small relative importance of water expenditure over

[8] According to Diaz and Sanchez (2008) and Schiersch (2012), there seems to exist an optimal size for firms which maximizes efficiency levels. This is explained due to "bureaucratic frictions, lack of motivation of workers, and difficulty in monitoring" (Diaz and Sanchez, 2008), that can be easily matched by the functioning of a household.

their budgetary constraints. As in Hung et al. (2017), larger household sizes (*largehsize*) tend to present higher levels of water waste, probably due to coordination and control problems. As expected, the index of declared efficient habits of water consumption (*wathabit*) presents a negative impact on the inefficiency term. For instance, Rajapaksa et al. (2019) show that fostering pro-environmental behaviors leads to significant reductions in water consumption.

Underperception of marginal prices (P_w*_under*), the water bill (*bill_under*) and water consumption (*w_under*) are significant at the 1% level. More precisely, those households which underestimate the value of these variables tend to present higher levels of water waste uncertainty (see Table 4) and lower efficiency scores (see Table 5). Despite they do not explicitly consider the existence of an inefficiency term, Binet et al. (2014) also find that individuals tend to increase water consumption when they underestimate marginal prices, and Rajapaksa et al. (2019) detect that monetary incentives foster reductions in water consumption.

Moreover, it seems that those households which lack of knowledge on marginal prices (P_w*_unk*) and water bills (*bill_unk*) also increase their levels of water waste uncertainty (see Table 4). However, their efficiency scores are superior to their counterpart. Therefore, providing better information only to those individuals who already underestimate economic information regarding residential water supply will likely increase consumer's surplus as well as reduce average water waste levels, as in Whichman (2017) and Brent and Ward (2019). On the other hand, a broad provision of information to the entire sample may lead to sustained reductions in average water waste at the expense of consumer's surplus losses due to less efficient residential water consumption.

Regarding water waste, we find that average levels of efficiency are not too high (for the entire sample, efficient water consumption represents more than 62% of total water consumption). These scores are higher for the subsample with good water habits and information. Moreover, we find the most significant changes in these scores can be found associated to underperception of water consumption and the overall charge in water bills. For instance, we observe that those who do not underestimate their bills present an increase superior to 30% in their efficiency scores.

Moreover, the estimated quantity of wasted water among those declaring a water bill charge inferior to the real one exceeds the 278 liters per household and day. This figure surpasses any other quantity of water waste and represents an increase of more than 105% of wasted water with respect to those who did not underestimate their water bills, while those who underestimate their consumption levels raise their water waste levels by more than 43%. Tackling other information biases, or water habits, seems to only reduce water waste by figures between 8% to 14%. Therefore, our results point towards driving efforts on improving the perception and understanding of residential consumers on their water bills and consumption levels.

Table 5 Mean values of income and price elasticities (*Elast*), basic consumption levels or minimum threshold (γ), efficient water consumption (w^*), observed water consumption ($\overline{w}$), water waste ($E(u/\varepsilon)$), and efficiency scores ($EFF = E(w^*/w)$)

Sample	*Elast*	γ	w*	$\overline{w}$	$E(u/\varepsilon)$	EFF
All	0.532	41.035	134.124	289.003	153.554	0.626
Water Habits						
Best habits	0.527	41.161	130.885	291.414	155.533	0.622
Worst habits	0.488	38.106	129.995	311.516	170.267	0.601
Information on P_w						
No underestimation	0.535	39.533	131.462	285.001	150.963	0.631
Underestimation	0.519	46.947	144.599	306.044	163.749	0.608
Info	0.531	40.838	134.284	288.722	152.741	0.624
No info	0.558	47.135	129.172	295.872	178.716	0.671
Information on w						
No underestimation	0.547	40.283	131.287	277.971	145.359	0.646
Underestimation	0.424	46.026	152.963	372.455	207.974	0.495
Info	0.553	36.790	145.074	305.353	162.294	0.609
No info	0.521	43.414	127.988	280.971	148.656	0.635
Information on Bill						
No underestimation	0.553	38.222	130.839	266.615	135.726	0.650
Underestimation	0.369	60.687	157.079	467.534	278.123	0.457
Info	0.530	39.574	133.564	284.920	148.224	0.614
No info	0.539	45.591	135.872	300.569	170.176	0.664

Notes: Water consumption is measured in liters. Worst habits limit is defined by the first quartile of households with the lowest indexes of water habits (*wathabit<0.61*). Best habits are defined by those habits above the third quartile of worst performers (*wathabit>0.77*).

The estimated average income and price elasticities[9] in absolute terms (*Elast*) equals 0.532 for the entire sample (see Table 5). Therefore, residential water demand in Gijón tends to be inelastic with respect to both income and price, implying that water is a necessary service whose share on household aggregate expenditure decreases with income levels and is rather insensitive to changes in marginal prices. This result is standard in previous literature (Arbués et al., 2003; Worthington and Hoffman, 2008; Nauges and Whittington, 2010; Reynaud, 2015; García-Valiñas and Suárez-Fernández, 2022).

Additionally, we also detect a pattern of lower average elasticities in those households who declare to have bad water habits, as well as underperceive information on prices, consumption and billing of their water demand (see Table 5). More precisely, we observe reductions ranging between 2.9% for marginal prices underperception, and 33.2% for water bill underperception. Therefore,

[9] Average elasticities are computed according to $Elast = \hat{\alpha} \cdot \mathrm{E}\left(\frac{I/w}{P_w}\right)$, where $\hat{\alpha}$ is the estimated coefficient of I/P_w of model (4) in Table 3, and $E\left(\frac{I/w}{P_w}\right)$ is the mean of corrected household income divided by water consumption and marginal prices.

better information and water habits, a proxy for environmental awareness, seem to increase sensitivity of households towards increasing price structures.

Furthermore, as in García-Valiñas et al. (2013), we also detect that minimum threshold levels of water consumption are also sensitive to changes in determinants of efficient water consumption (third column in Table 5). In this sense, we find that those who do not underestimate economic information regarding water supply and provide an answer to marginal prices, water consumption and bill charges present lower levels of non-discretionary water use. Moreover, those households who declare having better water habits present lower levels of discretionary water consumption than those who state having worse habits).

6. CONCLUSIONS

In a context of scarcity and sustainable growth, efficient patterns of residential water consumption should be promoted. In this sense, the evaluation of water waste levels of target groups or areas must be considered in the design of accurate and effective public policies. Furthermore, nudging policies require of further evidence on the importance of information biases or ignorance regarding water demand and usage.

This work provides new evidence on inefficient water demand and its determinants by considering microdata from a sample of 1068 households from the city of Gijón (Spain) between 2017 and 2021. We first expand the standard Stone-Geary demand model for water consumption with determinants for water waste. Secondly, we analyze the efficient residential water demand of households by considering a stochastic frontier analysis, allowing for different specifications of the inefficiency term. Finally, we analyze the impact of several information and socio-economic variables on the inefficiency term, and measure the optimal and waste levels of water consumption.

Our findings show that efficient water consumption is significantly associated to standard regressors in the literature, such as the number of members in a given household, the share of elder people or the efficiency of installed appliances and water-saving devices. Moreover, we find the stochastic frontier demand with a positive-truncated and heteroskedastic inefficiency term is the best specification for this context. Regarding the determinants of water waste, underestimation or ignorance of marginal prices, the bill and consumption levels of water lead to higher waste levels. On the contrary, when households declare better water habits or lower levels of income per member, they present higher levels of water consumption. Finally, we find that providing better information on the water invoice may lead to the largest average reduction of water waste (more than 140 daily liters per household), while fostering better water habits show the lowest reduction (around 15 daily liters per household).

7. APPENDIX

Table A1. Estimation of Control Function

Variables	$Iday/P_w$
Intercept	-34.01^{*}
	(-2.21)
mean_area_L12_$Iday/P_w$	0.530^{***}
	(13.62)
t	-0.144
	(-0.99)
hsize	10.58^{***}
	(29.12)
p_65	9.175^{***}
	(7.46)
p_fem	-10.45^{***}
	(-8.84)
p_work	27.06^{***}
	(21.41)
surf	0.0752^{***}
	(11.81)
old_house	-8.338^{***}
	(-10.91)
gard	10.01^{***}
	(8.98)
pool	21.10^{***}
	(11.36)
eff_k	7.501^{***}
	(8.64)
eff_devices	15.85^{***}
	(11.30)
avt	-0.259
	(-1.89)
avhum	0.342
	(1.56)
avrain	0.00807
	(0.51)
Covid	-1.810
	(-1.36)
Observations	14441
H_0: $Iday/P_w$ is exogenous	
Durbin $\chi^2(1)$	38.467^{***} (p=0.000)
Wu-Hausman F(1,14424)	38.524^{***} (p=0.000)
H_0: instruments are weak	
F(2,14424)	92.891^{***} (p=0.000)
H_0: instruments are exogenous (overidentifying restrictions)	
Sargan-Hansen $\chi^2(1)$	0.004 (p=0.9484)

t statistics in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.2. Parameter estimates of daily water stochastic frontier demand

Variable / Model	SF_HN_CF (M1)	SF_HN_CF_HK (M2)	SF_TN_CF (M3)	SF_TN_CF_HK (M4)	SF_TN_CF_IE (M5)
Intercept	-0.0350	-0.00228	0.0228	0.0352	0.0337
	(-0.60)	(-0.04)	(0.51)	(0.80)	(0.77)
I/P_w	0.00123***	0.000683**	0.00149***	0.00133***	0.00136***
	(4.42)	(2.70)	(6.71)	(6.10)	(6.26)
hsize	0.0309***	0.0410***	0.0321***	0.0347***	0.0341***
	(9.33)	(13.67)	(12.31)	(13.45)	(13.37)
p_65	0.0108	-0.00611	0.00338	-0.00105	0.000293
	(1.89)	(-1.25)	(0.77)	(-0.25)	(0.07)
p_fem	0.0172**	0.0187***	0.0198***	0.0203***	0.0203***
	(3.18)	(3.88)	(4.80)	(5.03)	(5.04)
p_work	-0.0410***	-0.0517***	-0.0473***	-0.0503***	-0.0489***
	(-4.38)	(-6.21)	(-6.50)	(-7.11)	(-6.92)
surf	0.000504***	0.000380***	0.000317***	0.000275***	0.000274***
	(13.36)	(10.49)	(9.76)	(8.44)	(8.44)
old_house	0.0403***	0.0477***	0.0499***	0.0528***	0.0520***
	(11.71)	(15.66)	(18.83)	(20.46)	(20.21)
gard	0.00662	0.0268***	0.0148***	0.0206***	0.0202***
	(1.20)	(5.42)	(3.35)	(4.76)	(4.69)
pool	0.0401***	0.0238**	0.0133	0.0100	0.00912
	(4.45)	(2.73)	(1.72)	(1.30)	(1.19)
eff_k	-0.0102*	-0.00718	-0.0103**	-0.00923**	-0.00926**
	(-2.47)	(-1.95)	(-3.22)	(-2.94)	(-2.96)
eff_devices	-0.0349***	-0.0382***	-0.0353***	-0.0351***	-0.0337***
	(-4.76)	(-5.75)	(-6.18)	(-6.25)	(-6.04)
avt	0.00258***	0.00105*	0.00121**	0.000821	0.000851*
	(4.55)	(2.10)	(2.78)	(1.93)	(2.01)
avhum	-0.00219**	-0.00167*	-0.00192**	-0.00177**	-0.00179**
	(-2.61)	(-2.23)	(-2.96)	(-2.79)	(-2.82)
avrain	0.000142*	0.0000850	0.0000471	0.0000357	0.0000351
	(2.44)	(1.68)	(1.07)	(0.83)	(0.82)
Covid	0.0142***	0.0108***	0.0143***	0.0125***	0.0125***
	(4.92)	(4.23)	(6.45)	(5.77)	(5.81)
$\hat{v}$	-0.00159***	-0.00125***	-0.00170***	-0.00158***	-0.00158***
	(-5.67)	(-4.91)	(-7.59)	(-7.20)	(-7.22)
λ	5.0922***		85.1119***		54.4365***
	(1650.04)		(174.32)		(149.83)
σ_u	0.32194***		5.8840***		3.8638***
	(135.16)		(12.05)		(10.64)
σ_v	0.06322***	0.06510***	0.069132***	0.07139***	0.07097***
	(47.88)	(50.75)	(66.66)	(68.17)	(68.67)
μ	0	0	-214.5***	-127.024***	
			(-6.03)	(-10.56)	
Observations	14441	14441	14441	14441	14441
Log likelihood	3842.2	5364.5	6778.1	7424.4	7409.3

Notes: *t* statistics in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

7.1.Appendix C

Table 8 Estimates on determinants of water waste

Variable / Model	SF_HN_CF_HK (M2)	SF_TN_CF_HK (M4)	SF_TN_CF_IE (M5)
	$\boldsymbol{Var(u)}$	$\boldsymbol{Var(u)}$	$\boldsymbol{E(u)}$
Intercept	-3.426***	2.820***	-109.6***
	(-42.66)	(25.73)	(-6.67)
I/hsize	0.000395***	0.0000795***	0.00518***
	(28.03)	(8.34)	(5.58)
largehsize	0.887***	0.427***	27.58***
	(12.01)	(8.14)	(5.54)
wathabit	-0.461***	-0.433***	-37.14***
	(-4.97)	(-6.54)	(-4.87)
P_w_under	0.283***	0.0606*	3.512
	(7.82)	(2.36)	(1.63)
w_under	-0.0311	0.156***	11.62***
	(-0.68)	(4.79)	(3.77)
bill_under	1.261***	0.770***	60.85***
	(31.49)	(27.00)	(6.78)
P_w_unk	0.507***	0.169**	15.83***
	(6.84)	(3.22)	(3.48)
w_unk	-0.0656	0.0315	6.134*
	(-1.80)	(1.24)	(2.37)
bill_unk	0.731***	0.294***	29.01***
	(22.46)	(12.71)	(6.14)

Notes: *t* statistics in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

REFERENCES

Agthe, D. and Billings, R., 1987. Equity, price elasticity, and household income under increasing block rates for water. American Journal of Economics and Sociology 46: 273–286.

Aigner, D., K. Lovell and P. Schmidt., 1977. Formulation and Estimation of Stochastic Frontier Production Function Models. Journal of Econometrics 6, 21–37.

Amsler, C., Prokhorov, A., & Schmidt, P. (2016). Endogeneity in stochastic frontier models. Journal of Econometrics, 190(2), 280–288. https://doi.org/10.1016/j.jeconom.2015.06.013

Arbués, F., & Villanúa, I. (2016). Potential for Pricing Policies in Water Resource Management: Estimation of Urban Residential Water Demand in Zaragoza, Spain. Http://Dx.Doi.Org/10.1080/00420980601038255, 43(13), 2421–2442. https://doi.org/10.1080/00420980601038255

Arbués, F.; Villanúa, I.; Barberán, R., 2010. Household size and residential water demand: An empirical approach. Australian Journal of Agricultural and Resource Economics, 54, 61–80.

Battese GE, Coelli TJ (1995) A model for technical inefficiency effects in a stochastic frontier production function for panel data. Empirical Economics 20:325–332

Beutel, A. M., & Marini, M. M. (1995). Gender and values. American sociological review, 436-448.

Binet, M.-E., Carlevaro, F. and Paul, M.: 2014, Estimation of residential water demand with imperfect price perception, Environmental and Resource Economics 59, 561–581.

Brent DA, Ward MB (2019) Price perceptions in water demand. J Environ Econ Manag 98:102266.

Burnham, K.P. and Anderson, D.R. (2002) Model Selection and Inference: A Practical Information-Theoretic Approach. 2nd Edition, Springer-Verlag, New York.

Caudill, S. B., J. M. Ford and D. M. Gropper, 1995. Frontier Estimation and Firm-Specific Inefficiency Measures in the Presence of Heteroscedasticity. Journal of Business and Economic Statistics 13, 105–111.

Clarke AJ, Colby BG, Thompson GD (2017) Household water demand seasonal elasticities: a stone-geary model under an increasing block rate structure. Land Econ 93(4):608–630.

DellaVigna, S., 2009. Psychology and economics: Evidence from the field. Journal of Economic literature, 47(2), 315-72.

Dharmaratna D, Harris E (2012) Estimating residential water demand using the Stone-Geary functional form: the case of Sri Lanka. Water Resour Manage 26(8):2283–2299

Diaz, M. and Sanchez, R. (2008), "Firm size and productivity in Spain: a stochastic frontier analysis", Small Business Economics, Vol. 30 No. 3, pp. 315-323.

EEA (2012), *Towards efficient use of water resources in Europe*, Publications Office, 2012, https://data.europa.eu/doi/10.2800/95096

Espey, M., Espey, J., Shaw, W.D., 1997. Price elasticity of residential demand for water: a meta-analysis. Water Resources Research 33 (6), 1369–1374.

Garcia, S. and Reynaud, A. (2004) Estimating the benefits of efficient water pricing in France. Journal of Resource and Energy Economics 26: 1–25.

García-Valiñas, M. and Arbués, F. (2021) Wastewater tariffs in Spain. In *Oxford Research Encyclopedia of Global Public Health*; Oxford University Press: Oxford, UK.
García-Valiñas, M. A., Martínez-Espiñera, R. and González-Gómez, F.: 2010, Affordability of residential water tariffs: Alternative measurement and explanatory factors in Southern Spain, Journal of Environmental Management 91(12), 2696–2706.

García-Valiñas, M., Athukorala, W., Wilson, C., Torgler, B. and Gifford, R.: 2013, Nondiscretionary residential water use: The impact of habits and water-efficient technologies, Australian Journal of Agricultural and Resources 58(2), 185–204.

Garcia-Valiñas, M.A., Martinez-Espineira, R.; Suárez-Varela, M. (2021) Price and Consumption Misperception Profiles: The Role of Information in the Residential Water Sector. Environ. Resource. Economics, 80, 821–857.

García-Valiñas, M. Á., & Suárez-Fernández, S., 2022. Are Economic Tools Useful to Manage Residential Water Demand? A Review of Old Issues and Emerging Topics. Water, 14(16), 2536.

Gaudin S, Griffin RC, Sickles RC (2001) Demand specification for municipal water management: evaluation of the Stone-Geary form. Land Econ 77(3):399–422

Grafton, R. Q., Ward, M. B., To, H. and Kompas, T.: 2011, Determinants of residential water consumption: Evidence and analysis from a 10-country household survey, Water Resources Research 47, 1–14.

Hadjispirou, S., Koundouri, P. and Pashardes, P. (2002) Household demand and welfare implications of water pricing in Cyprus. Environment and Development Economics 7: 659–685.

Hadri, K., 1999. Estimation of a Doubly Heteroscedastic Stochastic Frontier Cost Function. Journal of Business and Economic Statistics 17, 359–363.

Hausman, J.A. and Leonard, G.K. (2002). The competitive effects of a new product introduction: a case study. The Journal of Industrial Economics, 50(3), 237-263.

Hausman, J.A. and Ros, A.J. (2013). An econometric assessment of telecommunications prices and consumer surplus in Mexico using panel data. Journal of Regulatory Economics, 43, 384-304.

Hoyos, D. and Artabe, A.: 2017, Regional differences in the price elasticity of residential water demand in Spain, Water Resources Management 31, 847–865.

Huang, C. J. and J. T. Liu., 1994. Estimation of a Non-Neutral Stochastic Frontier Production Function. Journal of Productivity Analysis 5, 171–180.

Hung, M.F., Chie, B.T., Huang, T.H., 2017. Residential water demand and water waste in Taiwan. Environ. Econ. Policy Stud. 19 (2), 249–268.

Jayarathna, L., Rajapaksa, D., Managi, S., Athukorala, W., Torgler, B., García-Valiñas, M. A., Gifford, R. and Wilson, C.: 2017, A GIS based spatial decision support system for analysing residential water demand: A case study in Australia, Sustainable Cities and Society 32, 67–77.

Kumbhakar, S. C., S. Ghosh and J. T. McGuckin., 1991. A Generalized Production Frontier Approach for Estimating Determinants of Inefficiency in U.S. Dairy Farms. Journal of Business and Economic Statistics 9, 279–286.

Madhoo YN (2009) Policy and nonpolicy determinants of progressivity of block residential water rates: a case study of Mauritius. Appl Econ Lett 16(2):211–215

Martínez-Espiñeira R, Nauges C (2004) Is really all domestic water consumption sensitive to price control? An empirical analysis. Appl Econ 36(9):1697–1703.

Martinez-Espiñeira, R. (2002). Residential Water Demand in the Northwest of Spain. Environmental and Resource Economics 2002 21:2, 21(2), 161–187. https://doi.org/10.1023/A:1014547616408

Martínez-Espiñeira, R., & Francis, S. (2019). An Estimation of Residential Water Demand Using Co-Integration and Error Correction Techniques. Https://Doi.Org/10.1080/15140326.2007.12040486, 10(1), 161–184. https://doi.org/10.1080/15140326.2007.12040486

Martins, R., & Fortunato, A. (2007). Residential water demand under block rates – a Portuguese case study. Water Policy, 9(2), 217–230. https://doi.org/10.2166/WP.2007.004

Meeusen, W. and J. van den Broeck., 1977. Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error. International Economic Review 18, 435–444.

Monteiro, H.; Roseta-Palma, C., 2011. Pricing for scarcity? An efficiency analysis of increasing block tariffs. Water Resour. Res., 47, 1–11.

Mu, X., D. Whittington, and J. Briscoe. 1990. "Modeling Village Water Demand Behavior: A Discrete Choice Approach." Water Resources Research 26(4):521–9.

Nauges, C.; Thomas, A. 2000. Privately Operated Water Utilities, Municipal Price Negotiation, and Estimation of Residential Water Demand: The Case of France. Land Econ., 76, 68–85.

Nordin JA, 1976. A proposed modification on Taylor's demand analysis: comment. Bell J Econ 7(2):719–721

Pérez-Urdiales, M., García-Valiñas, M. A. and Martínez-Espiñeira, R., 2016, Responses to changes in domestic water tariff structures: A latent class analysis on household-level data from Granada, Spain, Environmental and Resource Economics 63(1), 167–191.

Pint, E. (1999) Household responses to increased water rates during the California drought. Land Economics 75: 246–266.

Rajapaksa, D.; Gifford, R.; Torgler, B.; Garcia-Valiñas, M.; Athukorala, W.; Managi, S.; Wilson, C., 2019. Do monetary and non-monetary incentives influence environmental attitudes and behavior? Evidence from an experimental analysis. Resour. Conserv. Recycl., 149, 168–176.

Rathnayaka, K., Malano, H., Arora, M., George, B., Maheepala, S. and Nawarathna, B.: 2017, Prediction of urban residential end-use water demands by integrating known and unknown water demand drivers at multiple scales I: Model development, Resources, Conservation and Recycling 117, 85–92.

Renwick, M.E., and R. Green, 2000. Do Residential Water Demand Side Management Policies Measure Up? An Analysis of Eight California Water Agencies. Journal of Environmental Economics and Management 40(1):37–55.

Reynaud, A., 2015, Modelling household water demand in Europe. insights from a cross-country econometric analysis of EU-28 countries, Technical Report EUR 27310 EN, Joint Research Center.

Rinaudo, J.-D., Neverre, N. and Montginoul, M.: 2012, Simulating the impact of pricing policies on residential water demand: A Southern France case study, Water Resources Management 26, 2057–2068.

Rizaiza, O. 1991. "Residential Water Usage: A Case Study of the Major Cities of the Western Region of Saudi Arabia." Water Resources Research 27(5):667–71.

Roibás, D., García-Valiñas, M. A. and Fernandez-Llera, R.: 2018, Measuring the impact of water supply interruptions on household welfare, Environmental and Resource Economics 73, 159–179.

Salthouse, T. A. (2009). When does age-related cognitive decline begin? Neurobiology of aging, 30(4), 507-514.

Schiersch, A., 2013. Firm size and efficiency in the German mechanical engineering industry. Small Bus. Econ. 40, 335e350.

Schleich, J. and Hillenbrand, T., 2009, Determinants of residential water demand in Germany, Ecological Economics 68(6), 1756 – 1769.

Sexton, S., 2015. Automatic bill payment and salience effects: Evidence from electricity consumption. Review of Economics and Statistics, 97(2), 229-241.

Sims, C. A., 2003. Implications of rational inattention. Journal of monetary Economics, 50(3), 665-690.

Taušová, M.; Culková, K.; Kudelas, D.; Gabániová, L'.; Košcˇo, J.; Mehana, I. Evaluation of Water Resources through Efficiency Index and Water Productivity in EU. *Energies* **2022**,*15*,9123. https:// doi.org/10.3390/en15239123

Thaler, R. H., 1986. The psychology and economics conference handbook: Comments on Simon, on Einhorn and Hogarth, and on Tversky and Kahneman. The Journal of Business, 59(4), S279-S284

UN (2015), *The 2030 Agenda for Sustainable Development*, Resolution adopted by the General Assembly on 25 September 2015.

UN-Water, 2021: UN-Water Analytical Brief on Water Use Efficiency. Geneva, Switzerland.

UNESCO, UN-Water, 2020: United Nations World Water Development Report 2020: Water and Climate Change, Paris, UNESCO.

Wichman, C. J., 2017. Information provision and consumer behavior: A natural experiment in billing frequency. Journal of Public Economics, 152, 13-33.

Williamson, O. E. (1967). Hierarchical control and optimum firm size. Journal of Political Economy, 75, 123–138.

Wooldridge, J. M.: 2015, Control function methods in applied econometrics, The Journal of Human Resources 56(2), 420–445.

Zelezny, L. C., Chua, P. P., & Aldrich, C. (2000). New ways of thinking about environmentalism: Elaborating on gender differences in environmentalism. Journal of Social issues, 56(3), 443-457.