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# Are Economic Tools Useful to Manage Residential Water Demand? A Review of Old Issues and Emerging Topics

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**Abstract:** The analysis of residential water demand has long attracted attention from researchers. However, the central topics at issue have evolved considerably, transitioning from estimating price and income elasticities to using experimental techniques that assess how to motivate households towards water conservation. In this literature review, we contribute to the existing literature by giving an updated overview of the state of the art in the central topics regarding residential water demand. Moreover, we present some interesting lines of research to be explored in the future. Thus, we first review some traditional key drivers of residential water demand. Second, we discuss the role of public policies when managing residential water demand, paying special attention to pricing tools. Next, we briefly review some of the methodological issues with respect to traditional econometrics and discuss related modeling. We then discuss the role of experimental designs and nudging on residential water use. Finally, we include a summary of the main literature findings, and close the discussion introducing some emerging and promising research topics.

**Keywords:** residential water demand; price perceptions; pricing policies; non-pricing policies; stone-geary; field experiment

**JEL Classification:** Q21; Q25; D12; D90



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## 1. Introduction

Water demand modelling allows researchers and policy makers to assess the impact of different kinds of policies on several social and economic dimensions, such as welfare and/or affordability. Residential water demand analysis has attracted the attention of numerous researchers for decades, frequently starring as the subject of several literature reviews [1–5]. The issues of greatest interest have evolved over the years, with some traditional topics—such as price elasticity estimation—coexisting alongside more innovative subjects, such as the information shortages related to water consumption and tariffs, experimental design of residential water demand analysis, or attitudinal features.

Thus, economists have carefully analyzed the role of water prices when managing water demand—and this tool has traditionally provoked great interest among researchers. Several institutions [6–8] have encouraged water managers to design water pricing schedules aimed at achieving competing objectives, including sustainability, efficiency, equity, and cost recovery. This multiplicity of economic and social aims has also been demonstrated in a range of academic papers [9,10]. The variety of features under consideration introduces complexity into water price schedules and, as a consequence, to their modelling in the demand function. Non-pricing policies are commonly assessed, finding heterogeneous impacts of those policies on residential water use [5,11].

Experimental studies are increasingly used to study a variety of topics, including water conservation, with researchers designing their own policies for assessment [12–17]. In this context, nudging frameworks have become increasingly popular, and can be contrasted with the classical approach of analyzing the impact of real policies by way of a natural experiment. In any case, both methods attempt to compare monetary and non-monetary policies in the field of residential water demand management.

This paper is a literature review aimed at describing the latest findings on residential water demand, but it also touches on some traditional issues. As such, the review primarily includes papers published in the last decade, while some seminal papers and key references may also be cited. This state of the art review is a timely contribution to the literature for several reasons. On the one hand, it provides an updated review on household water demand, reporting some recent trends in the field. In this respect, the paper is a significant contribution in practical terms, since it provides an overview of residential water demand modelling. Both policymakers and academics could use our findings as a starting point in their policy design and/or research. On the other hand, this review is focused on the role of prices when managing residential water use. Apart from price elasticities, additional topics are discussed (price information, price perception), addressing how it is possible to complement pricing policies with other kind of strategies (smart meters, nudging, etc.).

The manuscript is structured as follows: first, a section on explanatory factors and key drivers of residential water use is developed, with special attention to public policies. Next, some key methodological issues are discussed. The fourth section delves into experimental design and the impact of nudging and other experimental treatments on residential water use. Finally, we conclude with a summary of the main literature findings, noting some emerging and promising research topics.

## 2. General Framework: Some Key-Drivers

When estimating residential water demand, several studies have proposed alternative approaches. But in general, it has been modelled according to the following generic form:

$$Q = f(P, Y, Z) \tag{1}$$

where $Q$ represents tap water consumption, $P$ and $Y$ denote water price and income, respectively, and $Z$ captures a set of exogenous factors that impact water use. As explained in later sections, this generic form has been developed and adapted depending on the context, the data set, and the issue addressed. Moreover, the previous equation has usually been estimated in an isolated manner, but a few papers modelling households' demand as an equation system can also be found. For example, Suárez-Varela [18], who estimated residential water demand as a Quadratic Almost Ideal Demand System, is an interesting exception.

In this section, a review of the main key-drivers of residential water use is presented, supported by studies estimating residential water demand and supplemented by other papers assessing residential water consumption. According to Abu-Bakar et al. [19] there are three groups of factors influencing residential water demand: contextual, environmental, and psycho-social features. The first subsection includes socioeconomic factors and other households' characteristics. The second group captures some geographical and seasonal variables with impact on water demand. The third group focuses on some attitudinal and psychological features, such as environmental concern, awareness, knowledge, or social norms. We also discuss the role of some public policies in the fourth subsection, where special attention is devoted to pricing policies.

### 2.1. Contextual Factors: The Effect of Households' Characteristics

Most studies have assessed the impact of socio-economic and demographic factors on residential water demand. In fact, Makki et al. [20] find that demographic and household characteristics are the most significant determinants of residential water consumption. This subsection explores some contextual factors frequently considered by previous studies, discussing their main effects.

#### 2.1.1. Income

Although this variable is usually difficult to observe at the household's level, and several papers have used proxies or have estimated this variable [21,22] when income information is not available, previous literature has broadly analyzed the relationship between income and residential water consumption [1,2,23,24]. Thus, "the idea that households with low water use are poor and large users are rich has been challenged for a number of years (...)" Nauges and Whittington [9] (p. 126). Higher income is usually correlated with higher individual water consumption [20,22,25–28], but that correlation is small [29]. In aggregated terms, Rinaudo et al. [30] show that water consumption is higher for municipalities with higher income levels.

Income elasticities have been calculated repeatedly, usually finding an inelastic water demand. That means that the proportion of income spent on water decreases with income [31], e.g., [32–34]. This can be explained because the water bill represents a small proportion of a household's budget [18]. Baerenklau et al. [35] estimate an income elasticity of 0.16. Similarly, Havranek et al. [24] find a mean income elasticity by 0.15, once publication selection and endogeneity bias have been controlled for.

As Makki et al. [20] explain, the influence of income is double, as it affects, on the one hand, additional lifestyle and leisure consumption (such as the shower and bath end-use categories), but also affordability regarding some electrical appliances, such as washing machines and dishwashers. In this regard, as demonstrated by Beal et al. [36], research shows that households with higher incomes tend to install water efficient technology [37,38]. However, and as we will discuss later, that fact does not necessarily mean that technology is used optimally.

Moreover, different income levels could be linked to different reactions under price changes. When estimating residential water demand in Granada (Spain), Pérez-Urdiales et al. [21], in a sensitivity analysis, provided separated estimates by income group. They found that lower-income households showed a higher price-elasticity.

#### 2.1.2. Age

Household composition, in which regards the age of family members, does not offer homogeneous results in previous literature. While some studies find lower levels of water consumption per capita in older people [39–42], others find the opposite effect [33,43]. As noted by Marzano et al. [44], elder and younger inhabitants have higher levels of recreational water consumption, for gardening and water-intensive outdoor activities respectively. Regarding families with children, Rathnayaka et al. [45], compare annual average water use of households with and without children across similar household sizes and dwelling types, finding that households with children consume less water per capita. However, concerning water conservation, both families with young children and older people are likely to demonstrate water conservation habits, while teenagers tend to consume more [20]. Pérez-Urdiales et al. [21], in their water demand estimation using Latent Class Models, detected that the higher the proportion of younger people than 16 years old in the family, the higher the probability of belonging to the lower-consumption groups.

#### 2.1.3. Gender

The effect of gender on residential water consumption is not usually assessed. In a recent analysis, Tong et al. [46] find that women consume twice as much water as men, mainly due to household care activities. So the use of water is clearly linked to different daily gender roles and tasks. However, females tend to be more sensitive to protect the environment than males [47]. According to Davies et al. [48], females consume less than males, while Beal et al. [36] find no significant differences in per capita or per household consumption between male and female respondents. In Millock and Nauges [38], the gender of the respondent was not an explanatory factor in adopting water saving equipment. However, there are few examples of analyses specifically considering gender issues when modelling residential water demand. Reynaud [4] used regional data in Germany and

Spain to estimate residential water demand, finding that—in some cases—the share of females in the region had a positive impact on households' water use.

#### 2.1.4. Formal Education

Education is other explanatory factor in residential water consumption, but its effect is not clear. For instance, Makki et al. [20] find that those with higher education levels consume more water, even though they are more concerned with water conservation behavior. On the contrary, Renzetti et al. [34] and Garcia-Valiñas et al. [49] find higher education levels strongly associated with lower water consumption. Gilg and Barr [50] find a positive influence of education on water saving behavior as well, while Grafton et al. [51] do not report a significant impact of higher education on residential water demand.

#### 2.1.5. Household Size

Generally, household size has a positive effect on water consumption [21,22,31,33,41,43]. Previous research has found that water consumption increases less than proportionally to the increase in household size, likely due to economies of scale [1,45,52]. As pointed out by Marzano et al. [44], per-household consumption increases with household size, but per-capita consumption decreases [53,54]. According to Arbues et al. [40], three patterns of water consumption can be distinguished regarding household size (small, medium and large households), with price semi-elasticities being different among them. Note that when the demand equation is semi-logarithmic, estimated coefficients can be interpreted as price semi-elasticities, which give the percentage change in the quantity of water demanded in response to a one unit change of the price variable, as explained in Arbues et al. [40].

#### 2.1.6. House Ownership

The influence of housing tenure has also been discussed by previous literature, finding that ownership tends to increase water conservation actions [50]. Some authors have remarked that owners are expected to have higher incentives than tenants to adopt water-saving devices technologies [21,38,51]. However, Pérez-Urdiales et al. [21] do not find a significant impact of house ownership on residential water demand.

#### 2.1.7. Housing Characteristics and Equipment

With respect to housing characteristics and water using equipment, previous research has identified numerous items that have an important effect on water demand. For instance, the size and age of the building, the number of rooms, the tenure of a swimming pool or garden and the type of dwelling make a difference in residential water consumption levels [28,30,31,43,49,51,55]. Furthermore, even the type of plants in the garden can affect the amount of water consumed [56].

Bigger houses with more bedrooms demand more water and single-family houses consume more water [43,57]. Per-capita analysis in Rathnayaka et al. [45] shows higher levels of water use in semi-detached dwellings compared to multi-storied dwellings and detached dwellings. Besides, some authors [31,49] demonstrate that those households equipped with a swimming-pool register higher levels of water demand.

The type of water meter installed is also relevant for the measurement of water use, since the equipment can be either individual or collective. Individual metering refers to having one meter for each household, that is, one single family, while collective meters are for multi-family units, where a group of apartments is considered by a water service to be a "unique subscriber" [57]. Nauges and Thomas [58] find evidence of lower water consumption when individual meters were used, suggesting that the installation of individual water meters may in turn encourage the adoption of water efficient equipment. When estimating residential water demand in the United Kingdom, Reynaud [4], finds that the proportion of households with metered water consumption is related to lower household consumption levels.

However, comparing water consumption between individual and collective metering contracts is not straightforward. Collective water consumption cannot be split into the number of households where there is a high percentage of empty houses, and that information is frequently unavailable. Indeed, in their analysis of residential water demand in Andorra La Vella, Reynaud et al. [57] found that the average per household water consumption was higher for single-family water subscribers compared to multi- family water subscribers. However, people living in multi-family units are much less likely to know how much water they use, since the payment is frequently included with other charges [59]. As will be discussed later, consumption and price misinformation can result in non-efficient consumption levels.

Finally, the installation of water saving devices or efficient appliances, technologies, and equipment also impacts water consumption [21,49]. According to Rathnayaka et al. [45], efficient showers, toilets, and front-loading clothes washers save an average of 35 liters per person per day. This issue will be further analyzed in the public policies section below.

### *2.2. Environmental Factors*

According to Abu-Bakar et al. [19], environmental issues are exogenous factors which influence water demand. This category includes all the variables outside the households' control such as climate, seasonality, or quality.

#### 2.2.1. Weather and Climatic Variables

Water use increases with temperature [30,39,40,42,43,60–62] and with the number of dry days [30], while it decreases with rainfall levels [26,28,31,41,43,60]. Furthermore, water consumption varies depending on temperature (maximum vs. average) and/or rainfall (annual vs. summer, number of rainy vs. dry days) which influences activities such as gardening, swimming pool use, and personal hygiene [5,26,31]. Interestingly, as Puri and Maas [63] explain, model choices with different specifications for weather metrics have a negligible effect on price elasticity estimates. As Dharmaratna and Harris [64] indicate, climate influences water demand positively due to high temperatures, but also negatively, when rainfall is high. Higher altitude is correlated with lower water consumption [26].

#### 2.2.2. Seasonality

Most residential water consumption data series are seasonal and nonstationary. For example, a seasonal population translates into higher water consumption per capita [30,41], probably due to recreational uses of water. However, seasonal inhabited dwellings have a significant negative effect on consumption [42]. Reynaud et al. [57] find higher water consumption during the winter (skiing season) in Andorra and Yudhistira et al. [65] find the lowest water consumption in August and January in Jakarta. Moreover, and as it is discussed latter, seasonality have impact on household's price elasticity.

#### 2.2.3. Water Quality

As Reynaud and Romano [5] explain, water quality affects household water consumption, emerging as a significant dimension in the provision of water services. Consumers reduce water consumption when they consider tap water quality inadequate [42,66]; for example, in Garcia-Valiñas et al. [11] the authors find that deterioration in water quality led to significant reductions in water consumption, whereas higher quality water increases residential water consumption [67]. Unsurprisingly, Zivin et al. [68] report increased purchases of bottled water when drinking water quality is poor, and Bontemps and Nauges [69] find water quality has an important effect on the decision whether to drink bottled or tap water.

### *2.3. Psychological, Attitudinal, and Behavioral Factors*

According to Beal et al. [36], some of the indirect drivers of water consumption include personal attitudes, values and behaviors related to environment and water conservation, socio-economic status and a sense of trust and fairness to institutions and to other consumers. Russell and Fielding [25] find that individual's beliefs, habits, and environmental consciousness are drivers of water conservation, because people's attitudes are strong predictors of household water consumption [70]. Maas et al. [71] notes that customers motivated by environmental and social issues use, on average, less water than those motivated by cost and convenience.

Environmental attitudes and behaviors play an important role in water conservation [72]. The recent study of Shahangian et al. [73] about the relation between socio-psychological factors and water-efficiency behaviors revealed that attitudes towards water conservation clearly affect the intention to adopt water-saving practices. Moreover, Ibáñez-Rueda et al. [74] detect that contact with nature has a positive impact on water use efficiency. The authors propose to promote school outings to natural areas, in order to acquaint schoolchildren with natural environments, contributing to optimize the use of water resources in the future. Furthermore, Millock and Nauges [38] conclude that environmental commitment increases the probability of adopting water-efficient equipment.

According to Attari [75], nearly 30% of water consumption can be reduced through conservation habits. Similarly, Rajapaksa et al. [15] find that promoting pro-environment behavior contributes to water conservation, with non-monetary interventions having higher impact on behavior and attitudes. However, in their analysis of residential water demand though latent class modelling, Pérez-Urdiales et al. [21] find that self-reported water-conservation habits do not have a significant impact on water demand when controlling for other variables.

## 3. The Role of Public Policies

Demand side policies are strategies designed to reduce water consumption, comprising price strategies and non-price strategies [76]. The effect of pricing policies in managing residential water demand is controversial, with some authorities and researchers finding them useful for reducing water consumption [76] and considering price an effective instrument in demand management [77]. Others, such as Randolph and Troy [59], strongly suggest that increasing water prices is not an effective method in the short or medium term. Stavenhagen et al. [78] (p. 1) find the highest-impact water demand management policies are the "renovation and maintenance of networks, and campaigns for water-saving technologies, followed by universal installation of water meters, rapid leak detection, public awareness campaigns, and municipal regulations", while reforms in tariffs were far less effective. According to Dascher et al. [76], financial incentives do not accurately predict water conscious consumption decisions, whereas other features (information on how to reduce water consumption; the feeling of effectiveness when engaging in conservation behavior, etc.) are found to be significant influences; thus, monetary savings are not a crucial factor for water conservation. Olmstead [37] show that price-based tools are better to non-pricing mechanisms on a number of points. However, rising water prices is always difficult from a political point of view. Since policy design is a controversial topic, this section provides a discussion of studies assessing the impact of both pricing and non-pricing policies on residential water demand.

### 3.1. Pricing Policies

Previous studies on water demand have determined that prices and tariffs play a significant role in water use, and several of its dimensions have been analyzed in detail. Traditionally, many papers were aimed to estimate price-elasticities. However, other features have also been assessed, such us the tariff schedule, information, or billing-related issues.

#### 3.1.1. Tariff Schedule

Since water pricing is aimed at different objectives [79,80], water tariffs exhibit a broad range of structures, from flat rates and fixed tariffs, to different types of variable tariffs that may be levied as increasing, linear, or decreasing block rates [80]. Sometimes, water tariffs are adapted to household features, such as in the case of allocation-based rates and special tariffs [80–82]. As expected, fixed tariffs where charges are not related to water usage are associated with greater water consumption compared to volumetric tariffs [79,80].

Rather than using flat rates, a number of different water tariff structures have been implemented in attempts to encourage water conservation. Increasing block tariffs (IBT) is frequently adopted as one of the alternatives [83]. According to the meta-analysis by Marzano et al. [44], 42% of papers estimating price elasticities under increasing block rates. As Wichman [84] indicates, IBT discourages the consumption of water since households pay higher rates when they increase consumption, potentially inducing conservation among high users without placing a burden on low income/low users. Some authors find that IBTs reduce water consumption more intensively than other pricing schedules [85–87]. Using simulation models, Sahin et al. [88] also find that, although the predicted water consumption savings are lower than when adopting water restrictions, IBTs can lead to water consumption reductions, suggesting that the optimization of tariffs based on seasonality and water availability may be useful. In some circumstances, super-increasing block rate pricing has been applied to manage scarcity of water resources, in which the user pays for its entire water consumption at the rate of the last block reached [31]. In addition, tariff structures have been shown to affect price elasticities, as explained in the next section.

#### 3.1.2. Price Elasticities

The price of water is one of the most relevant variables in estimating residential water demand. The classical approach to assess the relation between water price and consumption is to calculate the price elasticity of the water demand, i.e., measuring the degree of responsiveness of water consumption to a change in water price, ceteris paribus. More precisely, it indicates the percentage of change in household water consumption in response to a one percent change in water price, holding constant all the other determinants of the demand (Note that this is a traditional view of price elasticity with alternative approaches under block-tariffs, such as the overall price elasticity or the unconditional/conditional price elasticity. For further details, check [86]). Although any commodity demand is expected to decrease when price rises, the case of water is quite particular.

Numerous authors have studied price elasticities for residential water demand, repeatedly finding that it is inelastic [4,5,34,43,65], even in developing countries [3]. Three meta-analyses reporting summary statistics of these elasticities—from Espey et al. [89], Dalhuisen et al. [90] and Sebri [91]—find that water demand is price inelastic, with an average range between −0.37 and −0.51.

According to Sebri [91], price elasticities differ also depending on country's geographic location and the level of development. More recently, Marzano et al. [44] find that papers dealing with price endogeneity estimate higher price elasticity values. Moreover, some studies reporting the largest values for price elasticity (higher than one) have modelled residential water demand considering the piecewise linear budget constraint implicit in block pricing schedules [86]. Moreover, price elasticity increases with water consumption [27].

As Lee and Tanverakul [92] indicates, price elasticities also vary depending on household characteristics. Reynaud et al. [57] find higher price elasticity for single-family units than for multi-family units. Price elasticities could also vary depending on the time span analyzed. According to Havranek et al. [24], short run analyses are more than twice as frequent as long-run analyses, but the difference in estimated elasticities is small as it is found also in Yudhistira et al. [65]. For example, when studying short and long-run residential water consumption, Nauges and Thomas [93] estimate a higher price elasticity in the long run than in the short run, but the difference is just 0.14 (−0.26 and −0.40, respectively). Price elasticity is also higher in peak periods than in off-peak periods [44,94].

There are several reasons why water demand exhibits low responsiveness to changing prices. On the one hand, some intrinsic characteristics of water, such as the fact that it is a basic need with few substitutions, makes it hard to reduce household water consumption even in a context of price increases. On the other hand, users' lack of information and comprehension of water tariffs [31,33,95], along with the complexity and incomplete information given in water bills result in consumers with limited knowledge of the price of water [96–99]. According to Carter and Milon [100], informed households are more responsive to both average and marginal price signals. Additionally, water bills usually account for a small proportion of household expenditures [1,2,90,101], even though *water poverty* exists in some cases (That is, when water bills represent a proportion of the household budget higher than 3%. This threshold should be interpreted with caution, since some high-consuming recreational water uses, such as swimming pools, might result in expenditures higher than 3% of household budget, which are not due to *water poverty* [102]). In a recent study, Suárez-Varela [18] reported an average weight of 0.6% for households' budget expenditures, similarly to the figures provided by Olmstead et al. [86] or Tanishita and Sunaga [27]. Dharmaratna and Harris [64] find that water bills in developed countries represent less than 1% of the average household income. These low figures could generate rational inattention when making decisions concerning to water consumption [101]. This issue directly relates to the information and price perception issues discussed in the next section.

### 3.1.3. Price Perception and Information

As mentioned previously, when water tariffs are structured in blocks, average and marginal prices generally differ. Although theoretical models set marginal prices as the relevant signal for consumers, empirical studies do not always support that hypothesis. Actually, there is much controversy in the literature regarding this issue.

Whether users react to average or marginal prices was first discussed by Howe and Linaweaver [103] who compare the two prices in their water demand analysis (According to Marzano et al. [44] and Puri and Maas [63] using average instead of marginal price yields higher estimates of price elasticity). Thus, some authors, include both marginal and average prices in their estimations [32,58]. However, others prefer using average prices [33,43,61,104] or marginal prices [30,42,60,105,106]. Some authors consider consumers' perceived price as the relevant factor [31]. Recently, Cook and Brent [107] discuss which is the relevant price, concluding that there is clear empirical evidence that most customers do not understand water tariffs due to their complexity, so it is probable that they do not respond to changes in marginal price.

In terms of testing empirically which is the best option, Opaluch [108,109] was the first to propose a test of whether consumers react to average or marginal prices in a linear demand function when price tariffs are structured in blocks.

However, Opaluch's test has been criticized [31] since is based on a linear specification of water demand, which is not consistent with the theoretical restrictions of a demand function. Moreover, and as shown in Table 1, many papers implementing Opaluch's test have returned inconclusive results.

**Table 1.** Summary of papers testing the perceived price using Opaluch's or Shin's tests.

| Paper | Country | Year | Data | Opaluch's Price Test | Shin ($k$) Price Test |
|---|---|---|---|---|---|
| Chicoine et al. [110] | Illinois, USA | 1982–1983 | 100 households [a] | No MP or AP rejected | — |
| Kulshreshtha [111] | Canada | 1986 | 1384 households | No MP or AP rejected | — |
| Nauges and Thomas [58] | France | 1988–1993 | 116 municipalities [b] | No MP or AP rejected | — |
| Ruijs et al. [32] | Brazil | 1996–2004 | 39 municipalities [a] | No MP or AP rejected | — |
| Nieswiadomy and Molina [112] | Texas, USA | 1981–1985 | 101 households [b] | — | −0.43–1.55 [1] |
| Nieswiadomy [85] | USA | 1984 | 430 water utilities | — | 0.88–1.26 |
| Nieswiadomy and Cobb [113] | USA | 1984 | 229 cities | — | −0.32–−0.64 |
| Carter and Milon [100] | Florida, USA | 1997–1999 | 742 households [a] | — | 0.40–1.31 [2] |
| Bell and Griffin [114] | Texas, USA | 1999–2003 | 734 households [b] | — | −0.76–−2.89 [3] |
| Monteiro and Roseta-Palma [42] | Portugal | 1998, 2000, 2002, 2005 | 278 municipalities [a] | — | −0.18 |
| Binet et al. [31] | France | 2004 | 173 households [a, c] | — | 1.5 |
| Almendarez-Hernández et al. [115] | Mexico | 2010–2014 | 7 municipalities [b] | — | 1.08 |
| Cabral et al. [116] | Mexico | 2004 | 2407 households | — | 1.79–2.34 |
| Puri and Maas [63] | Colorado, USA | 2006–2014 | 21,874 households [a] | — | 1.13 |

Notes: *AP*, average price, *MP*, marginal price. Data type: [a] unbalanced panel data. [b] balanced panel data. [c] Shin's test adapted. [1] Decreasing block rates: $k = 1.55$, increasing block rates: $k = -0.43$. [2] Informed group: $k = 1.31$, uninformed group: $k = 0.40$. [3] Water supply: $k = -0.76$ MP, water sewage: $k = 2.89$. Source: Own elaboration.

The issue was also studied by Shin [117], who introduced a price-perception parameter, $k$, in the electricity demand function. This test was quickly extended to the water demand literature. According to Shin [117] the perceived price, $P^*$, and denoting the marginal and average price with $MP$ and $AP$ respectively, can be written as follows:

$$P^* = MP(AP/MP)^k \tag{2}$$

Thus, when the price perception parameter estimate is equal to zero, $k = 0$, perceived price equals marginal price ($P_t^* = MP$), and when the price perception parameter is equal to one, $k = 1$, perceived price is equal to average price ($P_t^* = AP$). In his empirical application, Shin suggests that consumers respond to average prices rather than marginal prices when facing decreasing block structures.

As shown in Table 1, using Shin's test some papers conclude that households systematically overestimate marginal price [42,114], while others find that residential users underestimate their price because their perceptions are even lower than the average price [31,116]. Applying Shin's methodology in the field of residential water demand, Nieswiadomy and Molina [112] find customers reacting to marginal prices when blocks are increasing, and average prices when block rates are decreasing. Aubuchon and Roberson [118] show that under conservation rate structures, aggregate demand does not respond to either marginal or average price.

However, there are some drawbacks to this test, as explained in Binet et al. [31]. The authors develop a generalized Shin's approach, including a perceived net income corrected by the *Nordin's difference* [119] in the demand model, and correcting the specification error in Shin's traditional model that emerges as "a source of inferential biases in model estimation and testing" Binet et al. [31] (p. 579). According to Taylor [120], it is difficult to analyze the effect of changes in the intramarginal rates under block rate tariffs, since the marginal price is only modified through an income effect, not by changes in those rates. Furthermore, marginal prices vary depending on the quantity of water consumed. One solution could be the use of a marginal price corresponding to the user's consumption block, plus a difference variable for those cases with fixed quotas or free allowances; effectively acting as a rate structure premium (the difference between the total bill and what one would have paid if all units were charged at the marginal price). This represents the income effect of the tariff structure, namely Nordin's difference, as suggested by Nordin [119]. Nordin's solution is highly controversial due to the high information costs imposed on consumers in having to study tariff structures and changes in intramarginal rates [112,121].

Other methodologies have also been used to assess price perceptions. For instance, an alternative viewpoint is presented by Ito [122], who employed the Encompassing Test [123] in the energy sector. He included marginal and average prices in the regression, with four possible outcomes depending on the coefficients' significance. Clarke et al. [96] provide an example of the encompassing test in water when estimating water demand in Arizona (USA), finding evidence in favor of a lagged average price specification rather than lagged marginal price. With respect to the effect of an increase in the price of the third block of an IBT, Nataraj and Hanemann [124] find consumers respond to marginal prices close to the kink points. Similarly, Olmstead et al. [86] also suggest that those users react to marginal price, due to the high concentration of observations around the kink points. Finally, Wichman [84] finds users responding to average price by exploiting the divergence in average and marginal prices when an IBT is introduced using Differences-in-Differences (DD) technique.

Furthermore, since water tariffs are non-linear, consumers have serious difficulties understanding the actual marginal price structures [21,99,124,125] and adopting rational price-quantity decisions [17]. "The misperception of prices is most likely to occur when pricing schedules are complex, when the connection between consumption and payoffs is remote, and when other features of the economic environment make it difficult to learn from past experience" Liebman and Zeckhauser [126] (p. 2). For example, Martins and Fortunato [39] explain how the complexity of water tariffs in their study (IBT plus fixed quotas) increases the difficulty of interpreting prices, therefore sending confusing signals to customers.

In general, many studies have found that consumers are uninformed about prices, tariffs, and their own water consumption [31]. Brent and Ward [99] find that there is a higher probability that households will have information on their bill rather than their marginal price. Recently, some authors [127,128] detect that households are far from knowing water price, bill and consumption. Regarding the role of information, studies have reported heterogeneous results. On the one hand, Pérez-Urdiales et al. [21] did not find significant impact of price information on residential price-elasticity. On the other hand, Gaudin [95] finds that providing price information in the water bill increases the price elasticity of water demand. Similarly, Carter and Milon [100] studied the effect of price knowledge on households' demand for water, finding that informed households are more responsive to both average and marginal prices. Binet et al. [31] find that users underestimated the price of water, which led to overconsumption. In this concern, Rajapaksa et al. [15] discover that households who are aware of average and marginal prices tend to reduce water consumption when such policies are implemented.

#### 3.1.4. Price Reforms

Changes in tariffs may have an impact on water demand; for example, Ratnasiri et al. [87] show that IBT produces a negative effect on water consumption, indicating that those structures are more "conservation-oriented" than a uniform pricing policy. Baerenklau et al. [35] find that switching from uniform rates to IBT water budgets reduces water demand by 17%. Analyzing the introduction of a third price block in an IBT, Nataraj and Hanemann [124] find that doubling the marginal price leads to a decrease in water consumption of 12% among high-use households. Similarly, in Romano et al. [26], increasing the prices of the tariff caused a reduction in residential water consumption. Wichman [84] use DD to capture the overall treatment effect of the change in tariff structure on consumption, finding that a move from flat rates to IBT induced an overall increase in consumption due to the lower rates for the first units of consumption. Similarly, Zhang et al. [129] find adopting IBT pricing structures result in reductions of annual residential water demand around 3–4% in the short term and 5% in the long term. Interestingly, after controlling for temperature and rainfall, Olivier [130] finds a 13% average reduction in consumption following a price increase in water tariffs and the introduction of metering programs (which replaces fixed billing), along with an extension of the network to low-consuming poor neighborhoods. However, since price elasticity is not uniform across users, most of the poorest households experienced an increase in water bills of 31.5%, while richer households, who could adapt their consumption, managed to reduce the impact of the price increase on their bills. Regarding the effect of tariff changes on price elasticity, some authors have not found any significant impact of the tariff reform on price elasticity [21,65].

#### 3.1.5. Billing

Binet et al. [31] suggest that increasing information about marginal prices in water bills might reduce consumption. However, according to evidence in Wichman [97], increasing billing frequency from bimonthly to monthly boosted customers' water demand between 4% and 9% in response. Monteiro et al. [98] find that consumer awareness of water bills increases price elasticity, although they do remain price-inelastic [131]. In this regard, Beal et al. [36] explored the effect of increasing awareness of consumption (via receipt of billing information) on perceived water use, finding that those who receive more information are in a better position to estimate how much they may be consuming and how to better manage their consumption. In Gaudin et al. [132], price elasticity increases around 30% when the bill includes information on prices. Sometimes the water authority prints only the average price paid and does not show any details of the tariff, making it difficult for consumers to understand the costs and giving rise to another perception bias involving bills [31]. Thus, an emphasis on making water bills clearer, along with billing reforms, is needed to promote water conservation behaviors, especially among certain social groups [46]. In any case, consumers are, in general, poorly aware of their water bills [127].

### 3.2. Non-Pricing Policies

Non-pricing policies for water demand management have been classified by many different authors according to different categories. For example, Kenney et al. [133] distinguish between restrictions, technology, and education. Similarly, other authors have classified non-pricing tools into four categories: technological, educational, informational, and regulatory policies [11]. Cominola et al. [54] distinguish between technological strategies involving the installation of water efficient appliances; financial strategies focused on modifying water tariffs, studying price, and income elasticities; legislative strategies and different regulations and restrictions on water use; maintenance strategies that seek to reduce leakages in water supply to increase its efficiency; and educational strategies, which include education and public awareness campaigns. In this paper, non-pricing policies are aggregated into two groups. First, there are policies involving mandatory reductions of water use through regulation, rationing, and imposing restrictions on water consumption. A second category of policies aims to encourage voluntary reductions in water consumption, using tools such as educational campaigns or advice and rebates for adopting water-efficient technologies. In fact, mandatory restrictions on water use (rationing) are effective in changing consumers' behavior, producing reductions in the range of 19–29% [22,134]. However, this type of actions is controversial, since water is a basic need [76] and rationing produces welfare losses that negatively affect consumers [22,135].

Besides, numerous public campaigns have sought to encourage voluntary reductions of water consumption. On one hand, decades of educational campaigns have attempted to get citizens to be more environmentally conscious, informing users about how they can save water [11]. The outcomes of this type of policies on water conservation is not clear. Some authors have detected significant impacts of these programs on residential water demand [85,134]. Recently, Wang and Chermak [136] estimate an average household's water consumption decreases by 2.9% one month after conducting an education program. However, some other authors have found that the effects of these types of programs dissipate in the long-run [13].

Another common policy encourages the acquisition and installation of water efficient devices, as well as the improvement of pipes and repairs on older buildings. In fact, Lee et al. [137,138] find the use of multiple efficient appliances achieved water savings of about 31% reduction in household water demand. Similarly, Grafton et al. [51] and Renwick and Archibald [139] found water savings ranked between 8% and 25%. However, some of those results are reduced in the long-run [137]. Furthermore, as Dieu-Hang et al. [140] explain, policies, public information, and education campaigns aimed at influencing household behaviors in water conservation might generate a double saving effect, given that conservation water use behaviors are linked to a higher probability of adopting water-efficient appliances. Since the costs associated with purchasing water saving appliances are an important barrier to water conservation, rebates for water efficient appliances are routinely used [134,141].

Yet, when installing efficient devices, the so-called *rebound effect* could arise. That is, there may be situations where habits were not consistent with technologies, and an effect in the opposite direction could be observed. Campbell et al. [142] find clear evidence of a rebound effect whereby residential water consumption increased after the installation of water efficient equipment. Conversely, Bennear et al. [143], analyzed the impact of high-efficiency toilets on water consumption and found no evidence of a rebound effect. Pérez-Urdiales and García-Valiñas [144] find different behavioral patterns depending on the kind of efficient appliance considered. Thus, they show that households who tend to invest in water efficient electrical appliances (dishwashers, washing machines) also exhibit better water conservation habits. Surprisingly, the authors detect the opposite effect in the case of non-electrical water efficient technologies (i.e., low-flow devices).

## 4. Brief Notes on Methodology

### 4.1. Approaching to Data Set

There are three main issues to consider when using a data set to study water demand. The first question is the level of data disaggregation. Databases employed in water demand analysis can be composed of individuals or households, as in Rathnayaka et al. [45]. Alternatively, data can be aggregated by suburbs [87], municipalities, cities, or towns [42], or by regions or countries [26,30]. The second consideration is the dimension of the data set, as there may be panel data, cross section, or time series data, with each case requiring different econometric modelling techniques. Some examples of different data dimensions include the use of panel data by Pérez-Urdiales et al. [21], Jayarathna et al. [55] using a cross section, or Martínez-Espiñeira and Nauges [105] who analyze time series data. Third, note that the specification of the dependent variable (which may refer, for example, to water household consumption or per head consumption) is also an important subject to discuss, since interpretation of the estimates might be different. For instance, using per capita water consumption as the dependent variable enables to analyze the presence of the economies of scale in residential water consumption.

Some authors study water demand using Geographic Information Systems (GIS) [55,145]. House-Peters and Chang [146] stress the importance of technological advances in spatial sciences, which will produce increasingly effective models for water demand. Due to the seasonality and non-stationary characterizing water demand, seasonal auto-regressive integrated moving average models are also used to estimate and forecast water demand [147]. Finally, new technologies in the water sector (as smart metering) have emerged in the past decade. Water smart meters are monitoring devices which provide households with real-time information on their consumption [106]. See Makki et al. [20] for a review on different smart meters and Stewart et al. [148] for a discussion on the benefits of smart metering. These technologies offer the possibility of generating large data sets by capturing real-time consumption data [13,106].

### 4.2. Dealing with Price Endogeneity

Water demand estimation does not fit the classic econometric modelling techniques due to the fact that tariff structures are non-linear. Under these price schedules, price becomes endogenous since it depends on the consumption block, as explained in Roseta-Palma et al. [131]. When variable block tariffs are applied in water prices, the simultaneous determination of marginal price and water demand introduces the problem of price endogeneity [149]. Reynaud et al. [57] notes that average price depends on consumption level, and the level of consumption is affected by the average price. Recently, Marzano et al. [44] conducted a thorough meta-analysis under different scenarios, finding that models that deal with price endogeneity report more elastic water demand. This finding stresses the importance of choosing an adequate estimation methodology.

To address the issue of price endogeneity, several authors have developed different procedures as follows:

- Instrumental Variables (IV). Using instrumental variables to assess the price issue has been the standard procedure for many years (see Arbués et al. [1]). As Arbués et al. [1] explain, to obtain unbiased and consistent parameters under OLS there should not be correlation between the error term and any explanatory variable in the model, but under block tariffs, prices are endogenously determined by the quantity demanded. These authors also explore different approaches to this technique using two-stage least squares (2SLS) or three-stage least squares (3SLS). There are frequent examples in the literature that use IV [31,42,64,116,149].
- Control function (CF). Similar to IV, the control function estimation technique regresses the endogenous explanatory variable on the exogenous explanatory variables and a set of instruments, including the price and the error estimated in the first stage in the demand function [150]. This technique has previously been applied in some papers such

as Carter and Milon [100] or Pérez-Urdiales et al. [21]. As Pérez-Urdiales et al. [21] indicate, under non-linear models, this technique is more appropriate than 2SLS.

- Discrete Continuous Choice (DCC). Another approach for dealing with price endogeneity is the discrete continuous choice (DCC) model [35,37,86,101,151]. DCC models, suggested by Hewitt and Hanemann [151], address the problem of endogeneity in water demand functions, assuming that consumers are informed about water tariffs. These models consider that the observed demand is the result of, first, the choice of the block of consumption and, second, a perception error which may place consumption on a different block from the one selected. Several authors have chosen DCC as their estimation method [37,86,106,152,153]. Interestingly, Vásquez Lavín et al. [152], who estimates a DCC model for the residential water demand by comparing six functional forms (log-log, full-log, log-quadratic, semi-log, linear, and Stone–Geary), concluded that the functional form chosen affects the values of both expected consumption and price elasticity. Some authors have extended DCC models to accommodate specific IBTs [153]. The main drawback of this method is assuming that consumers are fully informed about tariff structures, which is doubtful [31]. Recently, Wang et al. [101] proposed modelling consumer behavior based on a simple heuristic which generate more accurate predictions than modelling through DCC models.

### *4.3. Functional Forms: The Role of Stone–Geary Models*

It is assumed that residential water demand depends on water price, income, and the availability and prices of the substitutes and complements of water, as well as on consumer preferences [5]. The case of water demand is a quite particular one, since most indoor water uses, such as personal hygiene, cooking, or cleaning, are not easily substituted. Furthermore, household habits tend to be rigid/inflexible in the short run [5]. In addition, complementary goods are typically durable equipment, which is unlikely to be replaced in the short term; for example, washing machines, sanitary equipment, dishwashers, and other devices.

To estimate residential water demand, it should be taken into account that water is used by households as a composite good [5], which consists of the direct use of water for drinking plus the indirect use, i.e., as a complement to several household activities (washing, cooking, hygiene, gardening). As a result, water is a necessity in some uses, while it can be substituted or reduced in some other uses; in the latter, use is more likely to be affected by price changes. In this context, specifying a residential water demand function based on a Stone–Geary utility function is consistent with that idea [22,41,42,64,105,132]. The main difference between double-log and the Stone–Geary models is that the latter allows for a non-constant price elasticity of demand; that is, a price elasticity sensitive to the price of water. Furthermore, it allows modelling the water consumption level, which is unresponsive to changes in prices [34]. However, it should be noted that linear (e.g., Chicoine et al. [110], Nieswiadomy and Molina [125]), semi logarithm, or double logarithm forms have been applied in the literature (e.g., Arbues et al. [40], Olmstead et al. [86], Espey et al. [89], Dalhuisen et al. [90], Sebri [91]). Note that log-transformation is convenient to deal with skewed variables and it also has the advantage that the coefficient of the price is the price elasticity of the water demand, as explained in Marzano et al. [44].

According to a Stone–Geary utility function, the maximization of utility in water consumption is a process in which the household purchases a subsistence level of water, which would be consumed regardless of water tariffs, and then allocates fixed proportions of the remaining income (namely, *supernumerary* income) to purchase additional quantities of water, as explained in Roibás et al. [22] (see Deaton and Muellbauer [154] for further details). One explanation for the frequent use of the Stone–Geary function to estimate residential water demand is the numerous authors who find very low-price elasticities, raising the possibility that there is a proportion of water use that does not respond to changes in prices. Since this is a non-discretionary water consumption, as Roibás et al. [22] explain, it is also theoretically consistent. As Dharmaratna and Harris [64] note, the Stone–

Geary functional form has two advantages compared to the Cobb-Douglas: (1) it allows for non-constant price elasticities and, (2) it assumes that water consumption has two components, a fixed quantity which does not change immediately after price changes, and a varying quantity which is instantaneously modified.

One issue deserving further attention is the quantity of water estimated as non-responsive to changes in prices. Table 2 displays a summary of previous studies estimating a residential demand function based on a Stone–Geary utility function. Some interesting figures are reported in the table, such as the minimum threshold estimated and the average water consumption. In relative terms (as a percentage of the average water consumption), the threshold is higher in developed countries, with several studies estimating values greater than 70%. Some authors provide an estimate of the minimum threshold for different seasons or regions. Nauges [155] and Schleich [156] provide regional estimations for minimum threshold, while Gaudin et al. [132] and Clarke et al. [96] estimate a higher threshold in the summer, and Garcia-Valiñas et al. [49] estimate a threshold dependent on efficient water habits and technologies.

**Table 2.** Demand function based on a Stone–Geary utility function: Estimated threshold.

| Reference | Country | Year | Average Consumption (L/day) | | Estimated Threshold (L/day) | |
|---|---|---|---|---|---|---|
| | | | Person | Household | Person | Household |
| Al-Qunaibet and Johnston [157] | Kuwait | 1973–1981 | 153 | - | 42 | - |
| Gaudin et al. [132] | Texas | 1981–1985 | 515–859 | - | 432–485 | - |
| Martínez-Espiñeira and Nauges [105] | Spain | 1995–1999 | 213 | - | 157 | - |
| García-Valiñas et al. [41] | Spain | 2005 | 171 | - | 112 | - |
| Monteiro and Roseta-Palma [42] | Portugal | 1998, 2000, 2002, 2005 | - | 248 | - | 209 |
| Dharmaratna and Harris [64] | Sri Lanka | 2001–2005 | 135 | 569 | 21–35 | 91–149 |
| Hung and Chie [104] | Taiwan | 2005 | 287 | 905 | 77 | 243 |
| Garcia-Valiñas et al. [49] | Australia | 2009–2010 | 137 | - | 92–103 | - |
| Renzetti et al. [34] | Canada | 2000–2010 | 459 | 1033 | 365 | 810 |
| Clarke et al. [96] | Arizona | 2001–2011 | - | 1152 | - | 942–1037 |
| Hung et al. [158] | Taiwan | 2005 | 226 | 767 | 123–198 | - |
| Roibás et al. [22] | Spain | 1991–2000 | 307 | 1154 | 197 | - |

Source: Own elaboration.

## 5. Experimental Economics and Nudging

Over the past several decades, many natural experiments have been analyzed in the water sector. Researchers have assessed real changes implemented by governments and authorities in some aspects of the water sector, such as changes in water prices or tariff structures [84,87,130]. More recently, following the work by Ferraro et al. [12], Fielding et al. [159], Fielding et al. [13], Ferraro and Price [160] or Ferraro and Miranda [161], several ad-hoc experiments in the field of residential water sector have also been designed and conducted. Some of those experiments cover monetary and/or non-monetary treatments, including *nudging*.

*Nudges*, according to Thaler and Sunstein [162] (p. 6), are "purposeful changes of people's choice architecture that steer their behavior in certain directions without significantly changing their monetary incentives or coercing them (...) any factor that significantly alters the behavior of Humans, even though it would be ignored by Econs". As Moreu Carbonell [163] explains, nudges are a tool for guiding citizens' behaviors towards desirable goals without coercion or using economic incentives. Actually, this is the main difference between nudges and other experiments. In some natural and lab experiments, users face incentives to change their behavior, or they are given some behavioral rules to change their conduct. In Rajapaksa et al. [15], households received monetary benefits to reduce water consumption. However, in contrast to the experimental traditional approach, nudges do not modify economic conditions. Instead, information is given in the form of tips regarding tariffs or self-consumption, or comparing their behavior with that of their neighbors or with their own consumption in the past. For example, Novak et al. [164] designed a system to stimulate water savings by combining smart-meter-based consumption visualization and water saving tips. An important stream of literature analyzes those nudges promoting an environmentally desirable behavior (See Schubert [165] for a review on green nudges and its ethical implications.). Some examples of nudges applied to the residential water sector are briefly described below.

Ferraro and Price [160], who conducted an experiment giving information to water users, find that information based on norms is more effective than technical advice, and that social comparison increased the reduction in water consumption - the effect was equivalent to a rise in average price of around 12–15%. By comparing different interventions designed to affect water conservation in households, Seyranian et al. [166] find that giving information alone (i.e., water saving tips) was the least effective approach. In contrast, consumers exposed to social norms, social identity, or personal identity, reduced their consumption in the short and long-term. Similarly, Ferraro et al. [12] found technical advice had a negligible impact, while including normative messages and social comparison significantly reduced water consumption. Overall, the social comparison intervention was the only one that had a lasting impact [12]. Jessoe et al. [167] compared three behavioral interventions using Home Water Report devices (HWRs). They estimated water conservation effects (4–5%) across the three treatments proposed, which combined social comparison (reporting the average consumption in the area and the average of the most efficient households in the area) and conservation tips. Finally, Beal et al. [36] conclude that increasing users' information about their own consumption (providing feedback) has the potential to improve and encourage their future water saving behaviors.

Tom et al. [168] analyzed two experiments with water conservation programs, providing information useful towards a behavioral change for water conservation, finding that the program with greater detail in measurement and feedback is more effective. Strong and Goemans [169] discussed an experiment in which households purchased an electronic device that allowed them to see how much water they were using at any moment and their cumulative use for a billing cycle, making it possible to adjust behavior during the billing period in response to learning that their intended water consumption differs from their actual consumption. Recently, Miranda et al. [170] find nudging towards water conservation able to reduce water consumption, especially in the intervention comparing users' consumption with that of their neighborhood. Interestingly, Otaki et al. [171], who studied different communication methods in historical self-comparisons of water consumption, found them effective in water savings even regardless of the level of water consumption.

The way in which information is presented also matters. Jaeger and Schultz [172] compared the effect of sending restriction information, a strong warning, or normative information communicating community compliance to water restrictions, revealing that immediate reductions were evidenced for those receiving a strong warning and normative information, but only those who received normative information present long-term reductions of their water usage.

Most research in this field uses average treatment effects [12,160,167,173–175] as the main procedure to assess the effect of the nudge. Also, DD [170] or tests comparing average water consumption [164,176,177] are usually performed. However, one important issue missing in the above-mentioned papers is that they all focus on comparing water consumption before and after the nudge, but do not provide estimations of water demand and/or price elasticities. Two interesting exceptions are Strong and Goemans [106] and Brent and Wichman [17]. It is noteworthy that, in both cases, the analysis is supported by the use of water smart readers (WSR). In this respect, Cominola et al. [54] show an interesting review of these technologies and their application in the residential water sector. In addition to providing households with near to real-time information on water consumption [106], these technologies could provide users with clearer information of which activities consume more water [13]. However, as Strong and Goemans [106] indicate, WRS by themselves do not give households information on water prices or tariffs' structures unless they are accompanied by some additional communications. Thus, it is necessary to develop some visualization system to summarize the information [106,164,167]. Additionally, technology acceptance is also a significant issue to deal with [173].

In Strong and Goemans [106], households were subsidized to purchase a WRS providing them with real-time information on flow rate and consumption over the billing period. In order to identify the effect of WSR ownership on households, authors split their sample into before and after receiving the device. As the authors indicate, households in Strong and Goemans [106] were self-selected into the WSR program, due to their potential endogeneity of participation. By estimating water demand with a DCC model, including a dummy for WSR ownership, Strong and Goemans [106] find WSR increased water consumption almost 9%. Then, they conducted different estimates for those with and without WSR, showing differences between the parameter estimates across the two samples of the effect of the treatment on the treated. Interestingly, Strong and Goemans [106] detect that having the WSR made households more responsive to changes in price and less responsive to changes in income.

Brent and Wichman [17] provided households with WSR and messaged them with information on their consumption and given tips to save water, which resulted in savings of roughly 4%. Then, authors use difference in discontinuity to assess the price sensitivity effect of the nudge, finding that households' response to the nudge was similar regardless of the economic incentive of the family to conserve water. Brent and Wichman [17] also studied the degree to which the nudge affects price sensitivity, finding limited evidence of an economically meaningful relationship between prices and nudges.

Many papers have conducted field experiments in the ground of residential water use, but there is still a long way to go. For instance, the effects of interventions could dissipate in the long-term [13]. Nauges and Whittington [16] remark that some of the treatments based on social comparisons could also generate costs for different agents involved. Among others, the authors mention the costs of information delivery, reductions in water utility revenues, or the moral "tax" on households. Bhanot [178] examining the effect on water conservation of social information and peer rank messages, shows that the different frames used in the peer rank treatment affects differently water consumption, being the competitive frame the worst option. Definitively, Brent et al. [174] find financial nudges a preferred alternative to manage water demand.

## 6. Conclusions

The analysis of the demand for water has been receiving increasing attention in recent decades, since it is the basis from which we may assess the impact of public policy reforms on some key economic problems, such as water scarcity or sustainable water consumption. Water demand modelling has also emerged as an interesting tool for policy makers and managers to evaluate the impact of different policies in terms of affordability or welfare.

The topic has evolved in the last decades, moving from the seminal papers estimating price-elasticity [1] towards behavioral studies analyzing the impact of several *ad-hoc* designed experimental treatments on water demand [169]. The latest issues, yet to be broadly explored, have revealed that this topic is not exclusive to the field of economic analysis but also extends to other disciplines, such as psychology or sociology. Thus, the use of techniques such as nudging and social norms have emerged as a powerful tool for the management of water resources.

Residential water demand has been assessed for decades, concluding that demand is not very sensitive to price changes, since price-elasticity estimates are, in general, lower than one. However, research studies have progressively questioned some basic assumptions of residential water demand linked to informational issues, adapting both theoretical and empirical modelling to the fact that, in many cases, consumers are not sufficiently aware of water consumption, prices and tariffs, leading to price misperceptions [31]. Water tariffs are a key policy instrument, but they probably need to be combined with informative policies on water tariffs schedules to ensure they are powerful and effective, since households do not have perfect information on either water consumption or prices [31,99,107]. Under certain conditions, financial nudges have proved to be more effective and to have more persistent effects in reducing water consumption than social nudging [174].

Moreover, some demand modelling frameworks have detected the presence of strong habits in the field of residential water use. Based on an Stone–Geary utility function, some studies have estimated a threshold which is invariant to changes in prices or income [22]; however, the threshold could be reduced using non-pricing tools [49]. Additionally, that threshold appears to be significantly different depending on the level of country development, indicating that contextual issues are quite important. Water demand modelling becomes more complex in developing countries, where households take water from different sources [3]. Most studies focused on developed countries have estimated minimum thresholds above 60% of average household water consumption and in general, higher than 100 L per person and day. These findings mean that there still room to improve residential water use efficiency.

However, some topics remain relatively unexplored in the field of residential water demand, such as gender, cultural, attitudinal, or technological issues. Exploring different gender demand patterns could be interesting, especially with respect to whether differences are merely based on the different roles in household chores [46]. Pro-environmental attitudes could also be an important driver of residential water demand, considering that it is observed that those households more concerned and active with the environment are more efficient with respect to their water demand. Moreover, links between direct tap water demand and indirect water demand (that is, water demand derived from the demands of other commodities, water footprint) or water-energy nexus [179] could also be assessed, since water management is a global issue, sharing similar problems as other resources management, such as energy.

Behavioral economics is also an increasing field that may be the subject of research in the next decades. As mentioned previously, several experiments have been developed in the last years, but only a few have analyzed the impact of their treatments on water conservation using water demand functions. Besides, the impact that smart metering technologies have on water demand and price sensitivity should be broadly investigated [54]. There is still a long road ahead when it comes to design the most adequate way to visualize the information generated by these new technologies [164]. As Strong and Goemans [106] conclude, better informed households would adopt more efficient decisions, but that fact does not necessarily mean that they would reduce their water consumption in all the scenarios. It is clear that these questions are excellent candidates for a detailed exploration in future research.

Finally, it is crucial to remark that high quality information is needed to get an accurate estimation of residential water demand. The combination of actual data on water consumption and prices should be complemented by information from surveys and interviews. In this regard, governments should step up their efforts to compile public information in the sector. Definitively, the collaboration among public institutions, water suppliers and researchers is essential to carry out a rigorous analysis in the water field.

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## References


1. Arbués, F.; García-Valiñas, M.Á.; Martínez-Espiñeira, R. Estimation of residential water demand: A state-of-the-art review. *J. Socio-Econ.* **2003**, *32*, 81–102. [CrossRef]
2. Worthington, A.C.; Hoffman, M. An empirical survey of residential water demand modelling. *J. Econ. Surv.* **2008**, *22*, 1–26. [CrossRef]
3. Nauges, C.; Whittington, D. Estimation of Water Demand in Developing Countries: An Overview. *World Bank Res. Obs.* **2010**, *25*, 263–294. [CrossRef]
4. Reynaud, A. *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: Ispra, Italy, 2015. [CrossRef]
5. Reynaud, A.; Romano, G. Advances in the Economic Analysis of Residential Water Use: An Introduction. *Water* **2018**, *10*, 1162. [CrossRef]
6. OECD. *Social Issues in the Provision and Pricing of Water Services*; Technical Report; OECD: Paris, France, 2003.
7. OECD. *Pricing Water Resources and Water Sanitation Services*; Technical Report; OECD: Paris, France, 2010.
8. EEA. *Assessment of Cost Recovery through Water Pricing*; Technical Report 16/2013; European Environment Agency: Copenhagen, Denmark, 2013.
9. Nauges, C.; Whittington, D. Evaluating the Performance of Alternative Municipal Water Tariff Designs: Quantifying the Tradeoffs between Equity, Economic Efficiency, and Cost Recovery. *World Dev.* **2017**, *91*, 125–143. [CrossRef]
10. Massarutto, A. Servant of too many masters: Residential water pricing and the challenge of sustainability. *Util. Policy* **2020**, *63*, 101018. [CrossRef]
11. Garcia-Valiñas, M.; Martínez-Espiñeira, R.; To, H. The Use of Non-pricing Instruments to Manage Residential Water Demand: What Have We Learned? In *Understanding and Managing Urban Water in Transition*; Grafton, Q., Daniell, K., Nauges, C., Rinaudo, J., Chan, N., Eds.; Springer: Dordrecht, The Netherlands, 2015; Volume 15. [CrossRef]
12. Ferraro, P.J.; Miranda, J.J.; Price, M.K. The Persistence of Treatment Effects with Norm-Based Policy Instruments: Evidence from a Randomized Environmental Policy Experiment. *Am. Econ. Rev.* **2011**, *101*, 318–322. [CrossRef]
13. Fielding, K.S.; Spinks, A.; Russell, S.; McCrea, R.; Stewart, R.; Gardner, J. An experimental test of voluntary strategies to promote urban water demand management. *J. Environ. Manag.* **2013**, *114*, 343–351. [CrossRef]
14. Bernedo, M.; Ferraro, P.J.; Price, M. The Persistent Impacts of Norm-Based Messaging and Their Implications for Water Conservation. *J. Consum. Policy* **2014**, *37*, 437–452. [CrossRef]
15. Rajapaksa, D.; Gifford, R.; Torgler, B.; Garcia-Valiñas, M.; Athukorala, W.; Managi, S.; Wilson, C. Do monetary and non-monetary incentives influence environmental attitudes and behavior? Evidence from an experimental analysis. *Resour. Conserv. Recycl.* **2019**, *149*, 168–176. [CrossRef]
16. Nauges, C.; Whittington, D. Social Norms Information Treatments in the Municipal Water Supply Sector: Some New Insights on Benefits and Costs. *Water Econ. Policy* **2019**, *5*, 1–40. [CrossRef]
17. Brent, D.A.; Wichman, C.J. Do behavioral nudges interact with prevailing economic incentives? Pairing experimental and quasi-experimental evidence from water consumption. *Work. Pap.* **2020**, 1–46. [CrossRef]
18. Suárez-Varela, M. Modeling residential water demand: An approach based on household demand systems. *J. Environ. Manag.* **2020**, *261*, 109921. [CrossRef]
19. Abu-Bakar, H.; Williams, L.; Hallett, S.H. A review of household water demand management and consumption measurement. *J. Clean. Prod.* **2021**, *292*, 125872. [CrossRef]
20. Makki, A.A.; Stewart, R.A.; Beal, C.D.; Panuwatwanich, K. Novel bottom-up urban water demand forecasting model: Revealing the determinants, drivers and predictors of residential indoor end-use consumption. *Resour. Conserv. Recycl.* **2015**, *95*, 15–37. [CrossRef]
21. Pérez-Urdiales, M.; García-Valiñas, M.A.; Martínez-Espiñeira, R. Responses to Changes in Domestic Water Tariff Structures: A Latent Class Analysis on Household-Level Data from Granada, Spain. *Environ. Resour. Econ.* **2016**, *63*, 167–191. [CrossRef]
22. Roibás, D.; Garcia-Valiñas, M.A.; Fernandez-Llera, R. Measuring the Impact of Water Supply Interruptions on Household Welfare. *Environ. Resour. Econ.* **2019**, *73*, 159–179. [CrossRef]
23. Reynaud, A.; Lanzanova, D.; Milovanović, M.B.; de Roo, A. Informing Water Policies with a Residential Water Demand Function: The Case of Serbia. *Eur. J. Comp. Econ.* **2016**, *13*, 247–266.
24. Havranek, T.; Irsova, Z.; Vlach, T. Measuring the Income Elasticity of Water Demand: The Importance of Publication and Endogeneity Biases. *Land Econ.* **2018**, *94*, 259–283. [CrossRef]
25. Russell, S.; Fielding, K. Water demand management research: A psychological perspective. *Water Resour. Res.* **2010**, *46*, 1–12. [CrossRef]
26. Romano, G.; Salvati, N.; Guerrini, A. Estimating the Determinants of Residential Water Demand in Italy. *Water* **2014**, *6*, 2929–2945. [CrossRef]
27. Tanishita, M.; Sunaga, D. Heterogeneity and Temporal Stability of ResidentialWater Use Responsiveness to Price Change. *Water* **2021**, *13*, 2329. [CrossRef]
28. Stitzel, B.; Rogers, C.L. Residential Water Demand Under Increasing Block Rate Structure: Conservation Conundrum? *Water Resour. Manag.* **2022**, *36*. [CrossRef]

29. Whittington, D.; Nauges, C.; Fuente, D.; Wu, X. A diagnostic tool for estimating the incidence of subsidies delivered by water utilities in low- and medium-income countries, with illustrative simulations. *Util. Policy* **2015**, *34*, 70–81. [CrossRef]
30. Rinaudo, J.D.; Neverre, N.; Montginoul, M. Simulating the Impact of Pricing Policies on Residential Water Demand: A Southern France Case Study. *Water Resour. Manag.* **2012**, *26*, 2057–2068. [CrossRef]
31. Binet, M.E.; Carlevaro, F.; Paul, M. Estimation of Residential Water Demand with Imperfect Price Perception. *Environ. Resour. Econ.* **2014**, *59*, 561–581. [CrossRef]
32. Ruijs, A.; Zimmermann, A.; van den Berg, M. Demand and distributional effects of water pricing policies. *Ecol. Econ.* **2008**, *66*, 506–516. [CrossRef]
33. Schleich, J.; Hillenbrand, T. Determinants of residential water demand in Germany. *Ecol. Econ.* **2009**, *68*, 1756–1769. [CrossRef]
34. Renzetti, S.; Dupont, D.P.; Chitsinde, T. An empirical examination of the distributional impacts of water pricing reforms. *Util. Policy* **2015**, *34*, 63–69. [CrossRef]
35. Baerenklau, K.A.; Schwabe, K.A.; Dinar, A. The Residential Water Demand Effect of Increasing Block Rate Water Budgets. *Land Econ.* **2014**, *90*, 683–699. [CrossRef]
36. Beal, C.D.; Stewart, R.A.; Fielding, K. A novel mixed method smart metering approach to reconciling differences between perceived and actual residential end use water consumption. *J. Clean. Prod.* **2013**, *60*, 116–128. [CrossRef]
37. Olmstead, S.M. Reduced-Form versus Structural Models of Water Demand under Nonlinear Prices. *J. Bus. Econ. Stat.* **2009**, *1*, 84–94. [CrossRef]
38. Millock, K.; Nauges, C. Household Adoption of Water-Efficient Equipment: The Role of Socio-Economic Factors, Environmental Attitudes and Policy. *Environ. Resour. Econ.* **2011**, *46*, 539–565. [CrossRef]
39. Martins, R.; Fortunato, A. Residential water demand under block rates—A Portuguese case study. *Water Policy* **2007**, *9*, 217–230. [CrossRef]
40. Arbués, F.; Villanúa, I.; Barberán, R. Household size and residential water demand: An empirical approach. *Aust. J. Agric. Resour. Econ.* **2010**, *54*, 61–80. [CrossRef]
41. García-Valiñas, M.A.; Martínez-Espiñeira, R.; González-Gómez, F. Affordability of residential water tariffs: Alternative measurement and explanatory factors in Southern Spain. *J. Environ. Manag.* **2010**, *91*, 2696–2706. [CrossRef]
42. Monteiro, H.; Roseta-Palma, C. Pricing for scarcity? An efficiency analysis of increasing block tariffs. *Water Resour. Res.* **2011**, *47*, 1–11. [CrossRef]
43. Hoyos, D.; Artabe, A. Regional Differences in the Price Elasticity of Residential Water Demand in Spain. *Water Resour. Manag.* **2017**, *31*, 847–865. [CrossRef]
44. Marzano, R.; Rouge, C.; Garrone, P.; Grilli, L.; Harou, J.J.; Pulido-Velazquez, M. Determinants of the price response to residential water tariffs: Meta-analysis and beyond. *Environ. Model. Softw.* **2018**, *101*, 236–248. [CrossRef]
45. Rathnayaka, K.; Malano, H.; Arora, M.; George, B.; Maheepala, S.; Nawarathna, B. Prediction of urban residential end-use water demands by integrating known and unknown water demand drivers at multiple scales I: Model development. *Resour. Conserv. Recycl.* **2017**, *117*, 85–92. [CrossRef]
46. Tong, Y.; Fan, L.; Niu, H. Water conservation awareness and practices in households receiving improved water supply: A gender-based analysis. *J. Clean. Prod.* **2017**, *141*, 947–955. [CrossRef]
47. Torgler, B.; García-Valiñas, M.A. The determinants of individuals' attitudes towards preventing environmental damage. *Ecol. Econ.* **2007**, *63*, 536–552. [CrossRef]
48. Davies, K.; Doolan, C.; van den Honert, R.; Shi, R. Water-saving impacts of Smart Meter technology: An empirical 5 year, whole-of-community study in Sydney, Australia. *Water Resour. Res.* **2014**, *50*, 7348–7358. [CrossRef]
49. Garcia-Valiñas, M.; Athukorala, W.; Wilson, C.; Torgler, B.; Gifford, R. Nondiscretionary residential water use: The impact of habits and water-efficient technologies. *Aust. J. Agric. Resour.* **2014**, *58*, 185–204. [CrossRef]
50. Gilg, A.; Barr, S. Behavioural attitudes towards water saving? Evidence from a study of environmental actions. *Ecol. Econ.* **2006**, *57*, 400–414. [CrossRef]
51. Grafton, R.Q.; Ward, M.B.; To, H.; Kompas, T. Determinants of residential water consumption: Evidence and analysis from a 10-country household survey. *Water Resour. Res.* **2011**, *47*, 1–14. [CrossRef]
52. Maldonado-Devis, M.; Almenar-Llongo, V. Heterogeneity in Domestic Water Demand: An Application of Multilevel Analysis to the City of Valencia (Spain). *Water* **2021**, *13*, 3400. [CrossRef]
53. Arbués, F.; Barberán, R.; Villanúa, I. Price impact on urban residential water demand: A dynamic panel data approach. *Water Resour. Res.* **2004**, *40*. [CrossRef]
54. Cominola, A.; Giuliani, M.; Piga, D.; Castelletti, A.; Rizzoli, A. Benefits and challenges of using smart meters for advancing residential water demand modeling and management: A review. *Environ. Model. Softw.* **2015**, *72*, 198–214. [CrossRef]
55. Jayarathna, L.; Rajapaksa, D.; Managi, S.; Athukorala, W.; Torgler, B.; Garcia-Valiñas, M.A.; Gifford, R.; Wilson, C. A GIS based spatial decision support system for analysing residential water demand: A case study in Australia. *Sustain. Cities Soc.* **2017**, *32*, 67–77. [CrossRef]
56. Domene, E.; Saurí, D. Urbanisation and Water Consumption: Influencing Factors in the Metropolitan Region of Barcelona. *Urban Stud.* **2006**, *43*, 1605–1623. [CrossRef]
57. Reynaud, A.; Pons, M.; Pesado, C. Household Water Demand in Andorra: Impact of Individual Metering and Seasonality. *Water* **2018**, *10*, 321. [CrossRef]

58. Nauges, C.; Thomas, A. Privately Operated Water Utilities, Municipal Price Negotiation, and Estimation of Residential Water Demand: The Case of France. *Land Econ.* **2000**, *76*, 68–85. [CrossRef]
59. Randolph, B.; Troy, P. Attitudes to conservation and water consumption. *Environ. Sci. Policy* **2008**, *11*, 441–455. [CrossRef]
60. Martínez-Espiñeira, R. Residential Water Demand in the Northwest of Spain. *Eur. Assoc. Environ. Resour. Econ.* **2002**, *21*, 161–187. [CrossRef]
61. Arbués, F.; Villanúa, I. Potential for Pricing Policies in Water Resource Management: Estimation of Urban Residential Water Demand in Zaragoza, Spain. *Urban Stud.* **2006**, *43*, 2421–2442. [CrossRef]
62. Martínez-Espiñeira, R. An estimation of residential water demand using co-integration and error correction techniques. *J. Appl. Econ.* **2007**, *10*, 161–184. [CrossRef]
63. Puri, R.; Maas, A. Evaluating the Sensitivity of Residential Water Demand Estimation to Model Specification and Instrument Choices. *Water Resour. Res.* **2020**, *56*, 1–14. [CrossRef]
64. Dharmaratna, D.; Harris, E. Estimating Residential Water Demand Using the Stone-Geary Functional Form: The Case of Sri Lanka. *Water Resour. Manag.* **2012**, *26*, 2283–2299. [CrossRef]
65. Yudhistira, M.H.; Sastiono, P.; Meliyawati, M. Exploiting unanticipated change in block rate pricing for water demand elasticities estimation: Evidence from Indonesian suburban area. *Water Resour. Econ.* **2020**, *32*, 1–15. [CrossRef]
66. Roibás, D.; García-Valiñas, M.Á.; Wall, A. Measuring welfare losses from interruption and pricing as responses to water shortages: An application to the case of Seville. *Environ. Resour. Econ.* **2007**, *38*, 231–243. [CrossRef]
67. Piper, S. Impact of water quality on municipal water price and residential water demand and implications for water supply benefits. *Water Resour. Res.* **2003**, *39*, 1127. [CrossRef]
68. Zivin, J.G.; Neidell, M.; Schlenker, W. Water Quality Violations and Avoidance Behavior: Evidence from Bottled Water Consumption. *Am. Econ. Rev.* **2011**, *101*, 448–453. [CrossRef]
69. Bontemps, C.; Nauges, C. Carafe ou bouteille? Le rôle de la qualité de l'environnement dans la décision du consommateur. *Econ. Previs.* **2009**, *2*, 61–79. [CrossRef]
70. Corral-Verdugo, V.; Bechtel, R.B.; Fraijo-Sing, B. Environmental beliefs and water conservation: An empirical study. *J. Environ. Psychol.* **2003**, *23*, 247–257. [CrossRef]
71. Maas, A.; Goemans, C.; Manning, D.; Kroll, S.; Arabi, M.; Rodriguez-McGoffin, M. Evaluating the effect of conservation motivations on residential water demand. *J. Environ. Manag.* **2017**, *196*, 394–401. [CrossRef]
72. Arbués, F.; Bolsa, M.Á.; Villanúa, I. Which factors determine water saving behaviour? Evidence from Spanish households. *Urban Water J.* **2016**, *13*, 511–520. [CrossRef]
73. Shahangian, S.A.; Tabesh, M.; Yazdanpanah, M. How can socio-psychological factors be related to water-efficiency intention and behaviors among Iranian residential water consumers? *J. Environ. Manag.* **2021**, *288*, 1–11. [CrossRef]
74. Ibáñez-Rueda, N.; Guardiola, J.; González-Gómez, F. The role of nature contact and connectedness to nature as determinants of household water use: A case study from Spain. *Water Environ. J.* **2021**, *36*, 282–291. [CrossRef]
75. Attari, S.Z. Perceptions of water use. *Proc. Natl. Acad. Sci. USA* **2014**, *111*, 5129–5134. [CrossRef]
76. Dascher, E.D.; Kang, J.; Hustvedt, G. Water sustainability: Environmental attitude, drought attitude and motivation. *J. Consum. Stud.* **2014**, *38*, 467–474. [CrossRef]
77. Ferrara, I. Residential Water Use. *OECD J.* **2008**, *2008*, 153–180. [CrossRef]
78. Stavenhagen, M.; Buurman, J.; Tortajada, C. Saving water in cities: Assessing policies for residential water demand management in four cities in Europe. *Cities* **2018**, *79*, 187–195. [CrossRef]
79. Barraque, B. Full cost recovery of water services and the 3T's of OECD. *Util. Policy* **2020**, *62*, 100981. [CrossRef]
80. Grafton, R.Q.; Chu, L.; Wyrwoll, P. The paradox of water pricing: Dichotomies, dilemmas, and decisions. *Oxf. Rev. Econ. Policy* **2020**, *36*, 86–107. [CrossRef]
81. Pérez-Urdiales, M.; Baerenklau, K.A. Learning to live within your (water) budget: Evidence from allocation-based rates. *Resour. Energy Econ.* **2019**, *57*, 205–221. [CrossRef]
82. Arbués, F.; García-Valiñas, M. Water Tariffs in Spain. *Oxf. Res. Encycl. Glob. Public Health* **2020**, 1–56. [CrossRef]
83. Whittington, D.; Nauges, C. An Assessment of the Widespread Use of Increasing Block Tariffs in the Municipal Water Supply Sector. *Oxf. Res. Encycl. Glob. Public Health* **2020**. [CrossRef]
84. Wichman, C.J. Perceived price in residential water demand: Evidence from a natural experiment. *J. Econ. Behav. Organ.* **2014**, *107*, 308–323. [CrossRef]
85. Nieswiadomy, M.L. Estimating urban residential water demand: Effects of price structure, conservation, and education. *Water Resour. Res.* **1992**, *28*, 609–615. [CrossRef]
86. Olmstead, S.M.; Hanemann, M.; Stavins, R.N. Water Demand under Alternative Price Structures. *J. Environ. Econ. Manag.* **2007**, *54*, 181–198. [CrossRef]
87. Ratnasiri, S.; Wilson, C.; Athukorala, W.; Garcia-Valiñas, M.A.; Torgler, B.; Gifford, R. Effectiveness of two pricing structures on urban water use and conservation: A quasi-experimental investigation. *Environ. Econ. Policy Stud.* **2018**, *20*, 547–560. [CrossRef]
88. Sahin, O.; Bertone, E.; Beal, C. A systems approach for assessing water conservation potential through demand-based water tariffs. *J. Clean. Prod.* **2017**, *148*, 773–784. [CrossRef]
89. Espey, M.; Espey, J.; Shaw, W.D. Price elasticity of residential demand for water: A meta-analysis. *Water Resour. Res.* **1997**, *33*, 1369–1374. [CrossRef]

90. Dalhuisen, J.M.; Florax, R.; de Groot, H.; Nijkamp, P. Price and Income Elasticities of Residential Water Demand: A Meta-Analysis. *Land Econ.* **2003**, *79*, 292–308. [CrossRef]
91. Sebri, M. A meta-analysis of residential water demand studies. *Environ. Dev. Sustain.* **2014**, *16*, 499–520. [CrossRef]
92. Lee, J.; Tanverakul, S.A. Price elasticity of residential water demand in California. *J. Water Supply Res. Technol.* **2015**, *64*, 1–9. [CrossRef]
93. Nauges, C.; Thomas, A. Long-run Study of Residential Water Consumption. *Environ. Resour. Econ.* **2003**, *26*, 25–43. [CrossRef]
94. García-Valiñas, M.A. Efficiency and Equity in Natural Resources Pricing: A Proposal for Urban Water Distribution Service. *Environ. Resour. Econ.* **2005**, *32*, 183–204. [CrossRef]
95. Gaudin, S. Effect of price information on residential water demand. *Appl. Econ.* **2006**, *38*, 383–393. [CrossRef]
96. Clarke, A.J.; Colby, B.G.; Thompson, G. Household Water Demand Seasonal Elasticities: A Stone-Geary Model under an Increasing Block Rate Structure. *Land Econ.* **2017**, *93*, 608–630. [CrossRef]
97. Wichman, C.J. Information provision and consumer behavior: A natural experiment in billing frequency. *J. Public Econ.* **2017**, *152*, 13–33. [CrossRef]
98. Monteiro, H.; Martins, R.; Ramalho, J.; Ramalho, E. Are ill-informed residential water consumers less price-responsive? In Proceedings of the 6th World Congress of Environmental and Resource Economists, Gothenburg, Sweden, 25–29 June 2018.
99. Brent, D.A.; Ward, M.B. Price perceptions in water demand. *J. Environ. Econ. Manag.* **2019**, *98*, 102266. [CrossRef]
100. Carter, D.W.; Milon, J.W. Price Knowledge in Household Demand for Utility Services. *Land Econ.* **2005**, *81*, 265–283. [CrossRef]
101. Wang, X.; Lee, J.; Yan, J.; Thompson, G.D. Testing the behavior of rationally inattentive consumers in a residential water market. *J. Environ. Econ. Manag.* **2018**, *92*, 344–359. [CrossRef]
102. Reynaud, A. Private Sector Participation, Regulation and Social Policies in Water Supply in France. *Oxf. Dev. Stud.* **2010**, *38*, 219–239. [CrossRef]
103. Howe, C.W.; Linaweaver, F.P. The impact of price on residential water demand and its relation to system design and price structure. *Water Resour. Res.* **1967**, *3*, 13–32. [CrossRef]
104. Hung, M.F.; Chie, B.T. Residential Water Use: Efficiency, Affordability, and Price Elasticity. *Water Resour. Manag.* **2013**, *27*, 275–291. [CrossRef]
105. Martínez-Espiñeira, R.; Nauges, C. Is all domestic water consumption sensitive to price control? *Appl. Econ.* **2004**, *36*, 1697–1703. [CrossRef]
106. Strong, A.; Goemans, C. The impact of real-time quantity information on residential water demand. *Water Resour. Econ.* **2015**, *10*, 1–13. [CrossRef]
107. Cook, J.; Brent, D. Do Households Respond to the Marginal or Average Price of Piped Water Services? *Oxf. Res. Encycl. Glob. Public Health* **2021**. [CrossRef]
108. Opaluch, J.J. Urban Residential Demand for Water in the United States: Further Discussion. *Land Econ.* **1982**, *58*, 225–227. [CrossRef]
109. Opaluch, J.J. A Test of Consumer Demand Response to Water Prices: Reply. *Land Econ.* **1984**, *60*, 417–421. [CrossRef]
110. Chicoine, D.L.; Deller, S.C.; Ramamurthy, G. Water Demand Estimation Under Block Rate Pricing: A Simultaneous Equation Approach. *Water Resour. Res.* **1986**, *22*, 859–863. [CrossRef]
111. Kulshreshtha, S. Residential water demand in Saskatchewan Communities: Role played by block pricing system in water conservation. *Can. Water Resour. J. Rev. Can. Ressour. Hydr.* **1996**, *21*, 139–155. [CrossRef]
112. Nieswiadomy, M.; Molina, D. A note of price perception in water demand models. *Land Econ.* **1991**, *67*, 352–359. [CrossRef]
113. Nieswiadomy, M.; Cobb, S.L. Impact of pricing structure selectivity on urban water demand. *Contemp. Econ. Policy* **1993**, *11*, 101–113. [CrossRef]
114. Bell, D.R.; Griffin, R.C. An annual quasidifference approach to water price elasticity. *Water Resour. Res.* **2008**, *44*, 1–9. [CrossRef]
115. Almendarez-Hernández, M.A.; Polanco, G.A.; Trejo, V.H.; Ortega-Rubio, A.; Morales, L.F.B. Residential Water Demand in a Mexican Biosphere Reserve: Evidence of the Effects of Perceived Price. *Water* **2016**, *8*, 428. [CrossRef]
116. Cabral, R.; Ayala, L.; Delgado, V.H. Residential Water Demand and Price Perception under Increasing Block Rates. *Econ. Bull.* **2017**, *37*, 508–519.
117. Shin, J.S. Perception of Price When Price Information Is Costly: Evidence from Residential Electricity Demand. *Rev. Econ. Stat.* **1985**, *67*, 591–598. [CrossRef]
118. Aubuchon, C.P.; Roberson, J.A. Price perception and nonprice controls under conservation rate structures. *J.-Am. Water Work. Assoc.* **2012**, *104*, E446–E456. [CrossRef]
119. Nordin, J.A. A Proposed Modification of Taylor's Demand Analysis: Comment. *Bell J. Econ.* **1976**, *7*, 719–721. [CrossRef]
120. Taylor, L. The demand for electricity: A survey. *Bell J. Econ.* **1975**, *6*, 74–110. [CrossRef]
121. Billings, R.B.; Agthe, D.E. Price Elasticities for Water: A Case of Increasing Block Rates. *Land Econ.* **1980**, *56*, 73–84. [CrossRef]
122. Ito, K. Do Consumers Respond to Marginal or Average Price? Evidence from Nonlinear Electricity Pricing. *Am. Econ. Rev.* **2014**, *104*, 537–563. [CrossRef]
123. Davidson, R.; MacKinnon, J.G. *Estimation and Inference in Econometrics*; Oxford University Press: New York, NY, USA, 1993. [CrossRef]
124. Nataraj, S.; Hanemann, W.M. Does marginal price matter? A regression discontinuity approach to estimating water demand. *J. Environ. Econ. Manag.* **2011**, *61*, 198–212. [CrossRef]

125. Nieswiadomy, M.; Molina, D. Comparing residential water estimates under decreasing and increasing block rates using household data. *Land Econ.* **1989**, *65*, 280–289. [CrossRef]
126. Liebman, J.B.; Zeckhauser, R.J. *Schmeduling*; Unpublished manuscript; Harvard University: Cambridge, MA, USA, 2004.
127. Garcia-Valiñas, M.A.; Martinez-Espineira, R.; Suárez-Varela, M. Price and Consumption Misperception Profiles: The Role of Information in the Residential Water Sector. *Environ. Resour. Econ.* **2021**, *80*, 821–857. [CrossRef]
128. Barberán, R.; López-Laborda, J.; Rodrigo, F. The Perception of Residential Water Tariff, Consumption, and Cost: Evidence of its Determinants Using Survey Data. *Water Resour. Manag.* **2022**, *36*, 2933–2952. [CrossRef]
129. Zhang, B.; Fang, K.H.; Baerenklau, K.A. Have Chinese water pricing reforms reduced urban residential water demand? *Water Resour. Res.* **2017**, *53*, 5057–5069. [CrossRef]
130. Olivier, A. Water tariffs and consumption drop: An evaluation of households' response to a water tariff increase in Manaus, Brazil. *Water Policy* **2010**, *12*, 564–588. [CrossRef]
131. Roseta-Palma, C.; Carvalho, M.; Correia, R. Nonlinear Pricing with Reference Dependence. *Oxf. Res. Encycl. Glob. Public Health* **2020**, 1–13. [CrossRef]
132. Gaudin, S.; Griffin, R.C.; Sickles, R. Demand Specification for Municipal Water Management: Evaluation of the Stone-Geary Form. *Land Econ.* **2001**, *77*, 399–422. [CrossRef]
133. Kenney, D.S.; Goemans, C.; Klein, R.; Lowrey, J.; Reidy, K. Residential Water Demand Management: Lessons from Aurora, Colorado. *J. Am. Water Resour. Assoc.* **2008**, *44*, 192–207. [CrossRef]
134. Renwick, M.E.; Green, R.D. Do Residential Water Demand Side Management Policies Measure Up? An Analysis of Eight California Water Agencies. *J. Environ. Econ. Manag.* **2000**, *40*, 37–55. [CrossRef]
135. Grafton, R.Q.; Ward, M.B. Prices versus Rationing: Marshallian Surplus and Mandatory Water Restrictions. *Econ. Rec.* **2008**, *84*, S57–S65. [CrossRef]
136. Wang, J.; Chermak, J.M. Is less always more? Conservation, efficiency and water education programs. *Ecol. Econ.* **2021**, *184*, 106994. [CrossRef]
137. Lee, M.; Tansel, B.; Balbin, M. Influence of residential water use efficiency measures on household water demand: A four year longitudinal study. *Resour. Conserv. Recycl.* **2011**, *56*, 1–6. [CrossRef]
138. Lee, M.; Tansel, B.; Balbin, M. Urban Sustainability Incentives for Residential Water Conservation: Adoption of Multiple High Efficiency Appliances. *Water Resour. Manag.* **2013**, *27*, 2531–2540. [CrossRef]
139. Renwick, M.E.; Archibald, S.O. Demand Side Management Policies for Residential Water Use: Who Bears the Conservation Burden? *Land Econ.* **1998**, *74*, 343–359. [CrossRef]
140. Dieu-Hang, T.; Grafton, R.Q.; Martínez-Espiñeira, R.; Garcia-Valiñas, M. Household adoption of energy and water-efficient appliances: An analysis of attitudes, labelling and complementary green behaviours in selected OECD countries. *J. Environ. Manag.* **2017**, *197*, 140–150. [CrossRef]
141. Price, J.I.; Chermak, J.M.; Felardo, J. Low-flow appliances and household water demand: An evaluation of demand-side management policy in Albuquerque, New Mexico. *J. Environ. Manag.* **2014**, *133*, 37–44. [CrossRef]
142. Campbell, H.; Johnson, R.; Larson, E. Prices, devices, people, or rules: The relative effectiveness of policy instruments in water conservation. *Rev. Policy Res.* **2004**, *21*, 637–662. [CrossRef]
143. Bennear, L.S.; Taylor, L.; Lee, J. Participation Incentives, Rebound Effects and the Cost-Effectiveness of Rebates for Water-Efficient Appliances. *Duke Environ. Econ. Work. Pap.* **2011**. [CrossRef]
144. Pérez-Urdiales, M.; García-Valiñas, M.Á. Efficient water-using technologies and habits: A disaggregated analysis in the water sector. *Ecol. Econ.* **2016**, *128*, 117–129. [CrossRef]
145. Jacobs, H.E.; Scheepers, H.M.; Sinske, S.A. Effect of land area on average annual suburban water demand. *Water* **2013**, *39*, 687–694. [CrossRef]
146. House-Peters, L.A.; Chang, H. Urban water demand modeling: Review of concepts, methods, and organizing principles. *Water Resour. Res.* **2011**, *47*, W05401. [CrossRef]
147. Mombeni, H.A.; Rezaei, S.; Nadarajah, S.; Emami, M. Estimation of Water Demand in Iran Based on SARIMA Models. *Environ. Model. Assess.* **2013**, *18*, 559–565. [CrossRef]
148. Stewart, R.A.; Willis, R.; Giurco, D.; Panuwatwanich, K.; Capati, G. Web-based knowledge management system: Linking smart metering to the future of urban water planning. *Aust. Plan.* **2010**, *47*, 67–74. [CrossRef]
149. Szabó, A. The value of free water: Analyzing South Africa's free basic water policy. *Econometrica* **2015**, *83*, 1913–1961. [CrossRef]
150. Wooldridge, J.M. Control Function Methods in Applied Econometrics. *J. Hum. Resour.* **2015**, *56*, 420–445. [CrossRef]
151. Hewitt, J.A.; Hanemann, W.M. A Discrete/Continuous Choice Approach to Residential Water Demand under Block Rate Pricing. *Land Econ.* **1995**, *71*, 173–192. [CrossRef]
152. Vásquez Lavín, F.A.; Hernandez, J.I.; Ponce, R.D.; Orrego, S.A. Functional forms and price elasticities in a discrete continuous choice model of the residential water demand. *Water Resour. Res.* **2017**, *53*, 6296–6311. [CrossRef]
153. Klassert, C.; Sigel, K.; Klauer, B.; Gawel, E. Increasing Block Tariffs in an Arid Developing Country: A Discrete/Continuous Choice Model of Residential Water Demand in Jordan. *Water* **2018**, *10*, 248. [CrossRef]
154. Deaton, A.; Muellbauer, J. An Almost Ideal Demand System. *Am. Econ. Rev.* **1980**, *70*, 312–326.

155. Nauges, C. How much water do residential users really need? An estimation of minimum water requirements for French households. In Proceedings of the XVII Annual Conference of the European Association of Environmental and Resource Economists, Amsterdam, The Netherlands, 24–27 June 2009.
156. Schleich, J. How low can you go? Price responsiveness of German residential water demand. In Proceedings of the XVII Annual Conference of the European Association of Environmental and Resource Economists, Amsterdam, The Netherlands, 24–27 June 2009.
157. Al-Qunaibet, M.H.; Johnston, R.S. Municipal Demand for Water in Kuwait: Methodological Issues and Empirical Results. *Water Resour. Res.* **1985**, *21*, 433–438. [CrossRef]
158. Hung, M.F.; Chie, B.T.; Huang, T.H. Residential water demand and water waste in Taiwan. *Environ. Econ. Policy Stud.* **2017**, *19*, 249–268. [CrossRef]
159. Fielding, K.S.; Russell, S.; Spinks, A.; Mankad, A. Determinants of household water conservation: The role of demographic, infrastructure, behavior, and psychosocial variables. *Water Resour. Res.* **2012**, *48*, 1–12. [CrossRef]
160. Ferraro, P.J.; Price, M.K. Using Nonpecuniary Strategies to Influence Behavior: Evidence from a Large-Scale Field Experiment. *Rev. Econ. Stat.* **2013**, *95*, 64–73. [CrossRef]
161. Ferraro, P.J.; Miranda, J.J. Heterogeneous treatment effects and mechanisms in information-based environmental policies: Evidence from a large-scale field experiment. *Resour. Energy Econ.* **2013**, *35*, 356–379. [CrossRef]
162. Thaler, R.H.; Sunstein, C.R. *Nudge: Improving Decisions about Health, Wealth, and Happiness*; Yale University Press: New Haven, CT, USA, 2008. [CrossRef]
163. Moreu Carbonell, E. *Integración de Nudges en las Políticas Ambientales*; Revista Aragonesa de Administración Pública: Zaragoza, Spain, 2018; pp. 451–485, ISSN 1133-4797.
164. Novak, J.; Melenhorst, M.; Micheel, I.; Pasini, C.; Fraternali, P.; Rizzoli, A. Integrating behavioural change and gamified incentive modelling for stimulating water saving. *Environ. Model. Softw.* **2018**, *102*, 120–137. [CrossRef]
165. Schubert, C. Green nudges: Do they work? Are they ethical? *Ecol. Econ.* **2017**, *132*, 329–342. [CrossRef]
166. Seyranian, V.; Sinatra, G.M.; Polikoff, M.S. Comparing Communication Strategies for Reducing Residential Water Consumption. *J. Environ. Psychol.* **2015**, *41*, 81–90. [CrossRef]
167. Jessoe, K.; Lade, G.E.; Loge, F.; Spang, E. Residential water conservation during drought: Experimental evidence from three behavioral interventions. *J. Environ. Econ. Manag.* **2021**, *110*, 102519. [CrossRef]
168. Tom, G.; Tauchus, G.; Williams, J.; Tong, S. The Role of Communicative Feedback in Successful Water Conservation Programs. *Appl. Environ. Educ. Commun.* **2011**, *10*, 80–90. [CrossRef]
169. Strong, A.; Goemans, C. Quantity Uncertainty and Demand: The Case of Water Smart Reader Ownership. *BE J. Econ. Anal. Policy* **2014**, *14*, 1–26. [CrossRef]
170. Miranda, J.J.; Datta, S.; Zoratto, L. Saving Water with a Nudge (or Two): Evidence from Costa Rica on the Effectiveness and Limits of Low-Cost Behavioral Interventions on Water Use. *World Bank Econ. Rev.* **2019**, *34*, 444–463. [CrossRef]
171. Otaki, Y.; Honda, H.; Ueda, K. Historical Self-Comparison of Water Consumption as a Water Demand Management Tool. *Water* **2019**, *11*, 844. [CrossRef]
172. Jaeger, C.M.; Schultz, P.W. Coupling social norms and commitments: Testing the underdetected nature of social influence. *J. Environ. Psychol.* **2017**, *51*, 199–208. [CrossRef]
173. Schultz, P.W.; Messina, A.; Tronu, G.; Limas, E.F.; Gupta, R.; Estrada, M. Personalized Normative Feedback and the Moderating Role of Personal Norms: A Field Experiment to Reduce Residential Water Consumption. *Environ. Behav.* **2014**, *48*, 686–710. [CrossRef]
174. Brent, D.A.; Lott, C.; Taylor, M.; Cook, J.; Rollins, K.; Stoddard, S. Are Normative Appeals Moral Taxes? Evidence from a Field Experiment on Water Conservation. 2017. Working Paper. Available online: http://faculty.bus.lsu.edu/papers/pap17_07.pdf (accessed on 27 June 2022).
175. Torres, M.M.J.; Carlsson, F. Direct and spillover effects of a social information campaign on residential water-savings. *J. Environ. Econ. Manag.* **2018**, *92*, 222–243. [CrossRef]
176. Willis, R.M.; Stewart, R.A.; Panuwatwanich, K.; Jones, S.; Kyriakides, A. Alarming visual display monitors affecting shower end use water and energy conservation in Australian residential households. *Resour. Conserv. Recycl.* **2010**, *54*, 1117–1127. [CrossRef]
177. Otaki, Y.; Ueda, K.; Sakura, O. Effects of feedback about community water consumption on residential water conservation. *J. Clean. Prod.* **2017**, *143*, 719–730. [CrossRef]
178. Bhanot, S.P. Rank and response: A field experiment on peer information and water use behavior. *J. Econ. Psychol.* **2017**, *62*, 155–172. [CrossRef]
179. Obringer, R.; Kumar, R.; Nateghi, R. Managing the water-electricity demand nexus in a warming climate. *Clim. Chang.* **2020**, *159*, 233–252. [CrossRef]