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The Role of Household Heterogeneity on Unplanned Water Demand Shifts

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Abstract: In this study, we investigate whether differences in sociodemographic and housing characteristics may lead to heterogenous reactions on water demand across households in the event of an unexpected shock. In this sense, we estimate a switching regression model for residential water usage in Gijón, Spain, between 2017 and 2021, exploiting the exogenous impact of the COVID-19 pandemic and various movement restriction phases. A rich dataset that integrates real data on water consumption and pricing, alongside reported household and housing characteristics, allows us to effectively control the heterogeneity of water consumers and test changes in marginal effects over time. Our findings reveal a significant increase in average water consumption coinciding with the onset of the pandemic. This increase in water usage was particularly pronounced among households with more members and those residing in older houses that also owned outdoor amenities such as gardens or swimming pools, among other socioeconomic and housing characteristics. Additionally, our study indicates that the price elasticity of water demand did not significantly differ from zero during the periods of the State of Alarm and the New Normal. This suggests that the implementation of movement restrictions and teleworking may have amplified households' preferences and dependence on water, thus fostering increased water consumption. Furthermore, our results point towards unchanged residential information or knowledge of the expense of water services despite the time spent at home.

Keywords: COVID-19; residential water consumption; water demand; Spain; Stone Geary

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1. Introduction

Recent research has stressed the urgent need to introduce novel policies aimed at the effective management and utilization of global water resources. According to Mekonnen and Hoekstra [1], approximately 4 billion people experience water stress conditions at least once a year. Furthermore, recent estimates from the Intergovernmental Panel on Climate Change (IPCC) in 2022 [2] indicated a significant reduction in water availability in multiple regions, including Western North America and the Mediterranean. This reduction is primarily attributed to the rise in global average temperature, leading to increased streamflow.

In this context, residential water demand modeling has emerged over the past few decades as an invaluable tool for analyzing and projecting the repercussions of public policies on household water consumption [3]. Nevertheless, these models primarily focus on estimating regular consumption patterns based on the observations of various structural variables, such as water tariffs, household and housing characteristics, while overlooking the influence of uncommon and unique events. Rare events may lead to the implementation of policies that have the potential to dramatically alter consumption patterns, serving as quasi-natural experiments for assessing the impact of specific regulations that might not have been explored otherwise.

The COVID-19 pandemic serves as a recent example of a rare event leading to significant changes in human behavior, mainly due to the implementation of various social distancing measures [4]. Notably, certain studies have suggested that the pandemic will result in long-term impacts on human behavior, particularly in relation to remote work [5–7]. Moreover, there is empirical support for the likelihood of increasing occurrences of pandemics similar to COVID-19, as indicated by Marani et al. [8]. This heightened risk can be attributed to the accelerated spread of contagious diseases [9], exacerbated by the impacts of climate change [10]. Given the probable recurrence of future lockdown events, it is important to investigate the impact of COVID-19 on human water consumption. This research is essential to shaping well-informed public policies aimed at promoting the sustainable and efficient use of water [11].

The existing literature assessing the impact of the COVID-19 on water usage is abundant (see Table A1 in the Appendix A for a more comprehensive review). While most studies have been focused on descriptive changes in actual consumption data, some studies have explored shifts in water usage habits through web-based surveys [12,13]. Evidence suggests an overall increase in water consumption during the COVID-19 crisis, but some researchers have also identified significant reductions in areas reliant on migration, commuting and tourism flows [14–18].

When examining residential water usage, there is an unequivocal rise due to a spatial and time reallocation in daily activities, including leisure, hygiene, and cooking [13,19]. Notably, those studies employing hourly data pinpointed changes in water usage patterns, such as a shift in the morning peak on midweek days and decreases in the evening peak [20].

However, there is still room for contributions in this field. First, a very limited number of studies have delved into how household characteristics influenced water usage patterns in the context of COVID-19 restrictions. We only found the study conducted by Nemati and Dat Tran [11], where they revealed that households with members aged 55 and above, or those equipped with individual meters, exhibited significantly larger increases in water usage compared to other households, while low-income households did not display noteworthy variations. According to Zechman Berglund et al. [21], water infrastructure is usually optimized according to observed time patterns, which rendered useless during the period of the pandemic. The redistribution of productive and leisure activities led to unexpected changes in water dynamics, changing its quality and availability across the world.

Second, prior research has predominantly relied on statistical or graphical analyses to evaluate water consumption trends during the pandemics. In this sense, there are no previous studies analyzing the effects of this shock in the water price sensitivity of households, or its impact in a wider time frame. It is paramount analyzing the mid-term (time scales of more than 1 year) consequences of pandemics in water consumption, which may lead to unstable water systems [22].

Finally, and to the best of our knowledge, there are no known studies specifically analyzing this issue in Spain, a developed country already presenting elevated water stress levels [23]. The present research aims to address all these gaps by estimating a model that assesses changes in socioeconomic, housing and price elasticities resulting from COVID-19 restrictions.

The outline of the paper is as follows. Section 2 describes the area of study, historical context, database, and analysis methodology. Section 3 presents the analysis results while Section 4 discusses their relevance and summarizes the major findings and their policy implications.

2. Materials and Methods

2.1. Area of Study and Context

The database comprises a collection of microdata obtained from a representative sample of 999 households equipped with individual water meters residing in the city of Gijón between 2017 and the first eight months of 2021. This microdata encompasses information concerning residential water consumption, along with associated water tariffs. The data have been provided by the Gijón Municipal Water Supplier (EMA). Additionally, we conducted a survey of the households through both postal and online methods, with the purpose of gathering household and housing characteristics that remain stable over time. Due to changes in household contract status with the EMA during the study period, our dataset consists of unbalanced panel data, incorporating a total of 26,860 observations.

The municipality of Gijón, situated on the northern coast of Spain, boasts a population that exceeds 270,000 residents and covers an area of 181.7 square kilometers. Gijon is characterized by having a mild climate, with average temperatures of 14 °C (Gijón City Council, 2022). Its population is spread across both rural and urban areas, with nearly 11% of inhabitants residing in non-urban spaces (see Figure 1). On 14 March 2020, the Spanish government implemented a State of Alarm across the entire nation, including the Gijón council. This measure entailed movement restrictions and a comprehensive lockdown, compelling the people of Gijón to carry out their daily activities exclusively within their homes. Between 2 May and 21 June 2020, the Spanish government's de-escalation plan (https://www.lamoncloa.gob.es/consejodeministros/Paginas/enlaces/280420-enlace-desescalada.aspx, accessed on 12 February 2024) took effect in Gijón, enabling citizens to gradually regain freedom of movement, social interaction, and the reopening of small businesses and hospitality establishments, albeit with certain restrictions.

From 22 June to 24 October 2020, the final phase of the de-escalation plan, known as the "New Normal" phase, unfolded. During this stage, there was a widespread relaxation of movement, leisure, and work restrictions (https://coronavirus.asturias.es/documents/70545/101334/documento-informativo-fase-1-principado-delegacion-gobierno.pdf/0520b98a-aa97-041d-0d79-bb04a41f470e, accessed on 12 February 2024). Key changes included the removal of restrictions on inter- and intraregional movement, a shift from maximum capacity limits in hospitality establishments to limits primarily guided by a 1.5-m social distancing requirement, public swimming pools allowing up to 75% of their normal capacity, and the discontinuation of mandatory teleworking, among other adjustments.

On 25 October 2020, a second State of Alarm was declared (https://www.boe.es/boe/dias/2020/10/25/pdfs/BOE-A-2020-12898.pdf, accessed on 12 February 2024) due to the rising number of positive COVID-19 cases. Its primary objective was to delegate authority from the Central Government to the Regional Administrations, with the aim of better managing the spread of the pandemic. In the case of the Principality of Asturias, and consequently Gijón, several measures were enacted to curb the virus. These included restrictions on access to the Autonomous Community, the imposition of a nighttime curfew from 10:00 pm to 6:00 am, lockdowns in larger cities like Gijón, and limiting public and private gatherings to no more than six individuals (https://sede.asturias.es/bopa/2020/10/26/20201026Su1.pdf, accessed on 12 February 2024). Starting on 14 December 2020 onward, hospitality establishments and large retailers were permitted to reopen, but under stringent space occupancy limitations, similar to those applied to public and private sports facilities (https://sede.asturias.es/bopa/2020/12/09/20201209Su1.pdf, accessed on 12 February 2024).

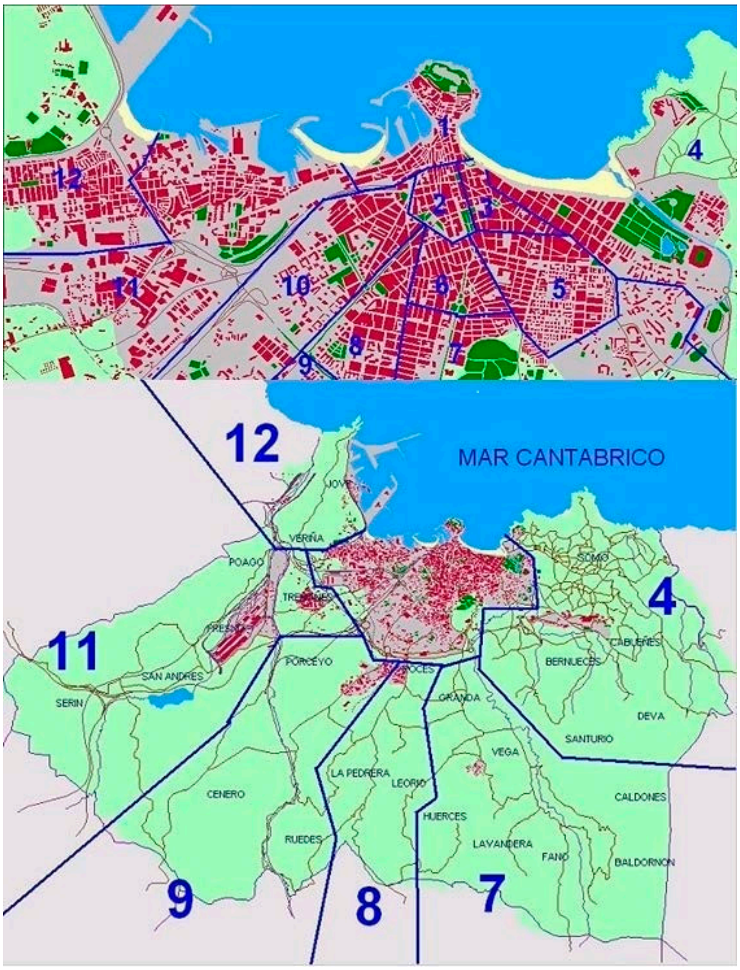

Figure 1. Map of the municipality of Gijón. Source: Own elaboration.

Finally, on 4 May 2021, the second State of Alarm came to an end, marking the removal of most movement restrictions. Nevertheless, some safety measures persisted, such as the requirement to wear facemasks in public spaces. Additionally, nighttime leisure activity limitations remained in effect, with hospitality establishments obligated to close at 1:00 am (https://coronavirus.asturias.es/documents/70545/0/2021_05_05+Resolucion+adaptacion+medidas+coronavirus.pdf/960335f7-fa18-981d-5422-13f5e7274956?t=1620233681341, accessed on 12 February 2024).

2.2. Variables

The variables chosen for the present study are described in Table 1. Water consumption is quantified in bimonthly cubic meters, as water services are billed every two months, typically covering a span of 60 days. Our sample indicates that the average bimonthly water consumption is 17.298 m^3.

Since self-reported household income data falls within discrete values confined to a specific range, we opted to construct a continuous income variable by adopting the approach outlined by Carlevaro et al. [24] and Binet et al. [25]. This approach involves estimating a generalized Tobit model to derive latent income levels, using data on various household and housing characteristics, including factors such as the percent of employed members and the percent of individuals with postsecondary education. Using this procedure, we obtained an average monthly household income of €2133.

Table 1. Variables description.

Variable	Name	Definition
Q	Water consumption	Bimonthly water consumption (m^3/period)
IMgP	Income/marginal price	Bimonthly household income after fixed water charges, corrected by Nordin's difference divided by price (€)
Memb	Household size	Number of family members
Seniors	Share of seniors	Proportion of members older than 65 (%)
Minors	Share of minors	Proportion of members younger than 18 (%)
Employed	Share of employed	Proportion of employed and self-employed members in the household (%)
Women	Share of women	Proportion of female members in the household (%)
Old_H	Old house	Dummy variable: 1 if the house/apartment is over 40 years old, 0 otherwise
Amenities	Index of outdoor amenities	Share of outdoor amenities (swimming pool and garden)
Dish	Dishwasher	Dummy variable: 1 if residence has a dishwasher
Eff_Dev	Index of efficient devices	Share of water-saving devices in residence
Eff_Appl	Index of efficient appliances	Share of water and energy-saving appliances in residence
Wat_Hab	Index of water-saving habits	Share of declared water-saving habits out of 13 possible habits
Unk_Cons	No consumption perception	Dummy variable: 1 if the respondent does not provide any estimation of his/her water consumption, 0 otherwise
Unk_Bill	No bill perception	Dummy variable: 1 if the respondent does not provide any estimation of his/her water bill, 0 otherwise
Out	No consumption	Dummy variable: 1 if household's consumption in the period is 0, 0 otherwise

Source: Own elaboration.

Furthermore, to mitigate the potential for omitted variable bias [25], household income was adjusted using the Nordin's difference term [26] and the fixed charges. This adjustment quantifies the income effect resulting from transitions between different water consumption blocks, and from fixed charges included in the provision of water services. As will be explained later on, the Stone-Geary demand function imposes the estimation of a common marginal effect for income and water prices, therefore, the relevant variable for measuring income and price elasticities will be the ratio between the adjusted household income and the price of the last block of water consumption (*IMgP*).

The price schedule is a two-part tariff, with both fixed and variable charges. The marginal price (price charged for the last cubic meter of water consumed) is determined by an increasing block tariff structure with three blocks. This pricing scheme includes a 10% Value Added Tax (VAT), a specific regional tax on water use whose variable part has adopted a super progressive structure (https://www.boe.es/buscar/act.php?id=BOE-A-2015-944, accessed on 12 February 2024) and a variable fee corresponding to the supply and sewage services. Most users are in the first tier since it is quite broad. Moreover, a slight update to the water tariff was applied in 2020. Table 2 captures the complexity of the variable component of the integrated water tariff scheme for residential users in Gijón:

In addition to the essential variables discussed earlier for estimating the water demand function, we incorporated additional control variables that are widely recognized in the water demand literature [3,27], such as household size (*Memb*) or household composition in terms of age, employment status, and gender (*Senior*, *Minor*, *Employed*, *Women*). Moreover, housing characteristics and equipment are also significant issues to be considered. Thus, the age of the building (*Old_H*), outdoor (*Amenities*) and indoor equipment (*Dish*), and the efficiency of some appliances/devices using water were also considered (*Eff_Dev*, *Eff_Appl*).

Table 2. Variable charge of water tariffs in Gijón.

Water Consumption	Block 1 (≤30 m^3)	Block 2 (30–50 m^3)	Block 3 (>50 m^3)
	Before January 2020		
≤30 m^3	€1.02234/m^3		
30–50 m^3	€1.10224/m^3	€1.29892/m^3	
>50 m^3	€1.18204/m^3	€1.37872/m^3	€1.549/m^3
	From January 2020 onwards		
≤30 m^3	€1.05347/m^3		
30–50 m^3	€1.13337/m^3	€1.33984/m^3	
>50 m^3	€1.21317/m^3	€1.41964/m^3	€1.5985/m^3

Source: Own elaboration.

Some variables based on self-reported information taken from the survey were also built: water-saving habits (*Wat_Hab*) and three variables measuring lack of knowledge of the quantity of water consumed (*Unk_Cons*), the price of water, and the water bill paid (*Unk_MgP* and *Unk_Bill*). The latter variables are also interesting since it has been shown that households have misperceptions when it comes to estimating water prices, consumption, and bills [25,28]. As such, inattention or perception bias could generate suboptimal consumption decisions. Finally, another variable was included to control for those households that moved so their recorded consumption was zero. In fact, it was quite common during the lockdown for some households to move into secondary residences located in the countryside, so this variable partially captures that situation.

Table 3 displays the main descriptive statistics of the sample by period (pre-COVID, COVID, post-COVID). The average household size is 2.4 members, close to the representative average household in Asturias. The share of senior members in the household is around 29%, while the percentage of minors in the household is 10%. Those figures are in line with the large number of people older than 65 living in the city, with Gijón being one of the municipalities in Spain with the highest number of elderly people [29]. Around 43% of household members are employed or self-employed, and 53% of household members are women. Regarding the housing features, almost 50% of houses are older than 40 years, and 61% are equipped with a dishwasher. When looking at the quality of installed water devices, households tend to present low investment levels (less than two water-saving devices), while almost half of the electrical appliances using water are labelled as efficient.

Table 3. Summary statistics.

	PreCOVID (N = 17,927)		COVID (N = 6963)		PostCOVID (N = 1970)	
Variable	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Q	16.958	16.917	18.079	18.167	17.349	17.828
IMgP	4274.339	2215.979	4077.931	1992.412	4087.728	1980.246
Memb	2.443	1.067	2.438	1.074	2.437	1.076
Seniors	0.292	0.413	0.281	0.409	0.282	0.41
Minors	0.105	0.183	0.107	0.184	0.106	0.184
Employed	0.43	0.371	0.438	0.372	0.438	0.373
Women	0.527	0.282	0.53	0.284	0.529	0.283
Old_H	0.485	0.5	0.48	0.5	0.482	0.5
Amenities	0.122	0.26	0.12	0.258	0.121	0.259
Dish	0.616	0.486	0.619	0.486	0.62	0.485
Eff_Dev	0.211	0.249	0.212	0.248	0.213	0.249

Table 3. *Cont.*

	PreCOVID (N = 17,927)		COVID (N = 6963)		PostCOVID (N = 1970)	
Variable	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Eff_Appl	0.553	0.421	0.56	0.421	0.561	0.421
Wat_Hab	0.658	0.136	0.658	0.136	0.657	0.137
Unk_Cons	0.648	0.478	0.657	0.475	0.657	0.475
Unk_Bill	0.256	0.437	0.253	0.435	0.253	0.435
Out	0.016	0.127	0.018	0.131	0.022	0.148

Notes: the comparison of the main statistics of our sample with those of the population of the region of study proves its representativeness. According to the INE [30], the average number of members in an Asturian household was 2.20 persons, and about 59.2% of the population in Gijón was between the 18 and 64 years old (https://observa.gijon.es/pages/inicio/, accessed on 12 February 2024). Source: Own elaboration.

The average household declares practicing 8 out of 13 water-saving habits, while only 40% are aware of environmental campaigns aimed at implementing water savings. Finally, households are not well informed about their bimonthly water consumption levels (more than 64% do not provide any information on their last consumption levels). Interestingly, less than 26% do not provide any estimation of the value of their last water bill.

2.3. Methods

As in Irwin et al. [31], Menneer et al. [32], Bakchan et al. [16], Cominato et al. [33], and Nemati and Tran [11], the current study also estimates the impact of COVID-19 on residential water consumption by estimating a linear model. However, the richness of our data allowed us to go further by estimating the impact of COVID-19 on the marginal effects associated with water prices and other household characteristics. To that end, we considered the standard Stone-Geary demand specification (e.g., [34–41], in an exogenous switching regression context [42–44].

The Stone-Geary function offers a valuable framework for modeling water demand as a linear combination of determinants that are independent of changes in income and prices. This property is particularly advantageous, especially in the context of limited knowledge about water tariffs and the relatively small share of income allocated to water expenditures [3,27,45–47]. Furthermore, the versatility of this function extends to its ability to estimate income and price elasticities that are not fixed across households and over time [38].

We estimated the following exogenous switching regression model of residential water demand in which households faced three regimes (*R*): pre-COVID (before the second billing period of 2020), COVID (from the second billing period of 2020 to the second billing period of 2021) and post-COVID (the third and fourth billing periods of 2021):

$$\begin{aligned} Q_1 &= \sum_{j}^{K} \beta_{j1} x_{j1} + \sum_{t}^{5} \delta_{t1} b_{t1} + \alpha_1 \frac{I_1}{P_1} + \varepsilon_1 \text{ if } R = 1 \\ Q_2 &= \sum_{j}^{K} \beta_{j2} x_{j2} + \sum_{t}^{5} \delta_{t2} b_{t2} + \alpha_2 \frac{I_2}{P_2} + \varepsilon_2 \text{ if } R = 2 \\ Q_3 &= \sum_{j}^{K} \beta_{j3} x_{j3} + \sum_{t}^{5} \delta_{t2} b_{t2} + \alpha_3 \frac{I_3}{P_3} + \varepsilon_3 \text{ if } R = 3 \end{aligned} \quad (1)$$

where β_{jR} is the marginal effect associated with the *j* household characteristic x_{jR}, which is allowed to change over regimes of consumption *R*, and δ_{tR} are the marginal effects of the five billing period dummies b_{tR}. Similarly, the marginal effect of bimonthly income divided by water prices α_R can also change with the period of analysis. Finally, ε_R is a normally distributed error term (household and time subscripts are omitted for clarity).

Essentially, the exogenous switching regression allows to identify the average treatment effect (ATE) of being exposed to an exogenous shock (the Covid and lockdown periods in our case), as if it were a difference in differences model or a finite mixture model [48], where parameter heterogeneity is a function of experiencing the shock or not.

Since water consumption and marginal prices are simultaneously determined, it is very likely that a problem of endogeneity will arise when estimating model (1). In this sense, we followed the procedure of estimating the residual from a control function [49], using all block prices as instruments [50]. However, since most households are in the first block, we considered the first- and second-time lags of the first block price.

3. Results

According to Table 3, most variables (in particular, those variables obtained from the survey) do not have time variability, so slight changes were recorded due to changes in the sample size and composition. Regarding the variables that change over time, it is possible to observe that average water consumption experienced a significant increase during the COVID period (see Figure 2). In line with the findings of Irwin et al. [31], it appears that the impact of movement restrictions on water consumption follows a temporal pattern, with slight initial increases at the start of the States of Alarm, followed by more pronounced surges, and ultimately plateauing at levels akin to those seen before the onset of the pandemic. Regarding the income-price ratio, time variation comes from marginal price heterogeneity but also from a tariff adjustment in 2020. On average, the percentage of observations of zero water consumption tends to be low but increases starting from the COVID period onwards. This is likely explained by households moving from urban to rural secondary residences.

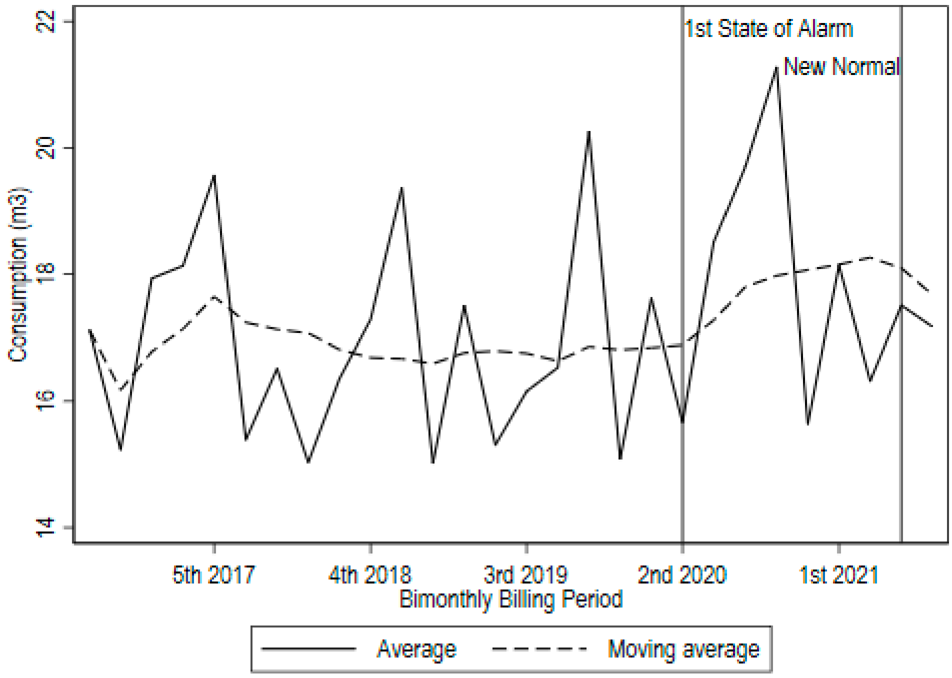

Figure 2. Time evolution of residential water consumption in Gijón. Source: Own elaboration.

Table 4 shows the estimation results of the Stone-Geary water demand function with district and billing effects for the three regimes. Table 4 shows the results of the Wald tests performed to check whether the estimated coefficient of each covariate is statistically different than that of the pre-COVID period. As can be seen in Table 3, the coefficient associated with the residual of the control function [49] is statistically different than zero, which reinforces the results of the tests on endogeneity and validity of instruments.

Table 4. Estimates of the water demand function over regimes.

	PreCOVID	COVID	PostCOVID
IMgP	0.001 ***	0.000	0.001 *
	(8.02)	(0.32)	(1.86)
Memb	4.753 ***	5.293 ***	5.272 ***
	(30.77)	(21.98)	(11.71)
Seniors	1.729 ***	1.828 ***	1.467
	(3.96)	(2.68)	(1.16)
Minors	−15.001 ***	−9.923 ***	−12.030 ***
	(−18.29)	(−7.70)	(−5.02)
Employed	−3.231 ***	−2.213 ***	−2.656 *
	(−6.77)	(−2.99)	(−1.94)
Women	−1.159 ***	−1.354 **	−0.770
	(−2.84)	(−2.13)	(−0.65)
Old_H	1.972 ***	1.184 ***	1.694 **
	(7.29)	(2.80)	(2.16)
Amenities	16.457 ***	17.162 ***	17.165 ***
	(28.12)	(18.90)	(10.19)
Dish	3.511 ***	2.814 ***	2.366 ***
	(12.04)	(6.13)	(2.78)
Eff_Dev	−1.880 ***	−2.450 ***	−2.340
	(−3.82)	(−3.16)	(−1.63)
Eff_Appl	−1.702 ***	−1.569 ***	−0.178
	(−5.27)	(−3.09)	(−0.19)
Wat_Hab	−6.339 ***	−6.648 ***	−7.043 ***
	(−7.41)	(−4.96)	(−2.83)
Unk_Cons	0.704 ***	0.118	1.224
	(2.69)	(0.29)	(1.60)
Unk_Bill	−0.113	0.018	0.636
	(−0.41)	(0.04)	(0.79)
Out	−14.627 ***	−15.487 ***	−13.982 ***
	(−15.62)	(−11.41)	(−6.22)
Control Function	−0.005 ***	−0.004 ***	−0.004 ***
	(−27.68)	(−15.05)	(−9.55)
Intercept	3.313 ***	9.808 ***	4.916 *
	(3.48)	(6.62)	(1.85)
District and billing period effects	YES	YES	YES
Var(e.q)		203.845 ***	200.234 ***
		(106.93)	(94.57)
N	15,919	6947	1967

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. t-statistics between brackets. Source: Own elaboration.

Focusing on the marginal effect of the income-price ratio (*IMgP*), it is significantly different than zero for the pre- and post-COVID regimes and presents the expected positive sign (water is a normal good) as in the previous literature (e.g., [3,41]). However, the effect dissipates during the COVID period. Additionally, the number of members living in the same residence (*Memb*) increases water consumption levels, as expected [25,37,40,41,50–52]. Moreover, the estimated marginal effect associated with the household size increased by 0.5 points during the lockdown period, suggesting that large families required stringent hygiene practices to control the increased chances of disease spread due to a more limited social distancing capacity (e.g., [53,54]). The top-left chart at Figure 3 shows a clearly steeper increase in average water consumption among households with 3 or more members.

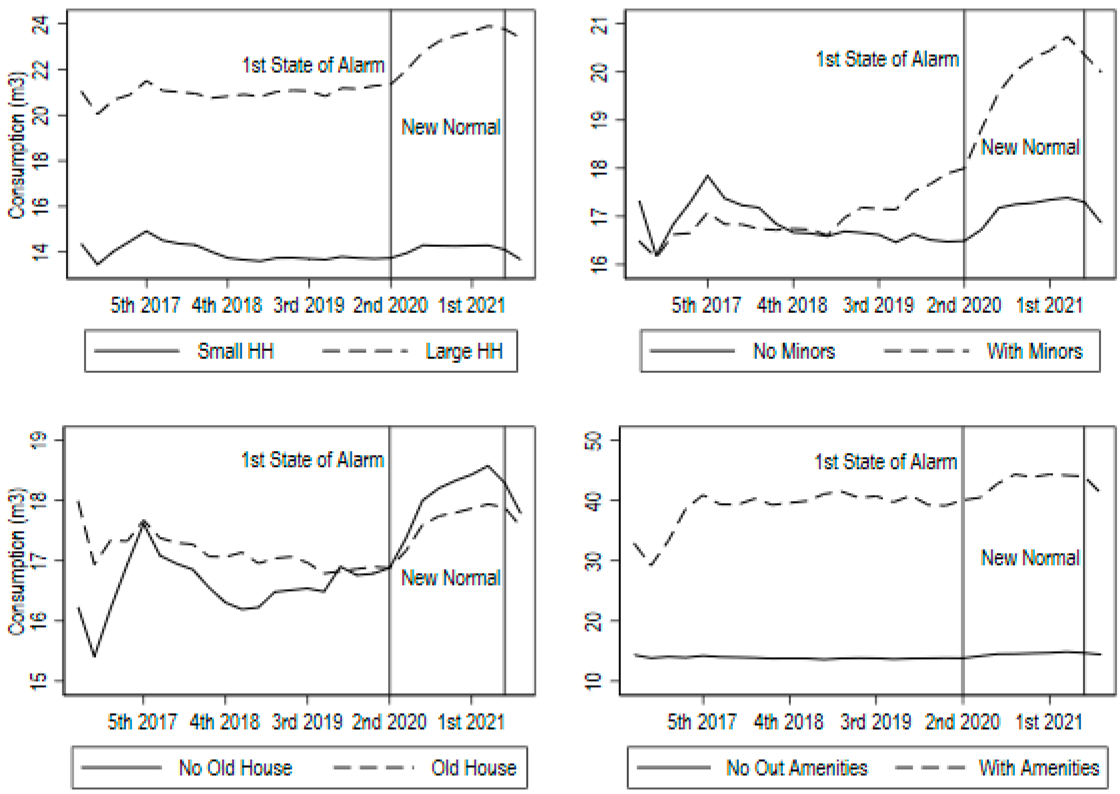

Figure 3. Time evolution of residential water consumption by household characteristics. Notes: each graph plots 6th order moving averages of water consumption (year averages). Small HH are households with 1 and/or 2 members. No Minors are households with no minor members. No Old House are households residing in houses less than 40 years old. No Out Amenities are households residing in houses without garden and/or swimming pool. Source: Own elaboration.

The age (*Seniors* and *Minors*) and gender composition (*Women*), as well as the employment status (*Employed*) of household members are also significant when explaining differences in water consumption. More precisely, aging households, and those with higher shares of male and unemployed members, put pressure on residential water demand, similar to the findings in other studies [25,51,52]. However, the negative marginal effect of the share of minors and employed members on water consumption decreases as households move from the pre- to the COVID-19 regime (see also the top-right chart at Figure 3, where average consumption became significantly steeper for those households with at least one minor member). These findings are consistent with the fact that minors and employed people had to change their studying and working spaces from the education center/office to their homes. Therefore, the water needs that used to be covered at those spaces, whether in terms of sanitation or hydration, had to be covered at home during lockdown periods.

Regarding housing characteristics, owning an old house (*Old_H*), a house with a garden and/or a swimming pool (*Amenities*), and equipped with a dishwasher (*Dish*) increased residential water consumption [25,55–60]. It is important to highlight the reduction in the marginal impact of old houses on water consumption during the pandemic, which is likely related to the temporary migration patterns from urban to rural areas in Spain at that time [61], which reduced average consumption levels in those buildings (see the bottom-left chart at Figure 3, where water consumption increases at a slower pace in old houses during the COVID-19 period). On the contrary, the marginal impact of owning outdoor amenities during the lockdown increases, due to a shift in the physical space where water-intensive activities took place [19,62]. See also the bottom-right chart at Figure 3, where water consumption increases at a faster pace across households owning outdoor amenities during the lockdown period.

Interestingly, the households that presented consumption misperceptions (*Unk_Cons*) also recorded higher levels of water consumption [25,28,63,64]. However, marginal effects decrease over time, being non-significantly different than zero during and after the pandemic. On the contrary, households equipped with water-saving technologies (*Eff_Dev* and *Eff_Appl*) and reporting good water habits (*Wat_Hab*) registered lower levels of water consumption. These results are also in line with previous literature, which has emphasized the role of technology and behavior when it comes to model water demand [50,59,65].

Regarding the significance of coefficient differences between periods, we observed in Table 5 that the impact of the income-price ratio is significantly lower when comparing the pre-COVID and COVID periods. Nevertheless, that difference ceases over time since the pre- and post-COVID coefficients are not significantly different. Additionally, we found the marginal effects of the number of household and minor members to be significantly different between the pre- and COVID regimes.

Table 5. Wald tests for differences in coefficients.

	PreCOVID–COVID Test	PreCOVID–PostCOVID Test
IMgP	16.98 ***	0.80
	(0.00)	(0.370)
Memb	3.67 *	1.23
	(0.055)	(0.266)
Seniors	0.02	0.04
	(0.890)	(0.841)
Minors	11.40 ***	1.43
	(0.00)	(0.232)
Employed	1.38	0.16
	(0.240)	(0.686)
Women	0.07	0.10
	(0.793)	(0.751)
Old_H	2.54	0.12
	(0.111)	(0.733)
Amenities	0.44	0.16
	(0.508)	(0.686)
Dish	1.69	1.68
	(0.193)	(0.195)
Eff_Dev	0.40	0.10
	(0.843)	(0.757)
Eff_Appl	0.05	2.43
	(0.822)	(0.119)
Wat_Hab	0.04	0.07
	(0.843)	(0.785)
Unk_Cons	1.49	0.43
	(0.222)	(0.511)
Unk_Bill	0.07	0.81
	(0.795)	(0.368)
Out	0.28	0.07
	(0.596)	(0.787)

Notes: * $p < 0.1$, *** $p < 0.01$. p-values between brackets. Source: Own elaboration.

To conclude, Table 6 displays the estimated price and household size elasticities. The estimated price elasticities in absolute terms are lower than one, implying the demand for water is price inelastic due to the absence of substitute goods, as has been shown in previous literature [3,27,45–47]. Not surprisingly, price elasticities during and after the pandemic registered lower values, being close to perfectly inelastic during the COVID crisis. This finding is in line with the existing evidence, since the pandemic led to an increase in water demand for health, food, and leisure reasons (e.g., [19,62,66]), irrespective of the existing price scheme or the change it underwent in early 2020.

Table 6. Price and household size elasticities.

Elasticities	PreCOVID	COVID	PostCOVID
Price	−0.205 ***	−0.012	−0.134 *
	(8.01)	(0.32)	(1.87)
Household size	0.696 ***	0.760 ***	0.788 ***
	(27.51)	(19.39)	(10.25)

Notes: * $p < 0.1$, *** $p < 0.01$. Source: Own elaboration.

Interestingly, the elasticity of water demand with respect to the number of household members increases over time. For instance, doubling the number of members of a given household would lead to an increase of bimonthly water consumption of almost 70% during the pre-COVID regime, while the post-COVID regime would lead to an increase of almost 80%. Definitively, the COVID crisis led to an increase in water consumption levels, a reduction in price elasticities and a slight increase in household size elasticities.

4. Discussion and Conclusions

In this study, we analyzed the influence of COVID-19-related movement and behavioral restrictions on residential water consumption and the price elasticity of demand. To accomplish this, we considered a rich and exclusive microdatabase, focusing on a selected group of households within the Spanish city of Gijón spanning years 2017 to 2021. Our empirical analysis encompassed the estimation of a water demand function on a switching regression model, incorporating district and billing period fixed effects, with a particular emphasis on the changes of marginal effects of water demand determinants and price elasticity with respect to the COVID-19 pandemic.

Our findings unequivocally demonstrate a substantial and notable surge in residential water consumption in Gijón during the COVID-19 pandemic. Several contributing factors can be discerned, primarily stemming from heightened personal and household hygiene practices [32,62,66–70]. This surge can be attributed, in part, to the increased focus on hygiene necessitated by the virus and, in part, to the fact that households concentrated their daily activities at home, leading to increased water use for personal and household cleanliness when people could no longer perform these activities outside their residences. Another pivotal factor contributing to this trend was the surge in home-cooked food preparation [19,66]. Additionally, we noted that households equipped with gardens or swimming pools displayed higher consumption levels than the overall average, a finding corroborated by previous literature [19,62].

Finally, our estimates of the price elasticity of water demand revealed that, during the COVID period, demand became almost perfectly inelastic, displaying minimal responsiveness to price fluctuations. As movement restrictions were lifted, the elasticity of demand increased, but remained below the pre-COVID levels.

While it is expected that extended periods spent at home could, in theory, make people more price-conscious and, as a result, render residential water demand more price elastic [3,71,72], our research points to a dominant influence of the new needs and preferences arising from the COVID-19 pandemic. Therefore, our work underscores the imperative need for the development of innovative tools to promote efficient water usage, particularly in contexts marked by restricted movement and lockdowns. These tools could encompass strategies like simplifying and increasing the transparency of water billing [73] or the implementation of "nudges" [74]. These nudges could help households gain a heightened awareness of their role in promoting environmental sustainability, either through social and historical comparisons of past consumption levels or by establishing clear environmental objectives [28,75–77].

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Literature review summary.

Reference	City/Region	Type of Data	Methods	Main Results
Irwin et al. (2021) [3]	Henderson (Nevada, US)	Water consumption of 98,099 users (residential: 96,303; commercial: 1730; schools: 66), 2017–2020 (five water bills per year and user). Available data by type of user	Water consumption model, DID	Substantial decreases in water usage among commercial users and schools were registered, while residential users increased their consumption. Average net water increases ranked from 47.8 to 478.3 million gallons
Nemati and Dat Tran (2022) [12]	Six states (US)	Daily water consumption from 2018 to 2020 at customer level (the number of customers was not reported)	Water consumption model- FE	Overall increase in water consumption ranked between 3.08% and 13.65%
Almulhim and Aina (2022) [13]	Dammam Metropolitan Area (Saudi Arabia)	Self-reported water habits from 810 respondents in a web-based survey conducted between February and May 2021. Interviews with managers and government officials	Statistical analysis and multiple regression analysis	Water consumption increased by more than 50% during the lockdown. Working from home was a key driver for the increase in water usage
Bera et al. (2022) [14]	Several regions (India)	Self-reported water habits from 1850 respondents in a web-based survey conducted from 18 August to 8 September 2020	Statistical and plot analysis	The results suggest significant increases in some water usage habits (hand and clothes washing and bathing frequency) during the COVID-19 crisis
Balacco et al. (2020) [15]	Five towns in Puglia (Italy)	Daily water consumption from 1 January, to 30 April, in 2019 and 2020 at town level	Plot analysis of instantaneous flows, daily cumulated volume, and daily water volume percentage change over time	Different patterns were detected depending on the town. Most of them reduced their daily water volume
Rizvi et al. (2021) [16]	Dubai (United Arab Emirates)	Hourly and daily water consumption in multiple residential buildings, comparing two different periods: 2 May to 6 June 2019 and 13 April to 1 May 2020	Statistical and plot analysis of residential water usage profiles	The COVID-19 health crisis led to significant increases in water usage at the residential level, with over a 30% increase during the Ramadan period
Bakchan et al. (2022) [17]	Austin (Texas, US)	Daily water consumption from January 2013 to December 2020 in 9 pressure areas	Water consumption model- FE	Negative change of water usage during the stay home-work safe period
Fritsche et al. (2022) [18]	Michigan (US)	Daily water consumption from 2026 to 2020 in 75 member partners at Great Lakes Water Authority	Statistical analysis and correlations	Variety of impacts was observed

Table A1. *Cont.*

Reference	City/Region	Type of Data	Methods	Main Results
Balacco (2023) [19]	Five towns in Puglia region (Italy)	Daily water consumption from 2019 to 2021 at town level	Plot analysis of daily volume over time	Different patterns were detected depending on the town. In some of them, daily water volume remained unchanged
Lüdtke et al. (2021) [20]	Harburg area provided by a water utility (Germany)	Aggregated hourly and daily water consumption for three different periods: between 1 January and 25 June 2018 and between 25 December, 2018 + 2019 and 25 June, 2019 + 2020	Water consumption model estimated through a linear mixed regression	The authors found a 14% increase in daily residential water consumption, with higher morning and evening demand peaks during the day
Evangelista et al. (2022) [21]	Soccavo district of Naples (Italy)	Daily water consumption from 1 January 2019 to 31 December 2020 at meter level (637 residential meters)	Plot analysis of daily and weekly average patterns	Total residential water volume increases ranked from 1.3% to 5.8% depending on the period. Daily patterns registered substantial changes
Menneer et al. (2021) [33]	Camborne and Redruth area of Cornwall (UK)	Hourly water consumption of 280 households living in remote and rural areas in spring 2020 compared with spring 2019. Face-to-face surveys were conducted from 2017 to 2018	Daily and hourly water consumption patterns model: plot analysis and mixed linear regression	Hourly water usage increased by 17%, while a one-hour delay in peak morning usage was detected
Cominato et al. (2022) [34]	Joinville (Brazil)	Hourly and daily water consumption in 14 social housing buildings (280 apartments), comparing pre-pandemic period (1 March 2019 and 16 March 2020) and the pandemic period (17 March 2020 to 31 May 2021)	Hourly and daily consumption before and after social-distancing government decree was compared using plot analysis, non-parametric paired Wilcoxon test, and water consumption model Prais-Winsten OLS regression	Water consumption registered a small significant increase during the COVID-19 period. Hourly patterns also changed
Abu-Bakar et al. (2021) [78]	Several regions in South and East England (UK)	Weekly residential water consumption at an hourly resolution of 11,528 households from January to May 2020	Plot analysis of weekly consumption and cluster analysis based on hourly patterns	Households are clustered into 4 groups depending on their diurnal and night-time patterns
Kalbusch (2020) [79]	Joinville (Brazil)	Daily water consumption of 1178 users (residential: 913; commercial: 159; industrial: 58; public consumer units: 48) comparing the pre-pandemic period (21 February to 16 March 2020) to the pandemic period (17 March to 12 April 2020). Available data by type of user	Daily consumption before and after social-distancing government decree was compared using non-parametric paired Wilcoxon test and water consumption model using a Prais-Winsten OLS regression	Water usage by the commercial, industrial and public sectors decreased (53%), while an increase (11%) was observed in the residential sector
Dziminska et al. (2021) [80]	Bydgoszcz (Poland)	Hourly water consumption of 3 similar apartment buildings within the same housing estate from 16 May 2019 to 6 October 2020	Analysis of hourly water patterns using plot and cluster analysis	Three synthetic patterns of hourly water consumption were detected based on the division into business days and days free from work and holidays
Kazak et al. (2021) [81]	Wrocław (Poland)	Monthly water consumption for 10 groups of users in 23 District Metered Area (DMA) zones from January 2018 to April 2020	Visual analytics approach to observe changes in water usage patterns	Restrictions caused by COVID-19 did not change total water consumption. However, some transfers between different groups of users were observed
Talib et al. (2023) [82]	Dubai (United Arab Emirates)	Monthly water consumption of over 200 communities from July 2017 to December 2020	Water consumption model using several machine learning models. Plot analysis	Water consumption increased by 20% in 2020

Table A1. *Cont.*

Reference	City/Region	Type of Data	Methods	Main Results
Tleuken et al. (2021) [83]	Almaty, Shymkent, and Atyrau (Kazakhstan)	Yearly and monthly water consumption from January 2011 to April 2021 for different residential building types in different areas of these cities	Statistical and plot analysis	Residential water consumption increased during the COVID-19 crisis, but the increase was not statistically significant
Li et al. (2021) [84]	California (US)	Water consumption of 395 water retailers from 2014 to 2020. Available data by type of user	Water consumption model, OLS	Total urban water usage in April 2020 declined by 7.9% compared with previous years (from 2014)

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