Urban water demand for manufacturing, construction and service industries: a microdata analysis

Pilar Gracia-de-Rentería, Ramón Barberán and Jesús Mur

ABSTRACT

This study analyses the industrial demand for urban water using a panel dataset of firms operating in the city of Zaragoza (Spain) and looking at three sectors (manufacturing, construction and services) disaggregated on 24 subsectors. Evidence in favour of using the marginal price rather than the average price is obtained, and the selection of the price is found to influence the value of the elasticities. Based on a translog cost function, the direct price elasticity of water (−0.86), the output elasticity (0.73) and the cross-price elasticities between water and capital, labour and supplies (being all of them substitutes) were estimated. By subsectors, the influence of price is only significant in those with a higher share of water in the total production cost. These results indicate that pricing can be used as a tool for managing water demand by promoting conservation of the resource. However, these results also indicate that the simultaneous use of other instruments is advisable to reinforce the impact of pricing policy on water consumption.

Key words | elasticities, industrial activities, microdata, urban water, water demand

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HIGHLIGHTS

- The determinants of industrial water demand are analysed using firms' microdata.
- Manufacturing, construction and services activities are considered.
- The marginal water price is a more suitable specification than the average one.
- The price of water can be effective for managing water demand.
- Price effectiveness is conditioned by the water share in the total production cost.

INTRODUCTION

In a context of increasing water scarcity, public authorities face the challenge of making the satisfaction of human needs compatible with environmental conservation (WWAP 2015; UN Environment 2019). For this purpose, it is key to implement water demand management strategies that promote the reduction of water consumption and its efficient use. Among the possible demand management measures, there is a consensus on the particular relevance of economic instruments, especially prices because they could encourage water efficiency providing a signal of water scarcity and allow cost recovery (World Bank 1993; EEA 2012; OECD 2016). However, evidence on pricing effects on water demand remains unclear since price elasticities vary strongly according to water uses and between different empirical studies for similar uses. This uncertainty, along with the age

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of most of the previous papers, make necessary more and updated studies focusing on water demand elasticities according to the European Environment Agency (Dige *et al.* 2017).

Researchers have paid considerable attention to the estimation of urban water demand, due to its influence on the wellbeing and population health and on the economic development of countries, as well as the extensive use of pricing in the cities. The attention has focused mainly on household demand and much less on industrial demand, as seen in literature reviews (Arbués *et al.* (2003); Worthington & Hoffman (2008), for domestic uses, and Renzetti (2002); Worthington (2010); Renzetti (2015), for industrial uses).

Moreover, most of studies focusing on industrial uses analyse only the manufacturers. There are fewer referring to services, and the construction sector has not received any attention. Furthermore, in this literature, it is not frequent to analyse water demand for a vast number of sectors and subsectors. Several papers present results only for the aggregate industry (Dupont & Renzetti 2001; Hussain *et al.* 2002; Féres & Reynaud 2005; Gómez-Ugalde *et al.* 2012; among others), for a few subsectors (Lynne 1977; Lynne *et al.* 1978; Renzetti 1988, 1992, 1993; Moeltner & Stoddard 2004; among others) or for a unique subsector of special interest (Ziegler & Bell 1984; Dupont & Renzetti 1998; Angulo *et al.* 2014; among others).

The lack of sectoral disaggregation is generally due to data availability constraints, something that also has usually determined the use of aggregated data rather than microdata (Grebenstein & Field 1979; Dupont & Renzetti 2001; Hussain *et al.* 2002; Gracia-de-Rentería *et al.* 2019; Revollo-Fernández *et al.* 2020, among others). However, microdata are widely recognised as the preferred approach for estimating water demand functions (Arbués *et al.* 2003) since they reveal the individual behaviour of agents and avoid aggregation biases when individuals are not homogeneous. Unfortunately, microdata are difficult to obtain, especially in the case of industrial activities.

The objective of this paper is to contribute to this literature by estimating urban water demand for industrial uses in the municipality of Zaragoza (Spain) in the period 1993–2012, using firms' microdata and covering all industrial activities (manufacturing, construction and services sectors) disaggregated on 24 subsectors. In particular, it focuses on assessing the economic determinants of publicly supplied water demand, obtaining the direct price and the output elasticities of water, and the cross-price elasticities of water with other inputs.

The remainder of the paper is organized as follows. The next section presents an overview of the methodological framework. Then, the case study, the data and the econometric estimation were addressed. The two last sections detail and discuss the results and conclusions.

METHODOLOGICAL FRAMEWORK

When analysing water demand for industrial uses, one should bear in mind that water is an input that is incorporated in the industrial processes along with other inputs such as capital (K), labour (L) and supplies (S) (or materials, M). Therefore, the theoretical model that underlies this issue is the classical KLM production approach, in which water (W) is considered as a separate input from other supplies.

In this context, the production function could be directly estimated, or the cost function can be immediately derived (and estimated) considering the input prices as exogenous and for a given output level. The latter approach allows using estimated parameters to directly obtain output, own and cross-price elasticities, so it has been the most popular strategy for analysing the economic determinants of industrial water demand (Grebenstein & Field 1979; Babin *et al.* 1982; Renzetti 1988, 1992; Dupont & Renzetti 1998, 2001; Reynaud 2003; Féres & Reynaud 2005; Angulo *et al.* 2014; Gracia-de-Rentería *et al.* 2019). In contrast, the direct use of the production function has been almost negligible and devoted to estimate water shadow princes and, as a secondary objective, price elasticities (see Kumar 2006; Revollo-Fernández *et al.* 2020; Vásquez-Lavín *et al.* 2020). Although the production or cost function estimation is the most adequate model, most researchers faced problems to obtain information regarding all the industrial inputs, so they have opted for a simplified demand function in which the amount of water demand depends only on its price and the level of activity (De Rooy 1974; Lynne 1977; Lynne *et al.* 1978; Ziegler & Bell 1984; Williams & Suh 1986; Renzetti 1993; Malla & Gopalakrishnan 1999; Moeltner & Stoddard 2004; Bell & Griffin 2008; Gómez-Ugalde *et al.* 2012; Vallés & Zárate 2013), as usually done for domestic demand estimation.

So, in this study, following the most suitable approach, the cost function was considered. Among the possible specification, the translog cost function was chosen since it is flexible, parsimonious, satisfies price homogeneity and allows us to specify a multi-product technology (Reynaud 2003), although other alternative specifications are considered and discussed in the 'Econometric estimates' section. So, the translog cost function can be defined as follows:

$$\ln G = \alpha + \alpha_Y \ln Y + \sum_i \alpha_i \ln p_i + \frac{1}{2}\alpha_{YY}(\ln Y)^2 + \frac{1}{2}\sum_i \sum_{j \neq i} \alpha_{ij} \ln p_i \ln p_j + \sum_i \alpha_{Yi} \ln Y \ln p_i + u \quad (1)$$

where $i, j = K, L, S, W$; G is the total production cost, Y denotes the output, and p_i represents the price of input i.

Using Shepard's lemma, the cost-minimizing factor share equations can be obtained:

$$\frac{\partial \ln G}{\partial \ln p_i} = w_i = \alpha_i + \alpha_{Yi} \ln Y + \sum_j \alpha_{ij} \ln p_j \quad (2)$$

where $i, j = K, L, S, W$.

Cost function must guarantee price symmetry and first-order homogeneity in prices and output, which lead to the following constraints on the parameters of Equations (2) and (3):

$$\alpha_{ij} = \alpha_{ji} \quad i, j = K, L, S, W$$
$$\sum_i \alpha_i = 1; \quad \sum_i \alpha_{Yi} = 0; \quad \sum_j \alpha_{ij} = 0; \quad \sum_i \alpha_{ij} = 0 \quad (3)$$

The estimated model can be used to calculate the direct price elasticity (ε_{ii}), the cross-price elasticity (ε_{ij} and ε_{ji}) and the output elasticity (μ_{iY}):

$$\varepsilon_{ii} = \frac{\alpha_{ii} + w_i^2 - w_i}{w_i} \quad (4)$$

$$\varepsilon_{ij} = \frac{\alpha_{ij} + w_i w_j}{w_i}$$
$$\varepsilon_{ji} = \frac{\alpha_{ji} + w_i w_j}{w_j} \quad (5)$$

$$\mu_{iY} = \frac{\partial Q_i}{\partial Y} \cdot \frac{Y}{Q_i} = \frac{\alpha_{Yi}}{w_i} + \eta_Y \quad (6)$$

where η_Y is the cost elasticity with respect to the output.

CASE STUDY

Spain is one of the most arid countries in Europe and has serious problems with water shortages. These problems are especially severe in the Ebro basin, in the northeast quadrant of the Iberian Peninsula, where the municipality of Zaragoza is located (see Figure 1). The annual water balance (precipitation minus evapotranspiration) for this basin is clearly unfavourable: $-97\ \text{mm/m}^2$ on average in the period 1996–2010, compared with the Spanish average of $135\ \text{mm/m}^2$ (MITECO 2020). In this environment, water suffers strong demand pressures with frequent conflicts between agricultural and other uses, which are aggravated by the territorial conflicts over water allocation in Spain.

The municipality of Zaragoza, in 2012, was the fifth-largest municipality in Spain with 679,624 inhabitants, and its gross disposable per capita income was 16,197 €, which represented 115% of the Spanish average (IAEST 2020). Its economic structure is similar to other Spanish urban areas, characterized by a predominance of services (84%), followed by manufacturing (10%), construction (5%) and agriculture and farming (1%).

The service of drinking water supply, sanitation and wastewater treatment in Zaragoza is managed by its City Council. As usual in Spain, the water consumed by the users is controlled by individual meters and taxed by a tariff system approved by the City Council. The water tariff system in Zaragoza in 2012 consists of a binomial system which combines a fixed charge based on the supply pipe size and a variable volumetric charge based on the volume

Figure 1 | Location of the city of Zaragoza.

of water registered by the meter (Ayuntamiento de Zaragoza 2012), as in most cities in Spain. The amount of the fixed charge varies from 0.129 euros for meters with a diameter of up to 20 mm, to 623.724 euros for meters with a diameter of 500 mm. To calculate the volumetric charge for non-household users, a tariff with increasing block prices is applied, with two blocks. The price is 1.119 €/m^3 in the first block (from 0 to 0.616 m^3/day) and 3.077 €/m^3 in the second block (more than 0.616 m^3/day). Both the fixed and the volumetric charge comprise a supply charge and a sanitation and wastewater treatment charge. This tariff system has a triple function: to encourage the efficient use of water, to promote the conservation of water resources and to bear the costs of providing drinking water and wastewater services. According to the data supplied by the Zaragoza City Council for this investigation, the water tariff collected 58.3 million euros in 2012, covering 99.26% of the costs of the service. However, according to the calculations of Barberán *et al.* (2008), the real costs are at least 7% higher than those estimated by the City Council, so the real cost recovery rate would be less than 93%.

The volume of water registered by meters for domestic uses in Zaragoza in 2012 was 25,475,989 m^3. For the industrial activities, water consumption amounted to 753,256 m^3 for manufacturing, 7,026,899 m^3 for services and 72,000 m^3 for the construction sector. The evolution of this consumption in recent years showed a marked decreasing trend, both for domestic uses (with a reduction of 16.05% from 2000 to 2012) and for industrial activities (with a decrease of 17.54% in this period). In these activities, the strong reduction of water consumption in the manufacturing sector stands out (−47.05%), followed by the construction sector (−38.88%) and by services (−11.99%).

This evolution has been possible thanks to the City Council's efforts to promote social co-responsibility in the use of water not only by using the aforementioned rate design as an incentive to save water but also through awareness campaigns, stakeholders participation in water-related decision making and the development of information and research.

Moreover, the City Council has taken relevant actions to improve efficiency in the integral water cycle. Some of the most relevant measures carried out are the investments made to renew the supply networks, the modernization of the treatment and storage infrastructures, the adaptation of the water quality to the needs of each use (e.g., by collecting water from the aquifer for garden irrigation) and the establishment of criteria to ensure efficient use of water in new construction projects (such as the obligation to install water saving devices).

DATA

The database for this study is based on a sample of 8,615 firms operating in the municipality of Zaragoza from 1993 to 2012, in an unbalanced panel of 38,875 observations. The data are obtained from two sources. First, information about the quantity of water used by each firm was provided by Zaragoza City Council. Second, firms' accounting information was taken from the database Sistema de Análisis de Balances Ibéricos (SABI) (http://www.informa.es/en/financial-solutions/sabi). Combining both sources, information about the following variables was obtained: the production value, the cost and price of water, labour and capital inputs, and the cost of supplies.

Production value is measured by operating income. Production cost is obtained by adding the cost of all inputs: water, labour, capital and supplies.

The cost and the price of water for each company were obtained by combining the data about the quantity of intake water with the information about the current tariff system applied to non-domestic users for each of the years studied (Fiscal Ordinance 24.25 of Zaragoza City Council: 'Fee for services related to global water cycle').

For the price of water, two specifications were considered: the marginal and the average price. The marginal price of water (MP_W) is the price of the increasing block tariff for the last unit consumed by each company. The average price of water (AP_W) is obtained by dividing the water bill of each company by the quantity of water used. Note that when the marginal price is used, the cost of water includes only the volumetric charge, whereas if the average price is used, it includes the fixed charge and the volumetric charge.

The cost of labour is measured by personnel costs and its price is calculated by dividing total personnel cost by the number of employees.

The cost of capital is measured as the sum of the cost of debt and equity for each firm. The price of capital (P_k), defined as the weighted average cost of capital (WACC), is calculated as the weighted average of the cost of debt and equity:

$$P_k = \text{WACC} = \text{UCD}\left[\frac{D}{D+E}\right] + \text{UCE}\left[\frac{E}{D+E}\right] \quad (7)$$

where UCD is the after-tax unitary cost of debt, D is the firm's debt, E is the firm's equity (capital plus reserves) and UCE is the pre-tax unitary cost of equity.

Supply costs are measured by the costs of purchased goods and services. Since supplies include an extremely heterogeneous set of inputs (energy, raw materials, outsource services and other supplies), its price is treated as unobservable (as in Angulo et al. 2014; Gracia-de-Rentería et al. 2019), so its impact is confined to the random term u of Equation (1).

Monetary magnitudes measured by euros are expressed in real terms for 2012. Finally, the information taken from SABI allows us to classify the firms by sectors and subsectors, according to the International Standard Industrial Classification of All Economic Activities of United Nations (ISIC Rev. 4). Three main industrial sectors (manufacturing, construction and services) disaggregated in 24 subsectors (see Table 1) are considered. Table 1 also shows the number of observations and the mean values and standard deviation of the share of water in total costs.

Table 1 | Sectors and subsectors included in the study

Sector	Subsector	ISIC Rev. 4 Code	Definition	Number of observations	Water cost share (%)
Manufacturing				5,741	0.05 (0.21)
	M1	10, 11, 12	Food, beverages and tobacco	645	0.21 (0.53)
	M2	13, 14, 15	Textiles, wearing apparel, leather and related products	583	0.02 (0.05)
	M3	16, 17, 18	Wood and cork, paper and graphic arts	855	0.03 (0.06)
	M4	19, 20, 21	Manufacture of chemical and pharmaceutical products	181	0.12 (0.37)
	M5	22	Manufacture of rubber and plastics products	257	0.06 (0.13)
	M6	23	Manufacture of other non-metallic mineral products	99	0.06 (0.12)
	M7	24, 25	Manufacture of basic metals and fabricated metal products, except machinery and equipment	1,329	0.04 (0.09)
	M8	26, 27	Manufacture of computer, electrical, electronic and optical products	309	0.01 (0.02)
	M9	28	Manufacture of machinery and equipment	575	0.03 (0.10)
	M10	29, 30	Manufacture of transport equipment	169	0.04 (0.05)
	M11	31, 32, 33	Other manufacturing, repair and installation of machinery and equipment	739	0.02 (0.03)
Construction	C12	41, 42, 43	Construction	5,964	0.01 (0.07)
Services				27,170	0.14 (0.45)
	S13	45, 46, 47	Wholesale and retail trade	11,462	0.04 (0.4)
	S14	49–53	Transportation and storage	698	0.09 (0.32)
	S15	55, 56	Accommodation and food service activities	3,749	0.46 (0.45)
	S16	58–63	Information and communication	736	0.03 (0.14)
	S17	64, 65, 66	Financial and insurance activities	479	0.03 (0.12)
	S18	68	Real estate activities	2,123	0.09 (0.32)
	S19	69–75	Professional, scientific and technical activities	2,810	0.02 (0.14)
	S20	77–84	Administrative and support service activities	1,070	0.03 (0.19)
	S21	85	Education	844	0.08 (0.15)
	S22	86, 87, 88	Human health and social work activities	956	0.20 (0.38)
	S23	90–93	Arts, entertainment and recreation	923	0.44 (1.02)
	S24	94–99	Other service activities	1,320	0.33 (0.80)

Note: Figures in brackets are standard deviations.

ECONOMETRIC ESTIMATES

The first econometric issue is related to cost function specification, as mentioned in the 'Methodological framework' section. Table 2 shows that the translog specification is adequate for this case study, based on the results of Ramsey Regression Equation Specification Error Test (RESET) for the translog production function (let us note that the cost function proceeds directly from the production function). Table 2 also compares the translog production function (alternative hypothesis) against the Cobb–Douglas and the Constant Elasticity of Substitution (CES) specifications (null hypotheses). In the latter case, Kmenta (1967) strategy was followed, who uses a first-order approximation to the nonlinear terms that appear in the CES cost function.

Another issue concerns the existing debate in the literature about the water price specification. In this study, information for the average and the MPW was available, which is not very usual in the applied literature (the unique exceptions for the industrial sector are Ziegler & Bell (1984); Williams & Suh (1986); Vallés & Zárate (2013)). This information is essential for addressing this debate. According to economic theory, a rational user, with complete information, will base his consumption decisions on the notion of marginal price. However, another strand of the literature argues that perfect and complete information is an ideal assumption rarely meet in practice, for which it is preferable the use of the average price (Foster & Beattie 1981; Shin 1985; Nieswiadomy & Molina 1991).

Table 2 | Translog specification tests

Tests	Statistic	p-value	Conclusion
RESET: Functional form ($p = 4$)	1.9585	0.1178	Adequate functional form
Translog versus Cobb–Douglas	129.77	0.000	Translog
Translog versus CES	131.21	0.000	Translog

This dilemma was solved using two classical model selection criteria, such as the Mallow's Cp and the Akaike information criterion (AIC), as in Ziegler & Bell (1984) and Williams & Suh (1986). Results in Table 3 show that the two criteria agree in supporting the use of the marginal price. The Supplementary Appendix provides a brief discussion of the same dilemma but using the perceived price approach of Shin (1985), which also support the marginal price alternative.

The conclusion regarding the use of marginal price is in line with Williams & Suh (1986) in the context of industrial water and, among others, with Gibbs (1978), Nieswiadomy & Molina (1991) and Baerenklau et al. (2014), for domestic uses. However, other authors find that users respond to the average price, as in Ziegler & Bell (1984) for manufacturing water, and as in Foster & Beattie (1981), Arbués et al. (2004) and Wichman (2014) for domestic water, or even that there are no significant differences between both specifications (Polzin 1984).

The last econometric issue has to do with the estimation strategy. Here, there is no consensus on whether to estimate the cost function (1) or the cost share equations (2), so both functions were jointly estimated in a more efficient seemingly unrelated regression (SUR) framework. This approach has been widely used in the literature, as in Grebenstein & Field (1979), Babin et al. (1982), Dupont & Renzetti (2001), Féres & Reynaud (2005), Angulo et al. (2014) and Gracia-de-Rentería et al. (2019).

Table 3 | Model selection criteria

		Aggregate	Manufacturing	Construction	Services
C_p	Marginal price	78.35	37.96	50.90	78.00
	Average price	105.23	46.30	116.77	126.9
AIC	Marginal price	−34,751.91	−10,249.85	−3,363.33	−26,945.74
	Average price	−34,725.05	−10,241.47	−3,297.66	−26,896.82

Note: The AIC selects the model that minimizes the AIC statistic, whereas the criterion of C_p selects the model with a value of the C_p statistics closest to the number of parameters in the equation (33 in both cases).

The SUR model was estimated using a panel data framework with fixed effects. Fixed time effects were also included to account for business cycle, and a time trend as a proxy for technological progress. Furthermore, to avoid possible simultaneity problems due to the fact that the price of water is endogenously determined by the amount of water, the price is lagged by one period (as in Angulo et al. 2014; Gracia-de-Rentería et al. 2019). Results of estimation are shown in Table 4 for the marginal price. In addition, Table 5 presents the results for the average price.

All the parameters have the expected sign, and they are mostly statistically significant. The negative sign of the time trend means that the impact of technological change has contributed to reducing water consumption during the period, which is in line with the previous literature

Table 4 | Estimation results for the marginal price of water

	$\ln G$		w_K		w_L		w_W	
	Estimate	***p*-value**	**Estimate**	***p*-value**	**Estimate**	***p*-value**	**Estimate**	***p*-value**
α	0.0412	0.0000	0.0512	0.0000	0.0005	0.8620	0.0003	0.0200
Trend	−0.0027	0.0000	−0.0039	0.0000	−0.0003	0.2820	0.0000	0.0820
$\ln Y$	0.2555	0.0000	0.0016	0.0000	−0.0659	0.0000	−0.0002	0.0000
$(\ln Y)^2$	0.0899	0.0000						
$\ln P_K$	0.0512	0.0000	0.0132	0.0000	0.0021	0.0000	0.0000	0.4550
$\ln P_L$	0.0005	0.8620	0.0021	0.0000	0.0930	0.0000	0.0000	0.8640
$\ln P_W$	0.0003	0.0200	0.0000	0.4550	0.0000	0.8640	0.0001	0.0000
$\ln P_K \ln P_K$	0.0132	0.0000						
$\ln P_K \ln P_L$	0.0021	0.0000						
$\ln P_K \ln P_W$	0.0000	0.4550						
$\ln P_L \ln P_L$	0.0930	0.0000						
$\ln P_W \ln P_L$	0.0000	0.8640						
$\ln P_W \ln P_W$	0.0001	0.0000						
$\ln Y \ln P_K$	0.0016	0.0000						
$\ln Y \ln P_L$	−0.0659	0.0000						
$\ln Y \ln P_W$	−0.0002	0.0000						
No. of observations	31,613		31,613		31,613		31,613	
No of parameters	33		23		23		23	
RMSE	0.1531		0.0423		0.0577		0.0016	
R^2	0.8086		0.1010		0.2040		0.0071	
Chi^2	163,726.1		3,656.4		12,347.2		92.8	
p-value	0.0000		0.0000		0.0000		0.0000	
Correlation matrix of residuals								
			$\ln G$	**w_K**	**w_L**	**w_W**		
		$\ln G$	1					
		W_K	0.2708	1				
		W_L	−0.1816	−0.1896	1			
		W_W	−0.0367	−0.0339	0.1013	1		
Breusch–Pagan diagonality test for the SUR system					**chi^2(6)**	**4,900.638**	***p*-value**	**0.0000**

Note: For simplicity, the estimates of the fixed effects (temporal and for company) have been omitted. RMSE is the root-mean-square error. Number of firms = 5,081, t = 1993–2012.

Table 5 | Estimation results for the average price of water

	lnG		**W_K**		**W_L**		**W_W**	
	Estimate	***p*-value**	**Estimate**	***p*-value**	**Estimate**	***p*-value**	**Estimate**	***p*-value**
α	0.0531	0.0000	0.0621	0.0000	0.0027	0.4360	0.0003	0.0260
Trend	−0.0038	0.0000	−0.0049	0.0000	−0.0005	0.1220	0.0000	0.3890
$\ln Y$	0.2483	0.0000	0.0009	0.0000	−0.0658	0.0000	−0.0003	0.0000
$(\ln Y)^2$	0.0901	0.0000						
$\ln P_K$	0.0621	0.0000	0.0134	0.0000	0.0019	0.0000	0.0000	0.9450
$\ln P_L$	0.0027	0.4360	0.0019	0.0000	0.0926	0.0000	−0.0001	0.1190
$\ln P_W$	0.0003	0.0260	0.0000	0.9450	0.0000	0.1190	0.0000	0.6050
$\ln P_K \ln P_K$	0.0134	0.0000						
$\ln P_K \ln P_L$	0.0019	0.0000						
$\ln P_K \ln P_W$	0.0000	0.9450						
$\ln P_L \ln P_L$	0.0926	0.0000						
$\ln P_W \ln P_L$	−0.0001	0.1190						
$\ln P_W \ln P_W$	0.0000	0.6050						
$\ln Y \ln P_K$	0.0009	0.0000						
$\ln Y \ln P_L$	−0.0658	0.0000						
$\ln Y \ln P_W$	−0.0003	0.0000						
No. of observations	31,586		31,586		31,586		31,586	
No. of parameters	33		23		23		23	
RMSE	0.1530		0.0423		0.0577		0.0016	
R^2	0.8087		0.1031		0.2047		0.0131	
Chi^2	163,637.3		3,765.41		12,303.25		174.71	
p-value	0.0000		0.0000		0.0000		0.0000	

Correlation matrix of residuals

	ln G	**W_K**	**W_L**	**W_W**
$\ln G$	1.0			
W_K	0.2697	1.0		
W_L	−0.1809	−0.1875	1.0	
W_W	−0.0516	−0.0177	0.1180	1.0

Breusch–Pagan diagonality test for the SUR system **$chi^2(6)$** **4,975.615** ***p*-value** **0.0000**

Note: For simplicity, the estimates of the fixed effects (temporal and for company) have been omitted. RMSE is the root-mean-square error. Number of firms = 5,081, t = 1993–2012.

(De Rooy 1974; Ziegler & Bell 1984; Dupont & Renzetti 2001; Vallés & Zárate 2013; Angulo *et al.* 2014).

RESULTS AND DISCUSSION

Tables 6 and 7 show direct, output and cross-price elasticities, for the aggregate and the different sectors and subsectors considered. These elasticities were calculated using Equations (4)–(6) and based on the estimates of Table 4 for the marginal price and Table 5 for the average price.

A first comparison of the result when the marginal and the average prices are used shows that when elasticities are statistically significant, the sign of the elasticities is the same regardless the price used. However, direct price elasticities

Table 6 | Direct price and output elasticities

	With marginal price		With average price	
	ε_{WW}	ε_{WY}	ε_{WW}	ε_{WY}
Aggregate	−0.86***	0.73***	−0.99***	0.65***
Manufacturing	−0.52**	−0.37	−0.94***	0.19
Construction	−0.58	2.58***	−0.93***	−0.10
Services	−0.88***	0.83***	−1.00***	0.74***
Subsectors:				
M1	−0.62*	0.65**	−0.73***	0.76***
M2	1.55	−5.52*	−0.91	−2.60
M3	−0.03	−0.38	−1.04***	−0.23
M4	0.51	−1.44	−1.40*	0.29
M5	−0.73	0.98	−0.86***	1.06**
M6	−0.44	−2.13	−1.66*	2.08
M7	−0.86	0.35	−1.00**	0.54
M8	2.80	−6.10	0.02	2.69
M9	−1.06	0.91	−1.22***	0.92**
M10	−0.12	−0.65	−0.29	−1.85
M11	0.19	−2.17	−0.93*	0.55
S13	−0.77***	0.76***	−0.99***	0.52***
S14	−0.74	0.30	−0.91***	−0.16
S15	−0.91***	0.62***	−1.00***	0.68***
S16	−0.82	−2.73	−2.10	−1.47
S17	−2.88	5.39**	1.79	−2.27
S18	−1.24***	2.14***	−1.07***	0.56***
S19	−0.40	0.11	−1.08***	0.81*
S20	0.31	0.14	−1.05**	−0.77
S21	−0.85	0.58	−0.97***	1.06***
S22	−0.83***	0.90***	−1.00***	0.83***
S23	−0.97***	0.87***	−0.96***	0.78***
S24	−0.87***	1.13***	−0.86***	0.97***

Note: *, **, *** indicate statistical significance at the 10, 5 and 1% level.

are higher, and a greater number of sectors and subsectors have statistically significant elasticities, when the average price is used with respect to that obtained with the marginal price. This result is in line with the literature (Ziegler & Bell 1984; Williams & Suh 1986; Vallés & Zárate 2013), and it is reasonable in situations where the average price is higher than the marginal price, such as the water tariff structure that prevails in Zaragoza and that was explained in the 'Case study' section.

In contrast, the output elasticity is generally lower when the average price is used than with the marginal price. In the cross-price elasticities, the differences are less evident although, in the case of the substitution relationship between water and supplies, there are more statistically significant elasticities and with higher values when the average price is used. Previous evidence in the literature regarding the output and cross-price elasticities is very limited to make a comparison since the two only studies that provide these elasticities for the marginal and the average price (Williams & Suh 1986; Vallés & Zárate 2013) obtained much reduced differences between the elasticities estimated with the two prices and the sign of these differences is dissimilar.

Since in the previous section evidence in favour of the marginal price is found, the use of the elasticities obtained with the average price might imply an overestimated price elasticity and an underestimated output elasticity, and could induce the adoption of inadequate demand management policies. Consequently, henceforth, the focus will be on the marginal price results only.

The direct water demand elasticity is −0.86 for the aggregate, −0.52 for the manufacturing sector and −0.88 for the services sector, while the elasticity for the construction sector is not statistically significant. The higher elasticity obtained for services than for manufacturing is in line with Bell & Griffin (2008) and Gómez-Ugalde *et al.* (2012), but differs from Williams & Suh (1986), Hussain *et al.* (2002) and Reynaud (2003). These results are consistent with the water cost share of the sectors (as shown in Table 1), so that share positively influences the statistical significance of price elasticity (as shown, among others, in Renzetti 1993; Gracia-de-Rentería *et al.* 2019).

The estimated elasticity for the manufacturing sector is in the middle range of the estimated elasticities in the literature, which ranges between −0.01 (Vallés & Zárate 2013) and −1.34 (Hussain *et al.* 2002). However, the elasticity for the services sector appears in the upper range, which exhibit values for the aggregate sector between −0.14 (Williams & Suh 1986) and −0.27 (Reynaud 2003).

Results by subsectors show that there are a large number of them (subsectors M2–M11, S14, S16–S17, S19–S21) in which water demand is not affected by the price of the resource. This is also observed in other studies calculating

Table 7 | Cross-price elasticities

	With marginal price						With average price					
	M_{KW}	M_{LW}	M_{SW}	M_{WK}	M_{WL}	M_{WS}	M_{KW}	M_{LW}	M_{SW}	M_{WK}	M_{WL}	M_{WS}
Aggregate	0.001***	0.001***	0.0008***	0.06***	0.31***	0.49***	0.001***	0.001***	0.001***	0.05***	0.25***	0.69***
Manufacturing	−0.0001	0.001	−0.0001	−0.01	0.68	−0.16	−0.001	0.0005	0.0008***	−0.06	0.25	0.74***
Construction	0.0005	0.002**	−0.001*	0.20	5.67**	−5.29*	0.0027	0.0025***	−0.001**	0.46	2.49***	−2.02**
Services	0.001***	0.001***	0.001***	0.05***	0.26***	0.57***	0.001***	0.001***	0.002***	0.04***	0.19***	0.77***
Subsectors:												
M1	−0.02	0.01**	−0.002	−0.21	1.41**	−0.58	−0.02	0.008***	−0.0009	−0.16	1.15***	−0.26
M2	0.01	0.0005	−0.002	1.76	0.76	−4.07	0.02	−0.001	0.0004	1.35	−1.00	0.56
M3	0.0002	0.0009	−0.0005	0.02	1.14	−1.13	0.0003	0.0001	0.0008	0.02	0.11	0.91
M4	−0.002	0.005	−0.002	−0.04	0.98	−1.45	−0.05**	−0.01	0.008**	−1.08**	−1.89	4.37**
M5	0.005	−0.0006	0.0007	0.31	−0.33	0.76	−0.002	−0.003	0.003	−0.09	−1.28	2.24
M6	−0.01	0.006	−0.003	−0.47	3.73	−2.82	−0.005	0.004	0.00004	−0.16	1.79	0.03
M7	0.005	0.001	−0.0005	0.45	1.30	−0.90	0.005	0.0005	0.0003	0.30	0.35	0.35
M8	−0.003	0.003	−0.002	−0.61	8.03	−10.22	0.007	−0.004	0.002	0.74	−5.53	4.77
M9	−0.004	0.002	−0.0001	−0.32	1.60	−0.23	−0.003	0.001	0.0002	−0.20	1.10	0.32
M10	0.01	0.005	−0.003	1.03	4.77	−5.68	0.02	0.001	−0.001	1.00	0.92	−1.63
M11	0.003	0.00001	−0.0002	0.47	0.02	−0.68	−0.0009	0.0007	0.0001	−0.07	0.70	0.30
S13	−0.0001	0.0008	0.0002	−0.005	0.36	0.41	−0.0001	0.0004	0.0007***	−0.003	0.15	0.84***
S14	−0.005	0.003	−0.0003	−0.15	1.09	−0.21	0.001	0.003	0.0002	0.04	0.72	0.14
S15	0.007	0.005***	0.004***	0.03*	0.35***	0.52***	0.007	0.005***	0.005***	0.03	0.37***	0.60***
S16	0.003	0.0003	0.0001	0.23	0.35	0.24	0.01	−0.002	0.003	0.57	−1.38	2.91
S17	−0.002	−0.0003	0.003	−0.42	−0.41	3.71	0.009	−0.0009	−0.004	1.22	−0.58	−2.43
S18	0.002**	−0.002	0.003	0.54**	−0.45	1.16	0.02***	−0.0009	0.003**	0.43***	−0.18	0.82**
S19	0.0009	0.00004	0.0001	0.16	0.09	1.16	−0.002	−0.00004	0.001	−0.16	−0.04	1.28
S20	0.0006	0.001	−0.002	0.09	1.61	−2.01	0.003	−0.0005	0.002	0.21	−0.46	1.30
S21	0.002	0.0009	0.0004	0.06	0.59	0.20	0.0005	0.001*	0.0009	0.009	0.63*	0.33
S22	0.0001	0.003***	0.0008	0.002	0.62***	0.21	0.002	0.002	0.003	0.02	0.43	0.55
S23	0.008	0.003***	0.005**	0.06	0.23	0.68**	0.007	0.003	0.006***	0.05	0.16	0.75***
S24	−0.003	0.004**	0.002	−0.02	0.56**	0.32	0.0001	0.002	0.004*	0.0008	0.32	0.53*

Note: *, **, *** indicate statistical significance at the 10, 5 and 1% level.

elasticities by subsectors (Renzetti 1993; Dupont & Renzetti 1998; Malla & Gopalakrishnan 1999). Usually, the non-significant elasticities are found in subsectors with a small participation of water in total cost (as shown in Figure 2 and also comparing Tables 1 and 6). In these cases, public policies attempting to encourage an efficient use of water by increasing its price would have a negligible impact. In the other subsectors, direct water demand elasticity ranges between −0.62 (subsector M1: food, beverages and tobacco) and −1.24 (subsector S18: real estate activities).

In the manufacturing sector, only subsector M1 (food, beverages and tobacco) has a statistically significant direct water demand elasticity. Other studies have found a high elasticity for the same case (Renzetti 1993; Dupont & Renzetti 1998; Malla & Gopalakrishnan 1999; Gracia-de-Rentería *et al.* 2019).

The other subsectors in which direct water demand elasticities are significant pertain to services. It is difficult to compare these results with the literature since it is rather unusual to disaggregate this sector. A series of papers have focused on the cases of wholesale and retail trade (Lynne 1977; Lynne *et al.* 1978), arts, entertainment and recreation (Moeltner & Stoddard 2004), and accommodation and food service activities (Lynne 1977; Lynne *et al.* 1978; Moeltner & Stoddard 2004; Angulo *et al.* 2014). The elasticities obtained in this study are higher than those reported in the cases of arts, entertainment and recreation (subsector S23), for which Moeltner & Stoddard (2004) report an elasticity of −0.62; and for the accommodation and food service activities (subsector S15), with elasticities ranging from −0.11 (Lynne *et al.* 1978) and −0.37 (Angulo *et al.* 2014). On the contrary, the elasticity estimated for wholesale and retail trade (subsector S13) is lower than in the literature, with values between −1.07 (Lynne 1977) and −1.33 (Lynne *et al.* 1978).

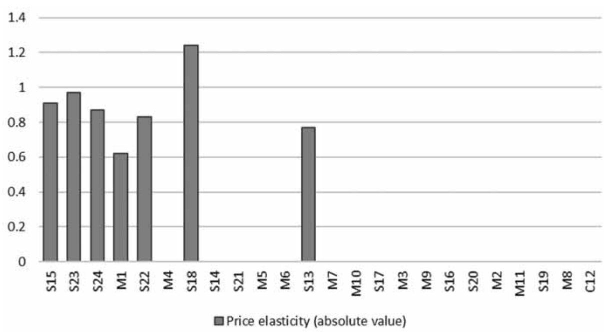

Figure 2 | Direct price elasticities, by subsectors ordered by water cost share.

Water demand is also affected by the production level, the output elasticity being 0.73 for the aggregate. For all the sectors, except manufacturing (where the impact is not significant), a positive output elasticity was obtained. This effect is stronger in the construction than in the service sector (2.58 and 0.83, respectively). The output elasticity obtained for the aggregate of services appears in the upper range of elasticities estimated in the literature, which ranges between 0.18 (Williams & Suh 1986) and 1.22 (Gómez-Ugalde *et al.* 2012).

Results disaggregated by subsectors show, once again, that in many of them (practically the same as in the case of the price elasticity: M2–M11, S14, S16, S19–S21) the output does not statistically affect water demand. In the cases of subsectors with a significant output elasticity, it ranges between 0.62 (subsector S15: accommodation and food service activities) and 5.39 (subsector S17: financial and insurance activities); high values compared with those of the literature. Only in two subsectors (subsectors M2 and S17) the output elasticity is statistically significant without being the price elasticity significant. In these two subsectors, the highest elasticities are obtained (one of them has a negative sign), indicating that the change in the size of companies is associated with a change in technology (when the volume of production increases, in subsector S17, technologies that require greater use of water per unit of product are used, while in subsector M2, the opposite happens).

Cross-price elasticities indicate that all the inputs are substitutive for the aggregate and for the services sector. However, in the construction sector, water and labour are substitutive, but water and supplies are complementary, whereas the relationship between water and capital is not statistically significant. In the manufacturing sector, cross-price elasticities are not statistically significant. Results obtained in the literature regarding cross-price elasticities are controversial, although a good number of studies obtained, as in this study, a relationship of substitutability between water and capital (Dupont & Renzetti 2001; Féres & Reynaud 2005; Kumar 2006; Angulo *et al.* 2014; Vásquez-Lavín *et al.* 2020), between water and labour

(De Rooy 1974; Grebenstein & Field 1979; Babin et al. 1982; Dupont & Renzetti 2001; Féres & Reynaud 2005; Angulo et al. 2014; Vásquez-Lavín et al. 2020), and between water and supplies (Angulo et al. 2014; Gracia-de-Rentería et al. 2019; Revollo-Fernández et al. 2020; Vásquez-Lavín et al. 2020).

There are also many subsectors in which water demand is not affected by any input price (subsectors M2–M11, S13–S14, S16–S17, S19–S21, similar subsectors as for the price elasticity). Otherwise, water is a substitute of the other inputs. In the manufacturing sector, the only statistically significant elasticity is found in subsector M1 (food, beverages and tobacco), where water and labour are substitutive. In the service sector, subsector S15 (accommodation and food service activities) stands out as the only subsector where the substitutability between water and all other inputs is statistically significant.

Results also indicate that the relationship between water and the other inputs is asymmetric. Thus, the effect of a variation in the price of water on the quantity demanded of the other inputs is very limited (the elasticity being almost zero in all cases), whereas the effect of a variation in the price of the other inputs on the quantity demanded of water is greater. This asymmetry is consistent with the results obtained in the literature (Grebenstein & Field 1979; Babin et al. 1982; Dupont & Renzetti 2001; Féres & Reynaud 2005; Kumar 2006; Gracia-de-Rentería et al. 2019; Vásquez-Lavín et al. 2020) and might be attribute to the reduced magnitude of the price of water and the low weight that this input represents in the cost share of companies.

CONCLUSIONS

This study analyses industrial water demand in an urban environment using microdata from 8,615 companies operating in the city of Zaragoza (Spain) from 1993 to 2012. Using a translog cost function, the effect of the price of water, the price of other inputs and the output level on the amount of water demanded were estimated. These effects are estimated for the industrial aggregate, for the manufacturing, construction and service sectors, and for 24 subsectors. For this purpose, a microdata panel was built to better control the individual behaviour of agents, thus avoiding the possible aggregation bias due to the existence of a strong heterogeneity across sectors and subsectors observed in this study.

Moreover, the availability of microdata makes possible to use the true marginal and average water prices that companies face, and analyse which of these specifications is more appropriate. In this regard, model selection criteria provide evidence for the use of the marginal price. Moreover, the estimated values indicate that direct price elasticity is higher when the average price is used than when the marginal price is used; the cross-price elasticity between inputs is also higher (particularly between water and supplies), while the output elasticity is lower. Therefore, the adequate selection of the price in the calculation of the elasticities becomes relevant for the design of the water demand management policy. In particular, the use of the average price may induce policymakers to adopt wrong policies because they will tend to believe that pricing policy is more effective than it actually is and that economic growth has a lower impact on the industry's water consumption than it actually has.

According to the results for the aggregated, water demand is found inelastic (−0.86), but high enough to allow policymakers to use the price as a tool to encourage resource conservation. In addition, since the elasticity is less than 1, an increased water price also allows increased collection for providing the water service if necessary. So, it seems that, as proposed by international organizations, water prices could be used as a tool to encourage efficiency in water use, promote conservation of the freshwater resource and achieve recovery of the costs of providing the service. This result provides new evidence to insist on the use of prices as a tool for water demand management, in line with the Water Framework Directive. However, with this value of the price elasticity, policymakers should be aware of the limitations of pricing policy and therefore must be prepared to adopt complementary water demand management measures, such as information campaigns, financial support for technological innovation, subsidies for technical change and adoption of technical standards, with special attention to the water-consuming equipment.

The output elasticity (0.73) indicates that water demand varies in the same direction as the production level. Here, pricing policy can be a tool to counteract the effect that economic growth may have on water demand. Specifically, if production increases a 1%, a 0.85% price increase would be need to offset its impact on water consumption. Under these conditions, in contexts of economic growth, policymakers should take measures in addition to price increases if they want to avoid increasing water consumption. These measures should be aimed at encouraging companies to adopt more water-efficient technologies.

The substitution elasticities reveal that there is substitutability between inputs. A relative increase in the other input prices is found to contribute to increase water use. Therefore, policymakers should be alert to changes in the relative structure of prices and their impact on water demand.

Results vary considerably between sectors and subsectors, but there is a regular pattern. Thus, a higher or lower water share in the total production cost tends to determine whether water price becomes relevant to influence the amount of water demanded. Specifically, when water has a lower share in the total cost, price does not have, in general, a significant impact on demand, contrary to what happens in cases with a greater share. The influence of water share in the cost is not so clear in the case of statistical significance of output elasticity and cross-price elasticities because there are some notable exceptions to the above pattern.

Therefore, water price increases reduce consumption in the manufacturing and service sectors taken as a whole, but when distinguished by subsectors, only in a few of them, the influence of price on consumption is significant. Nevertheless, companies in these subsectors absorb a substantial part of the water consumed by industry (77% of the total consumed by the companies in the sample). Then, although increasing the price of water will only be effective in reducing consumption for a few subsectors, its impact on water consumption in the manufacturing and service sectors is still significant. Under these conditions, it does not seem necessary or efficient to adopt specific policies aimed at those subsectors where the price does not significantly affect water consumption.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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