Urban water demand for industrial uses in Spain

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Abstract

This study estimates the demand for urban water in Spanish industry, with particular attention to differences between sectors. A panel dataset for the Spanish Autonomous Communities in the period 1993-2013, broken down into 11 sectors, was used. The results indicate that water pricing policy can be used effectively as a mechanism to encourage reduced water use (elasticity of -0.66), but there is a strong sectoral heterogeneity that recommends the additional use of other types of instruments. In general, sectors where water represents a larger proportion of total costs present greater elasticity.

Keywords: water demand; Spanish industry; demand elasticity; sectoral heterogeneity; panel data

Introduction

There is a general consensus on the importance of ensuring the long-term sustainability of water resources and, in the short run, making sure they are allocated efficiently and equitably. There is also consensus on the particular importance of demand management policies as an instrument for achieving these objectives.

Specifically, the EU Water Framework Directive (European Union 2000), and many international organisations (World Bank 1993; OECD 2009; EEA 2012), recognise the leading role of economic instruments, especially prices.

However, the effectiveness of prices as a tool for managing water demand is a subject of discussion in the applied literature, as in many cases very low or insignificant price elasticities of demand are obtained (among others, Renwick and Green 2000; Renzetti 2002; Martínez-Espiñeira and Nauges 2004; Arbués, Barberán, and Villanúa 2004; Wichman, Taylor, and von Haefen 2016). Uncertainty as to the effectiveness of pricing policies especially affects industrial uses, due to the small number of studies estimating the demand for urban water for this sector (see Renzetti 1992; De Gispert 2004; Worthington 2010), compared to the ample literature on domestic uses (see Brookshire et al. 2002; Arbués, García-Valiñas, and Martínez-Espiñeira 2003; Worthington and Hoffman 2008; Nauges and Whittington 2010).

The scarcity of studies on industrial uses is mainly due to the difficulty of getting the necessary data. This is even harder if we want to analyse demand behaviour for the entire set of a country’s industries. Because of this, most existing literature on industrial water demand is based on local studies (among others, Reynaud 2003; Féres and Reynaud 2005; Arbués, García-Valiñas, and Villanúa 2010; Angulo et al. 2014), or national studies using a small sample of companies (such as Renzetti 1988, 1992; Wang and Lall 2002; Kumar 2006; Ku and Yoo 2012). Very few have analysed water use for the whole industrial sector of a country (among others, Grebenstein and Field 1979; Mitchell et al. 2000; Dupont and Renzetti 2001; Renzetti and Dupont 2003; Dachraoui and Harchaoui 2004). Also, although most studies warn of the strong heterogeneity in water use among different industries, very few have obtained detailed enough data to then offer results broken down by industry (among others, Babin, Willis, and Allen

1982; Renzetti 1988, 1992, 1993; Féres and Reynaud 2005; Féres, Reynaud, and Thomas 2012). In order to contribute to the analysis of the effectiveness of pricing policy in water demand management, in this study we estimate the demand for urban water for industrial uses in Spain in the period 1993-2013, taking into account sectoral heterogeneity. Based on the joint estimation of the translog cost function and the input cost share functions, using a SURE approach, we obtain the direct price elasticity of water, the output elasticity, and the cross-elasticities of the different inputs. Before estimating water demand, we first analyse the stochastic properties of our series, using various unit root and cointegration tests.

The analysis of urban water demand for industrial uses is especially important because in urban environments, where an ever-increasing proportion of the population and economic activity are concentrated, industrial uses compete with other uses that require drinking water (domestic, services and some municipal uses). Additionally, because urban water requires higher investment and operation costs (for treatment, transportation, etc) than self-supplied water of aquifers or surface watercourses by the industries themselves, and because the high potential of pollution from industrial runoff is a threat to water quality in that urban environments (Bartram et al. 2002; WWAP 2017).

Our goal is to provide additional evidence on industrial water demand, especially on the role of prices, and to improve the treatment of different aspects in the literature, such as the range of study (we estimate water demand for the whole Spanish industrial sector), heterogeneity (taking into account differences between sectors in water use) and technical rigour (for example, in discussing the functional form of the demand function or the stochastic properties of the data series).

After this introduction, Section 2 presents the case study and Section 3 the data. Section 4 describes the model and estimation techniques. The results are shown in Section 5, with the conclusions in Section 6.

Case study

Freshwater is a scarce resource in Spain, with a high spatial and temporal variability that is being exacerbated by climate change. The consequence is that, in many areas of the country, water supply is not fully guaranteed at all times, despite the extensive network of hydrological regulation infrastructure. In this context, the competition for water is increasingly intense, conflicts between users and between regions are more frequent, and the effects on economic growth, employment and well-being are apparent (Candela et al. 2008; Serrano Rodríguez 2013; WWAP 2015, 2016).

Spain's total exploitable water resources (including total renewable surface water and regular renewable groundwater) amount to 46,300 Hm^3, while the total water withdrawal was 37,350 Hm^3 in 2012, according to FAO (2018). By major sectors, 68.19% corresponded to agriculture, 17.60% to industry (extracted by the companies themselves) and the remaining 14.21% to urban uses supplied through the municipal networks of drinking water (urban water).

Water is used by industry for several purposes, such as cleaning, cooling, heating, steam generation, ingredient in a finished product, dissolution of other raw materials, or sanitary uses (water used by industry workers for cleanliness and hygiene). Some of these uses do not require drinking water, so companies can use surface or groundwater captured directly using their own facilities and equipment (self-supplied water). However, most companies use drinking water supplied through a municipal network, because they do not have the (technical or economic) capacity to self-supply or because they use water for purposes that may have an influence on human health, such as sanitary uses and food processing (according to the EU Drinking Water Directive –European Union 1998- they have to use drinking water).

Thus, the proportion of water from the municipal supply networks and from self-supply varies considerably among the different industrial sectors. According to INE (2013), in 2010, the entire Spanish manufacturing industry obtained 30.89% of its water from the municipal supply networks, while the sector with the largest percentage obtained 83.55% and the sector with the lowest percentage only 10.92%.

In Spain, the water supplied through municipal networks to end users is registered by municipal meters installed at the points of consumption and, subsequently, taxed via a tariff that determines the fee to be paid by each user in each period of time. On the contrary, the water self-supplied by the companies is not metered and thus not taxed via a tariff (OECD 2009, 2017). This circumstance limits the analysis of the effectiveness of pricing policy.

The most frequent tariff structure in Spain is a two-part tariff, with a fixed fee based on the caliber of the meter, and a volumetric fee based on an increasing block tariff (OECD 2010; Arbués and Barberán 2012; García-Rubio et al. 2015). The increasing block tariffs are justified by its contribution to sustainability of water resources, because they contribute to discourage the waste of water (OECD 2010); in contrast, the increasing block tariffs cause equity problems because they put larger consumers (households or companies) in a disadvantaged position, in comparison with those with a smaller size (Barberán and Arbués 2009; OECD 2010; García-Rubio et al. 2015).

The distribution of urban water in Spain, recorded by meters in 2013 is as follows (INE 2015a): 69.07% is used by households, 21.63% is used by companies and the remaining 9.30% is destined to public municipal uses (watering gardens, street cleaning, sewer cleaning, supply to buildings, etc.). Moreover, also in 2013, urban water used by companies is distributed by sectors as follows (INE 2017): 40.87% manufacturing industry; 3.86% energy industry; 2.20% construction; 50.06% services; and 3.01% agriculture.

During the period 2000 to 2013, the water supplied to industrial companies via municipal networks in Spain decreased by 17.32% (INE 2015a, 2017), in contrast with the sharp increase in production, 34.17%, measured through industrial GDP at market prices (INE 2016). Consequently, water use per unit of production value decreased by 38.38% during this period. The contraction of water intensity coincided with an increase of 79% in the price of water in real terms: the average price of urban water in 2013 prices was €1.02/m^3 in 2000 and €1.83/m^3 in 2013, which apparently confirms the effectiveness of prices in encouraging water savings in Spain.

Data

The main source for this study is the "Industrial Companies Survey" (henceforth, ICS), conducted by the Spanish National Statistics Institute (INE) yearly since 1993 (INE 2015a), supplemented with other statistical sources. This survey refers to the set of companies located in Spain whose main activity is classified as pertaining to the industrial sector. Let us note that these data can be disaggregated by Autonomous Communities (AC) and industrial sectors.

Specifically, the data used in this study come from a customized report on these magnitudes, for Spanish industrial companies with 20 or more employees since the ICS reports water expenditure only for companies of that size or higher.

With this information, we have a panel dataset for the Spanish AC in the period 1993-2013, broken down into 11 sectors. This gives a total of 3,927 observations.

Table 1 provides details on the sectors considered and its correspondence with the Spanish “National Classification of Economic Activities” (CNAE-2009) (INE 2009), equivalent to the United Nations’ “International Standard Industrial Classification of All Economic Activities” (ISIC Rev. 4). The last column reports the participation of each industrial sector in the total production value reported in the ICS.

Table 1. Sectoral breakdown.

Sector	**CNAE-2009/ ISIC Rev. 4 code**	**Definition**	**Distribution of the value of production (% average for the period 1993-2013)**
1	01-09	Mining, energy, water supply and waste management	19.40
2	10, 11, 12	Food, beverages and tobacco	16.81
3	13, 14, 15	Textiles, wearing apparel, leather and related products	3.41
4	16, 17, 18	Wood and cork, paper and graphic arts	5.82
5	19, 20, 21	Manufacture of chemical and pharmaceutical products	9.71
6	22, 23	Manufacture of rubber, plastics products and other non-metallic mineral products	8.34
7	24, 25	Manufacture of basic metals and fabricated metal products, except machinery and equipment	10.53
8	26, 27	Manufacture of computer, electrical, electronic and optical products	5.55
9	28	Manufacture of machinery and equipment	4.22
10	29, 30	Manufacture of transport equipment	13.93
11	31, 32, 33	Other manufacturing, repair and installation of machinery and equipment	2.28

The largest sectors are 1 (mining, energy, water, and waste), 2 (food, beverages, and tobacco) and 10 (manufacture of transportation equipment), while the smallest are 11 (other manufacturing, repair and installation of machinery and equipment), 3 (textiles, wearing apparel, leather and related products), and 9 (manufacture of machinery and equipment).

The variables considered in this study are the value of production and the total cost of production, as well as the cost, price, and amount of the factors of production: water, capital, labour, energy and supplies. The value of production was approximated through "total operating income" registered in the ICS, while the cost of production is the sum of the cost of the factors of production.

The cost of water was measured through the ICS's "expenditure on water" variable. The ICS does not report the price of water paid and the quantity of water used by the companies. So, the price of water was estimated based on data from INE (2015b) related to the average water costs paid by the users of each AC, complemented with data provided by the Spanish Association of Water Supply and Sanitation (AEAS) on the relationship between the average water costs paid by the industrial users and by all users of each AC. Specifically, to obtain the average industrial water price in each AC, we have adjusted the average cost obtained from the INE (2015b) applying the ratio obtained from AEAS. Finally, the quantity of water consumed was calculated as the quotient between the cost and price of water.

The cost of labour was obtained based on the ICS's variable "expenditure on personnel". The quantity of work is the number of hours worked yearly, also from the ICS. The price of labour has been calculated as the quotient between expenditure on personnel and the number of hours worked.

The cost of capital has been approximated through "total allocations for depreciation of fixed assets", from the ICS, during the period 1993-2007. Data for the interval 2008-2013 was estimated using the "total operating expenditures" (which includes allocations for depreciation of fixed assets) and the series of allocations for depreciation of fixed assets and total operating expenditures for the previous period.

The quantity and the price of capital come from BBVA Foundation and Ivie (2015). Specifically, the quantity of capital was measured through productive capital stock. We proxy the price of capital by means of the user cost of capital of Jorgenson (1963), including the cost of depreciation and the market interest rate.

Energy cost was calculated as the sum of expenditure on gas, electricity and other fuels, according to the ICS. The price of energy was calculated as the average of the national prices of gas, electricity, diesel and fuel oil, weighted according to the expenditure that these energy products represents in each industrial sector in each AC. The data on the prices of gas and electricity in Spain come from Eurostat (2016), while the prices of diesel and fuel oil are from the European Commission (2016). The quantity of energy used was calculated as the quotient between the cost and price of energy.

The cost of supplies was obtained as the sum of "total purchases and work", "external services" (not including expenditure on water, gas, electricity, and other fuels) and "other operating expenditures" (excluding allocations for depreciation of fixed assets). These data are from the ICS. Given that the cost of supplies includes very heterogeneous factors, its price was treated as unobservable (Angulo et al. 2014).

All monetary variables were expressed in real terms, using the implicit deflators obtained from the Spanish Regional Accounts (INE 2016). The deflator corresponding to each AC was applied to the corresponding series of output, while the aggregated national deflator was applied to the input cost series.

Table 2 includes a description of the main variables in this study. Water represents a very small share of total costs (0.06%). The annual average of industrial use of urban water is 241.30 million m^3, having decreased -58% over the period, from 370.54 to 155.39 million m^3. Meanwhile, the price of water almost tripled (0.88 €/m^3 in 1993 against 2.02 €/m^3 in 2013).

Table 2. Cost, price and quantity of inputs. Main indicators.

	Average 1993-2013	**1993**	**2013**
Production cost (billions of €)	451.68	271.58	494.79
Share of total cost (%)			
Water	0.06	0.07	0.07
Capital	4.61	5.31	4.29
Labour	19.83	26.38	18.84
Supplies	73.10	65.81	73.56
Energy	2.39	2.44	3.24
Price			
Water (€/m^3)	1.37	0.88	2.02
Capital (%)	16.65	23.59	13.18
Labour (€/hours worked)	21.56	22.23	23.12
Energy (€/Kwh)	0.06	0.08	0.08
Annual aggregated quantity			
Water (millions of m^3)	241.30	370.54	155.39
Capital (billions of €)	338.23	265.08	411.87
Labour (millions of hours)	2,908.95	2,754.85	2,334.42
Energy (billions of Kwh)	179.68	105.08	168.27

Note: Values in euros are expressed in 2013 prices.

Our data also indicate that Spanish industrial sectors are very heterogeneous in what respects water use. Specifically, Figure 1 shows the disparity in the use of urban water per euro of output. Use is more intensive in sectors 5 (manufacture of chemical and pharmaceutical products), with 1.22 l/€, and 2 (food, beverages, and tobacco), with 1.14 l/€. Meanwhile, sectors 8 (manufacture of computer, electrical, electronic and optical products), with 0.34 l/€, and 9 (manufacture of machinery and equipment), with 0.35 l/€, are the least intensive water consumers. This aspect highlights the importance of considering sectoral heterogeneity in the estimation of water demand.

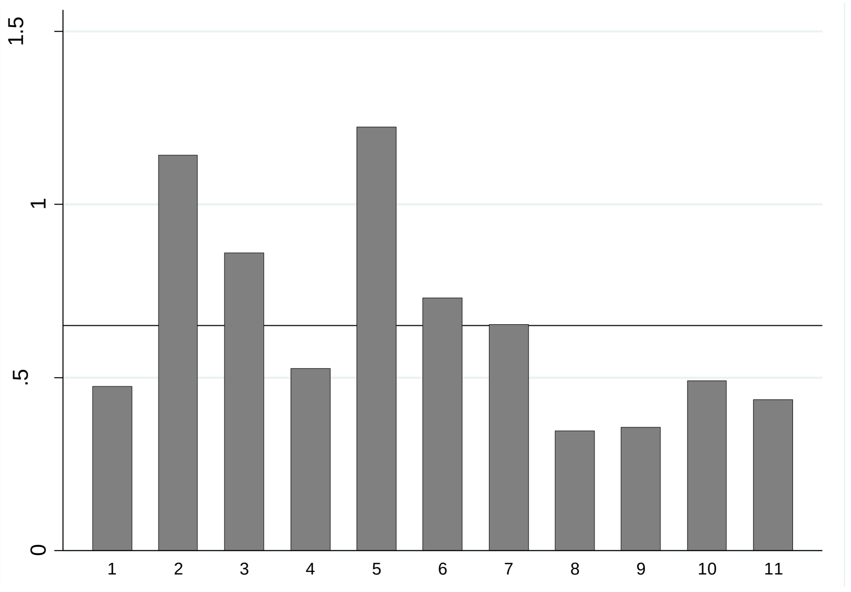

Figure 1. Urban water consumption per euro of production, by sectors. Average for 1993-2013 (l/€).

Specification and estimation of the model

The study follows the dominant approach in recent literature, based on the specification of derived demand functions obtained from the corresponding cost function (among others, Dupont and Renzetti 2001; Féres and Reynaud 2005; Angulo et al. 2014). This option is possible because of the availability of information about the quantities, costs and prices for the industrial inputs. However, researchers interested in this field do not usually have the necessary data, so they tend to specify simplified demand functions, in which the quantity depends on the price of water and various indicators related to the level of activity, following the tradition in the analysis of water for domestic uses (for example, Moeltner and Stoddard 2004; Arbués, García-Valiñas, and Villanúa 2010; Gómez-Ugalde et al. 2012).

The model specified in this paper is based on a translog production function with the inputs water (W), capital (K), labour (L), energy (E) and supplies (S). The translog function was chosen for its good characteristics: it is parsimonious, flexible, and allows working with multi-product technology (Reynaud 2003); moreover, the associated cost function is homogeneous in prices (Christensen, Jorgenson, and Lau 1971, 1973). As known, the cost function has the following structure:

$$\mathrm{lnG} = \alpha + \alpha_{\mathrm{Y}}\mathrm{lnY} + \sum_{\mathrm{i}=1}^{5} \alpha_{\mathrm{i}} \ln \mathrm{p_i} + \frac{1}{2}\alpha_{\mathrm{YY}}(\mathrm{lnY})^2 + \frac{1}{2}\sum_{\mathrm{i}=1}^{5}\sum_{\mathrm{j}=1}^{5} \alpha_{\mathrm{ij}}\ln \mathrm{p_i} \ln \mathrm{p_j} + \sum_{\mathrm{i}=1}^{5} \alpha_{\mathrm{Yi}}\mathrm{lnY} \ln \mathrm{p_i} \qquad (1)$$

with $\mathrm{i, j = W, K, L, E, S}$; G is the total cost of production, Y is the value of production, and $\mathrm{p_i}$ are the prices of the different inputs.

Applying Shephard’s lemma, the cost-minimising input demand functions or cost share equations for each input can be obtained:

$$\frac{\partial \mathrm{lnG}}{\partial \mathrm{lnp_i}} = \mathrm{w_i} = \alpha_{\mathrm{i}} + \alpha_{\mathrm{Yi}}\mathrm{lnY} + \sum_{\mathrm{j}=1}^{5} \alpha_{\mathrm{ij}}\mathrm{lnp_j} \qquad (2)$$

where $\mathrm{i = W, K, L, E, S}$.

The cost function must satisfy the constrains of price symmetry and homogeneity in prices and output, which implies the following restrictions on the parameters of equations (1) and (2):

$$\alpha_{ij} = \alpha_{ji}$$

$$\sum_{i=1}^{4} \alpha_i = 1;\ \sum_{i=1}^{4} \alpha_{Yi} = 0;\ \sum_{j=1}^{4} \alpha_{ij} = 0;\ \sum_{i=1}^{4} \alpha_{ij} = 0 \qquad (3)$$

with $\mathrm{i = W, K, L, E, S}$.

Table 3 confirms that the translog cost function is adequate to our case. This table shows the results of RESET test for the linear model of (1); the testing equation includes up to four powers of the linear estimate of the endogenous in (1). It also provides the results for comparing the translog function (alternative hypothesis) against the Cobb-Douglas and the CES functions, respectively (null hypotheses). In the latter case, we follow the suggestion of Kmenta (1967), using a first-order approximation to the nonlinear terms that intervene in CES cost function (see Henningsen and Henningsen 2011, for the details).

Table 3. Translog specification tests.

Tests / Hypothesis	**Statistic**	**p-value**	**Conclusion**
RESET test: Functional form			
p=2	0.09	0.764	*Adequate functional form*
p=4	2.15	0.092	
Translog vs Cobb-Douglas specification			
	11.95	0.000	*translog*
Translog vs CES specification			
	12.31	0.000	*translog*

There is no consensus in the literature as to whether it is preferable to estimate the cost function or the cost share equations for each input. Guilkey and Lovell (1980) propose a synthetic approach based on the joint estimation of the two functions in a SURE framework. This approach has been widely used in industrial water analysis in recent decades (Grebenstein and Field 1979; Babin, Willis, and Allen 1982; Dupont and Renzetti 2001; Renzetti and Dupont 2003; Dachraoui and Harchaoui 2004; Féres and Reynaud 2005; Guerrero 2005; Linz and Tsegai 2009; Angulo et al. 2014), and it is also used in this study.

After estimating the system of equations (1) and (2), the direct price elasticity (ε_{ii}) of each input is calculated as:

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

Also the relationship between inputs according to the cross-price elasticity (ε_{ij} and ε_{ji}) can be evaluated:

$$\varepsilon_{ij} = \frac{\alpha_{ij} + w_i w_j}{w_i}$$

$$\varepsilon_{ji} = \frac{\alpha_{ji} + w_i w_j}{w_j} \tag{5}$$

Finally, the demand elasticity of factor i with respect to output (μ_{iY}) is obtained as usual:

$$\mu_{iY} = \frac{\partial Q_i}{\partial Y} . \frac{Y}{Q_i} = \frac{\alpha_{Yi}}{w_i} + \eta_Y \tag{6}$$

where η_Y represents the cost elasticity with respect to output.

Previous to the estimation, the adequacy of this approach has to be confirmed, checking whether the relation between the variables is spurious or there is a long-run equilibrium relationship, as is implicitly assumed in a model like (1) and (2). The corresponding integration and cointegration analysis appears in Appendix, and confirm the consistence of our approach. Specifically, all the variables are I(1). Moreover, the group of variables selected are cointegrated; both in the sphere of the production function and in the cost function. This is a key point that has received little attention in the literature. To date, no study has performed this type of analysis in the field of water for industrial uses, and only a few have done so in the domestic sphere (see Martinez-Espiñeira 2007; Zaied and Binet 2015; Zaied and Cheikh 2015).

Next step is to jointly estimate the translog cost function of (1) and the derived demand functions of (2), restricted by the conditions in (3). It should be noted that the strong heterogeneity of data makes it advisable to add fixed effects to account for unobserved factors. A time trend is also included in the cost function to capture the effects of technology in reducing water consumption (similar to, for example, De Rooy 1974; Ziegler and Bell 1984; Dupont and Renzetti 2001; Renzetti and Dupont 2003;

Vallés and Zárate 2013; Angulo et al. 2014). Finally, the price of water has been lagged one period to avoid endogeneity problems, following Dachraoui and Harchaoui (2004) and Angulo et al. (2014). Main results appear in Table 4 (for reasons of space, the estimated fixed effects are omitted).

Table 4. SUR estimation of the translog model.

	lnG		W_W		W_K		W_L		W_E	
α	0.04915	(0.00)	0.00021	(0.00)	-0.00073	(0.57)	0.01881	(0.00)	0.00568	(0.00)
$Trend$	-0.00679	(0.00)	-0.00006	(0.00)	-0.00012	(0.54)	-0.00316	(0.00)	0.00048	(0.00)
lnY	0.99009	(0.00)	0.00004	(0.09)	-0.00324	(0.00)	-0.01642	(0.00)	-0.00216	(0.00)
$(lnY)^2$	0.00255	(0.00)								
lnP_W	0.00021	(0.00)	0.00022	(0.00)	-0.00143	(0.00)	-0.00027	(0.05)	-0.00005	(0.62)
lnP_k	-0.00073	(0.57)	-0.00143	(0.00)	0.01094	(0.04)	0.02354	(0.00)	-0.00055	(0.72)
lnP_L	0.01881	(0.00)	-0.00027	(0.05)	0.02354	(0.00)	0.10897	(0.00)	0.00877	(0.00)
lnP_E	0.00568	(0.00)	-0.00005	(0.62)	-0.00055	(0.72)	0.00877	(0.00)	-0.01169	(0.00)
$lnP_W lnP_W$	0.00022	(0.00)								
$lnP_K lnP_K$	0.01094	(0.04)								
$lnP_L lnP_L$	0.10897	(0.00)								
$lnP_E lnP_E$	-0.01169	(0.00)								
$lnP_W lnP_K$	-0.00143	(0.00)								
$lnP_W lnP_L$	-0.00027	(0.05)								
$lnP_W lnP_E$	-0.00005	(0.62)								
$lnP_K lnP_L$	0.02354	(0.00)								
$lnP_K lnP_E$	-0.00055	(0.72)								
$lnP_L lnP_E$	0.00877	(0.00)								
$lnY lnP_W$	0.00004	(0.09)								
$lnY lnP_K$	-0.00324	(0.00)								
$lnY lnP_L$	-0.01642	(0.00)								
$lnY lnP_E$	-0.00216	(0.00)								

Note: The p-value is shown in parenthesis.

Results and discussion

Table 5 shows the direct price elasticity of water, the estimated water demand elasticity with respect to the output and the cross-price elasticities, for the aggregate and for each sector in the study. These elasticities were calculated using equations (4), (5), and (6), based on the results of the estimation presented in Table 4.

Table 5. Direct, output and cross-price elasticity for the industry, disaggregated by sectors.

	E_{WW}	E_{WY}	M_{KW}	M_{LW}	M_{EW}	M_{SW}	M_{WK}	M_{WL}	M_{WE}	M_{WS}
Aggregate	-0.66	1.07	-0.03	0.00	0.00	0.001	-2.18	-0.22	-0.05	3.10
	(0.00)	(0.00)	(0.00)	(0.30)	(0.75)	(0.00)	(0.00)	(0.30)	(0.75)	(0.00)
Sector 1	-0.25	1.32	103.82	-10.84	-18.58	-1.94	0.07	-0.01	-0.01	-2.66
	(0.75)	(0.00)	(0.23)	(0.25)	(0.62)	(0.68)	(0.23)	(0.25)	(0.62)	(0.68)
Sector 2	-1.69	1.31	0.10	0.00	0.03	-0.01	7.23	0.26	0.93	-6.74
	(0.05)	(0.00)	(0.00)	(0.91)	(0.45)	(0.06)	(0.00)	(0.91)	(0.45)	(0.06)
Sector 3	0.11	1.23	-0.14	-0.01	-0.05	0.01	-10.12	-1.98	-1.76	13.75
	(0.94)	(0.00)	(0.01)	(0.43)	(0.29)	(0.02)	(0.01)	(0.43)	(0.29)	(0.02)
Sector 4	-0.76	1.32	-0.02	0.00	0.00	0.00	-1.72	-0.19	0.15	2.51
	(0.00)	(0.00)	(0.22)	(0.77)	(0.69)	(0.12)	(0.22)	(0.77)	(0.69)	(0.12)
Sector 5	-1.54	1.33	-0.02	0.00	-0.03	0.00	-1.41	-0.44	-1.14	4.53
	(0.29)	(0.02)	(0.74)	(0.89)	(0.38)	(0.46)	(0.74)	(0.89)	(0.38)	(0.46)
Sector 6	-0.92	1.29	-0.03	0.00	0.00	0.00	-2.37	-1.23	0.05	4.48
	(0.02)	(0.00)	(0.32)	(0.26)	(0.93)	(0.10)	(0.32)	(0.26)	(0.93)	(0.10)
Sector 7	-0.93	0.71	-0.01	0.00	0.01	0.00	-1.04	-0.49	0.38	2.08
	(0.00)	(0.00)	(0.49)	(0.59)	(0.44)	(0.28)	(0.49)	(0.59)	(0.44)	(0.28)
Sector 8	-0.64	0.74	-0.11	-0.01	0.02	0.01	-7.53	-2.76	0.61	10.32
	(0.56)	(0.02)	(0.07)	(0.09)	(0.64)	(0.04)	(0.07)	(0.09)	(0.64)	(0.04)
Sector 9	-0.80	1.20	0.00	0.00	0.00	0.00	-0.02	-0.36	0.16	1.03
	(0.35)	(0.00)	(0.99)	(0.82)	(0.88)	(0.75)	(0.99)	(0.82)	(0.88)	(0.75)
Sector 10	-1.88	1.49	-0.15	0.01	0.04	0.01	-10.95	3.58	1.43	7.83
	(0.19)	(0.00)	(0.00)	(0.21)	(0.30)	(0.12)	(0.00)	(0.21)	(0.30)	(0.12)
Sector 11	-0.90	1.52	-0.01	0.00	0.00	0.00	-1.05	1.26	0.01	0.68
	(0.18)	(0.00)	(0.69)	(0.40)	(1.00)	(0.85)	(0.69)	(0.40)	(1.00)	(0.85)

Note: The p-value is shown in parenthesis.

The direct water demand elasticity is -0.66 for the aggregate, meaning that water demand is normal and inelastic. This result is in the middle range of the elasticities obtained in the literature on the industrial aggregate, which ranges from values under -0.1 (Ziegler and Bell 1984; Canizales and Bravo 2011; Vallés and Zárate 2013) to elasticities around -1.1 (Féres and Reynaud 2005; Kumar 2006). Considering the total industrial water used in 2013, this value implies that a 1% increase in the price will lead to a water saving of 1.3 Hm^3, with a total additional amount of 930,793 € paid per year by industrial users.

We also observe that our elasticity is significantly higher than the elasticities obtained for residential users in Spain, which ranges from values under -0.1 (Arbués, Barberán, and Villanúa 2004; Martínez-Espiñeira and Nauges 2004; García-Valiñas 2005; Martínez-Espiñeira 2007) to magnitudes around -0.3 (Martínez-Espiñeira 2002, 2003). This result indicates that pricing policy in Spain would be effective to encourage reduced use of water in industry, and that industrial users react more intensely to changes in the price of water than households.

The sectoral analysis shows that the price of water has a significant effect on the demand for urban water only in sectors 2 (food, beverages, and tobacco), 4 (wood and cork, paper and graphic arts), 6 (manufacture of rubber and plastic products and other non-metallic mineral products) and 7 (manufacture of basic metal and fabricated metal products, except machinery and equipment). In the other cases, the direct elasticity of water does not reach the usual standard of 5% significance.

Sector 2 is the only case where water demand is elastic (-1.69), at 5% significance. The result corroborates the evidence provided in the literature, where food, beverages and tobacco usually has the highest elasticity because of its high water intensity (Renzetti 1993; Dupont and Renzetti 1998; Malla and Gopalakrishnan 1999; Guerrero 2005; Canizales and Bravo 2011). This implies that a 1% increase in the price of water will encourage a water saving of 1,1 Hm^3. Since this is the only sector with an elastic water demand, it is also the only one in which this water saving will lead to a water cost saving (763,507 €/year).

The elasticity obtained in sector 4 (-0.76) is in the middle range of results obtained in similar studies, which were between -0.59 and -0.91 (Babin, Willis, and Allen 1982; Renzetti 1992, 1993; Wang and Lall 2002; Reynaud 2003; Kumar 2006). The same applies to sector 7 (-0.93), where the estimated elasticities range from -0.24 to

-1.67 (Babin, Willis, and Allen 1982; Renzetti 1993; Wang and Lall 2002; Reynaud 2003). In contrast, the estimation obtained for sector 6 (-0.92) is comparatively high, where it ranges from -0.15 to -0.78 (Babin, Willis, and Allen 1982; Renzetti 1993). In these sectors, the reduction of water that would be achieved given a 1% increase in the price of water is moderate (0.05, 0.09 and 0.15 Hm^3, respectively). This also implies a reduced cost of 25,218, 16,003 and 11,089 €/year, respectively.

Overall, the results indicate that in sectors with less intensive use of urban water, where water represents a lower share in their cost structure (see Figure 1), the direct price elasticity of water tends to be not significant; the opposite holds in more intensive water consumption activities. Looking at sectors with a significant elasticity, there is a clear pattern: greater elasticity is associated with more intensive use of urban water. Given that there is a firm long run tendency to decrease water intensity over time, as indicated by official statistics and confirmed in our own estimates by the negative coefficient for the trend variable in Table 4, a future scenario could be foreseen where direct price elasticities are even less significant.

Water demand elasticity with respect to output is 1.07 for the aggregate, so the volume of urban water needed varies (almost) proportionally to production, ranging from 0.71 (sector 7) to 1.52 (sector 11). This result is in the upper range of elasticities obtained in the literature and is significant in all sectors. Thus, it is necessary to persist in the application of demand management policies, including pricing policy, in order to encourage the reduction of consumption. Otherwise, the foreseeable growth of industrial production will lead to an increase in water consumption in the industrial sector.

Cross-price elasticities show that the variation in water demand when the price of other inputs changes is greater than the variation in the demand for other factors when the price of water changes. This result can be attributed to the low price of water and its small share in the total costs. However, as expected, the signs obtained in both cases are consistent and have similar levels of significance.

Cross-price elasticities for the aggregate indicate that water and capital are complementary but water and supplies are substitutive, while the relationship between water and the inputs labour and energy is not significant. The evidence in the existing literature is very disparate. Previous studies found that water and capital could both be complementary (Grebenstein and Field 1979; Kumar 2006, among others) or substitutive (Dupont and Renzetti 2001; Féres and Reynaud 2005, among others). The same can be said in reference to the pair water and supplies: some studies found a relationship of complementarity (Féres and Reynaud 2005; Kumar 2006), and others of substitutability (Guerrero 2005; Angulo et al. 2014). The results for the relationship between water and the inputs labour and energy are also diverse but, like in our case, most studies obtain non-significant elasticities (Dupont and Renzetti 2001; Féres and Reynaud 2005; Guerrero 2005; Kumar 2006). The result regarding the relationship between water and capital seems to indicate that capital renewal is not contributing to reduce water use but, on the contrary, favouring its increase. This is a worrisome result since one would expect that technological innovation, through the renewal of capital, would contribute to reduce the intensity of industrial water use. The reduction in the quantity of water consumed seems to depend, mainly, on innovation both in product and in production processes, which is revealed by the substitutability between water and supplies.

The analysis by industrial sectors corroborates that the relationship between water and the inputs labour and energy is not significant. The relationship between water and the inputs capital and supplies is significant only in a few cases (sectors 2, 3, 8 and 10). The sign of the relationships between inputs coincides with that of the aggregate in sectors 3 (textiles, wearing apparel, leather and related products), 8 (manufacture of computer, electrical, electronic and optical products), and 10 (manufacture of transport equipment), but not in sector 2 (food, beverages and tobacco). The latter is very intensive in the use of water and the substitutability between water and capital indicates that the renewal of productive capital, especially in washing processes, does contribute to the reduction of water use; the relationship of complementarity between water and supplies indicated that the demand for water is closely related to the volume of raw materials processed, despite the improvements in the production processes.

Conclusions

The results of this study of urban water demand by the Spanish industry provide new evidence supporting the effectiveness of prices for incentivising industrial companies to use less water, more efficiently. In particular, we have obtained a price elasticity (-0.66) that justifies the use of pricing as an instrument for managing water demand, in line with the recommendations of international institutions such as the OECD and the European Commission. The comparison with the results obtained for domestic users enables us to confirm that pricing policy is more effective in the case of industrial users.

The results also show a strong heterogeneity among industries. In general, in sectors where urban water accounts for only a small fraction of total costs, water demand elasticity tends not to be significant. The opposite holds in sectors where water represents a higher proportion of total costs; in these cases, a greater elasticity is associated with intensive water use. This dispersion means the pricing policy must be complemented with other instruments to contribute to water sustainability. We also find that the intensity of water use decreases over time, so that we could expect the elasticity of demand to decrease and become less significant over time, leading to a greater need for additional instruments.

To ensure that the additional instruments are effective, they must be chosen to suit the unique characteristics of each industry and their different water uses. For example, if water is mainly used for sanitary purposes, the introduction of efficiency certification for bathroom fittings (that classify these devices according to the amount of water they consume), the adoption of standards in building regulations (that forces to install mechanisms of water saving in the new construction buildings) and the implementation of plans to promote a sustainable use of water among larger water users (that force them to carry out plans to reduce water) can be very effective (in Spain, the municipalities are responsible for these regulations, used very often in recent years).

On the other hand, if water is intended for cleaning, cooling, or production processes, financial support for innovation in water-saving technologies and stimulate good practices such as water reuse can be key factors. In all cases, information and consumer awareness about the water footprint of the goods and services they consume and about the scarcity of drinking water could be used to redirect demand toward less water-intensive products.

We also find that the production level is significant in determining demand for water (elasticity of 1.07), so that an increase in production will lead to a similar increase in urban water consumption, which underlines the importance of supplementing pricing policy with other measures, such as those above, with the aim of reducing water use.

Finally, the results show that water pricing policies affect the use of other factors of production, especially input capital and supplies. At the same time, the price of these other factors of production affects the use of urban water, interfering with water conservation policies. Thus, water management policy should not ignore them, especially in the case of possible significant changes in the relative prices of the factors.

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Appendix. Stochastic analysis: integration and cointegration tests

This Appendix provides results regarding the stochastic structure of the series and the cointegration hypothesis for the translog model of (1)-(2).

This study involves a panel dataset, so tests suitable for the case should be used. Specifically, the LLC (Levin, Lin, and Chu 2002), IPS (Im, Pesaran, and Shin 2003), Fisher (Choi 2001), and Hadri (2000) panel unit root tests were used. In all cases, the test equation includes a constant and a time trend; the cross-section averages are subtracted to make the equations more robust to possible cross-sectional dependence. Energy prices $\left(\ln P_{\text{gas}}, \ln P_{\text{electricity}}, \ln P_{\text{diesel}}, \ln P_{\text{fuel}}\right)$ are yearly nationally referenced prices, and therefore, unit root tests for univariate time series were used: the Augmented Dickey-Fuller (ADF) (Dickey and Fuller 1979), Phillips-Perron (PP) (Phillips and Perron 1988) and Dickey-Fuller GLS (DFGLS) (Elliott, Rothenberg, and Stock 1996) tests. The testing equation for these tests includes a constant and a time trend.

Table A1 shows the results for the aggregated data (that is, without considering the sectoral breakdown and using the AC as panel units). Despite a few discrepancies, the tests for the levels do not reject the unit root null hypothesis. On the contrary, the tests for the first difference clearly point to the rejection of a second unit root. So, it can be concluded that both the univariate and the panel variables are integrated of order one.

Table A1. Unit root test (not robust to cross-sectional dependence).

Panel series variables

	LLC	**IPS**	**Fisher**				**HADRI**	**Conclusion**
			P	**Z**	**L**	**Pm**		
	H_0: All panels have a unit root		H_0: All panels have a unit root				H_0: All panels are stationary	
	H_1: All panels are stationary	H_1: Some panels are stationary	H_1: Some panels are stationary.				H_1: All panels are stationary	
lnY	0.84	1.00	1.00	1.00	1.00	1.00	0.00	**I(1)**
ΔlnY	0.00	0.00	0.00	0.00	0.00	0.00	1.00	
lnQ_W	0.09	0.30	0.77	0.85	0.83	0.77	0.00	**I(1)**
ΔlnQ_W	0.00	0.00	0.00	0.00	0.00	0.00	1.00	
lnQ_K	0.27	1.00	0.98	1.00	1.00	0.98	0.00	**I(1)**
ΔlnQ_K	0.00	0.00	0.00	0.00	0.00	0.00	1.00	
lnQ_L	0.88	1.00	1.00	1.00	1.00	1.00	0.00	**I(1)**
ΔlnQ_L	0.00	0.00	0.00	0.00	0.00	0.00	1.00	
lnQ_E	0.53	0.68	0.76	0.99	0.98	0.76	0.00	**I(1)**
ΔlnQ_E	0.00	0.00	0.00	0.00	0.00	0.00	1.00	
lnG	0.43	1.00	1.00	1.00	1.00	1.00	0.00	**I(1)**
ΔlnG	0.00	0.00	0.00	0.00	0.00	0.00	0.92	
lnP_W	0.01	1.00	1.00	1.00	1.00	1.00	0.00	**I(1)**
ΔlnP_W	0.00	0.00	0.00	0.00	0.00	0.00	0.50	
lnP_K	0.00	0.57	0.24	0.95	0.94	0.25	0.00	**I(1)**
ΔlnP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
lnP_L	0.14	0.45	0.08	0.97	0.79	0.08	0.00	**I(1)**
ΔlnP_L	0.00	0.00	0.00	0.00	0.00	0.00	1.00	

Time series variables

	ADF	**PP**	**DFGLS 1 LAG**		**DFGLS 2 LAG**		**Conclusion**
	H_0: The variable has a unit root H_1: The variable is stationary						
lnP_{gas}	0.10	0.10	-3.08	(-3.50)	-3.19	(-3.28)	**I(1)**
ΔlnP_{gas}	0.00	0.00	-3.94	(-3.47)	-2.65	(-3.22)	
$lnP_{electrity}$	0.91	0.92	-1.00	(-3.50)	-1.10	(-3.28)	**I(1)**
$\Delta lnP_{electricity}$	0.00	0.00	-3.88	(-3.47)	-2.67	(-3.22)	
lnP_{diesel}	0.01	0.01	-3.08	(-3.50)	-3.32	(-3.28)	**I(1)**
ΔlnP_{diesel}	0.00	0.00	-3.19	(-3.47)	-3.42	(-3.22)	
lnP_{fuel}	0.07	0.08	-2.89	(-3.50)	-3.67	(-3.28)	**I(1)**
ΔlnP_{fuel}	0.00	0.00	-2.73	(-3.47)	-3.16	(-3.22)	

Note: The Table shows the p-value of the tests, except for the cases of DFGLS 1 LAG and DFGLS 2 LAG where it appears the value of the statistic (in parenthesis the critical value at 5%).

The Fisher test combines the p-values of univariate ADF unit root tests for the panel units using the inverse-chi-squared distribution (P), the inverse normal distribution (Z), the inverse logit transformation (L), and a modified version of the inverse-chi-squared transformation (Pm) (see Choi 2001; for details). The DFGLS 1 LAG and DFGLS 2 LAG tests include one and two lags, respectively.

Table A2 completes this information with the panel unit root tests of Pesaran (2007), CIPS, Moon and Perron (2004), ta and tb, and Sargan-Barghava test of Bai and Ng (2010), PMSB. The four tests are robust to cross-sectional dependence so they are a good complement to the so-called first generation unit root tests of Table A1. Once again, despite some small discrepancies, the conclusion remains the same: all the series are I(1).

Table A2. Panel unit root test robust to cross-sectional dependence.

H_0: The variable has a unit root H_1: The variable is stationary					
Variable	CIPS	MP		PMSB	Conclusion
		ta	tb		
lnY	0.665	0.108	0.0968	0.846	I(1)
lnQ_W	0.090	0.259	0.003	0.563	I(1)
lnQ_K	0.560	0.408	0.404	0.099	I(1)
lnQ_L	0.150	0.405	0.037	0.618	I(1)
lnQ_E	0.240	0.741	0.993	0.060	I(1)
lnG	0.965	0.774	0.997	0.878	I(1)
lnP_W	0.135	0.147	0.146	0.593	I(1)
lnP_K	0.640	0.244	0.000	0.059	I(1)
lnP_L	0.125	0.519	0.824	0.135	I(1)

Note: The Table shows the p-value of the tests. Only the results for the variables in levels are shown, given that the unit root null hypothesis is rejected in all the cases, for variables in first differences. PMSB is the panel modified Sargan-Barghava test of Bai and Ng (2010) for testing non-stationarity in the idiosyncratic component of the panel series, CIPS is the Pesaran (2007) test for panel unit roots; ta and tb are Moon and Perron (2004) tests for panel unit roots.

The next step is to test for cointegration. Table A3 shows the results using the test of cointegration of Pedroni (1999, 2001), robust to cross-sectional dependence. When testing for interregional cointegration, there can be cross-sectional correlation among the panel units, so the Pedroni test seems suitable. Furthermore, the analysis has been replicated for the variables in the production function (quantities of output and inputs) and in the cost function (input prices and total expenses). The duality approach indicates that there is a one-to-one relationship between the two functions so we expect to find cointegration, or lack of cointegration, in the two cases. The results are conclusive. The relationship between the output and the quantities of inputs and between the total cost and the input prices is a long-run relationship, whether we consider Spanish industry as a whole or we perform the analysis on a sectoral basis.

Table A3. Cointegration analysis.

H_0: Variables do not cointegrate
H_1: Variables cointegrate

	Production function			**Cost function**			**Conclusion**
	rho	**t**	**ADF**	**rho**	**t**	**ADF**	
Aggregated	-12.54***	-72.81***	-33.12***	-1.07	-65.44***	-20.64***	**Cointegration**
sector 1	3.81***	-2.31**	4.86***	6.87***	0.11	5.08***	**Cointegration**
sector 2	2.11**	-6.63***	0.24	6.83***	-0.86	11.89***	**Cointegration**
sector 3	2.05**	-7.14***	1.53	7.02***	0.47	7.32***	**Cointegration**
sector 4	2.48***	-8.29***	2.76***	6.28***	-4.34***	8.14***	**Cointegration**
sector 5	2.66***	-4.64***	0.21	6.62***	-1.15	9.89***	**Cointegration**
sector 6	3.06***	-5.43***	1.98**	6.06***	-1.60	7.63***	**Cointegration**
sector 7	3.29***	-4.32***	6.85***	6.49***	1.14	10.62***	**Cointegration**
sector 8	3.28***	-3.55***	4.04***	6.27***	-1.24	8.41***	**Cointegration**
sector 9	3.11***	-3.63***	4.55***	6.47***	-0.57	10.61***	**Cointegration**
sector 10	4.03***	-0.55	2.61***	6.39***	0.29	8.02***	**Cointegration**
sector 11	2.75***	-4.07***	6.14***	7.00***	-1.21	10.45***	**Cointegration**

Note: Table shows the value of the so-called rho, t and ADF statistics whose distribution, under the null hypothesis, is standard normal. *, ** and *** mean rejection of the null hypothesis at 10%, 5% and 1%, respectively.

Production function refers to the hypothetical cointegration existing between the variables $lnY,\ lnQ_W, lnQ_K, lnQ_L,\ lnQ_E$; cost function refers to the hypothetical cointegration existing between the variables $lnG,\ lnY, lnP_W,\ lnP_K,\ lnP_L,\ lnP_{gas},\ lnP_{electricity}, lnP_{diesel}$, and lnP_{fuel}.