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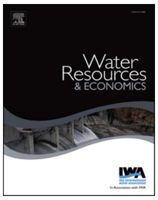

Water demand in the Chilean manufacturing industry: Analysis of the economic value of water and demand elasticities

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ABSTRACT

In this article, we estimate both the economic value of water and own-price and cross-price elasticities of water for the Chilean manufacturing industry using the production function approach. Estimating the production function allows us to estimate the marginal productivity of water which corresponds to its economic value. Our estimations are based on panel data obtained from the National Industrial Survey for the period 1995–2014, accounting for more than 10,000 industrial plants. We use a translog specification for the production function, considering water, capital, labor, energy, and intermediate material as explanatory variables. We find substitution patterns among most inputs, except for energy and water, which are found to be complements. Our results suggest that the manufacturing sector is characterized by an elastic water demand, with an average economic value of water of 8.071 [USD/m^3]. Based on our findings, there is room to increase water prices in most sectors without affecting the competitiveness of firms. Knowing the economic value of water and its price elasticity could help policymakers to design water policies that promote more efficient use of this scarce resource.

1. Introduction

Despite the crucial importance of water for many human activities, its future supply cannot be assured because of a combination of natural conditions and anthropogenic interventions that have degraded water quality and reduced its availability [1–5].

According to FAO [6], at the global level, the most intensive water sector is agriculture (70%), followed by industry (19%), and municipality (11%). However, according to official projections, because of population growth and economic development, it is expected that water use in the industrial sector will increase by as much as 400% by 2050, with emerging and developing countries accounting for the largest share of this increase [7]. Thus, the expected increase in water use and reduction in supply will force policymakers to search for innovative ways to regulate water allocation with the aim of increasing efficiency and sustainability of different water uses [3].

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Based on the abovementioned facts, knowing water demand and the related determinants are important for implementing informed water policies. Accordingly, the literature contains many attempts to estimate water demand in both the residential and industrial sectors [8–11].

In this study, we estimate the economic value of water (EVW) and own-price and cross-price elasticities of water for the Chilean manufacturing industry using a production function approach similar to that of Ku and Yoo [12]. We use a panel data of industrial plants for the period between 1995 and 2014 from the Annual Industrial National Survey (ENIA in its Spanish acronym).[1]

By using the production function approach, it is possible to recover productivity for each production factor, particularly for water, which corresponds to the economic value for this resource. Knowing the EVW may contribute to water management, for example, in the regulation or promotion of efficient water use by industries and in the welfare analysis of water allocation at a basin scale in which industrial uses compete with forestry, agriculture, or residential uses. The EVW can provide information that is useful for policymakers in designing water policies that consider both efficiency in water use and competitiveness of the industrial sector based on environmental goals, and the ability of the industry to absorb a change in water cost [1]. The marginal productivity provides an estimation of the EVW that represents a firm's maximum willingness to pay for water [13]. Therefore, a comparison of this value with the actual water cost faced by firms can inform policymakers as to whether there is room for increasing prices without affecting the competitiveness of the industry [1]. Estimations of water price elasticities could inform the development of demand-side policies, based on the use of price incentives to induce a reduction in water consumption. However, this approach is only worth implementing when the price elasticity of demand is high enough to trigger a significant reduction in water consumption [8].

This article includes six sections. Section 2 offers a literature review, followed by the methodology in section 3. The case study and results are then described in sections 4 and 5. Finally, section 6 presents our conclusions.

2. Literature review

We performed a literature search for empirical studies focused on the industrial sector using Google Scholar. We searched for the subjects "*industrial water demand,*" "*shadow price of water,*" "*marginal value of water,*" "*water price elasticity,*" "*economic value of water,*" and similar phrases. We first prioritized research articles published in scientific journals, then public reports from government institutions, and finally unpublished works, such as working papers. From this search, we identified 42 empirical studies assessing both EVW (13 studies) and water price elasticity (29 studies), dating from 1969 to 2019. These studies are highly concentrated in developed countries. For instance, the USA and Canada account for 46% of studies on EVW and 58% of studies on water price elasticity. On the other hand, Chinese studies on EVW represent 46% of studies investigated, but its representation regarding water price elasticity studies is negligible.

Studies on EVW are conducted using different approaches: production function/marginal productivity, cost function, production frontier, or computable general equilibrium (CGE) models (Table 1). Previous studies include the analysis of EVW either for a specific sector (i.e., chemical, paper, or food) or in general for an entire industry. Values for the EVW of specific sectors range from 0.122 [USD/m^3] for the chemical industry [14], to 84.7 [USD/m^3] for the food sector [15], whereas studies analyzing a whole industrial sector report values from 0.035 [USD/m^3] [16] to 20.39 [USD/m^3] [17].

Water price elasticities are also estimated using either a cost function approach (14 studies), a production function approach (3 studies), or from the estimation of a water demand (12 studies). Details are given in Table 2.

Alike the estimation of EVW, price elasticity studies cover several industrial sectors such as paper and chemicals [31,34,36,38,51]; food, beverages, and textiles [40,41]; and hotels and restaurants [1,52], whereas others are focused on the entire manufacturing industry [32,33,37,39,46]. Estimates for price elasticity range from −4.37 in the high-tech sector [49] to −0.024 in hotels [52]. Among those studies, 74.5% report inelastic values for water demand, whereas 21.5% report elastic values and the remaining 4% show elasticity equal to −1 (unitary price elasticity). Unfortunately, a comparison of these elasticity estimates is difficult because the studies were conducted under different contexts (e.g., tariff structures, cost of water access, and reuse and recycling of water).

In conclusion, international evidence on EVW for industry is limited and focused mostly on the USA or China, with only one study from Latin America [17], whereas, studies on water price elasticity are less restricted but still highly concentrated in developed countries, with little evidence from Latin America [43,48,51].

3. Materials and methods

The assessment of EVW through demand or cost function approaches requires the existence of a water market, knowledge of the relevant tariff structure, cost data and/or marginal prices [10]. Lack of appropriate data on marginal prices has pushed researchers to use average prices as proxies, which is inconsistent with economic theory [39] since, from a theoretical perspective, companies maximize profits when marginal prices (not average prices) equal marginal costs [53]. Furthermore, when water comes from one's own sources, the information on the associated cost (i.e. pumping cost) is not publicly available [46] limiting the application of the cost function approach. Fortunately, even when marginal prices or costs cannot be observed or the tariff structure is unknown, the production function/marginal productivity approach can still be used to assess the marginal value of water as it does not require price information. The marginal productivity approach is based on the fact that marginal cost must be equal to the marginal value of

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[1] Note that the ENIA is an annual census of industrial plants.

Table 1
Previous studies-economic value of water[a] (USD/m^3).

Article	Country	Approach	Industrial Sector	EVW USD/m^3
Russell [18], from Frederick et al. [19]	USA	Marginal costs	Industrial processing	0.17
Young and Gray [14], from Frederick et al. [19]	USA	Not defined	Chemical industry	0.12
Young and Gray [14], from Frederick et al. [19]	USA	Not defined	Paper industry	0.15
Kollar et al. [20], from Frederick et al. [19]	USA	Total costs	Textile, cotton	0.30
Kane and Osantowski [21], from Frederick et al. [19]	USA	Marginal costs	Meat packing industry	0.27 to 0.386
Dachraoui and Harchaoui [22]	Canada	Total costs	General	1.11
Feng et al. [23]	China	CGE Model	General	6.44887
He et al. [24]	China	Dynamic CGE Model	General	0.531
Li and Ma [25]	China	Meta Frontier Model	General	5.85
Wang et al. [26]	China (provincial level estimates)	Directional Distance Function	General	0.079 to 17.19
Gao et al. [15]	China (basin level)	Minimum Costs	Food and Energy	42.3 to 84.7
Liu et al. [16]	China (basin level)	Input – Output Model	General	.0035 to 0.103
Revollo-Fernández et al. [17]	Mexico (Mexico Valley)	Production function/Marginal productivity	General	2.33 to 20.39

[a] In 2014 USD values.

production for a firm to maximize profits. Furthermore, a water demand function can be derived from the first-order conditions of the profit maximization problem. The marginal productivity function allows an estimation of EVW that reflects a firm's maximum willingness to pay for water [13].

We use the revenue function to homogenize the multiple outputs produced by firms [53]. Our econometric model is based on the translog function [54], which has been previously used for the analysis of water issues in (i) cost function estimations [1,33,38,40], and (ii) production function estimations [12,17]. The revenue function is:

$$\ln Q_{it} = \beta_0 + \sum_{k=1}^{K} \beta_k \ln F_{ikt} + \sum_{k=1}^{K} \delta_k (\ln F_{ikt})^2 + \sum_{k=1}^{K} \sum_{\substack{j=1 \\ k \neq j}}^{K} \theta_{kj} (\ln F_{ikt}) \left(\ln F_{ijt}\right) + \mu_{it}, \tag{1}$$

where Q_{it} is the total revenue of plant i in period t, F_{ikt} is the k-th production factor of plant i in period t, $\beta_0, \beta_k, \delta_k,$ and θ_{kj} are parameters to be estimated.[2] Since we have panel data we follow Baltagi [55] and Wooldridge [56] and define the error term as $\mu_{it} = \varepsilon_i + v_{it}$, in which ε_i is an unobservable plant-specific effect (time invariant) and v_{it} are the idiosyncratic disturbances that vary with plants and time [56].

Deriving equation (1) with respect to F_{ikt}, we obtain the product-input elasticities (σ_{F_k}):

$$\sigma_{F_{ik}} = \frac{\partial \ln Q_{it}}{\partial \ln F_{ikt}} = \beta_k + 2\delta_k \ln F_{ikt} + \sum_{\substack{j=1 \\ j \neq k}}^{K} \theta_{kj} \ln F_{ijt}. \tag{2}$$

Additionally, using the definition of marginal productivity $\left(\frac{\partial Q_{it}}{\partial F_{ikt}}\right)$, we can express equation (2) as:

$$\sigma_{F_{ik}} = \frac{\partial \ln Q_{it}}{\partial \ln F_{ikt}} = \frac{\partial Q_{it}}{\partial F_{ikt}} \frac{F_{ikt}}{Q_{it}} = \rho_{F_{ik}} \frac{F_{ikt}}{Q_{it}} \Rightarrow \rho_{F_{ik}} = \sigma_{F_{ik}} \frac{Q_{it}}{F_{ikt}}. \tag{3}$$

We obtain the inputs' marginal productivities denoted by $\rho_{F_{ik}}$. For the specific case of water under perfect market conditions, marginal productivity (ρ_{iw}) should be equal to the EVW for a specific firm.

Linearizing equation (3) through natural logarithms, deriving with respect to each F_{ik}, and assuming price is equal to marginal productivity, that is, $\rho_{F_{ik}} = P_{F_{ik}}$, we obtain the direct ($\gamma_{F_{ik}}$, Eqn 4) and crossed ($\gamma_{F_{ik}F_{ij}}$, Eqn 5) input-price elasticities:

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[2] Some observations have inputs with zero consumption. To avoid having an undefined value (ln(0)) in the definition of the objective function, we transformed the value to 0.001. We also estimate the model with other values including ln(1) = 0 and 0.0001, and found no quantitative nor qualitative differences in the results. The proportion of cases with zero inputs was below 10% in the worst case and negligible in most of them (0.01%).

Table 2
Previous studies-price elasticity estimates.

Article	Country	Approach	Industrial Sector	Price Elasticity
Turnovsky [27]	USA	Water demand	NA	−0.63/-0.5
Elliott [28], from Schneider and Whitlatch [29]	USA	Water demand	General	−0.73
Schneider and Whitlatch [29]	USA (Columbus)	Water demand	General	−1.16
Oh [30]	USA (Hawaii)	Water demand	General. Mostly sugarcane sector	−1.67/0.28
De Rooy [31]	USA (New Jersey)	Water demand	Chemical industry	−0.89/-0.590
Grebenstein and Field [32]	USA (45 regions)	Total costs	Manufacturing industry	−0.8/-0.33
Babin et al. [33]	USA	Total costs	Manufacturing industry	−0.66/-0.38
Ziegler and Bell [34]	USA (Arkansas)	Water demand	Paper and chemical industry	−0.08
Williams and Suh [35]	USA (120 locations)	Water demand	General	−0.97/-0.44
Renzetti [36]	Canada (British Columbia)	System of equations (costs)	Petrochemicals, heavy industry, forest, and light industry	−0.54/-0.12
Renzetti [37]	Canada (British Columbia)	System of equations (costs)	Manufacturing industry	−1.91
Renzetti [38]	Canada	Total Costs	Petroleum, pulp, paper, metals, and chemical industry	−0.59/-0.15
Dupont and Renzetti [39]	Canada	Total Costs	Manufacturing industry	−0.7752/-0.6901
Dupont and Renzetti [40]	Canada	Total costs	Food processing industry	−0.38/-0.26
Malla and Gopalakrishnan [41]	USA (Hawaii)	Water demand	Food industry and others	−0.37
Hussain et al. [42]	Sri Lanka	Water demand	General	−1.34
Wang and Lall [13]	China	Production function/Marginal productivity	General	−1.2/-0.57
Féres and Reynaud [43]	Brazil (Sao Paulo)	Total costs	General	−1.18/-1.06
Goldar [44], from Kumar [45]	India	Production function/Marginal productivity	Not informed	−0.64/-0.4
Kumar [45]	India	Total costs	Leather, distillery, chemicals, sugar, among others	−0.942/-0.31
Renzetti and Dupont [46]	Canada	Total costs	Manufacturing industry	−0.77/-0.69
Reynaud [47]	France (Gironde)	Total costs	General	−2.21/-0.91 −0.79/-0.1
Féres and Reynaud [48]	Brazil (Sao Paulo)	Total costs	Metals, food, textile, chemical, among others	−1.085
Liaw et al. [49]	China, Taiwan	Total costs	High technology industry	−4.37/-1 −1/-0.1
Bruneau et al. [50]	Canada	Water demand	General	−0.27
Féres et al. [51]	Brazil (Paraíba do Sul watershed)	Water demand	Rubber and plastics, pulp, chemicals, among others	−0.53 −0.23
Ku and Yoo [12]	South Korea	Production function/Marginal productivity	General	−1.44
Angulo et al. [1]	Spain (Zaragoza)	Total cost	Hotels and restaurants	−0.375
Deyà-Tortella et al. [52]	Spain (Balearic Islands)	Water demand	Hotels	−0.024
Revollo-Fernández et al. [17]	Mexico (Mexico Valley)	Production function/Marginal productivity	General	−0.061

$$\gamma_{F_{ik}} = \frac{\partial \ln F_{ikt}}{\partial \ln P_{F_{ik}}} = \frac{\sigma_{F_{ik}}}{2\delta_k + {\sigma_{F_{ik}}}^2 - \sigma_{F_{ik}}}, \tag{4}$$

$$\gamma_{F_{ik}F_{ij}} = \frac{\partial \ln F_{ikt}}{\partial \ln P_{F_j}} = \frac{\sigma_{F_{ij}}}{\theta_{kj} + \sigma_{F_{ik}} \cdot \sigma_{F_{ij}}}. \tag{5}$$

Given the error structure, we can estimate either fixed effects (FE) or random effects (RE) models by making different assumptions about μ_{it} [55]. The FE model assumes ε_i are parameters to be estimated, while v_{it} are independent and identically distributed error terms, IID $(0, \sigma_v^2)$. A Within transformation (obtaining the deviation from individual means, $Z_{it} - \overline{Z}_i$ for any variable Z) allows us to avoid the estimation of each individual fixed parameter (ε_i) while obtaining the remaining relevant behavioral parameters (Within estimators) [55]. Alternatively, we could estimate an RE model that assumes ε_i is independent and identically distributed in the population, IID $(0, \sigma_\varepsilon^2)$, while v_{it} is IID $(0, \sigma_v^2)$. The RE model also assumes that explanatory variables are independent of both ε_i and v_{it}, and that ε_i are independent of v_{it}. To test this exogeneity hypothesis, we use the Hausman specification test. The null hypothesis was rejected, suggesting that the RE estimator is inconsistent; therefore, our results are based on the FE model. Equations (2)–(5) were constructed using the estimated parameters, whereas the delta method [56] was used to determine their standard errors.

4. Data

The latest data available indicate that the total consumptive water use in Chile is 10.9 billion m^3/year and non-consumptive use is 154.7 billion m^3/year [57]. The industrial sector accounts for 12% of consumptive water use; according to official projections, this is expected to rise by 5% (relative to 2015) by 2030 because of population growth and economic development, thus increasing pressure on water resources [57,58]. Manufacturing industries are usually located in urban areas, particularly in the three main Chilean regions of Valparaíso (V region), Santiago (metropolitan region), and Concepcion (VIII region) [59]. Within the manufacturing industry, water is used in diverse ways: as a refrigerant, in transport, in cleaning or dilution of intermediate goods, and as part of the final product [39].

In this article, we use the ENIA survey, a census of industrial facilities with more than ten employees conducted annually throughout the country. Data from ENIA cover 1995 to 2017; unfortunately, for confidentiality reasons, it was only possible to obtain a panel for data between 1995 and 2014 [60] without region identifiers,[3] which total 71,908 observations distributed over 20 years. We used the ISIC Rev. 3 code to link each company with each production sector. This includes 10,528 plants with observations for a period of 1–20 years.

Observations were grouped according to ISIC Rev. 3 guidelines as follows: 151—meats, vegetables, and fats; 152–155—beverages and dairy; 153—milling industry and animal feed; 154—other foods; 17—textiles; 18—clothing; 19—leather products; 20—wood products, except furniture; 21—paper; 22—editing and reproduction; 24—chemicals; 25—rubber and plastic items; 26—non-metallic minerals; 27—base metals; 28—other metals; 29—machinery and equipment; 31–33—other electric and precision products; 34–35—transport and automotive; and 36—furniture.[4]

Input variables are as follows: water consumption (W) in cubic meters, considering only water intake (meaning that we did not include any reused or recirculated water); capital (K), taken as the stock at the end of the period, including the fixed assets, machinery, buildings, and vehicles; labor (L), taken as the number of workers; energy (E) in terms of expenditure for various fuels and electricity; and intermediate materials (M) in terms of expenditure, which are calculated from the intermediate costs minus water and energy costs used as production factors separately. Finally, revenue (Q) is the dependent variable. All monetary variables are measured in thousands of dollars from 2014.[5]

Table 3 provides the descriptive statistics of variables used in the model. As shown, water use is heterogeneous across periods. For instance, mean water use presents a constant reduction over time, from 9048 m^3 during the period 1995–1999 to 5169 m^3 during the period 2010–2014, while mean production value shows a constant increase from USD 3809 during the period 1995–1999 to USD 5696 during the period 2010–2014.[6]

Water consumption at the sector level (Table 4) shows that 40% of firms account for 51% of water use, with meats, vegetables, and fats (ISIC 151) as the most water-intensive sector (15.4% of total water use), followed by other foods (ISIC 154; 10.3%), chemicals (ISIC 24; 9.03%), non-metallic minerals (ISIC 26; 8.48%), rubber and plastic items (ISIC 25; 7.89%), and textiles (ISIC 17; 6.93%).

Fig. 1 shows the evolution of total water consumption at sector level for the six most intensive water-use sectors. There is a decreasing trend from 1995 to 2010, with a steep descent in all sectors in 2000. A slight cycle of recovery can be observed between 2000 and 2006, until a new generalized consumption decrease in all analyzed sectors in 2007. Each water consumption cycle is compatible with the occurrence of two economic crises around 2000 and 2008, respectively.

Despite the decreasing trend in industrial water consumption during the period 1995–2014, official projections -considering population growth and economic development [57,58]- suggest that by 2030 the industrial water demand will increase 5% relative to 2015 consumption levels.

5. Results and discussion

Appendix B shows the regression outcomes. We have mixed results in terms of significance. Squared variables and interactions without water are all significant at the 99% confidence level, except for the *Energy-Labor* (E*L) and *Capital-Energy* (K*E) interactions. While we controlled for years, this is not reported in Appendix B because it is not relevant to the discussion.[7]

Seventeen interactions of the type *Water-ISIC sector* (W*ISIC#) are significant at the 95% confidence level, whereas some interactions of type *Capital-Water-ISIC sector* (K*W*ISIC#) are not significant. The F-statistic for general significance of parameters is significant at 99.9%, whereas the total R^2 indicates that the model explains 95.1% of variation of the sample.[8] On the other hand, the ρ coefficient shows the fraction of variance of individual errors is 71% with respect to total perturbations.

Table 5 shows own-price and cross-price elasticities and productivities for the K, L, E, M, and W inputs, indicating interactions as expected: 1) both the product-input elasticities (σ_{F_i}) and marginal productivities (ρ_{F_i}) are positive; 2) the own-price elasticity (γ_{F_i}) is

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[3] In the official database, regional identifiers were eliminated for confidentiality purposes.

[4] To better capture industries features, the ISIC aggregation "manufacture of food products and beverages – (15)" was disaggregated into four subcategories: 151, 152–155, 153 and 154. In addition, some categories were combined, such as "other electric and precision products - (31–33)" and "transport and automotive - (34–35)." Finally, divisions associated with codes 16, 23, 30, and 37 were removed.

[5] We use a reference exchange rate such that USD 1 = CLP 570.01 in 2014 (Source: Central Bank of Chile).

[6] Detailed descriptive statistics for entire panel given in Appendix A.

[7] Years are statistically significant; results are available upon request.

[8] The high R^2 is driven by size effects. This happens in regressions with firm/plant variables measured levels and when there is significant heterogeneity in firm/plant size.

Table 3
Descriptive statistics: Yearly average.

Period	Share of Sample (%)	Statistic	Q	L	E	M	K	W
1995–1999	29.42%	Mean	3809.867	55.727	81.978	2241.765	1679.978	9048.02
		SD	8172.761	76.891	245.001	4874.128	4120.039	18679.705
		Min	0	1	0	0.064	0	0
		Max	138037.328	731.000	4490.922	52651.812	36006.820	154193
2000–2004	28.26%	Mean	4120.252	49.779	91.805	2564.858	1625.408	6034.439
		SD	9282	75.143	269.431	5721.639	4052.178	14889.612
		Min	5.086	1	0	0	0	0
		Max	201183.516	732.000	4494.300	52596.844	35843.617	154406
2005–2009	25.95%	Mean	4998.329	55.380	147.154	3225.190	1679.582	5384.874
		SD	10449.606	82.843	382.915	6643.322	4056.035	14026.282
		Min	1.384	1	0	0.59	0	0
		Max	204872.797	731	4458.485	52547.113	35897.895	154372
2010–2014	16.36%	Mean	5696.146	59.075	154.764	3665.602	1725.887	5169.82
		SD	10808.505	84.565	368.573	6956.007	3890.222	13379.523
		Min	0.002	0	0	0.002	0	0
		Max	196814.312	732.000	4456.846	52383.254	35757.293	153807

Data source: National Institute of Statistics, Chile [60].

Table 4
Average yearly water use by sector.

International Standard Industrial Classification - ISIC	% Of Sample	% Of Total Water Consumption
T1: Meats, vegetables and fats (ISIC 151)	6.80%	15.44%
T2: Beverages and dairy (ISIC 152 & 155)	4.00%	5.40%
T3: Milling industry and animal feed (ISIC 153)	2.80%	2.42%
T4: Other foods (ISIC 154)	16.00%	10.30%
T5: Textiles (ISIC 17)	5.00%	6.93%
T6: Clothing (ISIC 18)	5.50%	2.90%
T7: Leather products (ISIC 19)	2.90%	3.01%
T8: Wood products, except furniture (ISIC 20)	6.50%	2.69%
T9: Paper (ISIC 21)	2.50%	2.55%
T10: Editing and reproduction (ISIC 22)	4.70%	2.72%
T11: Chemicals (ISIC 24)	5.50%	9.03%
T12: Rubber and plastic items (ISIC 25)	6.60%	7.89%
T13: Non-metallic minerals (ISIC 26)	5.40%	8.48%
T14: Base metals (ISIC 27)	1.70%	2.46%
T15: Other metals (ISIC 28)	8.00%	6.47%
T16: Machinery and equipment (ISIC 29)	6.10%	3.76%
T17: Other electric and precision products (ISIC 31–33)	2.50%	2.21%
T18: Transport and automotive (ISIC 34 & 35)	2.50%	2.01%
T19: Furniture (ISIC 36)	5.00%	3.34%

Data source: National Institute of Statistics, Chile [60].

negative because increases in prices decrease the input used; and 3) as expected, cross-price elasticity ($\gamma_{F_iF_j}$) signs are equal (i.e. the sign of $\gamma_{F_iF_j}$ must be equal to the sign of $\gamma_{F_jF_i}$, for $i \neq j$). Regarding interactions among inputs, most are positive, indicating that they are substitutes. Thus, by increasing the price of an input and, consequently, decreasing its use, the amount of the crossed input (substitute input) increases. By contrast, we find complementary inputs such as those in the cross-price elasticity of energy and water. In terms of productivity (ρ), the mean EVW is equal to 8.071 [USD/m^3], with 6.4 [USD/m^3] and 9.6 [USD/m^3] as the lower and upper bounds of the 95% confidence interval.

Table 6 shows the EVW and water own-price elasticity by economic sector in dollars (from 2014) in columns 2 and 3, respectively. It also depicts the average water cost by sector in column 4. As shown, water own-price elasticity is significant for all sectors, except for leather products (ISIC 19) and other metals (ISIC 28). Considering only statistically significant values, water own-price elasticity ranges from a minimum (in absolute value) of -1.125 for wood products, except furniture (ISIC 20), to a maximum of -1.501 for machinery and equipment (ISIC 29). The EVW (ρ_W) ranges between 5.605 [USD/m^3] for paper (ISIC 21) to 17.881 [USD/m^3] for wood products, except furniture (ISIC 20).

It is well recognized in the literature that the water cost paid by industries is lower than the EVW [61]. Therefore, there is room to develop a price policy aimed at increasing the water price faced by firms without compromising competitiveness. According to our results, it is possible to develop such a policy in most sectors, with the exception of: meats, vegetables, and fats (ISIC 151), beverages and dairy (ISIC 152 & 155), chemicals (ISIC 24), rubber and plastic items (ISIC 25), and non-metallic minerals (ISIC 26); for all the other sectors, the EVW is greater than the water cost faced by firms.

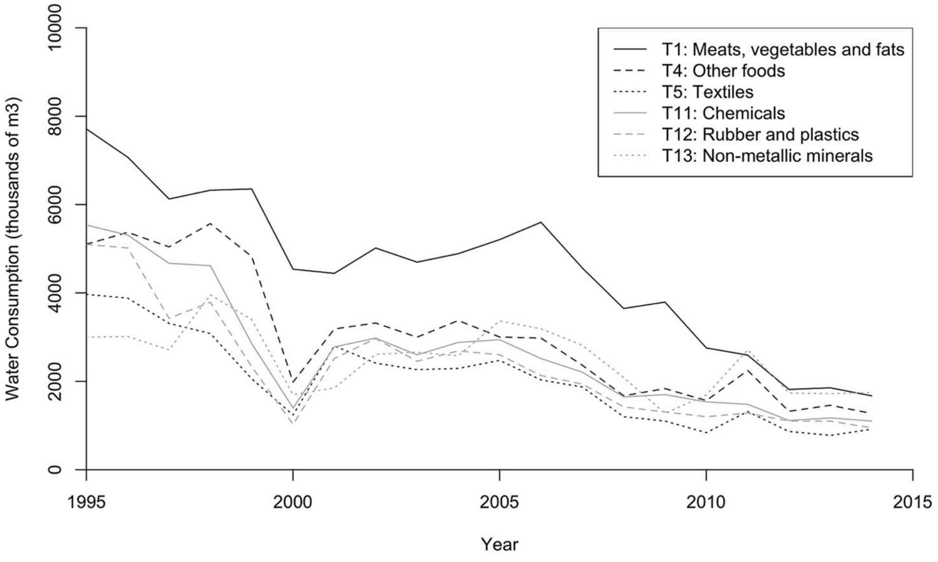

Fig. 1. Total Water Use by Sector (thousands of m^3 per year)
Data source: National Institute of Statistics, Chile [60].

Table 5
Inputs elasticities.

W	*K*	*L*	*E*	*M*	
σ_j	0.015***	0.030***	0.257***	0.079***	0.587***
	[0.012; 0.018]	[0.026; 0.035]	[0.245; 0.269]	[0.073; 0.085]	[0.577; 0.597]
ρ_j	8.071***	0.133***	20,072***	5.739***	1.627***
	[6.464; 9.678]	[0.114; 0.153]	[19,133; 21,011]	[5.309; 6.169]	[1.600; 1.655]
γ_{Wj}	−1.234***	13.661*	21.754***	−22.933$^+$	292.692
	[-1.426; −1.043]	[0.693; 26.629]	[13.166; 30.343]	[-48.710; 2.844]	[-271.02; 856.41]
γ_{Kj}	6.596*	−1.349***	11.514***	16.454**	263.129
	[0.458; 12.734]	[-1.445; −1.253]	[8.595; 14.434]	[4.802; 28.105]	[-286.72; 812.98]
γ_{Lj}	1.240***	1.359***	−2.321***	4.236***	16.466***
	[0.714; 1.766]	[0.984; 1.734]	[-2.691; −1.950]	[2.167; 6.305]	[11.261; 21.672]
γ_{Ej}	−4.267$^+$	6.340**	13.830***	−1.971***	43.053***
	[-9.313; 0.780]	[1.655; 11.025]	[6.971; 20.689]	[-2.294; −1.648]	[18.919; 67.188]
γ_{Mj}	7.301	13.593	7.207***	5.772***	−5.927***
	[-6.463; 21.064]	[-13.993; 41.180]	[5.033; 9.382]	[2.625; 8.919]	[-6.621; −5.233]

Confidence intervals (95%) in parentheses. $^+p < 0.1$, *p < 0.05, **p < 0.01, ***$p < 0.001$.

Our results on water own-price elasticity by sector are within the range of elasticity values reported by previous studies [13,42,43,49,51]. Among those studies that use a marginal productivity approach, our overall figure of water own-price elasticity (−1.234) is consistent with that reported by Ku and Yoo [12] in Korea and the upper bound reported by Wang and Lall [13] in China, but more elastic than the value reported by Revollo-Fernández et al. [17] in Mexico and Goldar [44] in India. Regarding EVW, in general, our results are in line with previous studies assessing differences between the EVW and price paid for it [1,12,13,17]. Our estimate (8.071 [USD/m^3]) is higher than those reported by Ku and Yoo [12] in Korea and by Wang and Lall [13] in China, as well as that reported by Angulo et al. [1] in Spain, which are 1.05 [USD/m^3], 0.37 [USD/m^3], and 4.9 [USD/m^3] respectively. However, our estimate is lower than that reported by Revollo-Fernández et al. [17] for Mexico, which is 19.4 [USD/m^3]. From a theoretical perspective, different EVW estimates are comparable through the theory of duality between cost and production. Compared with the value reported by Koopman et al. [62], who used a CGE model for the Netherlands, our estimate is twice as high, and compared with a programming model developed for Chile [63], our estimate is several times higher (8.071 [USD/m^3] vs. 0.399 [USD/m^3]).

6. Conclusions

Our results are useful for designing public policies based on both efficiency in water use and competitiveness of the industrial sector. For instance, our estimates suggest that the industrial sector in Chile could be targeted with a policy that aims to increase water price to promote sustainable use of water, as, in general, its price elasticity is high. However, such a policy could threaten industry

Table 6
Water value [USD/m^3] and water own-price elasticity.

Sector	ρ_W [USD/m^3]	γ_W	Average Cost [USD/m^3]
General	8.071*** [6.464; 9.678]	−1.234*** [-1.426; −1.043]	7.424
T1: Meats, vegetables, and fats (ISIC 151)	10.446*** [4.975; 15.916]	−1.182*** [-1.332; −1.033]	10.850
T2: Beverages and dairy (ISIC 152 & 155)	12.287* [1.936; 22.638]	−1.159*** [-1.302; −1.016]	15.495
T3: Milling industry and animal feed (ISIC 153)	14.891** [5.613; 24.169]	−1.139*** [-1.244; −1.034]	0.88
T4: Other foods (ISIC 154)	7.077*** [3.442; 10.713]	−1.270*** [-1.559; −0.981]	2.681
T5: Textiles (ISIC 17)	8.262** [2.165; 14.359]	−1.229*** [-1.484; −0.973]	2.724
T6: Clothing (ISIC 18)	7.989^{+} [-0.526; 16.504]	−1.237*** [-1.572; −0.902]	1.365
T7: Leather products (ISIC 19)	2.244 [-4.413; 8.901]	−2.732 [-16.812; 11.348]	1.487
T8: Wood products, except furniture (ISIC 20)	17.881*** [8.242; 27.519]	−1.125*** [-1.211; −1.040]	2.833
T9: Paper (ISIC 21)	5.605^{+} [-0.893; 12.103]	−1.356*** [-1.951; −0.760]	1.307
T10: Editing and reproduction (ISIC 22)	10.441** [2.930; 17.952]	−1.182*** [-1.354; −1.011]	1.607
T11: Chemicals (ISIC 24)	8.651** [2.266; 15.037]	−1.218*** [-1.451; −0.985]	16.009
T12: Rubber and plastic items (ISIC 25)	7.262** [2.652; 11.872]	−1.262*** [-1.534; −0.991]	13.451
T13: Non-metallic minerals (ISIC 26)	6.999^{+} [-0.323; 14.320]	−1.273*** [-1.669; −0.877]	26.948
T14: Base metals (ISIC 27)	6.745 [-2.853; 16.344]	−1.285*** [-1.773; −0.797]	31.057
T15: Other metals (ISIC 28)	2.302 [-2.454; 7.058]	−2.620 [-11.490; 6.251]	2.000
T16: Machinery and equipment (ISIC 29)	4.335 [-0.971; 9.641]	−1.501** [-2.434; −0.568]	19.378
T17: Other electric and precision products (ISIC 31–33)	9.001* [0.115; 17.887]	−1.210*** [-1.470; −0.949]	1.446
T18: Transport and automotive (ISIC 34 & 35)	13.326* [2.416; 24.235]	−1.150*** [-1.288; −1.011]	6.674
T19: Furniture (ISIC 36)	9.190** [2.314; 16.065]	−1.206*** [-1.412; −0.999]	1.881

Confidence intervals (95%) in parentheses. $^{+}$ $p < 0.1$, *p < 0.05, **p < 0.01, ***$p < 0.001$.

competitiveness in some specific sectors (e.g., meats, vegetables, and fats, and beverages and dairy) in which the EVW is lower than average water cost. This highlights the need to consider sustainability resource goals along with the industry's ability to absorb the change in water cost. From an industry perspective, the EVW can help inform cost–benefit analyses regarding implementation of water saving measures (reuse or recirculation) or a new water infrastructure. Moreover, it advises both public and private parties regarding the range in which water tariffs could be established.

This modeling framework entails limitations that need to be considered. For instance, because of aggregation considered (at the industry level), our results do not account for firm characteristics that are critical for policy purposes (firm location, conservation status of water source, among others). Because of the lack of available data, we could not assess the effect of water-saving measures on the EVW or the differences across regions.

In the context of increased water scarcity, and considering that water-related projects account for the largest share of public budgets, the inclusion of the EVW within policy assessment tools could provide policymakers with valuable information about the social consequences of water-related projects (infrastructure or institutional), not only for the industrial sector, but for all water users.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Felipe Vásquez-Lavín: Supervision, Writing - original draft, Conceptualization, Methodology. **Leonardo Vargas O:** Formal analysis, Investigation. **José I. Hernández:** Writing - original draft, Formal analysis, Software. **Roberto D. Ponce Oliva:** Project administration, Investigation, Writing - original draft, Writing - review & editing.

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Appendix A. Panel Descriptive Statistics

Table A
Descriptive Statistics

Period	%	Statistic	Q	L	E	M	K	W
1995	5.86%	Mean	3841.011	59.743	99.051	2262.474	1573.835	10216.474
		SD	7847.016	80.061	287.19	4843.423	3802.37	20145.897
		Min	30.166	1	0	0.364	0	0

(*continued on next page*)

Table A (*continued*)

Period	%	Statistic	Q	L	E	M	K	W
		Max	134363.109	730	4490.922	52651.812	35843.812	153692
1996	6.21%	Mean	3943.833	56.846	94.541	2160.225	1692.981	9418.561
		SD	8300.226	76.993	276.203	4628.748	4121.281	19245.213
		Min	9.06	1	0	0.064	0	0
		Max	129939.32	684	4138.477	52433.891	35790.273	152308
1997	5.98%	Mean	3805.435	56.613	74.682	2319.055	1735.897	8724.951
		SD	8023.882	78.280	210.030	5011.150	4221.035	17994.747
		Min	0.791	1	0	0.852	0	0
		Max	122735.234	731	4257.195	51762.973	36006.82	153966
1998	5.75%	Mean	3744.841	54.384	71.346	2270.428	1708.864	9541.181
		SD	8026.127	75.983	216.751	4904.859	4252.125	19118.888
		Min	0	1	0	0.15	0	0
		Max	134657.016	719	4445.274	52058.883	35880.492	152460
1999	5.63%	Mean	3700.709	50.743	68.958	2198.781	1687.154	7262.579
		SD	8655.257	72.448	219.486	4989.687	4189.902	16459.479
		Min	10.436	1	0	1.203	0	0
		Max	138037.328	708	4409.186	50683.449	35756.047	154193
2000	5.51%	Mean	4023.485	51.155	79.036	2495.781	1726.164	4128.668
		SD	9011.005	75.057	234.859	5600.695	4355.787	11960.494
		Min	17.124	1	0	1.092	0	0
		Max	123436.727	732	4207.41	52099.375	34857.684	149956
2001	5.41%	Mean	4004.035	49.996	88.56	2401.957	1659.226	6317.532
		SD	9504.429	77.467	263.323	5516.752	4112.783	15524.174
		Min	7.299	1	0	0.202	0	0
		Max	201183.516	727.000	4445.311	52275.727	35017.355	154406
2002	5.75%	Mean	4004.45	48.821	92.05	2407.942	1599.594	6998.388
		SD	9102.703	75.142	275.604	5525.654	4050.71	16420.84
		Min	6.517	1	0	1.071	0	0
		Max	108841.945	714	4242.841	52596.844	35035.258	152843
2003	5.70%	Mean	4198.476	49.37	98.774	2693.465	1613.554	6202.152
		SD	9159.155	74.434	286.141	5853.808	3979.608	15006.635
		Min	5.472	1	0	0	0	0
		Max	103554.633	726	4494.3	51520.453	35843.617	152361
2004	5.90%	Mean	4354.481	49.623	99.727	2807.395	1536.927	6452.336
		SD	9608.815	73.741	281.744	6057.636	3761.792	14929.983
		Min	5.086	1	0	0	0	0
		Max	169631.656	722	4273.884	51537.852	35446.105	154320
2005	5.80%	Mean	4535.214	53.033	117.076	2913.82	1545.329	6313.3
		SD	9746.428	80.814	331.355	6197.789	3899.378	15907.072
		Min	4.923	1	0	0.59	0	0
		Max	136990.578	706	4311.505	52022.465	35480.148	154372
2006	5.51%	Mean	4758.539	53.706	128.64	3057.325	1598.874	5991.989
		SD	10237.319	81.311	350.911	6447.251	3989.978	14966.416
		Min	2.906	1	0	0.657	0	0
		Max	141450.344	714	4395.606	52490.426	35897.895	152440
2007	5.24%	Mean	4915.75	55.386	141.531	3236.911	1608.715	5636.892
		SD	10279.389	85.272	365.443	6727.822	4040.563	14161.966
		Min	1.384	1	0	1.063	0	0
		Max	111057.016	725	4139.154	52547.113	35727.715	153558
2008	4.83%	Mean	5507.203	57.767	178.806	3489.189	1817.872	4306.921
		SD	10921.928	82.087	428.116	6851.444	4131.712	11462.31
		Min	4.642	1	0	1.664	0	0
		Max	152431.797	720	4334.635	52210.418	35136.625	147827
2009	4.56%	Mean	5433.479	57.854	180.746	3531.161	1882.963	4321.54
		SD	11190.632	85.065	440.945	7068.14	4252.637	12376.394
		Min	3.021	1	0	1.477	0	0
		Max	204872.797	731	4458.485	52453.375	35654.793	147884
2010	4.16%	Mean	5837.027	59.992	170.705	3801.056	1867.398	4048.527
		SD	11506.041	88.369	401.972	7396.641	4153.92	10378.972
		Min	5.924	1	0	0.05	0	0
		Max	157133.766	731	4285.08	51347.012	35757.293	137212
2011	3.89%	Mean	5286.27	55.318	152.301	3450.115	1629.33	5469.326
		SD	9776.54	81.056	356.656	6544.236	3664.047	13581.518
		Min	0.002	1	0	0.002	0	0
		Max	123241.727	732	4443.122	50741.625	33729.668	153807
2012	3.04%	Mean	5782.734	59.477	148.149	3777.806	1734.394	5161.721
		SD	10953.025	85.404	357.131	7228.174	3872.626	13149.571
		Min	4.057	1	0	0.882	0	0
		Max	137847.359	718	4374.97	52383.254	33685.590	152064
2013	2.68%	Mean	6091.249	60.111	145.444	3779.236	1916.761	5971.917

(*continued on next page*)

Table A (*continued*)

Period	%	Statistic	Q	L	E	M	K	W
		SD	11789.236	81.968	330.118	6968.165	4175.242	15534.762
		Min	2.241	0	0	0.594	0	0
		Max	196814.312	708	4437.687	50386.164	34475.797	151961
2014	2.60%	Mean	5574.992	61.692	150.262	3522.674	1436.59	5699.614
		SD	9841.823	85.028	380.340	6466.912	3454.989	15004.473
		Min	6.529	0	0	1.435	0	0
		Max	130321.32	711	4456.846	50505.516	35502.855	152302

Appendix B. Estimation Results

Table B

Estimation Results

Water coefficients		Other factors, squared variables and interactions without water		Interactions with water and Constant	
W*T2	0.163** (0.0500)	L	1.253*** (0.0525)	E*W	−0.00384^{+} (0.00200)
W*T3	0.0905*** (0.0203)	E	0.199*** (0.0312)	E*W*T4	−0.00341*** (0.000902)
W*T4	0.0395^{+} (0.0229)	K	0.0618*** (0.0183)	E*W*T17	−0.00539** (0.00201)
W*T5	0.0785*** (0.0176)	M	−0.326*** (0.0424)	K*W	0.00168 (0.00105)
W*T6	0.0780*** (0.0182)	L-squared	0.0401*** (0.00453)	K*W*T10	0.00192* (0.000922)
W*T7	0.0430* (0.0213)	E-squared	0.0163*** (0.00173)	M*W	−0.00769*** (0.00204)
W*T8	0.0557* (0.0219)	M-squared	0.0717*** (0.00259)	M*W*T1	0.00966*** (0.00132)
W*T9	0.0737*** (0.0180)	K-squared	0.00346*** (0.000528)	M*W*T2	−0.00599^{+} (0.00338)
W*T10	0.177*** (0.0449)	W-squared	0.00128** (0.000496)	M*W*T4	0.00783*** (0.00191)
W*T11	0.133*** (0.0299)	E*L	−0.00163 (0.00464)	M*W*T10	−0.00907** (0.00349)
W*T12	0.0767*** (0.0174)	K*L	0.0145*** (0.00285)	M*W*T11	−0.00413* (0.00190)
W*T13	0.0762*** (0.0185)	M*L	−0.115*** (0.00563)	L*W	0.00966*** (0.00241)
W*T14	0.0757*** (0.0193)	K*E	0.00240 (0.00175)	L*W*T1	−0.0125*** (0.00213)
W*T15	0.0677*** (0.0169)	M*E	−0.0325*** (0.00393)	L*W*T4	−0.00921*** (0.00229)
W*T16	0.0714*** (0.0169)	M*K	−0.0156*** (0.00217)	L*W*T7	0.00714^{+} (0.00398)
W*T17	0.132*** (0.0251)			L*W*T8	0.0117*** (0.00296)
W*T18	0.0877*** (0.0193)			Constant	9.874*** (0.928)
W*T19	0.0802*** (0.0171)				
		N	71,908		
		σ_u	0.353		
		σ_ε	0.223		
		ρ	0.714		
		F Statistic	714.92***		
		R-squared	0.951		

We omitted year controls. Variables in logarithm. Standard errors in parentheses. $^{+}$ $p < 0.1$; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

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