The determinants of groundwater demand for industrial uses.

Application to an urban environment

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Abstract: Designing policies to contribute to the sustainability of water resources requires an appropriate understanding of the use of the different sources of water and their determining factors. This work analyses the determinants of the demand for water captured underground for the industries (self-supply) in an urban environment with availability of water from the municipal network (publicly-supply). We apply a hurdle model using microdata for companies located in Zaragoza (Spain). We observe that self-supplied and publicly-supplied water are substitutes, so pricing policies focusing only on the latter have limited effectiveness for water conservation, confirming the need for integrated management. The variable cost of self-supply does not determine groundwater demand since there is no a groundwater volumetric tariff in Spain.

Key words: groundwater, hurdle model, integrated water management, self-supply, water demand
1. Introduction

Surface water (rivers, lakes, canals, etc.) and groundwater (water stored beneath the surface of the land in the porous geological formations known as “aquifers”) are closely related. This means that we need integrated water management policies which take into account all water masses (surface and groundwater) and the relationships between them, in order to protect their ecological health, in line with the proposals of the Water Framework Directive (European Commission 2000). This directive pays special attention to groundwater, which had been hardly considered up until then. Its goal is to reach good quantitative and chemical status, establishing targets such as regenerating all groundwater masses and ensuring equilibrium between extraction and inflow.

We focus on groundwater captured by industries that, together with agriculture, are the main users of water from the aquifers. Groundwater intake is particularly relevant for supplying industrial activities (including manufacturing and service sectors), as companies use water for different purposes, some of which do not require water of high quality. In these cases, companies do not need drinking water supplied through the municipal water supply system (publicly-supplied water) and they can use alternative sources, such as water recirculation (a procedure which lets water be used more than once in the production process) or self-supply (water captured directly using the company’s own facilities and equipment), some of which will be groundwater intake.

4,273.29 Hm$^3$ of water was used by industrial activities in Spain in 2012 (INE 2015). 16.64% came from publicly-supplied water, and the remaining 83.36% was captured by the companies themselves. The volume of self-supplied water (3,562.12 Hm$^3$) comes from various sources: surface water (67.44%), groundwater (29.68%), and seawater or other water resources (2.88%). Although groundwater is not the main source of self-supplied water, it has increased very fast in recent years (13.86% from 2000 to 2012).

The large share of self-supplied water in the total amount of water used by industrial activities contrasts with the low attention that the literature has given to this source. In fact, we have found only two studies which estimate the demand for self-supplied water in the industry (Renzetti 1993; Reynaud 2003), although many authors insist on the importance of self-supply in this sector (among others, De Rooy 1974; Ziegler and Bell 1984; Renzetti 1988, 1992).
The scarcity of this kind of studies is mainly due to lack of information, a consequence of the difficulty of monitoring self-supply. Also it is difficult to estimate the cost of self-supply water accurately because we need to consider the costs of investment, extraction and treatment assumed by the users, for which statistics are rarely available.

In general, the literature focuses on estimating demand for the different water sources (publicly-supplied, self-supply or recirculation water), implicitly assuming that the source of supply is determined exogenously. This is the case of Reynaud (2003), who estimate self-supplied water demand for 55 industrial and services companies located in France.

However, in reality, a considerable number of companies can choose their water sources and how much to use from each one. The situation can be proxied by a two-stage process where in the first stage the user decides whether to use a given source (for example, self-supply), whereas in the second stage decides on the volume of water to capture. This strategy is very common in other fields like health economics, consumption analysis, or to analyse the water recirculation decision (Bruneau and Renzetti 2014; Bruneau et al. 2010; Féres et al. 2012). However, as far as we know, in the case of self-supplied water we can only cite Renzetti (1993), who estimate self-supplied water demand in the U.S. using a survey of more than 2,000 manufacturing firms.

The purpose of this study is to examine the factors influencing the choice of the industrial companies between the water from the municipal supply network and the groundwater self-supplied, and to estimate the groundwater demand for industrial activities. We based our study on a sample of 2,893 companies located in Zaragoza (Spain), 44 of which use self-supplied water. We use a two-part hurdle model, which allows us to obtain the marginal effect of the different factors on the probability of self-supply and on the conditional and unconditional volume of self-supplied groundwater. The study is particularly relevant because it provides additional evidence to the scarce literature devoted to the relationship between publicly-supplied and self-supplied water, it explores the differences in self-supply between the manufacturing and the services companies, and it considers location of companies as a key factor in accessing groundwater sources, a point that has not hitherto been taken into account in the previous literature.
After this introduction, Section 2 presents the case study. Section 3 describes our data. Section 4 introduces the model and the corresponding estimation techniques. The results are discussed in Section 5. Finally, Section 6 presents our main conclusions.

2. The case study

The municipality of Zaragoza has the fifth largest population in Spain. Its production structure is similar to the national average, characterized by the dominance of the services sector (84% of employment), followed by manufacturing (10%), construction (5%) and farming (1%), according to data for 2012 from the Aragonese Statistics Institute (IAEST 2015).

The municipality is located in the centre of the Ebro river basin, on the mouths of two tributaries, the Gallego and the Huerva. The management and administration of the different water masses in this basin is the responsibility of the Ebro Hydrographic Confederation (henceforth, CHE), a public agency dependent on the Spanish government. The drinking water supply in the municipality has traditionally come from the Imperial Canal of Aragon, which runs alongside the Ebro, the source of its water, although since 2010 it has been supplemented with water channelled from the Pyrenees. The drinking water supply and wastewater services (sanitation and treatment) are the responsibility of Zaragoza City Council. Both services are taxed by a binomial tariff system which combines a fixed and a variable charge (volumetric charge). The fixed charge depends on the calibre of the meters which measure the water supplied to each user and the variable charge depends on the volume of water recorded in these meters and is obtained by applying an increasing block tariff.

There are two large groundwater masses underlying the municipality of Zaragoza: the Ebro-Zaragoza alluvial aquifer and the River Gallego alluvial aquifer (see Figure 1).

These two groundwater masses, known as the Zaragoza aquifer, provide the municipality with an abundant water source, easily accessed using wells only about twenty meters deep. The extracted water has a constant temperature and chemical composition and is turbidity-free, so it does not usually need any physical or chemical treatment before use. It is a resource with almost completely guaranteed availability and, for many users, at a lower cost than publicly-supplied water. The use of this resource is not subject to a supply tariff, unlike publicly-supplied water, it is only subject to a one-off administrative fee linked to the licensing procedure for groundwater extraction (the 1985 Spanish Water Act -España 1985- declared the use of groundwater subject to government license) and designed to cover the costs of the
procedure. This means that users bear only the cost of extraction (license fee, well drilling, pumping equipment and pumping water) and the municipal wastewater tariff if the self-supplied water is discharged into the municipal sanitation network.

FIGURE 1. Location of the Ebro-Zaragoza and Gallego alluvial aquifers.
Source: By the authors, based on CHE (2008a, 2008b)

3. Data

We have a sample of 2,893 companies located in Zaragoza, over the aquifer. For each company we observe the following data in 2012: the volume of publicly-supplied water and its fixed and variable cost, obtained from data provided by the Zaragoza City Council; the volume of self-supplied groundwater, obtained by combining information from the City Council and from the CHE; the fixed and variable cost of self-supplied, calculated from data provided by the CHE; and the value of production and the sector of activity, from the database “Iberian Balance sheet Analysis System” (henceforth, SABI) (http://informa.es/en/financial-solutions/sabi).

The data on the volume of publicly-supplied water were obtained based on records of the water meters installed in each company by the municipal water service. The data on the volume of self-supplied groundwater were obtained by means of two complementary procedures: the first one, as a difference between the volume discharged into the municipal sanitation network and the volume captured from the municipal supply network, based on
information from the meters installed by the municipal water service; the second one, as the volume authorised in the license to use groundwater, based on records from the CHE. With the data from the City Council we monitor the companies discharging used self-supplied water into the municipal sanitation network, and with the data from the CHE we monitor the companies that do not, for example, because they discharge it into the rivers channels or into the aquifer itself. Using both types of information, it was possible to build a dataset of companies who obtained water through self-supply, since no company of our sample self-supplies surface water according to the CHE (this is mainly due to the poor quality of this source of water and its reduced flow in many months of the year).

Table 1 offers additional detail in relation to companies that use self-supplied and publicly-supplied water. 1.55% of the companies in our sample capture water from the aquifer, but the self-supplied water used by these firms represent 45.00% of total water used by the industrial sector. In the manufacturing sector, the percentage of companies is 7.48% (representing 61.58% of total water volume), while in the services sector the percentage of companies is lower than 1% (representing 39.82% of water use). We also observe that companies using groundwater self-supply use a much higher total volume of water per euro of production (5.18 l/€) than companies using only publicly-supplied water (0.75 l/€).

For companies using self-supply, 80.65% of the water they consume is self-supplied. Again, this percentage is higher in manufacturing companies (87.93%) than in services (77.54%). However, the volume of self-supplied water per euro of production is greater in companies in the services sector (4.85 l/€) than in manufacturing (4.17 l/€).

To calculate the cost of self-supplied groundwater, we first need information on the depth of the aquifer at the location of the company and on the flow rate of self-supplied water. From the geographical coordinates for each company, taken from SABI, the Geological and Mining Institute of Spain (henceforth, IGME), in collaboration with the CHE, gave us the information on aquifer depth, based on IGME (2005) and Moreno et al. (2008). The flow rate of each company’s self-supplied water was estimated based on their volume of self-supplied water, assuming that they pump 16 hours a day, according to the standard of the Spanish Ministry of Agriculture, Food and the Environment (MAGRAMA 2009) for water captured by industries.
Table 1 Main magnitudes relating to water consumption. Average per company for 2012

<table>
<thead>
<tr>
<th></th>
<th>Aggregate</th>
<th>Manufacturing</th>
<th>Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of companies with self-supply</td>
<td>44</td>
<td>24</td>
<td>20</td>
</tr>
<tr>
<td>No. of companies without self-supply</td>
<td>2,849</td>
<td>297</td>
<td>2,552</td>
</tr>
<tr>
<td>Percentage of companies with self-supply (%)</td>
<td>1.55</td>
<td>7.48</td>
<td>0.78</td>
</tr>
</tbody>
</table>

For all companies:

- Quantity of publicly-supplied water (m³): 366.78, 550.38, 343.86
- Quantity of self-supplied water (m³): 300.12, 882.07, 227.49
- Total water consumed (m³): 666.89, 1,432.45, 571.35
- Percentage of self-supplied water (%): 45.00, 61.58, 39.82
- Quantity of self-supplied water per € of production (l/€): 0.75, 0.30, 0.81
- Quantity of publicly-supplied water per € of production (l/€): 0.75, 0.30, 0.81

Companies with self-supply:

- Quantity of publicly-supplied water (m³): 4,735.19, 1,619.90, 8,473.55
- Quantity of self-supplied water (m³): 19,732.64, 11,797.66, 29,254.62
- Total water consumed (m³): 24,467.84, 13,417.56, 37,728.17
- Percentage of self-supplied water (%): 80.65, 87.93, 77.54
- Quantity of self-supplied water per € of production (l/€): 4.47, 4.17, 4.85
- Quantity of publicly-supplied water per € of production (l/€): 0.71, 0.18, 1.35

Companies without self-supply:

- Quantity of publicly-supplied water (m³): 299.31, 463.96, 280.15
- Quantity of publicly-supplied water per € of production (l/€): 0.75, 0.31, 0.80

The average fixed cost of self-supplied groundwater (AFCS) was estimated according to MAGRAMA (2009), as follows:

\[
AFCS = \frac{F + CC + CM + OMC}{VS} \tag{1}
\]

where \(F\) is the one-off administrative fee that users must pay when processing the license to use groundwater, assumed to be valid for 20 years according to España (1960); \(CC\) is the cost of well construction (drilling, laying pipes and finishing the well), supposing this to be amortized over 20 years; \(CM\) is the cost of investment in machinery (pumping equipment), to be redeemed in 10 years; \(OMC\) is operating and maintenance costs (representing 2% of the investment cost); and \(VS\) is the annual volume of water captured from the aquifer.

We calculated the well construction costs based on the depth of the aquifer, while the cost of the pumping equipment was obtained according to its market price, depending on the
power needed for the pumps. The power was estimated using the approximation of Custodio and Llamas (1983):

\[ P = \frac{h \times Q}{r \times 75} \]  

(2)

where \( P \) is the power (in metric horsepower); \( h \) is the manometric height (in metres), which we make equal to the aquifer depth; \( Q \) is the flow rate (in litres per second); \( r \) is pump performance, considered to be 70% in all cases \((r = 0.70)\); and the constant 75 in the denominator enables us to go from kilogram-metres per second to metric horsepower.

The average variable cost of self-supplied groundwater \((AVCS)\) is the cost of the energy needed to capture a cubic metre of water, plus, if applicable, the cost of the municipal sanitation charge for companies which discharge self-supplied water into the municipal sanitation network.

We calculated the energy cost per cubic meter of water extracted \((UEC)\) according to Custodio and Llamas (1983), as follows:

\[ UEC = 0.002726 \frac{h \times k}{r} \]  

(3)

where \( h \) is the manometric height (in metres); \( k \) is the approximate price of energy \((\text{€}/\text{Kwh})\) for the average price of electricity in Spain (Eurostat 2016); \( r \) is pump performance (again, set at 70%); and the constant 0.002726 is energy consumption (Kwh) incurred by raising one \( m^3 \) of water one meter.

For those companies that only use publicly-supplied water, we need to know the fixed and variable average cost of self-supplied water that they would face up if they decided to capture water from the aquifer. So, for these companies, we have calculated \( AFCS \) and \( AVCS \) supposing that, if they decided to self-supply, they would capture the same percentage of self-supplied water as the average for the self-supplying companies.

The average fixed cost of publicly-supplied water \((AFCP)\) is obtained by dividing the municipal fixed charge of the publicly-supplied water supply and sanitation bill by the volume of publicly-supplied water captured. In turn, we calculated the average variable cost of publicly-supplied water \((AVCP)\) by dividing the municipal variable charge of the publicly-supplied water and sanitation bill by the intake volume.
The same as before, we need to estimate the fixed and variable average cost of publicly-supplied water that would face up those companies that only use self-supplied water, if they decided to use the public water network. In these cases we have estimated the corresponding \( AFCP \) and \( AVCP \) assuming that, if they decided to publicly-supply, they would captured the same volume in publicly-supplied water as they do in self-supply.

Finally, SABI contains information about the value of production and the sector of activity each company belongs to. Based on the last item, we generate the corresponding set of dummy.

Table 2 presents some descriptive data of the main variables that we are going to use in our model; we distinguish between all the companies (aggregate) and self-supplying companies. We confirm that the volume of production of the latter group is eight times higher than the sample average. Besides, more than half of the companies capturing water from the aquifer belong to the manufacturing sector, while only 11% of the companies in the sample in fact belong to this sector.

**Table 2 Average values of variables for the case study. 2012**

<table>
<thead>
<tr>
<th>Description</th>
<th>Aggregated sample</th>
<th>Self-supplying companies</th>
</tr>
</thead>
<tbody>
<tr>
<td>( VS ) Volume of self-supplied groundwater (m³)</td>
<td>300.12 (7,717.87)</td>
<td>19,732.64 (60,114.48)</td>
</tr>
<tr>
<td>( DS ) =1 if the company self-supplies; 0 if not</td>
<td>0.0155 -</td>
<td>1.00 -</td>
</tr>
<tr>
<td>( AFCS ) Average fixed cost of self-supplied groundwater (€/m³)</td>
<td>34.14 (262.84)</td>
<td>7.61 (29.58)</td>
</tr>
<tr>
<td>( AVCS ) Average variable cost of self-supplied groundwater (€/m³)</td>
<td>0.68 (0.27)</td>
<td>0.82 (0.65)</td>
</tr>
<tr>
<td>( AFCP ) Average fixed cost of publicly-supplied water (€/m³)</td>
<td>4.52 (30.30)</td>
<td>16.69 (71.85)</td>
</tr>
<tr>
<td>( AVCP ) Average variable cost of publicly-supplied water (€/m³)</td>
<td>1.38 (0.59)</td>
<td>2.95 (0.32)</td>
</tr>
<tr>
<td>( Y ) Value of production (thousands of €)</td>
<td>1,503.31 (10,500.0)</td>
<td>12,100.0 (20,500.0)</td>
</tr>
<tr>
<td>( DM ) =1 if the company belongs to the manufacturing sector; 0 if not</td>
<td>0.11 -</td>
<td>0.55 -</td>
</tr>
</tbody>
</table>

Note: Standard deviation appears in brackets.

The average fixed cost of water captured from the aquifer is substantially lower for self-supplying companies (€7.61/m³) than that for the aggregate (€34.14/m³). In contrast, the average variable cost of this source of water does not vary a great deal between both groups of companies; the reason may be that the depth to reach the aquifer is very similar for the self-supplying companies and for the group of not self-supplying companies (16.50 m and 19.91 m, respectively).
As for the cost of publicly-supplied water, it is clear that self-supplying companies face considerably higher price than companies only using publicly-supplied water. This is because the self-supplying companies capture a larger volume of water and are doubly penalized: the fixed charge increases according to the diameter of the pipes connecting to the network whereas the variable charge increases with consumption.

4. Model specification and econometric estimation

Our approach is based on the assumption that companies choose their sources of supply (publicly or self-supplied water) and the amount of each one in order to minimize the cost of production. The decision is taken in steps so that, first, the company decides whether to self-supply or not, and if it does, then decides the volume of water extracted from the aquifer.

The explained variable is the quantity of self-supplied water, in logs as indicated below, which has 2,849 zeros and 44 strictly positive values (see Table 1). Each zero reflects a decision of the respective company, so this is not a case of censored data; contrary, each zero contains valuable information about the decision to not self-supply. Conditional to a positive answer, the information on the quantity pumped from the aquifer must come from the 44 self-supplying companies. In sum, this is a classical corner solution outcome where a large amount of companies in the sample decided not to self-supply.

We are going to tackle this problem using a hurdle or two-tiered model (Wooldridge 2001), especially adequate when, as in our case, there are exclusion variables shaping the decision process (in our case, the average fixed costs). In order to pump water from the aquifer, each company must install the necessary infrastructure to ensure a regular flow of water, which often means a strong investment. For the company, this is a long run fixed cost. Once the company decides to take on that investment, the volume of groundwater pumped each season may respond to other short-run factors, like the volume of activity or the relative prices of publicly vs self-supplied water.

The selection equation in the two-part model described before is as usual a probit equation (other options are possible, see Cameron and Trivedi 2005):

\[
\begin{align*}
DS_i &= 1 \quad \text{if } h_i^* > 0 \\
DS_i &= 0 \quad \text{if } h_i^* \leq 0
\end{align*}
\]

with

\[
h_i^* = x_i' \beta_1 + \epsilon_{1i} \quad i = 1, 2, \ldots, N
\]  

where:
\[ x_1' \beta_1 = \beta_{1,1} + \beta_{2,FUCS} \ln AFCS_i + \beta_{1,AVCS} \ln AVCS_i + \beta_{1,FCP} \ln ACP_i + \beta_{1,AVCP} \ln AVCP_i + \beta_{1,\gamma} \ln Y_i + \beta_{1,di} DM_i \]

and where \( DS_i \) is a binary indicator of positive self-supplied groundwater; \( h_i^* \) is an unobservable variable representing the difference in minimization cost provided by the two options (i.e., self-supply or publicly-supply), which depends on a set of \( k_1 \) first stage factors, \( x_{1i} \) (the variables included are described in Table 2); \( N \) is the number of companies in the sample. Let us note that, for the probit case, \( Pr(DS_i = 1|x_{1i}) = \Phi(x_1' \beta_1) \), being \( \Phi(-) \) the normal cumulative distribution function which is the distribution assumed for \( \varepsilon_{1i} \).

For the quantity equation of the second stage, we prefer a double logarithmic model to prevent from negative estimates (other functional forms were discarded based on misspecification test), so that:

\[ \ln VS_i = x_2' \beta_2 + \varepsilon_{2i}; \quad \varepsilon_{2i} \sim N(0, \sigma_2^2) \]  \hspace{1cm} (5)

where:

\[ x_2' \beta_1 = \beta_{2,1} + \beta_{2,AVCS} \ln AVCS_i + \beta_{2,AVCP} \ln AVCP_i + \beta_{2,\gamma} \ln Y_i + \beta_{2,di} DM_i \]

and where \( VS_i \) is the quantity of pumped water conditioned to \( DS_i = 1 \); and \( x_{2i} \) is another set of \( k_2 \) explicative factors ruling in the second stage (also described in Table 2).

The ML estimation of (4) and (5) depends crucially on the relation between the error terms \( \varepsilon_{1i} \) and \( \varepsilon_{2i} \). If they are dependent, the decisions of self-supply and the quantity of self-supplying are related, after controlling for the other factors, which results in a selection bias in the quantity equation that must be taken into account; this is the purpose of the inverse of the Mill’s ratio (IMR from now on), or non-selection hazard, which characterizes the Heckman (1979) model. In contrast, if the error terms of (4) and (5) are not dependent, we have the Cragg (1971) model. In fact, the comparison between to two models is reduced to testing for the significance of the IMR in the corresponding Heckman equation, which is the nesting model:

\[ \ln VS_i = x_2' \beta_2 + \lambda \frac{\phi(-x_1' \beta_1)}{1 - \Phi(-x_1' \beta_1)} + \eta_i \]  \hspace{1cm} (7)
where \( \phi(.) \) and \( \Phi(.) \) are the standard normal density and distribution functions; \( \frac{\phi(-x'_1 \beta)}{1-\Phi(-x'_1 \beta)} \) is the IMR; and \( \eta_i \) is a random term assumed to be white noise. If \( \lambda = 0 \) we have the Cragg model whereas if \( \lambda \neq 0 \) we have Heckman. In a ML framework, the comparison amounts to a Likelihood Ratio, LR test. Main results in relation to estimation and testing appear in Table 3.

Table 3 Two-tiered model. Results of estimation

<table>
<thead>
<tr>
<th>Selection equation</th>
<th>Quantity equation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heckman Model</td>
</tr>
<tr>
<td>Constant</td>
<td>-5.2874 (0.97)</td>
</tr>
<tr>
<td>lnAFCS</td>
<td>-0.3013 (0.12)</td>
</tr>
<tr>
<td>lnAFCP</td>
<td>0.5579 (0.11)</td>
</tr>
<tr>
<td>lnAVCS</td>
<td>-0.5203 (0.16)</td>
</tr>
<tr>
<td>lnAVCP</td>
<td>2.5217 (0.32)</td>
</tr>
<tr>
<td>lnY</td>
<td>0.1055 (0.07)</td>
</tr>
<tr>
<td>DM</td>
<td>0.5743 (0.24)</td>
</tr>
<tr>
<td>Loglik</td>
<td>-68.4664</td>
</tr>
<tr>
<td>LR (k)</td>
<td>318.75 [0.0000]</td>
</tr>
<tr>
<td>LR(IMR)</td>
<td>0.39 [0.5316]</td>
</tr>
</tbody>
</table>

Notes: LR(k) means the Likelihood Ratio test that the regressors, other than the constant, are not significant; they are distributed as a Chi-squared with k degrees of freedom; k is the number of regressors in the equation other than the constant. LR(IMR) means the Likelihood Ratio test that the inverse of Mill’s ratio is not significant in the quantity equation of Heckman model; it is distributed as a Chi-squared with 1 degree of freedom. Estimated standard deviation in brackets; p-value in square brackets; ln in front of the variable means log transformation of the corresponding variable.

 Apparently, the selection equation works better than the quantity equations. All the regressors are significant in the first case at the usual 5% level, with the exception of the output \( (Y) \), and the pseudo \( R^2 \) is quite acceptable, 0.70. Let us note that the exclusion variables, the average fixed cost of self-supply \( (AFCS) \) and publicly-supply \( (AFCP) \), are highly significant and appear with the correct sign. The analysis of the quantity equations reveals that the selection bias is not a problem for this case, given that the LR(IMR) does not reject the null that the associated lambda parameter is zero. So the Cragg model is the preferred option. The \( R^2 \) of the equation is rather low, 0.25, and only two regressors are statistically significant at the usual 5%, the output \( (Y) \) and the average variable cost of the publicly-supplied groundwater \( (AVCP) \). However, the misspecification tests (Breusch-Pagan of heteroscedasticity, 0.13 with a p-value
of 0.72; Ramsey of functional form, 1.55 with a p-value of 0.22; and Jarque-Bera of normality, 1.21 with a p-value of 0.55) do not detect problems in the Cragg equation.

Using these estimates, it is quite simple to quantify different measures of interest for us, such as:

- The impact of variable $x_h$ on the probability of self-supply:

$$\frac{\partial P_i}{\partial x_{hi}} = \frac{\partial P(DS_i > 0)}{\partial x_{hi}} = \phi (x_i' \beta) \beta_{1h}$$

(11)

- The effect of variable $x_h$ on the conditional log of the volume of self-supplied groundwater (note that this conditional effect coincides with the parameters estimated in Table 3 for the Cragg model):

$$\frac{\partial E(\ln VS_i | DS_i > 0)}{\partial x_{hi}} = \beta_{2h}$$

(12)

- The effect of variable $x_h$ on the unconditional log of the volume of self-supplied groundwater:

$$\frac{\partial E(\ln VS_i)}{\partial x_{hi}} = \frac{\partial P(DS > 0)}{\partial x_{hi}} E(\ln VS_i | DS_i > 0) + \frac{\partial E(\ln VS_i | DS_i > 0)}{\partial x_{hi}} P(DS_i > 0)$$

(13)

The corresponding estimates, measured at the average sampling values of the regressors, appear in Table 4. As we specify a double logarithmic model, the marginal effects presented are interpreted as elasticities.
### Table 4 Marginal effects on the probability of self-supply and on the unconditional volume of self-supplied groundwater

<table>
<thead>
<tr>
<th></th>
<th>On the probability of self-supply water</th>
<th>On the unconditional volume of self-supplied water</th>
</tr>
</thead>
<tbody>
<tr>
<td>( AFCS )</td>
<td>-0.0036</td>
<td>-0.04462</td>
</tr>
<tr>
<td></td>
<td>(-0.00817; 0.00079)</td>
<td>(-0.05475; -0.03449)</td>
</tr>
<tr>
<td>( AFCP )</td>
<td>0.00725</td>
<td>0.31769</td>
</tr>
<tr>
<td></td>
<td>(0.00330; 0.01121)</td>
<td>(0.27774; 0.35764)</td>
</tr>
<tr>
<td>( AVCS )</td>
<td>-0.00694</td>
<td>-0.00725</td>
</tr>
<tr>
<td></td>
<td>(-0.01695; 0.00301)</td>
<td>(0.00330; 0.01121)</td>
</tr>
<tr>
<td>( AVCP )</td>
<td>0.0350</td>
<td>0.1422</td>
</tr>
<tr>
<td></td>
<td>(-0.00543; 0.07243)</td>
<td>(0.00543; 0.07243)</td>
</tr>
<tr>
<td>( Y )</td>
<td>0.00141</td>
<td>0.01422</td>
</tr>
<tr>
<td></td>
<td>(-0.00052; 0.00335)</td>
<td>(0.00141; 0.00335)</td>
</tr>
<tr>
<td>( DM )</td>
<td>0.00742</td>
<td>38.8965*</td>
</tr>
<tr>
<td></td>
<td>(-0.00112; 0.01561)</td>
<td>(-3.87810; 81.67114)</td>
</tr>
</tbody>
</table>

In brackets, the 95% confidence interval obtained for each estimated effect after bootstrapping the corresponding equations; number of bootstraps 1,000. *DM is a dummy variable, so this effect was obtained as the difference in the expected volume of water self-supplied in the unconditional model, evaluated at the average values, between the manufacturing and the non-manufacturing companies.

### 5. Discussion of results

The results obtained in the selection equation of Table 3 indicate that an increase of the cost of investment in self-supply (\( AFCS \)) and the average variable cost of captured groundwater (\( AVCS \)) reduces the probability of self-supplying water from the aquifer. This result coincides with Renzetti (1993) for the case of self-supplied water, and it is also consistent with the results obtained in the literature for the recirculation decision (Bruneau and Renzetti 2014).

In contrast, an increase in the average fixed cost of access to the public supply network (\( AFCP \)) or its average variable cost (\( AVCP \)) increases the probability of self-supplying groundwater, as a way of reducing the cost of water. Once again, we are in line with Renzetti (1993) for the case of self-supplied water (although in his study these variables are not significant), and with the results obtained for water recirculation by Féres et al. (2012) and Bruneau and Renzetti (2014).

Also, the probability of self-supply is positively influenced by the volume of production, although this effect is weakly significant (with a p-value of 0.07). In this point, the literature is not conclusive: Renzetti (1993) obtained a low significant p-value for this variable, while
Bruneau et al. (2010), Féres et al. (2012) and Bruneau and Renzetti (2014) conclude that the production level is a determining factor in the recirculation decision. Our conclusion, in this case, is that the decision to self-supply depends only weakly on the volume of production; other factors appear to be more decisive.

Companies in the manufacturing sector are more likely to capture water from the aquifer compared to companies in the services sector. This result is new in the literature and may be related to the predominant use of water in each sector. Thus, while manufacturing companies need large volumes of water for tasks which do not require high quality (cooling, washing, transporting raw materials, etc.), most service companies tend to use water for sanitary or personal care purposes requiring drinking water. Another reason is location. Manufacturing companies tend to be located in industrial districts on the outskirts of cities, in single-use buildings with direct access to the subsoil, while most service companies locate in the city centre, in mixed-use buildings without direct access to the subsoil (on upper floors of multi-story buildings or in lower floors of buildings with underground garages).

The results regarding the quantity equation of Table 3 show that the average variable cost of self-supplied groundwater \( (AVCS) \) does not influence the volume of self-supplied water, although its coefficient is negative as expected. Renzetti (2003) and Reynaud (2003) also conclude that this variable is hardly significant in the case of self-supplied water. However, the same variable appears to be very relevant in the case of recirculated water, with a negative impact on the volume of processed water (Renzetti 1988; Renzetti 1992; Dupont and Renzetti 1998; Bruneau and Renzetti 2014; Bruneau et al. 2010).

The literature usually attributes the lack of significance of price elasticities to the small unit cost of water and its low share in the cost structure of the company (Reynaud 2003). In our case, for the group of self-supplying companies, the average variable cost of self-supplied groundwater is 0.82 €/m³ which represents 0.32% of total costs. Additionally, if a company has decided to take on the necessary investments to capture water from the aquifer, it is not likely to be discouraged because of a moderate increase of the \( AVCS \), especially, as in our case study, where the energy cost needed to capture a cubic meter of water is very low compared to the price of publicly-supplied water.

On the contrary, the average variable cost of publicly-supplied water \( (AVCP) \) does determine the volume of self-supplied water. As expected, an increase in the price of publicly-
supplied water fosters its substitution by self-supplied groundwater. The substitutability of water inputs is not an unusual result in the specialized literature when compared, for example, with the case of recirculated vs intake water (Bruneau et al. 2010; Féres et al. 2012; Renzetti 1988; Renzetti 1992; Dupont and Renzetti 2001; Dupont and Renzetti 1998); on the contrary, Reynaud (2003) concludes that publicly-supplied and self-supplied water are complementary, although the elasticities obtained in that case are not significant.

The use of self-supplied water is also positively influenced by the level of production, indicating that larger companies capture larger volumes of groundwater. This result is in line with previous literature (Renzetti 1993; Reynaud 2003; Bruneau et al. 2010; Féres et al. 2012; Renzetti 1988; Dupont and Renzetti 2001; Dupont and Renzetti 1998); and also in the literature focusing on the demand for publicly-supplied water (see, for example, Renzetti 2002; Worthington 2010).

The coefficient of the dummy manufacturing variable is negative but not significant, indicating that, although manufacturing companies are more likely to capture water from the aquifer (as shown in the selection equation), once they have decided to self-supply, the sector of activity does not determine the volume of intake groundwater. In fact, most service companies only use publicly-supplied water, but those that decide to self-supply utilize groundwater for uses requiring large volumes, such as cooling or filling swimming pools. Let us note that the negative sign of this dummy may be influenced by the fact that the manufacturing self-supplying companies are smaller than similar companies in the service sector, with lower production values (11.8 million euros in manufacturing vs 12.5 million euros in services), and smaller numbers of workers (63 in manufacturing against 116 in services).

The marginal effects shown in Table 4 corroborate the importance of the exclusion variables introduced in the decision process. The first column indicates that a 1% increase in AFCS and AVCS reduces the probability of self-supply by -0.0036% and -0.00694%, respectively. In contrast, a 1% increase in AFCP, AVCP and in the production level increases the probability of self-supply by 0.00725%, 0.03350%, 0.00141% respectively; also, the probability of self-supply is 0.00742% higher for manufacturing companies. Notice that only the marginal effects associated to the average fixed cost of publicly-supply water (AFCP) is significant at the usual level of 5%; the average fixed cost of self-supply (AFCS), the output (Y), and the sector (DM) are 10% significant. Finally, it is evident that the impacts are small, but this
is not weird in the literature (see, for example, Deressa et al. 2011; Beltran et al. 2013; Raggi et al. 2013).

As said, the conditional effects of these factors on the quantity of self-supplied groundwater are not presented in Table 4, since they correspond directly with the estimates of the Cragg equation in Table 3. These results show that a 1% increase in $AVCS$ reduces the volume self-supplied by -0.0925% (let us note that the coefficient of this variable is not significant). Also, a 1% increase in $AVCP$ or in the production level raises the volume self-supplied by 7.55% and 0.37%, respectively. Finally, companies in the manufacturing sector consume 647.06 m$^3$ less water self-supplied than those in the services sector (this effect was obtained as the difference in the expected volume of water self-supplied in the conditional model, evaluated at the average values, between the manufacturing and the non-manufacturing companies; let us note that, again, this effect is not statistically significant). The strong impact of the price of publicly-supplied water ($AVCP$) on the volume of self-supplied groundwater reflects that once a company has made the necessary investments to be able to self-supply, any increase in the publicly-supplied water tariff leads to intense substitution of publicly-supplied water by self-supplied groundwater.

The second column of Table 4 shows the effect on the unconditional volume of self-supplied water. The small size of these effects is due to the small number of companies in the sample capturing water from the aquifer. The variable with the greatest impact is $AVCP$ (elasticity of 0.31769). The average variable cost of self-supply ($AVCS$) has a negative impact on the pumped quantity of -0.04462%, whereas the impact of the output is slightly positive, 0.01422% for a 1% increase in the volume of activity. Finally, the manufacturing dummy estimates an additional consumption of 38.8965 m$^3$ (its impact is not significant at a 5% level, but it is at a 10%).

6. Conclusions

This study has analysed the determinants of groundwater demand for industrial uses, in a two-stage process. The first stage examined the factors that determine the decision to capture groundwater as an alternative to publicly-supply, whereas the second stage focuses on the factors conditioning the volume of self-supplied groundwater.
The results obtained indicate that the decision to use groundwater depends inversely on its fixed and variable cost. Given that the self-supply costs depend, in turn, mainly on the depth of the aquifer at the location of each company, we confirm that location is a decisive variable in accessing alternative water sources. In other words, it makes clear the important role of urban policies and land-use planning. On the other hand, the license fee has a small impact on the fixed cost and none on the variable cost, as it is paid only once and it is the same for all users. Therefore, in Spain, the fee cannot be used directly to manage the demand for self-supplied groundwater and this management depends exclusively on government licenses and urban and land-use policies.

To have an economic instrument for managing demand for self-supplied groundwater, it would be desirable to supplement the current fixed fee with another volumetric fee, as it is the case in countries such as Australia, Belgium, France, the Netherlands, and Hungary (OECD 2010; Roth 2001). This new fee would make it possible to pass environmental and resource costs associated with water extraction and, consequently, it would also enable compliance with the cost recovery principle established in the Water Framework Directive.

Companies with higher fixed and/or variable costs for publicly-supplied water have greater incentives to opt for alternative water sources. Also, the volume of self-supplied groundwater increases more than proportionally as the variable cost of publicly-supplied water rises (elasticity of 7.73). This finding is novel since, as far as we know, our study is the first one which obtains a significant relationship of substitutability between publicly and self-supplied water in the industry.

This result implies that if policy-makers do not take into account the possibility of substitution of one type of water for another, they may overestimate the effectiveness of publicly-supplied water pricing, as an instrument to reduce pressure on the resource. Therefore, it provides evidence to emphasize the necessity of integrated water management, in line with the Water Framework Directive’s recommendation. To make progress on this matter, institutional mechanisms should be established to coordinate the different government agencies responsible for the different water masses and services associated with the water cycle, which in Spain belong to the three main government levels (city councils, autonomous regions, and the central government).
The demand for self-supplied groundwater is also conditional on the level of production (elasticity of 0.36), the same as with publicly-supplied water, meaning that greater output implies heavier use of groundwater. This result confirms the adequacy of measures directed to break the relationship between economic growth and demand for water, such as promoting research and technologies which reduce the intensity of water use in production processes.

Our results also indicate that manufacturing companies are more likely to self-supply and that, once they have made the decision, service companies capture 647.06 m³ more water from the aquifer than manufacturing ones. This means that the government agencies responsible for groundwater must monitor the behaviour of manufacturing companies (potentially harmful due to their high pollutant capacity), but also that of service companies, as possible consumers of large volumes of this water source.
References


