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Abstract

The sharp increase in energy prices and growing concern on environmental issues, among other things, are behind the renewed interest in energy demand estimation. However, there is sparce academic literature that takes the real situation of energy suppliers into account: high quality but incomplete data. In this paper, we propose a useful and rather simple instrument for estimating electricity demand with incomplete and/or imperfect data available to suppliers. In particular, using real data of expenditure and consumption of electricity, we employ a model of random effects for panel data in order to estimate residential and industrial electricity demand in Spain.

Keywords: Electricity demand, micro econometrics, panel data.

JEL classification: C13, C14, C23, Q41.

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1. Introduction

There are many reasons why the estimation of price elasticity of the demand for electricity is important. First and foremost is clearly the socio-economic importance of the production and consumption of electricity in contemporary societies. This justifies a detailed analysis of the effects of price changes from multiple perspectives (efficiency, distribution, economic growth, etc.). In addition, there are a number of factors that have triggered increasing interest in this matter over the recent years: energy deregulation; a large increase in the price of certain primary energy products; policies to correct the environmental damage caused by energy (in particular, those related to global warming); and the growing promotion of energy efficiency.

The analysis of the effects of price changes on the demand for electricity is, moreover, essential for planning and organizing the supply of electricity adequately. However, suppliers of electricity have many problems to estimate demand because the information they have is usually incomplete and/or imperfect. This paper presents a relatively simple procedure for estimating demand equations in these circumstances. This is especially pertinent in the case of Spain, where, after a period of government-controlled prices, there are large imbalances between regulated prices and supply costs that can lead to a sudden and sharp increase in the price of electricity.

The economic literature about energy demand dates back to the middle of the last century. Specifically, it began with the work of Houthakker (1951), who analyzed residential electricity consumption in the United Kingdom using cross-sectional data. Afterwards, Fisher and Kaysen (1962) made a study of residential and industrial electricity demand in the United States. They were the first to explicitly distinguish between the short term and the long term in residential demand. For their part, Baxter and Rees (1968) and Anderson (1971) focused on industrial electricity demand, while Houthakker and Taylor (1970), Wilson (1971) and Anderson (1973) addressed residential electricity demand. Noteworthy among the first empirical studies that used panel data in this field are Mount et al. (1973), who applied it to the entire electricity demand, and Houthakker et al. (1974) who used it in the context of residential demand. Afterwards, Lyman (1978) analyzed the residential, commercial and industrial demand for electricity, incorporating the use of data from companies and non-linear demand functions.

However, it was in the 1990s when empirical literature about electricity demand became very extensive and sophisticated (see, for example, Madlener, 1996). Many studies start from single-equation econometric models to estimate electricity demand, residential or industrial, applying different methodologies. A first alternative consists in estimating electricity demand through an aggregate model, using prices, income (or GNP) and climatic conditions as explanatory variables. Filippini (1999), García-Cerruti (2000), Hondroyiannis (2004), Holtedahl and Joutz (2004) and Narayan and Smyth (2005) can be classified in this group for the case of residential demand. Beenstock et al. (1999) covers residential and industrial demand. Kamerschen and Porter (2004) analyze industrial, residential and aggregate demand, and Bose and Shukla (1999) estimate residential, industrial, agricultural and commercial demand.

The use of aggregate data results in the loss of much information related to individual behavior. A second option, which is the one this article follows, consists in using microeconomic data to estimate electricity demand. Among the explanatory variables that are normally introduced in this case are stock of durable goods, type of housing or characteristics of the home in the case of residential demand, as well as company size, type of industrial sector and intensity of electricity in production for industrial electricity demand. Examples of this alternative are Baker et al. (1989), Leth-Petersen (2002), Larsen and Nesbakken (2004) and Filippini and Pachauri (2004), all of whom deal with residential demand of electricity. For industrial electricity demand, the contributions of Woodland (1993), Doms and Dunne (1995) and Bjørner et al. (2001) are noteworthy. In the case of Spain, academic literature about residential electricity demand is scarce, with Labandeira et al. (2006) as one of the main contributors. In particular, there is almost nothing on Spanish industrial and commercial demand for electricity. This article tries to fill that void by estimating residential as well as industrial electricity demand using panel data within a context of individual demand equations.

Likewise, this article provides a methodology that permits electricity suppliers to forecast the short-term evolution of electricity demand based on the incomplete (but high-quality) information that they have. To make the estimations, the article sets out with real data about consumption and spending on electricity in Spanish households and companies and obtains the rest of the necessary data from different public sources. The use of real data on consumption and spending is another advantage of the paper, as data from public surveys is normally used in most studies on demand for goods and services.

The main results of this research show that electricity demand is inelastic with respect to its price in the short term, although there are differences between residential and industrial demand. In the case of residential demand, consumers react in the short term to increases in the price of electricity (although less than proportionally), while the reaction of companies and large consumers is virtually non-existent. Furthermore, there is a certain relationship between the level of per capita household income and the price elasticity of demand for electricity. Finally, we observe that the price elasticities of electricity demand are, on average, very robust to different values used in the article for income elasticity and price elasticity.

The article is divided into six sections, including this introduction. Section Two presents the theoretical model and the econometric model used for estimation, followed by a description of the data used in Section Three. Section Four gives the main results obtained and Section Five analyzes the relationship between the elasticities obtained and the level of income or production. The article ends with a summary and conclusions. The article also includes, given its importance, an Annex describing the information used in more detail.

2. Model

2.1 Theoretical framework

When adjusting electricity consumption, we distinguish between domestic consumers and companies and large consumers. The theoretical framework for each of these groups is presented below.

a) Households

Households do not demand electricity for direct consumption but rather use it to produce a series of final goods and services (light, hot water, prepared food, etc.). As such, electricity can be considered an intermediate good for households, so we can analyze the demand for electricity following the basic framework of the household production theory. According to this theory, households acquire goods that they use as inputs in the production process to obtain goods that are useful for households (see Becker, 1965; Muth, 1966 or Deaton and Muelbauer, 1980, for a more detailed analysis). In the case that concerns us, households combine electricity, natural gas and capital equipment (appliances) to produce a composite energy good.

Adapting Filippini's model (1999), the production function of the final energy good (*x*) can be defined as a function dependent on the electricity consumed (*e*) as well as the natural gas consumed (*g*) and the stock of household appliances (*a*),

$$x = x(e, g, a) \tag{1}$$

The household has a utility function[1] that depends on the quantity of the composite energy good and the quantity acquired of a composite numerary good (*y*) that directly provides utility, as well as household characteristics that influence their preferences (*z*),

$$u = u(x, y; z) \tag{2}$$

Following Deaton and Muellbauer (1980), the household decision process can be modeled in each period as a problem of optimization in two stages. In the first stage, consumers behave like a company, minimizing the costs of producing the energy good, while in the second stage they maximize their utility. The problem for the consumer in the first stage is,

$$\begin{aligned} & Min\ p^e e + p^g g + p^a a \\ & s.t \\ & \quad x = x(e, g, a) \end{aligned} \tag{3}$$

where p^e is the price of electricity, p^g the price of natural gas and p^a the price of the stock of appliances. As a result, the cost function is obtained,

$$c = c(p^e, p^g, p^a, x) \tag{4}$$

Applying Shepard's lemma, we obtain the demand derived from inputs, so, for electricity,

$$e = \frac{\partial c(p^e, p^g, p^a, x)}{\partial p^e} = e(p^e, p^g, p^a, x) \tag{5}$$

[1] We assume that this has the normal properties of differentiability and curvature.

In the second stage, the household maximizes its utility, subject to its budget constraint,

$$
\begin{aligned}
&Max\ u(x,y;z) \\
&s.t \\
&\quad c(p^e,p^g,p^a,x)+y=r
\end{aligned}
\tag{6}
$$

where *r* is the household income level. Solving this problem, we obtain the demand functions of the goods *x* and *y*. In the case of the composite energy good, we get,

$$x^* = x^*(p^e,p^g,p^a,r;z) \tag{7}$$

Substituting this demand function in the demand function derived from electricity,

$$e = e(p^e,p^g,p^a,x^*(p^e,p^g,p^a,r;z) = e(p^e,p^g,p^a,r;z) \tag{8}$$

In response to variations in the price of electricity, households can modify their stock of appliances or reduce their use. However, given that the temporal scope of this paper is the short term, we assume that the stock of appliances remains constant. Also, in the short term, prices of appliances can be considered constant and be excluded from the model without causing biases in the estimation (Halvorsen, 1975).

b) Companies and large consumers

In the case of companies and large consumers, electricity is an input in their production process. Assuming that all companies consider the price of electricity and other factors exogenous and that each minimizes its production costs, the demand for electricity can be expressed as a function of the price of the factors and of the level of production (Bjørner et al., 2001).

As such, the problem for companies is the minimization of their production costs in the short term, subject to their production function (technology),

$$\begin{aligned} &Min\ p^e e + p^g g + p^o o + FC \\ &s.t \\ &\quad m = m(e,g,o,\bar{k}) \end{aligned} \tag{9}$$

where *m* is the company's production level of the final compound good, *o* is other inputs that are necessary in the production process, p^o is the price of those inputs, and *FC is* the company's fixed costs, determined by the company's capital stock ($\bar{k}$). The stock of capital remains constant (and implies only fixed costs) given the short-term analysis.

Solving the problem, we obtain the company's cost function, where we can distinguish between fixed costs (*FC*) and variable costs (*VC*)

$$c = c(p^e, p^g, p^o, m, \bar{k}) = FC(\bar{k}) + VC(p^e, p^g, p^o, m) \tag{10}$$

Applying Shepard's lemma, we derive the demand for electricity,

$$e = \frac{\partial c(p^e, p^g, p^o, m, \bar{k})}{\partial p^e} = \frac{\partial VC(p^e, p^g, p^o, m)}{\partial p^e} = q(p^e, p^g, p^o, m) \tag{11}$$

Assuming that, in the period under consideration, electricity and gas are separable from other inputs so that the relationships between electricity and gas with other inputs are neutral in terms of price, it is possible to exclude the price of other inputs from the model. Furthermore, if we assume that the price of the final composite good remains constant and given that the electricity demand function depends on the production level, this would be equivalent to functional dependence on the production value, which we denote *r*.

2.2 Econometric model

Once we obtain the demand function for electricity, we need to specify a functional form in order to estimate it. Although there is no consensus in the literature about the most appropriate functional form, most of the studies that use individual demand equations adopt a linear or logarithmic form. We choose to use a double logarithmic specification, because the estimated coefficients are equivalent to the elasticities and, as such, it is assumed that they are constant.[2] In this manner, we start from the following classical model of random effects for panel data,

$$\log e_{it} = \alpha + \beta \log p_{it}^{e} + \gamma \log p_{it}^{g} + \delta \log r_{it} + \sum_{j=2006}^{2007} \varsigma_j \, duyea_j + \sum_{k=1}^{11} \theta_k \, dumon_k + \\ + \sum_{l=1}^{n-1} \iota_l \, duprov_l + \sum_{l=1}^{n-1} \rho_l \, duprov_l * \log p_{it}^{e} + \eta_i + \varepsilon_{it} \tag{12}$$

where i indicates the household (company) and t the time period (month). Dummies for year, month and province ($duyea_j$, $dumon_k$ and $duprov_l$, respectively[3]) are incorporated in the consideration of possible spatial and temporal effects on the consumption of electricity. This way, effects that are unobservable due to consumer characteristics or location are controlled. η_i is the unobservable household (company) effects and ε_{it} is the idiosyncratic error term, in model (12) in which we assume we have data for every variable.

However, the absence of available information with respect to the price of gas and income (the value of production, in the case of companies) requires us to transform the initial model, using complementary information, to achieve a better estimation of price effects. Therefore, instead of estimating income elasticity (δ) and cross elasticity with respect to the price of gas (γ), these are regarded as known (see the next section) and the model is transformed to consider the effect of these two variables on electricity demand. Therefore, in the new specification, we subtract both variables multiplied by their respective elasticities from electricity consumption so that we obtain

$$\log e_{it} - \hat{\gamma} \log p_{it}^{g} - \hat{\delta} \log r_{it} = \alpha + \beta \log p_{it}^{e} + \sum_{j=2006}^{2007} \varsigma_j \, duyea_j + \sum_{k=1}^{11} \theta_k \, dumon_k + \\ + \sum_{l=1}^{n-1} \iota_l \, duprov_l + \sum_{l=1}^{n-1} \rho_l \, duprov_l * \log p_{it}^{e} + \varphi_i + \psi_{it} \tag{13}$$

$\hat{\gamma}$ and $\hat{\delta}$ being the known (estimated) parameters that we introduce for the crossed elasticity of the electricity demand with respect to the price of gas and income elasticity, respectively. φ_i is the unobservable heterogeneity corresponding to the household, firm or large consumer and ψ_{it} the idiosyncratic error term of the new model, driven by the fact that $\hat{\gamma}$ and $\hat{\delta}$ are estimates.

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[2] A very easy way to relax this assumption is to allow polynomials of the variables entering the specification as we will prove in the empirical section below.

[3] n represents the number of provinces in the sample.

Additionally, we introduce climatic variables that can affect the behavior of households in reducing their margin of reaction to a variation in the price of electricity. Therefore, the model is specified as,

$$\log e_{it} - \hat{\gamma}\log r_{it} - \hat{\delta}\log p_{it}^{g} = \alpha + \beta\log p_{it}^{e} + \sum_{j=2006}^{2007}\varsigma_j\, duyea_j + \sum_{k=1}^{11}\theta_k\, dumon_k + \\ + \sum_{l=1}^{n-1}\iota_l\, duprov_l + \sum_{l=1}^{n-1}\rho_l\, duprov_l * \log p_{it}^{e} + \kappa_1\, HDD_{lt} + \kappa_2\, HDD_{lt}^2 + \\ + \lambda_1\, CDD_{lt} + \lambda_2\, CDD_{lt}^2 + \Pi\, CDD_{lt} * \log\, p_{it}^{e} + \varsigma\, HDD_{lt} * \log p_{it}^{e} + \varphi_i + \psi_{it} \tag{14}$$

HDD_{lt} and CDD_{lt}, being the Heating Degree Days and the Cooling Degree Days, respectively, of the province *l* in the period *t*.

3. Data

This study was performed using monthly data for the period from September 2005 to August 2007[4]. The data was provided by one of the main Spanish electric companies, Iberdrola Distribución S.A.[5] We have observations from 422,696 households, 30,499 companies and 688 large consumers. Our total sample size is 10,144,728 observations for households; 555,637 for companies and 15,164 for large consumers.

Natural gas prices were calculated on the basis of rates set by the government in the successive Royal Decrees on rates published during the period. Since the data provided by Iberdrola Distribución comes from bills, income information is not available and we therefore need to match data from other sources to estimate (14). The only available proxy for income in the National Statistics Institute (hereafter referred to as INE, its initials in Spanish) database is gross disposable income for households; in Annex I we explain the procedure used to match the data.

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[4] In the period under study, consumers of electricity could either go to the market or make use of one of the integral tariffs regulated by the government. The great majority of consumers chose the latter of the two, that is, the regulated tariffs. These tariffs consisted of two parts: a fixed power term and a variable term for energy consumed which were revised annually. There was no specific tariff for residential use, although households in general made use of the 2.0 tariff which presented a lower power term and the highest energy term of all the tariffs. In the case of industrial consumers, the so-called "Large Consumers" (in the article) were those using the high voltage "Large consumers G4 Tariff" while the rest of the firms could make use of any of the other existing tariffs. Although the G4 tariff presented one of the highest power terms, its energy term was the lowest.

[5] In an aim to respect Spanish legislation on data protection, the data provided was not identified or associated to specific consumers. This limits the possibility to match and it implies the need to use indirect methods such as the one used in this paper.

A similar lack-of-data problem takes place in the case of companies and large consumers. In this case, in the INE database we have several alternatives related to production or added value. Our decision here depends on the sector the company belongs to. In particular, for companies belonging to the primary sector, added gross value is used; for industrial sector companies, net turnover is used; for building sector companies, operating revenues are used; and for service sector companies, production value is used. All of this data was obtained from the INE (see Annex I).

The parameters used for income and the price of gas, to obtain the dependent variable and estimate (14), are shown in Table 1. In the case of households, these values were taken from Labandeira et al. (2006), whilst in the estimations for companies and large consumers, the values are an average of the short run results provided by academic studies that analyze industrial demand for electricity (income elasticity) and the industrial demand for gas (price elasticity of gas); both of which are depicted in Table 2.[6] We also analyze the variation in the values of the price elasticities of electricity in the three samples for different values of the parameters corresponding to income elasticity and gas price elasticity. In particular, we suppose that the crossed elasticity is 0.1, household income elasticity is 0.9 and income elasticity of companies and large consumers is 0.6.

Table 1. Parameters used

Parameters	Households	Companies	Large Consumers
Cross-Price Elasticity of Gas	0.05	0.05	0.05
Income Elasticity	0.7	0.3	0.3

Source: Authors' production.

[6] As no individual data are available for adjusting the demand of electricity, after subtracting the product of the elasticities and the averages of the variables for gas price and income from the initial demand, there is a problem of measurement errors in the quantity of electricity demand. This affects the estimation of the standard errors of the coefficients, so it is corrected in the empirical exercise by using a method that provides standard errors robust to heteroskedasticity and autocorrelation (White, 1982). This procedure is indeed equivalent to calculating the elasticities on the average of the relevant variables.

Table 2. Literature on electricity demand

Authors	Country	Own-Price Elasticity	Cross-Price Elasticity	Income Elasticity
Panel A. Residential				
Houthakker & Taylor (1970)	USA	-0.13 (short-run) -1.89 (long-run)		0.13 (short-run) 1.94 (long-run)
Anderson (1973)	USA	-1.12 (long-run)	0.30 (long-run)	0.80 (long-run)
Houthakker et al. (1974)	USA	-0.90		0.14
Halvorsen (1975)	USA	-1.52	0.13	0.72
Lyman (1978)	USA	-2.10		
Baker et al. (1989)	U.K.	-0.76	0.19	0.13
Beenstock et al. (1999)	Israel	-0.58 (long-run)		
Bose & Shukla (1999)	India	-0.65		0.88
Filippini (1999)	Switzerland	-0.30		0.33
Leth-Petersen (2002)	Denmark			0.2788
Filippini & Pachauri (2004)	India	-0.452 (Winter months) -0.29 (Summer m.) -0.51 (Monsoon m.)	-0.27 (Winter m.) 0.26 (Summer m.) -0.65 (Monsoon m.)	0.64 (Winter m.) 0.63 (Summer m.) 0.60 (Monsoon m.)
Hondroyiannis (2004)	Greece	0		0.20
Hotledahl & Joutz (2004)	Taiwan	-0.16		0.23
Kamerschen & Porter (2004)	USA	-0.93	0.34	
Narayan & Smyth (2005)	Australia	-0.26	0.01	0.01
Labandeira et al. (2006)	Spain	-0.78	0.05	0.7
Panel B. Industrial				
Lyman (1978)	USA	-1.40		
Beenstock et al. (1999)	Israel	-0.44 (long-run)		0.99 (long-run)
Bose & Shukla (1999)	India	-0.04		0.73
Bjørner et al. (2001)	Denmark	-0.48		0.60
Kamerschen & Porter (2004)	USA	-0.35	0.01	0.25

Source: Taylor (1975) and author's production.

With respect to the climatic variables, we have the *Heating Degree Days* and *Cooling Degree Days*. Both variables were calculated on the basis of information given by the Spanish Meteorology Agency (Ministry of Environmental, Marine and Rural Affairs) on daily maximum and minimum temperatures of the provincial capitals that this study covers. Eighteen degrees Celsius is taken as the ideal temperature, considering an interval of ±5ºC in the vecinity of this temperature (13ºC-23ºC) within which we assume that individuals do not need to use heating or cooling equipment. The Spanish Meteorology Agency calculates average temperature in a province by using observed temperatures at different observatories in the selfsame province. We are aware that in large (or heterogeneous in terms of weather) provinces, the temperatures calculated in this manner would not adequately represent the temperature of every part of the territory. Yet the maximum disaggregated data available to us to match climatic variables with our data, refers to the province level. The problem of under-representativity of the situation in every part of the territory is, in some sense, mitigated when constructing HDD and CDD that refer to the number of days the observed temperature exceeds the temperature comfort level. This is due to the fact that although we have 28 different provinces in our data, most of them are not large enough to induce the defined variables to be non-significant for our analysis, because they are formed as averages from different observatories of the provinces and because HDD and CDD are used instead of the corresponding temperatures.[7]

4. Results

Given that the unobservable heterogeneity is included in the composite error term $v_{it} = \varphi_i + \psi_{it}$, the term presents autocorrelation over time for the same sample unit. So, we estimate the proposed models by general least squares in order to obtain consistent and efficient estimators.[8] We make three estimations of the corrected demand for electricity, one for each group of consumers of electricity including the prices of electricity and the time and space dummy variables mentioned as explanatory factors. In fact, we have carried out several exercises moving from an initially very general unrestricted model towards restricted models using the usual test on significance of the parameters to exclude explanatory variables from the specification. The results presented in this section correspond to what we consider the best model in terms of individual and joint significance of the regressors. The results obtained are shown in Table 3.

Table 3. Price elasticities of short-term electricity demand

	Households	Companies	Large Consumers
Elasticity	-0.2536	-0.0308	-0.0518

Note: with our model the price elasticity of demand is $\frac{\partial \log e}{\partial \log p^e} = \beta + \sum_{l=1}^{n-1} \rho_l duprov_l + \pi\ CDD + \varsigma HDD$, which is calculated using the estimated parameters (see Annex III) and the average of CDD. To obtain the average elasticity in the whole territory we used the average elasticity of each province weighted by the number of available observations in that province.

Source: Authors' production.

[7] We must notice that our specifications include HDD and CDD joint with province and time dummies in an attempt to effectively capture climatic effects different to geographic differences invariant in time or time differences invariant geographically. It does not avoid, of course, the problem that climatic variables pose when representing the whole territory of the province.

[8] With ordinary least squares, the estimators would be consistent but not efficient. In addition, as mentioned, the standard errors are corrected by White's (1982) procedure.

As expected, in the three cases electricity demand is inelastic with respect to its price in the period analyzed. That is, an increase in the price of electricity will give rise, *ceteris paribus*, to a less-than-proportional reduction in electricity demand. The results show a residential demand for electricity that is more rigid than that obtained by Labandeira et al. (2006) on the basis of data on electricity expenses from the INE's *Encuesta Continua de Presupuestos Familiares* (Continuous Survey on Family Budgets). This value strictly corresponds to the short-term estimation, while the results of Labandeira et al. (2006), on the other hand, try to include more middle- and long-term effects. In any case, the results obtained are within the normal values obtained by the literature (see, for example, Narayan and Smyth, 2005).

Price elasticity is lower in the case of companies and large consumers than it is in the case of households, and the values obtained for both types of non-residential consumers are significant. This is probably explained by the fact that households present a larger capacity to react in the short term, while companies generally have to make modifications (with positive cost) in their production processes to be able to reduce their electricity/power consumption. In fact, it is possible to speculate that companies will adapt when there is a sharp increase in the price of electricity and this will lead to structural changes that will affect their behavior as consumers. In other words, income and activity are important factors in explaining the demand for electricity by residential consumers and companies but, even though there are other variables like prices and climatic variables that affect residential demand for electricity, activity in itself explains the behavior of large consumers and companies regarding electricity demand (given the current price levels).

Also, a sensitivity analysis has been carried out through additional estimations of the models. In these estimations, the values used for income elasticity and the cross-price elasticity of natural gas are modified to incorporate the variation in the values obtained for these parameters by the academic literature. The results of the new estimations show values for price elasticities of electricity that are very similar to those obtained in the original model, for households as well as for companies and large consumers, which suggests that the estimated elasticities are robust to values for the elasticities within the range estimated in the empirical literature. In fact, the changes in the values corresponding to companies and large consumers are, in the most pronounced case, less than three percent and practically zero in the case of households. This exercise reiterates the fundamental result of the article: the adjustment of demand by companies occurs almost exclusively due to the state of their economic activity (business cycle), while households are much more flexible in accommodating their demand via prices.

It is also worth noting that the influence of climatic variables on residential demand is small but significant, such that if in one month the Heating Degree Days (Cooling Degree Days) increase one unit, electricity demand would vary 0.05% (0.63%) on average. In terms of degrees, when the average minimum (maximum) temperature in a month diminishes (increases) by one degree Celsius, electricity demand would increase 0.95% (8.36%)on average. It is worth pointing out that the influence on demand is greater on hot days than it is on cold days, as generating cold depends almost exclusively on electricity.

5. Elasticities and level of income or production

Once the price elasticities of electricity demand have been estimated, we use this information to analyze the relationship between them and the level of income (production). This analysis aims, in the case of households, to determine whether a larger income level leads to fewer concerns on the electricity price (lower electricity price elasticity in absolute terms). In the case of firms and large consumers, our objective is to study the influence of the firm's production level on the reaction to variations in electricity prices.

In this way, we present the relationship between the price elasticity and the level of income by province for the residential case, as well as between the elasticities and the level of production by provinces and by industrial sectors. To this effect, two non-parametric tests are used: Spearman's test of correlation by ranges and Kendall's test. To carry out these two checks, the price elasticity of demand in each province was estimated for each group of consumers, and by sectors for companies and large consumers. Once these estimations were obtained, in each group of data for the different provinces (sectors) we ordered the information following their adjusted price elasticity and their per-capita GNP/gross disposable household income in 2005.[9]

Table 4 shows Spearman's (r_S) and Kendall's (τ) statistical values for the three groups of consumers along with the critical values for making the contrast with a significance level of 5%. In

[9] In the case of activity sectors, we arrange them according to the added value in each of them in the year 2005.

both contrasts, the null hypothesis is the absence of association between the variables, which cannot be rejected for companies (that is, there is no relationship between the ranges). Contrary to this, in the residential case, the null hypothesis of absence of relationship between ranges is rejected in both contrasts, as it is for large consumers. As such, it is possible to affirm that the elasticity of demand by provinces is related to the per-capita income level of the province in the residential case, with the elasticity being lower (in absolute value) the higher the level of per-capita income. In the case of companies, the relationship between elasticity and per-capita GNP is non-existent, as the elasticity depends on other factors. Finally, in the case of large consumers there seems to be a certain relationship between the variables, although it is of little importance.

Table 4. Spearman's rank correlation coefficient and Kendall's τ statistic. Provinces

	Companies	Large Consumers	Residential
r_s	0.30	0.55	0.62
Critical value r_s	0.45	0.54	0.41
τ	0.21	0.45	0.45
Critical value τ	0.32	0.41	0.29
n	20	14	23

Source: Authors' production.

For the sectoral case, applicable to companies and large consumers, consumers are grouped according to activity classification codes and, afterwards, the demand elasticity of electricity for each group is estimated. After the data is put in order, the contrasts are made according to the information supplied in Table 5 (statistics and critical values). On this occasion, for companies as well as for large consumers, none of the contrasts allows us to reject the null hypothesis of absence of relationship; that is, price elasticities of demand for electricity by sectors do not depend on the added value in the sector. This does not mean that the level of activity has no bearing on the behavior of the demand. In fact, it is quite the opposite: the level of activity in a certain period conditions companies' and large consumers' demand for electricity; this is something that is not reflected in the calculated sectoral averages of activity levels.

Table 5. Spearman's rank correlation coefficient and Kendall's τ statistic. Sectors

	Companies	Large Consumers
r_s	0.17	-0.09
Critical value r_s	0.46	0.46
τ	0.10	-0.06
Critical value τ	0.33	0.33
n	19	19

Source: Authors' production.

6. Conclusions

In this paper, we have estimated the price elasticity of the demand for electricity in Spain, for the case of households as well as for companies and large consumers, using real data on prices and electricity consumption. We have also analyzed the relationship between these elasticities and the level of per-capita income. Our objective was twofold: to add to the small body of empirical literature in Spain on this matter, making it useful for the definition and analysis of energy and environmental policies, and to provide electricity suppliers with a rigorous, but simple, tool so that they can carry out demand estimations with incomplete information. Although the method is illustrated with an application for the case of Spain, which is especially interesting and relevant given the context of prices and policies, we feel that its usefulness transcends any temporal and spatial application.

We have observed how households react to prices in the short term, although their demand is inelastic with respect to prices. For their part, company and large consumer electricity are hardly affected by the variations observed in prices, with demand elasticities very close to zero. All of the previous results, especially those related to residential demand, are consistent with abundant international empirical evidence on the matter, which reinforces and validates the approach followed here. The existence of a relationship between the elasticity of electricity demand and the level of per-capita income of provinces for the case of households also emerges from the results of this article: elasticity diminishes (in absolute value) as the level of per-capita income increases. This relationship does not exist in the case of companies, although it does, to some extent, for large consumers. Finally, we have found no relationship between demand elasticity by sector of activity and the added value in those sectors.

As such, it should be expected that, even in the short term, an increase in the price of electricity would lead households to use electricity more efficiently. This means that, in response to the prospect of dramatic increases in the cost of electricity in the coming years, Spanish electricity suppliers should contemplate these reductions in demand when planning their strategies. On the contrary, the foreseeable increases in prices will hardly affect the consumption of electricity by companies and large consumers in the short term due to the the fact that changing their production systems would entail high costs . Given that these groups account for nearly two thirds of electricity consumption in Spain, it is foreseeable that the effects of the price changes will be tempered. This result is reinforced because in the residential case, as the level of income in a geographic area increases, its electricity demand becomes more elastic.

In any case, we must reiterate that the results of this paper probably indicate the lowest threshold of adaptation by agents to changes in the price of electricity, not only because we are dealing with short-term estimations, but also because the modeling does not include the related decision to consume durable goods that are linked to the use of energy products.

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ANNEX I

Description of the data used

As explained in Section 3, for the calculation of natural gas prices we use the rates set by the Spanish government (rate 3.1 for households, assuming an average consumption of 2500 kWh/year, and the arithmetic average of rates 3.2, 3.3 and 3.4 for companies and large consumers). To calculate the prices implicit in each of these rates, we assume an average consumption of 27,500 kWh/year; 75,000 kWh/year and 100,000 kWh/year, respectively. Prices are deflated through the Consumer Price Index (CPI), taking September 2005 as the basis. To obtain the Gross Disposable Income per household, we start from gross disposable income of households by provinces for 2004, as obtained from the INE. Given that we are dealing with annual data, the data is broken down into quarters for the purpose of estimation (seasonal analysis). The quarterly weightings used (see Table A1) were calculated on the basis of the information provided by the INE, which includes the time variability of income. Once the data was broken down into quarters, it was inflated according to the evolution of the CPI to obtain the data for 2005, 2006 and 2007. Lastly, given that the data on consumption corresponds to households, we divide income by the number of households in each province to get gross disposable income per household.

Table A1. Quarterly weightings of gross disposable income. 2004

	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
Weighting	0.2569	0.2382	0.2547	0.2501

Source: Authors' production.

The variable used as a proxy of the production value for companies and large consumers was obtained in the following procedure:

a) *Primary sector*: Gross quarterly added value (INE). The available data was deflated using the implicit deflator of the GNP [on the basis of data from *Contabilidad Nacional* (National Accounting)] to express it in real terms.

b) *Industrial sector*: Annual net revenue (INE) for 2005 and 2006. To break down the data into quarters, monthly data from the Industrial Production Index was used, calculating the arithmetic average of the monthly data in each quarter. Once the quarterly data was obtained, the quarterly weighting was calculated by dividing the data of each quarter by the quarterly aggregate for the year. In applying these weightings to the data on annual net revenue, we obtained the quarterly data. For 2007, the data from 2006 was inflated in each quarter by the increase in the industrial production rate for the corresponding quarters of 2007 to preserve the seasonal variability of industrial demand for electricity. Finally, the data was deflated to the base period of September 2005 using the Industrial Price Index.

c) *Building sector*: Monthly operating revenue. Deflated using the CPI for housing.

d) *Service sector*: Production value (Annual Services Survey and Annual Trade Survey of the INE). Only the annual data from 2005 is available. This was broken down into quarters according to the quarterly structure of Gross Added Value in the service sector in 2005. To obtain the quarterly data for 2006 and 2007, it was inflated using the implicit GNP deflator. Given that in the data base provided by Iberdrola Distribución S.A. there are data that correspond to services not included in these surveys, we calculated their production value by previously obtaining the weight in the Gross Added Value of the service sector data that was included, assuming that that weight also represents the weight of these services in the total value of the production sector. From this, we got the total value of the production of all services for which there is no data.

ANNEX II

Table A2. Descriptive statistics of the variables

	Mean	Standard Deviation	Minimum	Maximum
Companies				
Electricity Price (€/kWh)	0.0775	0.0222	0.0030	4.1717
Electricity Consumption (kWh)	9092.818	16756.66	0.1	2079949
Natural Gas Price (€/kWh)	0.0346	0.0013	0.0305	0.0358
Income Variable (10^3€)	4.22e+07	4.80e+07	239808.7	1.19e+08
HDD (ºC day)	116.2281	122.2563	0	487.1
CDD (ºC day)	72.8500	94.3253	0	433
Large Consumers				
Electricity Price (€/kWh)	0.0427	0.0298	0.0010	0.0954
Electricity Consumption (kWh)	1717346	5952585	1	1.07e+08
Natural Gas Price (€/kWh)	0.0346	0.0013	0.0305	0.0358
Income Variable (10^3€)	2.24e+07	3.04e+07	239808.7	1.19e+08
HDD (ºC day)	148.878	135.399	0	487.1
CDD (ºC day)	69.4012	94.0536	0	433
Households				
Electricity Price (€/kWh)	0.0848	0.5309	0.0003	1148
Electricity Consumption (kWh)	478.2762	762.4174	0.01	999822
Natural Gas Price (€/kWh)	0.0488	0.0016	0.0441	0.0503
Income Variable (10^3€)	9.6312	1.5512	6.8997	13.1919
HDD (ºC day)	115.073	122.505	0	487.1
CDD (ºC day)	75.0585	94.9811	0	433

Source: Author's production.

ANNEX III

Table A3. Parameter estimates. Large Consumers

Regressor	Coefficient	t-ratio
Log(electricity price)	-0.0010	-0.02
Intercept	8.0633	14.54
Dummy year 2006	0.0960	4.08
Dummy year 2007	0.1470	5.44
Dummy month 01	-0.1347	-4.25
Dummy month 02	-0.0678	-2.04
Dummy month 03	-0.0861	-2.48
Dummy month 04	-0.0254	-0.59
Dummy month 05	-0.2207	-4.14
Dummy month 06	-0.2159	-3.23
Dummy month 07	-0.5344	-6.93
Dummy month 08	-0.3079	-4.35
Dummy month 09	-0.2460	-3.71
Dummy month 10	0.0117	0.21
Dummy month 11	0.0237	0.61
Dummy province Albacete	-0.2419	-0.27
Dummy province Alacant	-0.1520	-0.23
Dummy province Araba	2.7565	2.13
Dummy province Ávila	2.2679	1.39
Dummy province Badajoz	-2.9857	-4.27
Dummy province Bizkaia	1.8353	1.88
Dummy province Burgos	-0.3181	-0.54
Dummy province Cáceres	-4.3039	-6.46
Dummy province Castelló	0.5440	0.73
Dummy province Cuenca	-21.8159	-1.78
Dummy province Gipuzkoa	2.5193	3.22
Dummy province La Rioja	-0.7332	-1.21
Dummy province León	-0.8835	-1.22
Dummy province Madrid	-0.1578	-0.27
Dummy province Murcia	-1.6563	-2.35
Dummy province Nafarroa	0.4473	0.77
Dummy province Palencia	0.0874	0.13
Dummy province Salamanca	-1.3443	-1.81
Dummy province Segovia	3.2215	1.11
Dummy province Soria	-0.4662	-0.45
Dummy province Toledo	-0.5585	-0.36
Dummy province Valencia	-0.3104	-0.46
Dummy province Valladolid	-0.6950	-1.15
Dummy province Albacete* log(electricity price)	0.0207	0.23
Dummy province Alacant* log(electricity price)	-0.0595	-1.06
Dummy province Araba* log(electricity price)	0.0293	0.28
Dummy province Ávila* log(electricity price)	0.1674	1.19
Dummy province Badajoz* log(electricity price)	-0.1118	-1.85
Dummy province Bizkaia* log(electricity price)	0.0038	0.04
Dummy province Burgos* log(electricity price)	-0.0579	-1.21
Dummy province Cáceres* log(electricity price)	-0.2599	-4.66
Dummy province Castelló* log(electricity price)	0.1121	1.69
Dummy province Cuenca* log(electricity price)	-2.7138	-1.66
Dummy province Gipuzkoa* log(electricity price)	0.0620	0.86
Dummy province La Rioja* log(electricity price)	-0.0606	-1.23
Dummy province León* log(electricity price)	-0.1214	-1.93

Dummy province Madrid* log(electricity price)	-0.0755	-1.58
Dummy province Murcia* log(electricity price)	-0.1833	-2.74
Dummy province Nafarroa* log(electricity price)	-0.0204	-0.43
Dummy province Palencia* log(electricity price)	0.0212	0.39
Dummy province Salamanca* log(electricity price)	-0.0638	-1.03
Dummy province Segovia* log(electricity price)	0.1331	0.52
Dummy province Soria* log(electricity price)	0.0510	0.51
Dummy province Toledo* log(electricity price)	-0.0064	-0.05
Dummy province Valencia* log(electricity price)	-0.0661	-1.13
Dummy province Valladolid* log(electricity price)	-0.0869	-1.79
HDD	-0.0009	-2.59
HDD^2	1.26e-06	2.32
CDD	0.0032	5.28
CDD^2	6.58e-06	6.92
CDD*log(electricity price)	0.0003	6.13

Source: Author's production.

Table A4. Parameter estimates. Companies

Regressor	Coefficient	t-ratio
Log(electricity price)	0.0415	1.41
Intercept	3.7422	17.01
Dummy year 2006	0.0050	1.55
Dummy year 2007	-0.0058	-1.44
Dummy month 01	0.0428	9.26
Dummy month 02	0.0670	14.36
Dummy month 03	0.0107	2.20
Dummy month 04	0.0473	8.13
Dummy month 05	-0.0583	-8.26
Dummy month 06	-0.0428	-5.12
Dummy month 07	-0.0869	-9.36
Dummy month 08	0.0050	0.56
Dummy month 09	0.0492	5.83
Dummy month 10	0.0583	7.88
Dummy month 11	-0.0126	-2.42
Dummy province Albacete	-0.1555	-0.63
Dummy province Alacant	0.1419	0.63
Dummy province Araba	-0.2862	-1.18
Dummy province Ávila	-0.4683	-1.63
Dummy province Badajoz	-0.6745	-2.24
Dummy province Bizkaia	-0.1831	-0.81
Dummy province Burgos	-0.3942	-1.61
Dummy province Cáceres	-0.8875	-3.45
Dummy province Canarias	0.5346	1.26
Dummy province Castelló	-0.6393	-2.70
Dummy province Cuenca	-0.4722	-1.41
Dummy province Gipuzkoa	-0.0039	-0.02
Dummy province La Rioja	-0.5776	-2.37
Dummy province León	-0.2434	-0.93
Dummy province Madrid	-0.3197	-1.44
Dummy province Murcia	-0.1943	-0.85
Dummy province Nafarroa	-0.5435	-2.33
Dummy province Palencia	-0.8352	-2.73
Dummy province Salamanca	-0.4311	-1.70
Dummy province Segovia	3.0044	0.20
Dummy province Soria	-0.6496	-1.83
Dummy province Toledo	-0.5474	-2.25
Dummy province Valencia	0.0915	0.41
Dummy province Valladolid	-0.4711	-1.97
Dummy province Albacete* log(electricity price)	-0.0574	-1.75
Dummy province Alacant* log(electricity price)	-0.0253	-0.84
Dummy province Araba* log(electricity price)	-0.0511	-1.58
Dummy province Ávila* log(electricity price)	-0.0634	-1.66
Dummy province Badajoz* log(electricity price)	-0.0741	-1.85
Dummy province Bizkaia* log(electricity price)	-0.0482	-1.59
Dummy province Burgos* log(electricity price)	-0.0760	-2.34
Dummy province Cáceres* log(electricity price)	-0.0795	-2.32
Dummy province Canarias* log(electricity price)	0.0240	0.43
Dummy province Castelló* log(electricity price)	-0.1224	-3.88
Dummy province Cuenca* log(electricity price)	-0.0868	-1.93
Dummy province Gipuzkoa* log(electricity price)	-0.0311	-1.01
Dummy province La Rioja* log(electricity price)	-0.0909	-2.81
Dummy province León* log(electricity price)	-0.0535	-1.54
Dummy province Madrid* log(electricity price)	-0.0761	-2.57
Dummy province Murcia* log(electricity price)	-0.0876	-2.86

Dummy province Nafarroa* log(electricity price)	-0.0866	-2.78
Dummy province Palencia* log(electricity price)	-0.0986	-2.43
Dummy province Salamanca* log(electricity price)	-0.0581	-1.72
Dummy province Segovia* log(electricity price)	0.4749	0.23
Dummy province Soria* log(electricity price)	-0.1128	-2.38
Dummy province Toledo* log(electricity price)	-0.1035	-3.21
Dummy province Valencia* log(electricity price)	-0.0321	-1.08
Dummy province Valladolid* log(electricity price)	-0.0578	-1.81
HDD	0.0005	10.98
HDD^2	-2.54e-07	-3.20
CDD	0.0001305	0.68
CDD^2	1.72e-07	1.32
CDD*log(electricity price)	-0.0002	-5.89

Source: Author's production.

Table A5. Parameter estimates. Households

Regressor	Coefficient	t-ratio
Log(electricity price)	-0.9129	-45.56
Intercept	-2.5357	-17.63
Dummy year 2006	0.0228	21.24
Dummy year 2007	0.0196	15.14
Dummy month 01	0.1689	86.92
Dummy month 02	0.1596	95.36
Dummy month 03	0.0597	30.19
Dummy month 04	-0.0104	-5.03
Dummy month 05	-0.0235	-8.81
Dummy month 06	-0.1185	-40.98
Dummy month 07	-0.1938	-57.62
Dummy month 08	-0.0636	-20.85
Dummy month 09	-0.0573	-18.67
Dummy month 10	-0.0553	-21.63
Dummy month 11	-0.1204	-57.33
Dummy province Albacete	0.3417	1.88
Dummy province Alacant	5.5100	35.11
Dummy province Araba	6.1369	33.51
Dummy province Asturias	3.3607	1.56
Dummy province Ávila	1.0749	4.65
Dummy province Badajoz	6.4797	24.92
Dummy province Bizkaia	5.3693	35.15
Dummy province Burgos	4.5803	27.21
Dummy province Cáceres	3.7436	20.25
Dummy province Cantabria	5.1032	15.02
Dummy province Castelló	5.7130	32.02
Dummy province Ciudad Real	17.7163	3.64
Dummy province Cuenca	-9.6437	-35.73
Dummy province Gipuzkoa	6.2123	39.82
Dummy province Guadalajara	1.6524	7.10
Dummy province La Rioja	5.0840	29.42
Dummy province León	4.4546	23.83
Dummy province Madrid	4.0969	27.85
Dummy province Murcia	5.3795	33.00
Dummy province Nafarroa	6.1079	37.82
Dummy province Palencia	5.2811	26.05
Dummy province Salamanca	1.7635	10.16
Dummy province Segovia	-3.6333	-0.19
Dummy province Soria	2.5698	8.59
Dummy province Toledo	-5.1227	-24.55
Dummy province Valencia	6.0418	39.42
Dummy province Valladolid	5.8484	36.84
Dummy province Albacete* log(electricity price)	-0.0052	-0.20
Dummy province Alacant* log(electricity price)	0.7165	32.72
Dummy province Araba* log(electricity price)	0.8537	33.43
Dummy province Asturias* log(electricity price)	0.6541	2.17
Dummy province Ávila* log(electricity price)	0.1636	5.06
Dummy province Badajoz* log(electricity price)	0.8999	24.81
Dummy province Bizkaia* log(electricity price)	0.7229	33.97
Dummy province Burgos* log(electricity price)	0.6709	28.63
Dummy province Cáceres* log(electricity price)	0.5085	19.74
Dummy province Cantabria* log(electricity price)	0.7005	14.78
Dummy province Castelló* log(electricity price)	0.7659	30.73
Dummy province Ciudad Real* log(electricity price)	2.5379	3.72
Dummy province Cuenca* log(electricity price)	-1.3680	-36.24

Dummy province Gipuzkoa* log(electricity price)	0.8555	39.38
Dummy province Guadalajara* log(electricity price)	0.2155	6.65
Dummy province La Rioja* log(electricity price)	0.7138	29.66
Dummy province León* log(electricity price)	0.6144	23.57
Dummy province Madrid* log(electricity price)	0.5306	25.88
Dummy province Murcia* log(electricity price)	0.6895	30.31
Dummy province Nafarroa* log(electricity price)	0.8409	37.38
Dummy province Palencia* log(electricity price)	0.7506	26.58
Dummy province Salamanca* log(electricity price)	0.2545	10.53
Dummy province Segovia* log(electricity price)	-0.4519	-0.17
Dummy province Soria* log(electricity price)	0.4181	10.01
Dummy province Toledo* log(electricity price)	-0.7791	-26.71
Dummy province Valencia* log(electricity price)	0.7822	36.59
Dummy province Valladolid* log(electricity price)	0.8055	36.45
HDD	0.0009	58.80
HDD^2	-1.59e-06	-58.78
CDD	0.0074	55.94
CDD^2	-2.09e-07	-4.70
CDD*log(electricity price)	0.0010	52.70

Source: Author's production.