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AN ANALYSIS OF THE WELFARE AND DISTRIBUTIVE IMPLICATIONS OF FACTORS INFLUENCING HOUSEHOLD ELECTRICITY CONSUMPTION

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An analysis of the welfare and distributive implications of factors influencing household electricity consumption.

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Abstract

The deep economic crisis and the sharp rise in electricity prices have had a strong effect on electricity demand by Spanish households. This paper aims to analyse the responsiveness of household electricity demand and the welfare effects related to both factors in the 2006-2012 period. The results show that the electricity consumption of medium-high income households is particularly responsive to price increases, whereas that of medium-low income households is more responsive to changes in income. The retail electricity price increases and the economic crisis have led to generally lower and steeper U-shape price elasticities of demand and higher and steeper N-shape income elasticities of demand. The joint impact of those two factors on the welfare of lower-income households is higher in relative terms (i.e., as a share of household income) than for other income groups. These results suggest that the economic crisis and increases in retail electricity prices have had detrimental welfare effects, especially on the lower-income segment of the population. They should be taken into account when

financing climate and energy policies through the electricity bill and provide a rationale to take such support, which pushes retail electricity price upwards, out of the electricity bill.

Key words: electricity demand, economic crisis, elasticities, welfare analysis
JEL code: D12, I31, Q41, R22

1. Introduction

There is an ever-lasting interest in the economic analysis of energy demand. This is partly due to societal concerns with respect to the environment, energy security and energy price impacts on low-income households (Bernard et al 2011). Household energy satisfies a varied range of needs that span from necessities and basics to recreational and luxury consumption. The relative importance of essential or luxury services of energy varies with income (Meier et al 2013). Overall, energy services may be regarded as a necessity good implying an income elasticity of demand that is greater than zero and smaller than unity (Jamasb and Meier 2010). Taking into account that the final electricity price has two components (the wholesale market price and the so-called "access fees" which include the costs of policies), the degree of sensibility to changes in price and income for different income groups is useful to analyze the welfare and distributional effects of electricity pricing policies. This issue is relevant in so far as climate and energy policies and, particularly, renewable electricity support schemes are being financed in many EU countries though the electricity bill. Policy makers are increasingly concerned about the distributional and welfare impacts of those climate and energy policies and, particularly, on the effects on the poorest segment of the population. Low-income households are more likely to be negatively affected by the economic crisis and by higher electricity prices. Too large welfare costs from energy and climate policies for the poorest segment of the population may generate a social backlash against the policy, making it socially unacceptable and politically unfeasible (del Río et al 2012, Neuhoff et al 2013).

The focus of this paper is on residential (household) electricity demand in Spain. The residential sector is responsible for 17% of the country's final energy consumption and 25% of its electricity consumption, whereas the shares in the EU are significantly higher (25% and 29%, respectively) (IDAE 2011a). In Spain, electricity represents 35% of overall energy consumption in the residential sector and 5%, 13% and 44% of all energy used for heating, water heating and cooking, respectively. All the energy used for air conditioning and lighting is covered by electricity (IDAE 2011b). The deep economic crisis experienced by Spain can be expected to have influenced electricity demand by households, with possibly wide-ranging implications in terms of welfare and distributional effects. GDP had growth rates between 1996 and 2008 in the range of 2.7% to 5.1%, significantly higher than for most other EU countries and the unemployment rate fell from 22.1% in 1996 to 8.2% al 8,2% in 2006. As in other developed countries, the Spanish economy entered into recession at the end of 2008. The impact of this crisis on unemployment and GDP rates has been particularly detrimental (Gruppe and Lange, 2014; Moro, 2014). Between 2009 and 2013, nominal GDP fell by an accumulated 6.7%, the unemployment rate rose to a historical high of 25.7% in 2012 and household disposable income fell by 4.3% in nominal terms. In parallel, the retail price of electricity has increased by 64% since 2007 (from 0.14 €/kWh to 0.23 €/Wh in 2013), raising the concerns of the government on its impact on the welfare of households, particularly the poorest ones[1]. This increase in the retail price can mostly be attributed to the objective of the government to reduce the so-called tariff-deficit, which now amounts to 30000M€[2]. Arguably, the economic crisis and the increase in prices are the two main factors behind the drastic reduction in electricity demand in the last years. Thus, residential electricity consumption increased at an average annual growth rate of 5% between 2000 and 2007 and decreased by 0.5% between 2008 and 2010.

The aim of this paper is twofold. First, we analyse the welfare and distributive implications of both factors (the economic crisis and the increase in electricity prices) on household electricity demand between 2006 and 2012 in Spain. The sample is segmented in two subperiods: 2006-2008 and 2010-2012. The impact of the economic crisis and the increase in electricity prices has been felt in the second subperiod[3]. The demand model has been estimated using a quartile regression of the cross-sections of the Family Budget Survey (EPF) from the National Statistical Office. This paper covers a gap in the literature since analyses on the impact of the economic crisis on electricity demand are virtually absent[4]. To our best knowledge, it is the first time that an electricity demand model estimated with the quartile

[1] It is about 15% higher than the EU average, where the increase has been lower (30%), over the same period.

[2] This tariff deficit has been the result of regulated prices for electricity being set below the regulated prices for electricity being set below the regulated costs, and the increase in regulated costs mostly, although not only, as a result of renewable energy net support costs (from about 1700M€ in 2006 to 7500M€ 2012). Net support costs are calculated as the whole feed-in tariffs and premiums paid to renewable electricity generators minus the average wholesale price.

[3] The average unemployment rate in the first subperiod was 10.2% and increased to 23% in the second subperiod. In addition, the electricity price increased by 30% in the second subperiod.

[4] Analyses of the welfare and distributional effects of these factors on electricity demand are relatively scarce and circumscribed to the increases in the electricity price.

regression method has been applied to such analysis. Furthermore, this is one of the few contributions to the analysis of the impact of higher electricity prices on household welfare.

This topic has both political and academic relevance. Particularly worrisome is the possibly unequal distribution of welfare losses across different income segments of the population. Both factors combined would further exacerbate fuel poverty if the lower-income households were the most affected, taking into account that electricity is not a luxury good, but a necessity in today's modern societies (at least below some consumption thresholds). As the focus of this study is on household energy consumption and the differences between income groups, our analysis is deemed relevant in the context of the fuel poverty problem. It connects to two main causes of energy poverty: household revenues (affected by the economic crisis) and energy costs (negatively influenced by higher electricity prices). In 2012, 7 million Spanish households (17% of the total) had "disproportionate expenditures on energy" (e.g., beyond 10% of their annual revenues), up from 12% in 2010 (Tirado et al 2014). These households can be expected to have had severe difficulties in paying their energy bills (Tirado et al 2012). Subjective indicators also suggest the importance of energy poverty: 9% of all households declared that they were incapable of maintaining an appropriate temperature in their homes during winter (Tirado et al 2014)[5]. Phimister et al (2015) show that between 10% and 27% of all Spanish households are fuel poor, depending on the indicator of fuel poverty chosen[6]. This range is even wider in Romero et al (2015) (between 6% and 24%).

Accordingly, the paper is structured as follows. The next section provides a brief review of the literature. Section 3 develops the hypotheses tested in the study. Section 4 summarises the methodological framework. Section 4 describes the data. The results are provided and discussed in section 5. The last section concludes.

[5] Almost 70% of the respondents to the December 2011 opinion poll of the Center for Sociological Research (CIS 2011) had reduced their expenditures on domestic energy and other household fixed costs in order to save money and as a result of the economic crisis (Tirado and López 2013).

[6] Other data suggest the increasing importance of electricity spending and its possible relationship with fuel poverty. For example, annual household expenditures on electricity have increased by 65% between 2006 and 2012 and the proportion of those expenditures with respect to household revenues has increased from 2.5% to 4.5% over the same period (Tirado et al 2014).

2. Literature review

The analysis of residential electricity demand has received considerable attention in the past (see Romero-Jordán et al 2014 for a review). Some studies have focused on household characteristics and their relation to electricity consumption, including age, employment status and number of children or retired persons in the households (see, among others, Baker and Blundell (1991), Yamasaki and Tominaga (1997), Liao and Chang (2002), Jamasb and Meier 2010)). However, few studies analise the distribution of elasticities across different household income levels.

Nesbakken (1999) gave some insights on this issue. It analysed energy consumption of households in Norway using a discrete choice model. The results showed that short run income elasticities were equal to 1 and hardly depended on income group. In the long run, low-income households had an elasticity of 0.18 (0.22 for high-income households). Households in the high-income group had a lower price elasticity of energy consumption (-0.66) than low-income households (-0.33). The author explained the unexpected higher price responsiveness of high-income households by their higher energy consumption.

More recently, Reiss and White (2005) use a sample of 1,300 Californian households and the generalized method of moments (GMM) to estimate how price elasticities vary as a function of income. Consumers with lower income levels are more responsive to price increases. The price elasticity for households with annual income levels lower than 18,000$ is -0.49, and -0.29 for the richest ones (>60,000$).

Using a pooled cross-section of 39,000 households from the Family Income and Expenditure Survey in Philippines, Manalo-Macua (2007) estimates an electricity demand function with a three-step methodology. His results lead to a U-shape for both the price and income elasticities per quartile. Price elasticities start with -0.96 for the first quartile, -1.11 for the second, -0.99 for the third and -0.81 for the fourth. The income elasticities are 0.50 for the first quartile, and 0.23, 0.30 and 0.76 for the 2^{nd}, 3^{rd} and 4^{th} quartile, respectively. Finally, to our knowledge, this is the only contribution estimating the welfare losses per quartile. The results show that losses increase in both absolute and relative terms with respect to income levels.

Fell et al (2010) use U.S. household electricity expenditure data from the Consumer Expenditure Survey over the period 2004–2006 to estimate income-specific price elasticities in four regions (Northeast, South, Midwest and West) with Ordinary least squares (OLS) and GMM techniques. Their results show very small differences between the price elasticities of different income categories (with maximum differences of 0.02) and U-shapes for 5 out of the 8 regions and estimation methods.

Jamasb and Meier (2010) use a panel dataset from a comprehensive survey of 14,000 UK households from 1991 to 2007 to analyse electricity, gas, and overall energy spending (i.e., not demand) for the whole sample and several income groups. Using fixed effects econometric models, they find significant differences among the income groups with respect to their income and price elasticities. In particular, households on low incomes are less sensitive to electricity price changes than higher-income households. Price elasticities increase from 0.804 for the poorest households to 1.329 for the fourth income group and decrease to 0.635 for the richest households. Income elasticities also follow an inverted U-shape at very low levels, from 0.046 for the first income group to 0.152 for the fourth and 0.098 for the richest households.

Meier et al (2013) analyse the socioeconomic determinants of household energy expenditures in Britain. They use panel data (5,000 households between 1991 and 2007) to estimate the relationship between energy spending and income over time. Their results show that the income elasticity of electricity spending is U-shaped with respect to income and smaller than unity (generally in the 0.2-0.6 range).

Alberini et al (2011) analyse residential electricity demand with U.S. household-level panel data for the period 1997–2007 (74,000 households in the 50 largest metropolitan areas). The price elasticity of demand increases with income, but the magnitude of this effect is small (−0.681 among households in the first income quartile, and −0.673, −0.663 and −0.645 among those in the second, third and fourth quartile, respectively).

What can we conclude from the results of the literature on the price and income elasticities for different income groups? The results regarding price elasticities are ambiguous: N-shape for California (Reiss and White 2005), U-shape for the United States as a whole (Fell et al 2010, Alberini et al 2011), monotonic increase with negative values for Philippines (Manalo-Macua

2007) and monotonic increase with positive values for the United Kingdom (Jamasb and Meier 2010)[7]. Concerning the income elasticity of demand, there are only a couple of studies, with opposing results. One finds a U-shape (Manalo-Macua 2007), whereas an inverted U-shape is found in Alberini et al (2011).

There are even fewer studies on the impacts on the welfare of households with different income levels. In fact, to our best knowledge, only Manalo-Macua (2007) has analysed this issue, concluding that both the absolute and relative welfare effects are an increasing function of income. However, the distributional implications of the price change depend upon the choice of welfare measure and the demand parameters being used[8]. Neuhoff et al (2013) calculate the distributional implications of renewable energy support in Germany, reaching the conclusion that, because of the rising surcharge for financing support of electricity from renewable energy, electricity's share of consumer spending will increase to 2.5 percent in 2013, of which 0.5 percentage points constitute this surcharge. However, the burden on low-income segments of the population is significantly higher. Romero et al (2015) carry out an econometric analysis of the determinants of fuel poverty in the Spanish households, concluding that low-income household and those with children are more likely to be energy poor. However, to our best knowledge an analysis of the economic crisis and higher electricity prices on the welfare of households with different income levels has not been carried out in Spain.

3. Hypotheses

Classic consumer demand theory and the literature reviewed in the previous section suggest the following set of hypotheses.

[7] Recall that the study of Jamasb and Meier (2010) is not about electricity demand, but about electricity spending.

[8] The author finds that using compensating variation alone, the loss increases as income group rises. However, distributional implications change when the author uses the parameters of per quartile demand and computing percentage loss instead: the loss of the income group is highest among the lower-income groups.

3.1. Hypotheses on the type of relationship between the price and income elasticities of electricity demand and household income quartiles.

Price changes are likely to have an asymmetric impact on the electricity demand of households with different income levels. The electricity demand of very poor households can be expected to cover only their very basic needs in electricity, given their very low income levels. These basic needs (such as cooking, personal hygiene and, possibly, heating) are crucial for survival. Electricity is used for many different purposes but the "basic needs" purpose is quite rigid, i.e., households have a low degree of flexibility to reduce electricity to cover basic needs since it is essential for living. This implies that the poorest households have a limited ability to reduce their electricity demand when they face higher electricity prices. Households with higher income levels will be more reactive to price changes, since their level of electricity demand covers their basic as well as other needs which, while important for a comfortable living, are not so essential. In other words, households with low (but not very low) and medium income levels may reduce their electricity demand without severely affecting their living conditions. On the other hand, households with very high incomes are likely to be highly insensitive to price changes, since their expenditure on electricity represents a negligible share of their total income/expenditure[9]. Therefore, both the poorest and the richest segments of the population would be relatively insensitive to price changes compared to medium-income households.

An increase in the income earned by households may also induce a different response regarding electricity demand for households with different income levels. An increase in income for the poorest households is likely to trigger a substantial increase in electricity demand since, as mentioned above, they have very low demand levels (very basic needs). Thus, a small increase in their electricity consumption has a major impact on their welfare. Therefore, these households would dedicate a substantial part of any increase in their incomes on electricity. Once those very basic needs are covered, further increases in their electricity demand induced by higher income levels would naturally be lower. Therefore, as income grows, the demand for electricity will rise proportionally more for the lower-income

[9] Advani et al (2013) show that, in Britain, electricity represents a larger share of the household budget for the poorest households (8% for the poorest decile) than for the richest ones (1% for the highest-income decile). According to the authors, this result provides confirmation that electricity is a necessity. Likewise, Neuhoff et al (2013) show that electricity represents only 1% of total expenditures for the richest German households.

households. When the basic electricity needs are satisfied (i.e., for very low-income households), an increase in income will lead to a proportionally lower increase in electricity demand. The following hypotheses are formulated:

H1: The relationship between the price elasticity of electricity demand and household income quartiles has a U-shape
H2: The relationship between the income elasticity of electricity demand and household income quartiles has an inverted U-shape.

3.2. Hypotheses on the impact of higher retail electricity prices and the economic crisis on the level of price and income elasticities

A second category of hypotheses are related to the impact of both factors on the price and income elasticities of electricity demand. On the one hand, it should be noted that both the economic crisis and the higher retail prices reduce the amount of money in the pockets of consumers which can be spent on electricity. The economic crisis directly reduces the disposable income for all types of households, whether low or high income ones, making them more reactive to electricity price increases. This is so because, with lower incomes, a certain price rise increases the opportunity costs of consuming electricity, since electricity competes with other goods in the household consumption basket. On the other hand, higher electricity prices are likely to result in lower (higher in absolute value) elasticities of demand because the price signal is stronger, providing a higher incentive for households to save on a more expensive good. Therefore, the influence of the economic crisis and the higher retail electricity prices go in the same direction.

While lower income levels will result in lower price elasticities for all households, this reduction is unlikely to be homogenous across different types of households. The low and medium income households will probably become more reactive to such reduction than the very-low and very-high income ones. The reason is that very low-income households have already lowered their electricity demand to the lowest possible extent (i.e., coverage of their very basic needs). Thus, with even lower incomes, a higher price would tend to have a negligible impact on their consumption since their margin of maneuver is much more limited than for middle-income households. Their reduction in electricity demand after an increase in electricity prices will be lower than for the medium-income households. Therefore, the following hypothesis is proposed.

H3: Both the economic crisis and the higher electricity prices will lead to lower price elasticities of demand for all households. The low and medium income households experience a greater reduction of their price elasticity of demand than the very- low and very-high income levels.

The economic crisis and the higher electricity prices would increase the income elasticity of electricity demand. Both factors work in the same direction in this context. Regarding the impact of the economic crisis, a lower income level (for the same quartile) would increase the income elasticity of electricity demand for all households. This is due to the relevance of electricity expenditures in the household consumption basket. Lower income levels would thus lead to a greater responsiveness of electricity demand to changes in income for all households, given the fundamental role of electricity in the life of households. On the other hand, a higher electricity price would tend to result in a greater income elasticity of demand for electricity. For the same level of increase in income, prices are higher and, thus, a greater total expenditure on electricity would result. The expenditure on electricity would be higher for the same level of demand (e.g., same quantity, higher price, ceteris paribus). This is so at least for electricity demand covering the very basic needs.

We could expect that the impact of both factors on the income elasticity of demand would differ across households with different income levels. With lower income levels for the poorest, there is a higher incentive to consume electricity when there is a small increase in income, given the basic character of electricity, especially for this segment of the population. Therefore, the income elasticity would increase more for the poorest households. In contrast, middle-income households, which have already covered their basic electricity needs, would tend to dedicate an extra unit of income to other goods in a situation of lower income levels. Thus, the following hypothesis is proposed:

H4: Both factors are likely to lead to higher income elasticities of demand for all households. The income elasticity is likely to increase more for the poorest households.

3.3. Hypothesis on the welfare effects of the factors influencing household electricity demand.

A final hypothesis concerns the welfare effects of the two factors with an influence on electricity demand. As the welfare effects of price changes depend on the necessity or luxury nature of energy services, the link between income and household energy spending is of great significance (Meier et al 2013). The welfare effect is measured using the equivalent variation (EV) which refers to how much more money a consumer would pay before a price increase to avert the price increase (Hicks 1939, Mas Collel et al 1995). Both factors would fall unequally on the welfare of households with different income levels. In particular, the welfare of the poorest segment of the population will be more affected. As mentioned above, the lowest-income households are less sensitive to electricity price increases (their price elasticities of demand are lower), since most of their electricity consumption will cover basic needs. Therefore, lower incomes or higher retail prices will hurt this group of households more strongly. Therefore, the following hypothesis is proposed:

H5: The factors influencing electricity demand have a more negative impact on the welfare of the poorest households than on the medium and high-income households.

4. Methods

In this paper we use the following Cobb-Douglas model to estimate household electricity demand:

$$E_{it} = \frac{\beta_1 Y_{it}^{\beta_2} C_{t_r}^{\beta_4} H_{t_r}^{\beta_5} \sum_{j=6}^{13} D_{jit}^{\beta_j}}{p_{t_r}^{\beta_3}} \qquad [1]$$

where E is electricity consumption of households measured in kWh, β_1 is the constant term, Y_{it} refers to annual household income, p_{t_r} is an index that captures average yearly changes in electricity price in the 17 regions, C_{t_r} and H_{t_r} are the number of annual cooling degree days and heating degree days of the region where the household is located, D refers to a set of j dummies which capture the heterogeneity of households with respect to electricity consumption. Subscripts i, t and r refer to households, years and the regions, respectively.

A first group of dummy variables captures the differences in the intensity of electricity consumption due to the existence of electric heating and/or water heating across households.

A second set of dummies captures the socioeconomic characteristics of households: household size, households with children and households with a retired breadwinner. Finally, we use a dummy for the households located in rural vs. urban areas and another for households located in areas with Mediterranean climate (warmer places) versus those in colder places.

We add the error term e_{it} to equation [1] and, them, we take logarithms. Therefore, parameters β_2 and β_3 can be interpreted as price and income elasticities of electricity demand. The model can be estimated with OLS, allowing us to capture the marginal effect of the covariates on electricity demand, respectively. However, this procedure only allows us to have a partial perspective on the determinants of consumption (Mosteller and Tukey, 1977). The quartile regression proposed by Koenker and Bassett (1978) circumvents this limitation and offers a complete picture of the determinants of electricity demand across the conditional distribution of the dependent variable C_e :

$$LE_{it} = L\beta_{\theta 1} + \beta_{\theta 2} LY_{it} - \beta_{\theta 3} Lp_{t_r} + \beta_{\theta 4} \tau LC_{t_r} + \beta_{\theta 5} LH_{t_r} + \sum_{j=6}^{13} \beta_{\theta j}\, d_{ji} + Le_{\theta it} \qquad [2]$$

$$\text{for } 0 < \theta < 1, \text{ with } Quantile_{\theta}\left(\frac{y}{x}\right) = x_i \beta_{\theta}$$

where y is the dependent variable and x is the set of covariates, with quartile θ being the conditional distribution in the θ quartiles. In the quartile regression, the estimation of the $\hat{\beta}_{\theta i}$ parameters is obtained by minimizing the asymmetric weighted sum of absolute deviations.

$$\min_{\beta \in R^k} \left\{ \sum_{i:\ln E_i \geq \beta X_i} \theta \left| \ln E_i - \beta_\theta X_i \right| + \sum_{i:\ln E_i < \beta X_i} (1-\theta) \left| \ln E_{it} - \beta_\theta X_i \right| \right\} \qquad [3]$$

The $\beta_{\theta j}$ parameters can be interpreted as the impact of the respective variable on the demand for electricity in quartile θ. Therefore, we can identify whether or not the reaction of households to changes in prices and income remains stable across the distribution of electricity consumption. Obviously, the OLS can be estimated for the n-percentiles of electricity consumption, although with an unconditional distribution of the dependent variable. However, the OLS would then suffer from adverse selection problems. An additional advantage of the quartile regression method is that it minimizes the impact of outliers in the tails of the distribution.

In order to analize the impact of a price increase on welfare we use the Equivalent Variation (EV) concept proposed by Hicks, which is defined as:

$$VE = e(p^0, v^1) - e(p^1, v^1) = G_e^1 - G \quad [4]$$

Where superindexes 0 and 1 indicate, respectively, the initial and final prices, $e(p, v)$ is the expenditure function, p is the price of electricity, v is the indirect utility function, G is the initial rent and Ge is the final equivalent rent defined as:

$$G_e^1 = e(P_0, v^1(P, G)) \quad [5]$$

VE is a measure of how much more money a consumer would pay *before* a price increase to avert the price increase. The simulation has been carried out using the microdata from the Family Budget Survey (EPF) in 2009[10]. This year has been used for two reasons. First, it is in the middle of the period being analysed. Second, and contrary to 2010 and 2011, consumption data are not "contaminated" by the increase in the VAT rates which were implemented in those two years. For reasons of simplicity, the price and income elasticities of the 50 quartile estimated for the period 2010 to 2012 have been used for the simulation.

4. Data

Table 1 provides a brief description of the variables used in this paper and indicates the data sources used for the analysis. The cross-sections of the EPF provide data on income and on the socioeconomic features of households[11]. This survey, conducted by the National Statistical Office (INE), provides very rich information on electricity consumption and on the living conditions, the economic structure and the location of households in Spain. The total expenditure of households has been used as a proxy of income in order to circumvent the problem of under-reporting of income, which is common in expenditure surveys (Poterba 1990, Sterner 2012, Romero-Jordán et al 2014). Following West and Williams (2004), expenditure has been adjusted by the household size using the equivalence scale proposed by

[10] In order to calculate the Equivalent Variation, we have used the programming tool for Stata developed by Sanz et al (2013).

[11] Unfortunately, those microdata have not a panel structure.

Haagenars et al., (1994) and modified by the OECD[12]. The number of cooling degree days and heating degree days has been calculated with the methodology proposed in Romero-Jordán et al, (2014). The electricity price index is provided by INE (2015). It has been weighted by the consumer price index (CPI) of each region.

Electricity expenditures are positively related to income levels (Figure 1a). As expected, the share of those expenditures in the household total expenditures is a decreasing function of income (Figure 1b). Electricity represents 4% of the total expenditures of the poorest households, but only 1% of the richest ones[13]. In spite of the crisis and the reduction of households' disposable income, both the absolute and the relative level of expenditures increased in the 2010-2012 period.

Table 1. Description of variables, sources of data and expected relationship with the dependent variable

Variable	Definition	Data Source	Expected relation with dependent variable
Electricity consumption	KWh per year	EPF-INE	Dependent variable
Income	Income of each household (€)	EPF-INE	(+)
Electricity price	Electricity Price index weighted by the CPI in each region.	EPF-INE	(-)
Electric water	Dummy: whether water is heated with electricity.	EPF-INE	(+)
Electric heating	Dummy: whether the household has electric cooking	EPF-INE	(+)
Household size	Number of household members	EPF-INE	(+)
Children	Dummy: presence of children in the household (<16 years)	EPF-NE	(+)
Retired	Dummy: whether the breadwinner is retired.	EPF-INE	(-)
Density	Dummy: whether the household is located in urban areas (>100,000 inhabitants)	EPF-INE	(+)
South-Levante zone	Dummy: whether the household is located in Andalucia or in the Mediterranean Coast.	EPF-INE	?
Rural area	Dummy: whether the household is located in a	EPF-INE	(-)

[12] This equivalence scale takes the value of 1 for the household head, 0.5 for each additional adult member and 0.3 for each child, respectively.

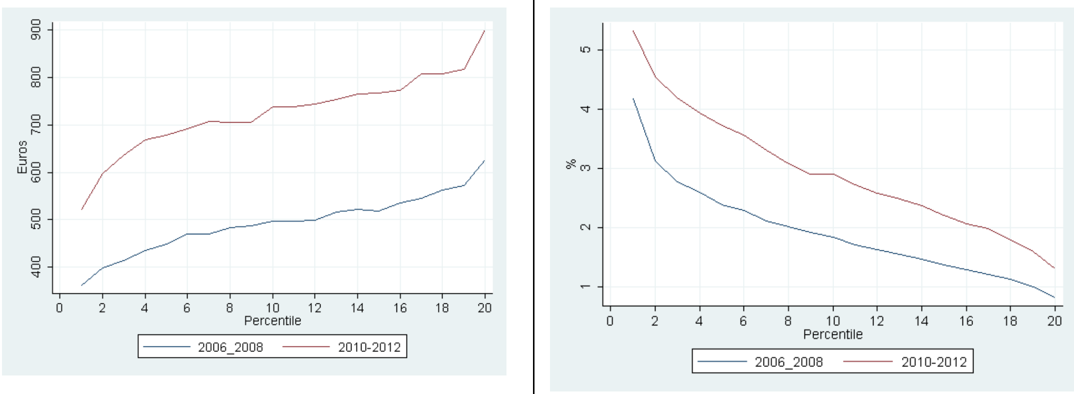
[13] The share of electricity expenditures in the total expenditures for the poorest households is similar to other countries. For example, Neuhoff et al (2013) show that the poorest households allocate 4.5% of their expenditure for power in Germany.

	rural area.		
Cooling degree days	Difference between average daily temperatures (Ta) and a reference temperature (T*) (18ºC) $$\mathrm{CDD} = \sum_{i=1}^{n} \max(0; \mathrm{Ta} - \mathrm{T}^{*})$$	Own elaboration with data provided by the National Meteorological agency (AEMET)	(+)
Heating degree days	Difference between a reference temperature (T*) (18ºC) and the average daily temperatures (Ta) $$\mathrm{HDD} = \sum_{i=1}^{n} \max(0; \mathrm{T}^{*} - \mathrm{Ta})$$	Own elaboration with data provided by the National Meteorological agency (AEMET)	(+)

Figure 1. Evolution of household electricity expenditure in Spanish households

a. Electricity expenditures (€)

b. Share in overall households' expenditures



5. Results and discussion.

Table 2 shows the results of the estimation of equation [2] for the period 2006-2008, whereas Table 3 provides the results for 2010-2012. The results are provided in a highly disaggregated manner. The price and income elasticities for both periods are represented in Figures 1 and 2.

The estimated coefficients have the expected sign and are statistically significant in most of the analysed cases. As expected, household size, electric heating, the presence of children in the household and the number of cooling and heating degree days have a clear positive impact on electricity consumption. It is worth noting that, during the expansion (2006-2008), the number of heating degree days had a much greater impact on electricity consumption than the number of cooling degree days. The opposite was the case during the recession.

The results on the relationship between the price and electricity demand show that price elasticities follow a U-shape in both periods. However, the economic crisis and the higher electricity prices have led to a steeper U-shape (compare figures 2 and 3), i.e., electricity consumption is more responsive to changes in electricity prices in the second period, especially for the middle-income quartiles (40 to 70). For instance, the price elasticity of demand for quartile 50 doubled (in absolute terms) from -0.15 to -0.33. In contrast, the change was more modest for both extremes of the distribution.

Price elasticities start relatively high at very low income levels, go down for medium-low income levels and reach a minimum for medium-high income households. They increase substantially for the richest households, to reach a similar level as for the poorest ones. These results suggest that the poorest and the richest segments of the population are more insensitive to electricity price variations than medium-income households. As mentioned in section 3.1, very poor households have a very limited leeway to reduce their electricity demand electricity prices increase, since this demand mostly covers their very basic needs. Households with very high income levels are insensitive to electricity price variations since electricity represents a very tiny fraction of their income. In the higher income groups there is a greater probability to have well-insulated energy efficient homes, which isolate them from higher energy prices.

In contrast, the price elasticity for medium-income households is comparatively high in absolute value. Households in this segment clearly react to changes in electricity prices, probably because electricity demand does not only cover their basic needs and represents a relatively high share of the household expenditures. An additional reason for the higher responsiveness of middle-income households compared to low-income ones could be that the former are likely to own a greater number of electricity-using appliances (Fell et al 2010) whose use may be adjusted in case of an increase in electricity prices. Ownership of appliances certainly depends on income and the geographical location of the household, with households in the first and second deciles having limited appliance ownership compared to other income groups (Fell et al 2010). Our results are also in line with those in the literature in

the sense that, despite the U-shape, there are not large differences between the price elasticities of different income groups[14]. Therefore, hypothesis 1 can not be rejected.
Regarding the income elasticity of demand, Figures 2 and 3 show that the relationship between income and electricity demand follows a N-shape. Similarly to the price elasticity of demand, the economic crisis has made electricity demand more responsive to income changes. However, in contrast to the price elasticity of demand, the responsiveness has increased more intensively in the quartiles 5 to 30.

The estimations of the income elasticity start at very low levels for the poorest households, increase for low and medium-low income levels, decrease for the medium-high income households and increase for the highest-income ones, i.e., a N-shape can be observed, especially in 2008-2012. This is in contrast to Meier et al (2013), who find a U-shaped relationship, although our results are in line with their findings regarding the small values of the elasticities. As income grows from very low levels, electricity demand increases more than proportionally. This may suggest that electricity is a very basic good for very-low income households, who tend to dedicate any extra income received on electricity. An increase in income may lead to an increasing number and usage of appliances in a household and thus a higher electricity demand. The lower income elasticity for the medium-high households indicates that, once the most basic electricity needs have been met, further increases in income will result in proportionally lower increases in demand. Thus, hypothesis 2 cannot be rejected.

Concerning the joint impact of the two factors on the level of the price and income elasticities of electricity demand, our results show that they have led to lower price elasticities of demand for all households. Both the economic crisis and the higher retail prices reduce the disposable income for all types of households. This could make households more reactive to electricity price increases. The low and medium income households experience a greater reduction of

[14] Fell et al (2010) argues that this could be due to multiple reasons. First, although lower-income groups respond to higher prices by using electricity-consuming products less, higher-income groups may respond to higher prices by buying more energy-efficient products but maintaining product use levels. Second, lower-income households may cut back their usage of many commonly found electricity-intensive appliances (e.g., air conditioning) more than higher-income households, but high-income households may also have more nonessential electricity-consuming products (not controlled in the estimation) that can easily be used less when electricity prices are high. This could include electric space heating, air conditioners, a swimming pool, or an electric cooking appliance.

their price elasticity than the very low and very-high income households, for the reasons given in section 3.2. Therefore, hypothesis 3 cannot be rejected.

Regarding the income elasticities of demand, our estimations show that they are generally higher in the second subperiod, suggesting that they have increased as a result of the aforementioned two factors. On the one hand, a reduction of income (for the same quartile) due to the economic crisis would have resulted in a greater income elasticity, given the importance of electricity demand in the household consumption basket. On the other hand, the income elasticity increases more for the poorest households. As proposed in 3.2, with lower income levels for the poorest, there is a greater incentive to spend any extra income on electricity, given the basic character of electricity, especially for this segment of the population. Therefore, hypothesis 4 cannot be rejected.

Table 2. Income and price elasticities per percentile in the 2006-2008 period

Results of the quartile regression											
Variable/ Quartile	5	10	20	30	40	50	60	70	80	90	95
Price	-0.1138 (0.019)***	-0.1295 (0.015)***	-0.1433 (0.017)***	-0.1407 (0.014)**	-0.1451 (0.011)***	-0.1507 (0.009)***	-0.1498 (0.010)***	-0.15 (0.013)***	-0.1545 (0.016)***	-0.163 (0.023)***	-0.1499 (0.029)***
Income	0.0846 (0.069)***	0.1076 (0.004)***	0.1311 (0.004)***	0.1383 (0.003)***	0.1405 (0.003)***	0.1452 (0.005)***	0.1482 (0.004)***	0.1494 (0.006)***	0.1482 (0.007)***	0.156 (0.009)***	0.1639 (0.010)***
Electric water	0.0971 (0.006)***	0.1275 (0.008)***	0.1666 (0.007)***	0.1995 (0.007)***	0.2158 (0.006)***	0.2363 (0.006)***	0.2526 (0.005)***	0.265 (0.006)***	0.2726 (0.007)***	0.2808 (0.013)***	0.3056 (0.015)***
Electric heating	0.0878 (0.008)***	0.1308 (0.011)***	0.1698 (0.009)***	0.196 (0.006)***	0.2248 (0.006)***	0.2473 (0.008)***	0.2974 (0.010)***	0.3414 (0.010)***	0.4172 (0.013)***	0.5102 (0.012)***	0.5549 (0.017)***
Household size	0.1451 (0.009)***	0.1607 (0.006)***	0.1603 (0.006)***	0.1595 (0.004)***	0.1642 (0.003)***	0.1594 (0.004)***	0.1561 (0.004)***	0.156 (0.004)***	0.1515 (0.005)***	0.155 (0.007)***	0.157 (0.009)***
Children	0.0931 (0.008)***	0.1246 (0.006)***	0.1497 (0.004)***	0.155 (0.004)***	0.1629 (0.005)***	0.1696 (0.005)***	0.169 (0.005)***	0.1664 (0.005)***	0.1606 (0.005)***	0.1484 (0.007)***	0.1434 (0.012)***
Retired	-0.0129 (0.005**	-0.0191 (0.005)***	-0.0193 (0.004)***	-0.0177 (0.006)***	-0.0119 (0.004)***	-0.0085 (0.004)**	-0.0012 (0.004)***	0.0061 -0.005	0.0145 (0.004)***	0.0255 (0.007)***	0.041 (0.009)***
Density	0.1236 (0.009)***	0.1664 (0.007)***	0.2076 (0.007)***	0.2358 (0.005)***	0.252 (0.005)***	0.2628 (0.004)***	0.272 (0.005)***	0.283 (0.006)***	0.2958 (0.008)***	0.3085 (0.008)***	0.3053 (0.010)***
South-Levante zone	0.064 (0.008)***	0.0924 (0.008)***	0.1158 (0.009)***	0.1328 (0.009)***	0.1374 (0.007)***	0.1432 (0.009)***	0.1479 (0.007)***	0.1625 (0.010)***	0.1711 (0.011)***	0.1603 (0.015)***	0.1598 (0.023)***
Rural area	-0.0015 (0.006)	0.0050 (0.004)	0.008 (0.005)*	0.0082 (0.005)*	0.0128 (0.005)***	0.0226 (0.006)***	0.0315 (0.006)***	0.0397 (0.008)***	0.0563 (0.008)***	0.0795 (0.013)***	0.1094 (0.014)***
Lcdd18	-0.0067 (0.005)	-0.0030 (0.003)	0.0070 (0.005)	0.0088 (0.004)**	0.0119 (0.005)**	0.0169 (0.005)***	0.0255 (0.005)***	0.0283 (0.006)***	0.0351 (0.006)***	0.059 (0.008)***	0.0821 (0.010)***
Lhdd18	0.0971 (0.011)***	0.1206 (0.009)***	0.146 (0.011)***	0.1596 (0.009)***	0.1602 (0.006)***	0.162 (0.006)***	0.1638 (0.007)***	0.1692 (0.012)***	0.1603 (0.011)***	0.1405 (0.020)***	0.1239 (0.022)***
Intercept	3.2823 (0.127)***	2.728 (0.088)***	2.1687 (0.096)***	1.9508 (0.088)***	1.9088 (0.072)***	1.8442 (0.064)***	1.7881 (0.077)***	1.7608 (0.106)***	1.8512 (0.098)***	1.8935 (0.164)***	1.9776 (0.224)***
Number of observations: 59,900											

Notes: Robust standard errors in parentheses *** Significant at the 99% confidence level ** Significant at the 95% confidence level *Significant at the 90% confidence level.

Table 3. Income and price elasticities per percentile in the 2010-2012 period

Results of the quartile regression											
Variable/ Quartile	5	10	20	30	40	50	60	70	80	90	95
Price	-0.2054	-0.223	-0.2648	-0.2792	-0.3143	-0.3327	-0.3357	-0.3328	-0.3252	-0.2627	-0.2084
	(0.022)***	(0.016)***	(0.015)***	(0.011)***	(0.014)***	(0.017)***	(0.018)***	(0.017)***	(0.018)***	(0.024)***	(0.040)***
Income	0.1429	0.1608	0.1617	0.1581	0.1546	0.1523	0.1425	0.1425	0.1416	0.1573	0.1735
	(0.006)***	(0.006)***	(0.005)***	(0.005)***	(0.005)***	(0.004)***	(0.004)***	(0.004)***	(0.004)***	(0.005)***	(0.006)***
Electric water	0.1209	0.1599	0.1968	0.2191	0.2282	0.2383	0.2465	0.2576	0.2673	0.2843	0.284
	(0.011)***	(0.008)***	(0.008)***	(0.005)***	(0.005)***	(0.005)***	(0.006)***	(0.006)***	(0.008)***	(0.011)***	(0.014)***
Electric heating	0.123	0.16	0.1971	0.2253	0.2609	0.2819	0.3112	0.3451	0.3917	0.442	0.4823
	(0.012)***	(0.009)***	(0.008)***	(0.007)***	(0.007)***	(0.007)***	(0.008)***	(0.008)***	(0.007)***	(0.013)***	(0.015)***
Household size	0.1595	0.1642	0.1623	0.1602	0.1563	0.1486	0.143	0.1416	0.1374	0.1399	0.1385
	(0.008)***	(0.006)***	(0.006)***	(0.005)***	(0.005)***	(0.005)***	(0.006)***	(0.005)***	(0.006)***	(0.008)***	(0.011)***
Children	0.1952	0.207	0.2175	0.2202	0.2145	0.2104	0.2006	0.1925	0.1849	0.1701	0.1578
	(0.005)***	(0.005)***	(0.005)***	(0.004)***	(0.004)***	(0.004)***	(0.005)***	(0.006)***	(0.006)***	(0.007)***	(0.010)***
Retired	-0.0321	-0.0276	-0.0238	-0.0137	-0.0133	-0.0067	-0.0018	-0.0027	-0.0067	-0.0025	0.0013
	(0.008)***	(0.006)***	(0.004)***	(0.003)***	(0.004)***	(0.004)*	-0.004	(0.004)	-0.004	-0.007	(0.009)
Density	0.1756	0.2126	0.2455	0.261	0.2646	0.2689	0.2792	0.2876	0.3011	0.3079	0.3092
	(0.011)***	(0.006)***	(0.004)***	(0.004)***	(0.005)***	(0.005)***	(0.006)***	(0.007)***	(0.005)***	(0.008)***	(0.010)***
South-Levante Zone	-0.0338	-0.0384	-0.0204	-0.0151	-0.019	-0.0125	0.0029	0.013	0.0164	0.0151	0.0241
	(0.014)**	(0.010)***	(0.010)**	(0.008)**	(0.006)***	(0.007)*	(0.006)	(0.007)*	(0.008)*	(0.011)	(0.016)
Rural Zone	-0.0186	-0.0216	-0.0173	-0.0017	0.0068	0.0164	0.0221	0.0298	0.0358	0.0502	0.0794
	(0.013)**	(0.010)**	(0.007)**	-0.006	-0.005	(0.006)***	(0.007)***	(0.007)***	(0.006)***	(0.007)***	(0.012)***
Lcdd18	0.0955	0.1153	0.1321	0.1472	0.1617	0.1699	0.1723	0.1775	0.1865	0.1932	0.205
	(0.007)***	(0.007)***	(0.004)***	(0.005)***	(0.003)***	(0.003)***	(0.003)***	(0.004)***	(0.004)***	(0.006)***	(0.007)***
Lhdd18	0.0591	0.0668	0.088	0.0938	0.086	0.0832	0.0889	0.0933	0.0866	0.0788	0.0697
	(0.010)***	(0.010)***	(0.010)***	(0.006)***	(0.006)***	(0.005)***	(0.004)***	(0.007)***	(0.007)***	(0.012)***	(0.019)***
Intercept	1.2258	0.7746	0.3412	0.2277	0.1719	0.1713	0.2649	0.2977	0.4284	0.7757	1.0553
	(0.121)***	(0.128)***	(0.091)***	(0.064)***	(0.100)*	(0.097)*	(0.085)***	(0.100)***	(0.107)***	(0.163)***	(0.264)***
Number of observations: 65,871											

Notes: Robust standard errors in parentheses *** Significant at the 99% confidence level ** Significant at the 95% confidence level *Significant at the 90% confidence level.

Figure 2. Price and income elasticities in the 2006-2008 period

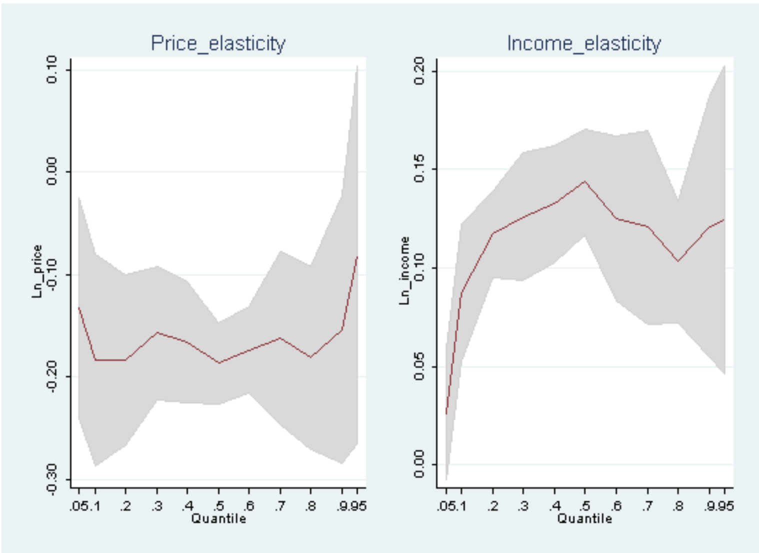
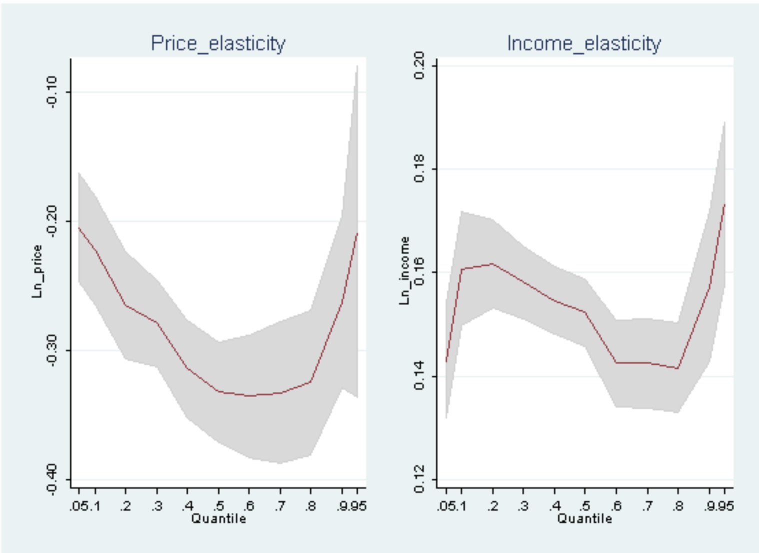


Figure 3. Price and income elasticities in the 2008-2012 period



Expressions [4] and [5] have been calculated. Table 4 shows the distribution of the accumulated welfare losses for the 2008-2012 period per income deciles. Column 4 shows the equivalent variation, whereas the results in terms of average income per decile are provided in column 5. Absolute welfare losses are, as expected, an increasing function of income: EV ranges from 128 € in the first quartile to 319 € in the last quartile with an average EV of 204 €. In those five years, the annual average welfare loss for households in the first decile has been 25€, and has increased monotonically to 63€ in the last decile. However, when the absolute figures are related to household income levels, the picture changes dramatically. We find that, in relative terms, the welfare loss is much greater for the poorest households. It is above 1% for the households in the first two deciles, three times as much as for those households in the richest decile. Then, as proposed in hypothesis 5, the welfare losses are a decreasing function of income. The calculated EV represents 1.2% of the income of the poorest households and goes down monotonically to reach a minimum of 0.45 for the richest ones. Thus, hypothesis 5 cannot be rejected.

These results suggest that both factors have had more detrimental welfare effects on the lowest-income segment of the population. This should be taken into account when financing climate and energy policies through the electricity bill, which has traditionally been the case in Spain with respect to the support for electricity from renewable energy sources[15]. The particularly negative impact on the poorest segment of the population may provide a rationale to take such support, which pushes retail electricity price upwards, out of the electricity bill. It is well-known that financing those policies through the public budget is less regressive than doing so through the bill (Advani et al 2013). In addition, the general benefits for society associated to such support (job creation, lower fossil fuel energy dependence and lower environmental impacts) would call for their inclusion in the public budget[16].

The findings suggest that the response of households to income and price changes, and consequently their response to policy measures, varies across different income groups. Some policy implications stem from this analysis. First, there is a need to mitigate the negative

[15] In addition to support for renewable electricity, support for energy provision in islands and the social tariff (until 2012) were some items financed though the electricity bill.

[16] In order to have a complete picture of the distributional effects of these policies, the benefits for given segments of the population should be compared to the welfare losses due to retail price increases. This is obviously beyond the scope of this paper.

impact on the welfare of the most vulnerable households, i.e., those with the lowest income levels, while incentivizing rich households to reduce some of their energy spending that is beyond basic needs. This may call for targeted-oriented policy measures that distinguish between income groups. Second, support might be provided either via income (e.g., rent transfers) or prices (lower electricity rates) or a combination of both[17]. In our opinion income-based support is generally preferable to price-based support. Assistance programs should neither subsidise electricity nor provide special electricity fares for low-income households. Public policies should mitigate those distributional effects while maintaining the price signal for all electricity consumers. In other words, policies should address the highly negative distributive impacts of the economic crisis and higher retail prices for the poorest households, but not by interfering with the basic price signal. In particular, we doubt that providing "special" (even "free", as it is often argued) fares could be an appropriate solution[18]. This would basically "kill" the price signal and the incentive to save on electricity by the lowest-income households, possibly leading to an inefficient outcome in terms of energy wastage. A balanced solution could be to give the poorest households an annual lump sum payment which would cover their basic electricity needs for humanity reasons. This would be funded either by all electricity consumers in their bills or by taxpayers through the public budget. This last option (i.e., budget-based support) would have the advantage of eliminating the aforementioned distributional problem taking place through the retail price. In addition, it would be more coherent since it would be part of "social" or "cohesion" policy, which does not have to be financed by electricity consumers. It would keep the price signal. Households which received the income transfer could still waste energy, but they would have an incentive not to do so.

Currently, price-based support exists in Spain for some electricity consumers under the so-called "social bonus" (*bono social*). It provides a 25% discount on the general retail electricity price for consumers with a contracted power capacity below 3kW, those who are 60 years or older, large families and households with all members being unemployed. It is financed by all

[17] In addition, support for the adoption of energy efficient equipment and practices could also address negative distributional impacts from policies which lead to higher electricity prices.

[18] Civil society organizations and political parties with representation in some regional parliaments have proposed that "poor" or "vulnerable" consumers enjoy "special", "social", or "free" rates electricity (see, e.g. Tirado et al 2014 for further details).

electricity consumers in their electricity bill. Thus, it is price-based support not being financed through the budget. This is exactly the opposite of what we recommend.

On the other hand, our results suggest that eliminating the aforementioned tariff deficit, by drastically increasing the final electricity prices for consumers could further exacerbate the negative impact on the welfare of the lowest-income segment of the population.

Table 4. Impact of prices on the welfare of households in the 2008-2012 period.

Quartile (expenditure)	Number of Households	Average household expenditure (Euros) (a)	Equivalent Variation (Euros) (b)	Relative Welfare loss (%) (b)/(a)*100
1	1,117	11,137.9	128.0	1.15
2	1,118	15,547.0	159.0	1.02
3	1,117	19,227.4	178.6	0.93
4	1,117	22,710.7	189.1	0.83
5	1,117	26,427.8	206.0	0.78
6	1,117	30,439.4	210.3	0.69
7	1,118	35,189.3	219.4	0.62
8	1,117	41,571.6	244.9	0.59
9	1,117	51,411.9	253.4	0.49
10	1,117	84,381.7	319.5	0.38
Total	22,346	31,362.2	204.2	0.65

6. Conclusions

This paper has analysed the responsiveness of household electricity demand and the welfare effects related to the deep economic crisis and the increase in electricity prices in the 2006-2012 period. It has been shown that both factors have had an impact on the price and income elasticities of electricity demand and on the welfare of households in Spain between 2006 and 2012. This impact has been different for households with different income levels. In particular, the electricity demand of medium-high income households is more responsive to price increases, whereas the demand of medium-low income households is more responsive to changes in income. The higher electricity prices and the economic crisis have led to lower and steeper U-shaped price elasticities and higher and steeper N-shaped income elasticities. Lower-income households have borne a greater welfare loss in relative terms, measured as equivalent variation.

Several policy implications stem from this analysis. First, it might be argued that addressing the negative welfare effects on the poorest segments of the population should not be a goal of energy policy but social policy more generally. However, it has also been argued that households affected by poverty are not coincidental with those being affected by energy poverty, at least in the Spanish case (Romero et al 2015). If this is so, then energy policy measures as part of a more comprehensive social policy would be required to tackle this difficult problem. Second, the need to mitigate the negative impact on the welfare of the most vulnerable households may call for targeted-oriented policy measures that distinguish between income groups. Third, income income-based support is generally preferable to price-based support since it keeps a more appropriate balance between efficiency and equity considerations. Fourth, **t**he fact that both factors have had more detrimental welfare effects on the lowest-income segment of the population should be taken into account when financing climate and energy policies through the electricity bill. All policies financed though the bill and leading to higher electricity prices have inherently regressive effects (Neuhoff et al 2013). Since the financing of those policies through the public budget is less regressive than financing through the bill, it would make sense to take such support, which pushes retail electricity price upwards, out of the electricity bill.

Finally, some of the limitations of this study suggest fruitful avenues for future research. First, the welfare analysis performed in this paper is circumscribed to the welfare losses experienced by electricity consumers. However, the welfare gains or losses for electricity generators and other actors (such as fossil-fuel providers) have not been considered. A complete welfare analysis would require taking the welfare of all actors into account. Second, our paper analyses the combined impact of the economic crisis and the increase in retail prices. Unfortunately, our data do not allow us to isolate the individual impact of each factor. Therefore, further research could focus on the analysis of their relative importance. Finally, the analysis of the elasticity of electricity demand and welfare effects in other countries is worth investigating.

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