economics for energy

Energy Demand for Heating in Spain: An Empirical Analysis wiith Policy Purposes

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Abstract

Household energy consumption, mostly due to residential heating, is a large component of energy demand in developed countries and thus a target for public policies aimed at reducing negative environmental effects and energy dependence. This paper uses detailed Spanish household micro data to model the related decisions on the type of heating energy source and on the amount of energy used for heating. This way, the article provides accurate estimates that may be used to assess the short and long term effects of public policies in this field. In particular, the relative prices of the three main energy sources for heating influence the discrete decision on the type of energy source in a sort of medium/long term effect. Moreover, the short-term demand reactions to energy price changes are found to be limited but variable across the different energy sources for heating in Spain.

Keywords: environment, energy, security, discrete, continuous, choice, taxes, prices

JEL Classification: C13, C14, C23, Q41

1. Introduction

Energy consumption is increasingly in the agendas of policy makers in many countries due to its associated environmental effects, mostly climate change but not only, and to the so-called energy security concerns when there is a high dependence on foreign energy stocks. This is the case of most developed nations, and particularly of Spain, where greenhouse gas emissions have been considerably over the Kyoto-mandated objectives and where energy dependence is extremely acute.

Households play an important role in total energy consumption of developed countries and, within their consumption share, heating constitutes a major source of expenditure. Therefore, any policy aimed to reducing energy consumption should target household heating. Many are the possibilities to achieve this objective, from building and planning standards to other conventional energy efficiency instruments such as energy taxes or other pricing devices (see Linares and Labandeira, 2010). However, before applying such instruments, it is desirable to have an indication on their effectiveness and also on their costs (including the distributional outcomes). Yet this is not an easy endeavour, as it requests a proper modelling of the demand for heating that could provide accurate results regarding the reaction of households. Accuracy on policy effects, that may provide good advice and minimize policy failures, cannot be achieved just by the existence of good and comprehensive household data but also rests on adequate demand modelling.

This is the general context for the paper: we are interested in providing precise and accurate results regarding Spanish demand of household heating, both at the extensive and intensive margins, so that the likely future public policies in the field, with environmental or energy security objectives, can be properly designed and assessed. To do so, we use a high-quality household survey that allows us to adjust a micro econometric model that takes into account the real nature of energy demand: a demand for services (in this case heating) that is associated to the purchase of durable goods that consume energy to produce the services. The paper thus contributes to the international literature in the field by providing new useful evidence on household energy demand for a country that has been quite active in energy investment and regulatory experiments, and by tailoring demand modelling to data availability.

There is now a considerable economic literature on energy demand. Although the first empirical papers can be traced back to the 1950s, the energy crises of the 1970s led to a subsequent larger interest. Many of the earlier papers employ aggregate data (see, for a recent application, Narayan and Smyth, 2005), but this involves an important loss in terms of individual behaviour. When using micro data, a first option is to estimate energy demand through standard econometric techniques (ordinary or generalized least squares) with different variables such as energy prices, income or climatic conditions (see Branch, 1993; Filippini and Pachauri, 2004). However, this does not contemplate the above-mentioned relationship between the discrete household decision of durable goods purchase and the continuous decision on energy consumption. As a consequence, the price effects obtained may not be accurate and may lead to a wrong assessment on the effectiveness and costs of energy policies.

Although it is possible to use a simultaneous equation model to estimate both an energy demand equation and a durable good equation (see Garbacz, 1984a; 1984b), it is instead customary to use sequential continuous-discrete models. The sequential nature of the model rests on the

household decision process. The household first takes the discrete decision on the purchase of durables that consume energy and, constrained by that, in a second stage takes the continuous decision on energy consumption. Following this approach, Hausman (1979) and Dubin and McFadden (1984) jointly model the demand for household appliances and for electricity through a parametric model with household micro data for the US. Hausman (1979) also links the household discount rates to the purchase of electric appliances and to the consumption of electricity. Hanemann (1984) provides a general framework to formulate econometric models in cases where consumers take related discrete and continuous decisions, also presenting a specific model for substitute goods. However, he does not consider unobservable individual heterogeneity, a crucial factor in Dubin and McFadden's (1984) model.

There are numerous applications to energy demand stemming from the methodological approach set by Dubin and McFadden[1]. Baker and Blundell (1991) deal with the demand for electricity, gas and durable goods in the UK; Bernard et al. (1996) and Nesbakken (2001) analyze electricity demand for heating in respectively Quebec and Norway; Vaage (2000) adapts Hanemann's (1984) model to study household energy demand and the demand for durables in Norway, whereas Halvorsen and Larsen (2001) use a discrete-continuous model to estimate the long-term effects of investing in new household appliances in Norway. More recently, Asadoorian et al. (2008) estimate residential electricity demand and the demand for durables using Chinese panel data.

With respect to Spain, the academic literature on household energy demand is rather scarce and there are not applications that incorporate the relationship between purchases of certain durables and energy consumption. For instance, Labandeira et al. (2006) use micro data to estimate a household energy demand system that does not contemplate the discrete decision on durables. In a recent paper, Labandeira et al. (2011) use high-quality micro data on electricity consumption to propose a method to calculate price elasticity of demand when information on other economic variables is incomplete or missing, even though, again, the discrete decision on the purchase of durables is not contemplated.

This paper focuses in heating, a major item within Spanish energy consumption, by using a detailed database on household consumption that is thoroughly described in the next section[2]. With the rich data from that survey, we examine the existence of a relationship between the discrete decision on the type of energy used for heating and the continuous decision on the

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[1] Many papers have also applied this methodology for the case of discrete-continuous decisions to the specific case of transport. For instance, Golberg (1998), West (2004) or Bhat and Sen (2006) consider the discrete decision on vehicle purchase and the continuous choice of distance travelled (petrol consumption). This contrasts with Newell and Pizer (2008) or Mansur et al. (2005), who model the type of car fuel as the discrete decision and the consumption of car fuels as the continuous decision.

[2] The decision to focus on household heating is also related to the lack of Spanish data to carry out any other demand analysis that considers both the decision on durables and energy consumption.

amount of energy. As the relationship is found to be strong, the following section presents the theoretical and empirical models that, linked to the previous literature, are suitable for the detailed Spanish household database. In section 4 we pay a special attention to the interpretation of the results of our estimations, also comparing them to those yielded by the academic literature. The paper ends with the general conclusions and policy implications, although it also contains several annexes that provide the full results of the estimations and further information on the employed data and household survey.

2. Spanish energy household data

The main data source for this paper is the Spanish Household Survey (SHS, *Encuesta de Presupuestos Familiares*), carried out by the Spanish National Institute for Statistics (INE). This is a survey that provides information on the amount and origin of households' incomes, on their expenditures on goods and services, also yielding detailed information on the characteristics and location of households. Indeed, the SHS is the main public source of micro data to know the behaviour of Spanish households and is used to obtain the national accounting aggregate for private consumption and also to calculate, from the distribution of expenditures, the structure of consumption necessary to calculate the retail price index.

The panel used in this article, for the period 2006-2008, contains 63,054 observations from households that remain in the sample a maximum of two years. Besides providing information on energy expenses, the SHS indicates the source of energy for heating in households and other relevant physical characteristics. All monetary variables are deflated using the retail price index of the INE to produce figures in comparable real terms. The survey does not yield information on climatic variables, so they cannot be included in the estimation. Annex A provides general information on Spanish households, Spanish housing and access to energy.

The SHS is constructed to be representative of Spanish households. So, under this circumstance, Table 1 indicates that a majority of Spanish families (around 60%) have heating in their houses[3]. Moreover, average household energy consumption was around 8 €/m² during the 2006-2008 period. The table also indicates that electricity, natural gas and liquid fuels (diesel, fuel-oil, etc.) are the main sources of energy for heating and that they also represent the biggest energy expenditure for households in terms of floor area (see Figure 1 for the density of energy expenditure per square meter for the main sources of energy). Indeed, heating is the main source

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[3] Although the high number of households without heating may look surprising when compared to other developed countries, they are due to milder winters in Mediterranean Spain. For instance, the SHS indicates that in Andalusia (a major Spanish southern region) only 20% of households had central heating in 2008. When comparing with other European countries, the figure is quite below the 70% average figure for the EU (EEA, 2011), even though some of the Spanish areas outside the Mediterranean climate regime may be close to this proportion.

for household energy expenditure in developed countries, as observed in Figure 2 for the Spanish case[4]. Therefore, these data vindicate our approximation to provide useful energy policy guidance: focusing on heating as major source of household energy expenditure (and thus quite relevant for the whole energy system) and on the energy sources that are used for heating in more than 90% of Spanish households.

Table 1. Energy and heating in Spanish households

|	**2006**	**2007**	**2008**
Average household energy consumption (€/m²)			
Total	8.39	8.32	8.55
Electricity	4.77	4.81	4.89
Natural gas	4.55	3.93	4.20
GLP	2.71	2.24	2.47
Liquid fuels	5.33	4.03	4.40
Solid fuels (coal, wood, etc.)	1.42	0.81	0.88
Heating availability			
Yes	59.64%	62.09%	63.75%
No	40.35%	37.91%	36.25%
Energy source for heating			
Electricity	20.90%	19.36%	20.71%
Natural gas	42.11%	43.74%	43.89%
GLP	6.23%	5.70%	5.53%
Other liquid fuels	27.89%	28.36%	27.34%
Solid fuels	2.87%	2.84%	2.49%
Solar energy	0.00%	0.00%	0.03%

Source: Own calculations from SHS.
Note: To calculate average energy consumption, housing with less than 35 m² or more than 300 m² were excluded as information on their exact size was not available.

As advanced in the introduction, when studying household energy demand for heating it is crucial to consider their previous decision on the type of source for heating. Indeed, Table 2 shows that during the short period considered in this paper a significant number of Spanish households changed their source of energy for heating (the figures indicate the annual changes from one source of heating to other). The obvious question is to distinguish if these changes have been motivated by changes in the prices of the different energy goods used for heating or by any other reason. Figure 3a depicts the evolution, in real terms, of the average prices of the three main sources of energy for heating: natural gas, liquid fuels and electricity. These prices were calculated from information provided by the SHS and thus are household-specific. Whereas during the 2006-2008 period natural gas and electricity prices remained rather stable in Spain, the average price of liquid fuels showed an important increase due to a high transmission of the

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[4] Despite suffering high temperatures during summers in large areas of the country, by 2008 only around 2.7% of Spanish household electricity consumption was due to air conditioning (MITyC, 2010), representing around 1% of total energy consumption (Figure 2). In any case, the SHS does not provide information on the existence of this facility in Spanish housing.
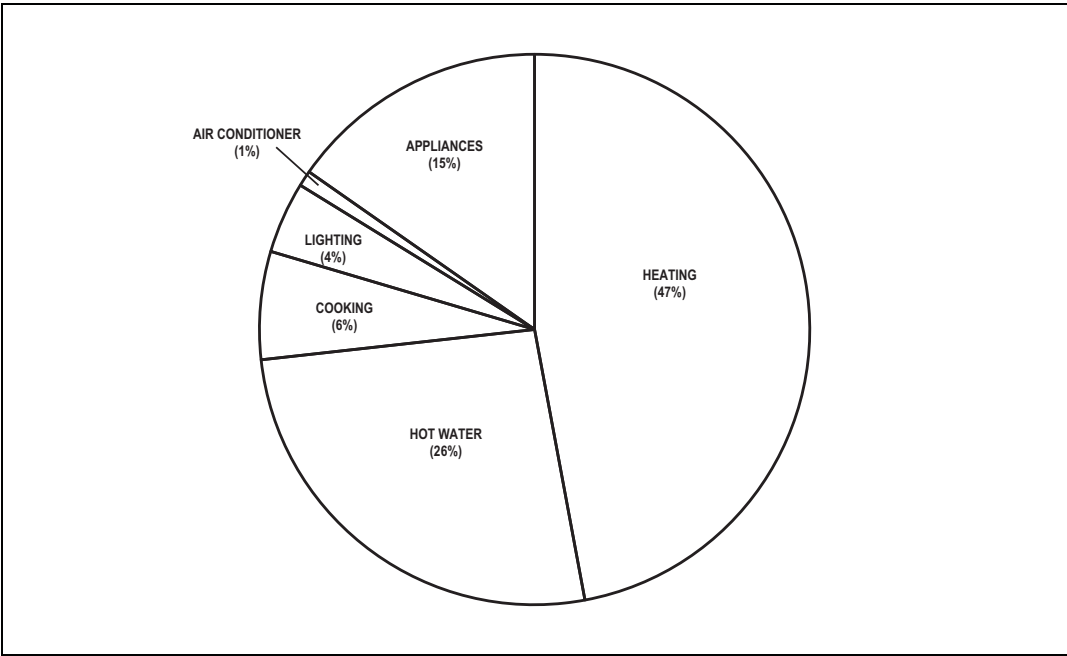
severe oil price hikes seen during those years. This evolution is consistent with the observed trends for Spanish households in the previous ten years (see Table 3b, with IEA data).

Figure 1. Energy expenditure density (€/m²)
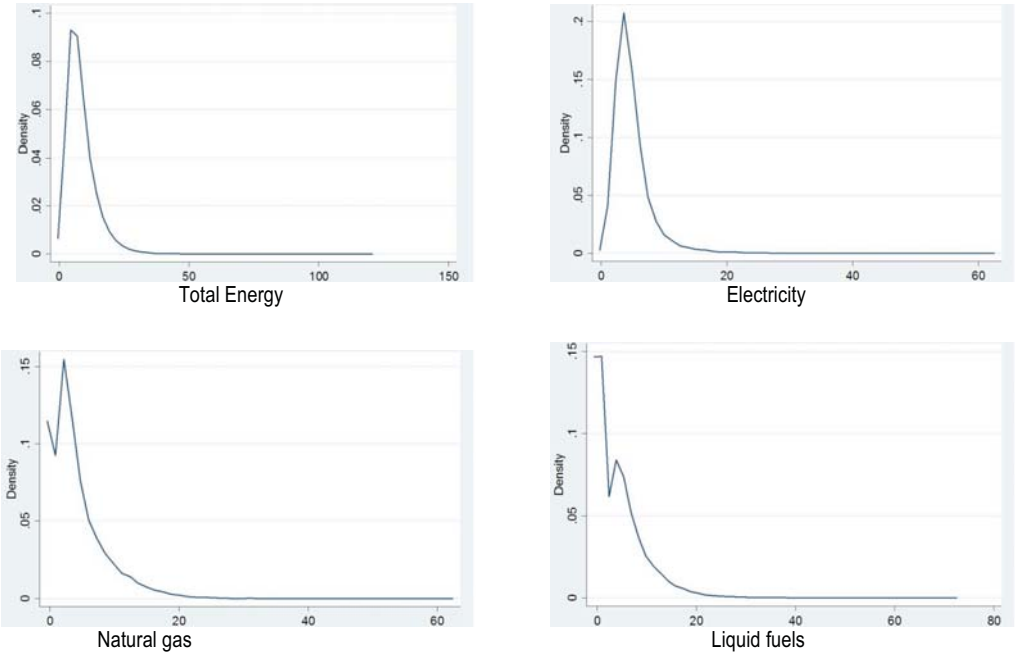
Source: Own calculations.

Figure 2. Distribution of final energy consumption by Spanish households. 2008

Source: MITyC (2010) and own calculations.

Therefore, we follow a discrete approach to examine the influence of price changes in the different energy sources for domestic heating on the choice of energy inputs for heating by households. Thus, we propose to estimate a panel data Logit model to take unobserved heterogeneity into account. In addition, the specification includes energy prices and household expenditures during the 2006-2008 period as explanatory variables (for more, see Annex B)[5]. The results showed that the price of liquid fuels is significant in all cases, with a positive influence on the adoption of natural gas and electricity and a negative influence on their own choice as energy sources for heating.

Table 2. Main energy sources for heating and changes during 2006-2008
(% and number of households)

2007 / 2006	Electricity	Natural Gas	Liquid Fuels	Others
Electricity	92.59% (612)	4.39% (29)	1.97% (13)	1.06% (7)
Natural Gas	1.24% (22)	95.16% (1,690)	2.08% (37)	1.52% (27)
Liquid Fuels	1.25% (15)	3.57% (43)	92.77% (1,117)	2.41% (29)
2008 / 2007	Electricity	Natural Gas	Liquid Fuels	Others
Electricity	94.38% (857)	1.87% (17)	2.31% (21)	1.43% (13)
Natural Gas	1.42% (32)	95.53% (2,158)	1.64% (37)	1.42% (32)
Liquid Fuels	0.72% (11)	2.87% (44)	94.91% (1,455)	1.50% (23)

Source: Own calculations.
Note: Only households staying for at least two periods in the sample were considered.

Therefore, the remarkable price increase in liquid fuels in 2006-2008 led household to reduce their use as source of heating and to demand more electricity and natural gas instead (see also Figures 3a). This result is reinforced by the fact that the energy price signals show a consistent pattern since the mid 1990s (Figure 3b), and also because only 10% of Spanish households are

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[5] We propose this model to be able to control unobserved heterogeneity that is potentially correlated with the explanatory variables, at the cost of assuming strict exogeneity of the regressors. Moreover, since the model requires a transformation to rule out the fixed effects, any variable without time variation also disappears from the estimated specification. However, we should interpret the results of the model as a way of describing the substitution among energy sources at the extensive margin.

under centralized central heating (IDAE, 2010) which, otherwise, could hinder changes in heating possibilities. Moreover, energy-heating choices were available to a large share of households because access to natural gas was quite widespread in 2008, even in areas with limited population (see Tables A3 and A4 in Annex A).

Figure 3a. Evolution of the prices of electricity, natural gas and liquid fuels (€/kWh)
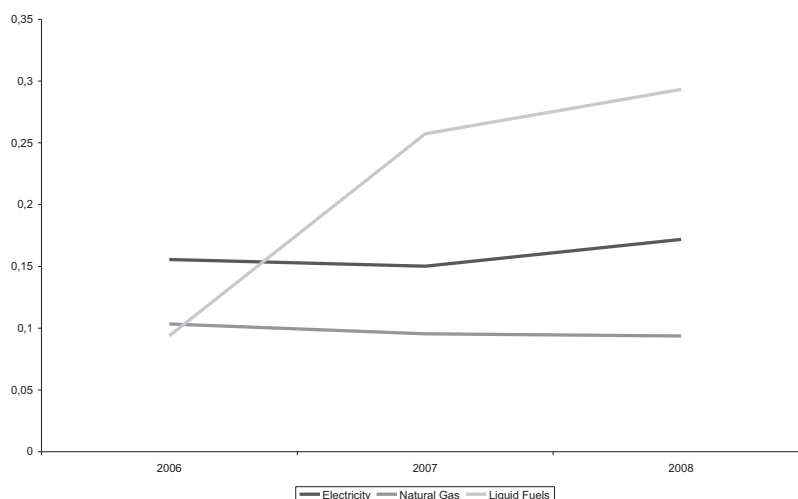
Source: SHS.

Figure 3b. Evolution of the prices of electricity, natural gas and liquid fuels (1996=100)
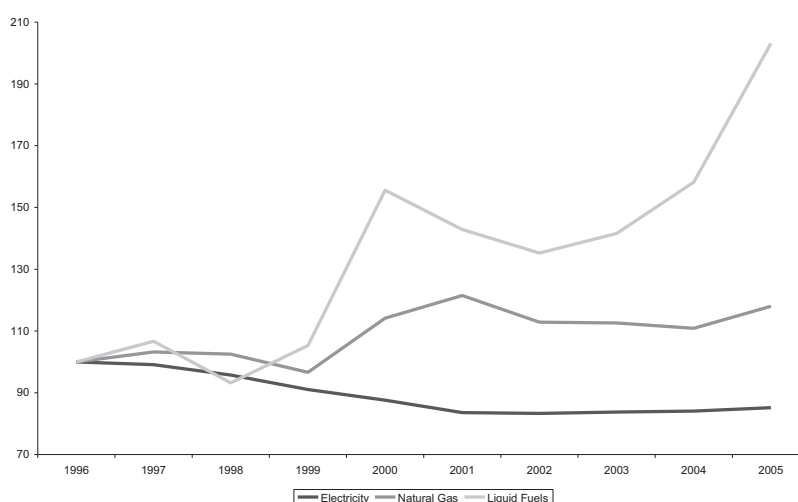
Source: IEA (2006)

The preceding means that, when studying Spanish household energy demand for heating, energy prices also influence the discrete decision on the type of energy to use. If this were not taken into

account, the elasticity price estimates would be biased and inconsistent and therefore not apt for suitable policy advice. Thus, prices have two different effects on the demand for heating, one at the extensive margin (changes in the source of energy) and another at the intensive margin (changes in the quantity consumed). However, we do not find any income effect on the decision to change the source of energy.

3. Modelling Spanish household energy demand for heating

3.1. Theoretical framework

As indicated in the previous section, a reliable estimation of household energy demand for heating requires the use of discrete and continuous approaches that could contemplate the two dimensions of households decisions: on the type of energy source and on the amount of energy. Thus we depart from Dubin and McFadden's (1984) model, using as discrete choice the use (or not) of the three main sources of energy for heating and as continuous choice the amount of energy employed for household heating. There is a model for each energy source k (natural gas, liquid fuels and electricity) in which the household decides first on the type of energy used for heating and, conditional to that choice, has an indirect utility function such as

$$V_k(h_k, y, p^e, p^g, p^l, z, \eta) \qquad (1)$$

where h_k is 1 if the household decides to have k as energy source, and 0 the decision is not to have it. Moreover, y is household total expenditure, p^e is the price of electricity, p^g the price of natural gas, p^l the price of liquid fuels, z are the observable characteristics of the household and housing, and η the unobservable characteristics of the household. In this setting the probability of the household deciding to have k as energy source for heating is

$$P_k(h_k = 1) = \Pr\{V_k(1, y, p^e, p^g, p^l, z, \eta) \geq V_k(0, y, p^e, p^g, p^l, z, \eta)\} \qquad (2)$$

If the household decides to have k as energy source for heating, the household's conditional demand for that energy good (continuous choice) is given by Roy's identity

$$x_k = \frac{-\partial V_k(1, y, p^e, p^g, p^l, z, \eta)/\partial p^k}{\partial V_k(1, y, p^e, p^g, p^l, z, \eta)/\partial y} = f_k(Z \mid h_k = 1) \qquad (3)$$

Therefore, we are interested in estimating the conditional demand function (3) conditioned by the previous decision on the use of energy source k. Since the discrete and continuous decisions are correlated, this has to be taken into account in the estimation of the conditional demand function.

3.2. Empirical implementation

There are several alternatives for estimating the preceding theoretical model. A first option would be to estimate the demand of energy for heating without considering the discrete decision on the type of energy source, although we have already noted that the first decision could have implications for the second one if they were correlated. As a result of such a potential correlation, this first alternative would not provide consistent parameter estimates (see section 2). A second alternative would be the use of a Tobit type I model that determines, in the same process, the choice of energy source and household energy consumption. In this case, we assume that the effects of the variables are the same in both decisions, which is very restrictive at the light of the descriptive statistics previously presented. A third option would employ a Tobit type II model with two processes: one determining the household choice of energy source and the other household energy consumption. Since the household decides on the future source of energy consumption, the Tobit type II can be set with dominance of the first decision, i.e., the classical sample selection model introduced by Heckman (1979), because once the household decides the source of energy, consumption takes place wherever consumption of the other source should be zero (except when households combine different sources).

Given that the choice of energy source for heating is a medium/long-term decision, whereas the decision on energy consumption is a short-term decision, it seems clear that we are in front of sequential choices: first the household decides the energy source to be used for heating and subsequently, conditioned by that choice, decides the amount of energy to provide a certain level of heating. Thus we opt for a Tobit type II approach with a discrete model for each energy source and, conditional to that, a continuous model for each energy source. In any case, we have estimated the three alternatives above and, using likelihood ratio tests, we have tested the Tobit type II model with first hurdle dominance against the other two alternatives[6]. As shown in Table 3, in all cases the statistic is bigger than the critical value at any standard significance level, so the null hypothesis of equality of coefficients is rejected in favour of our proposal of a sample selection model.

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[6] The notion of dominance was first introduced by Jones (1989).

Table 3. Likelihood ratio tests

	Type 2 Tobit vs. Type 1 Tobit		Type 2 Tobit vs. continuous model	
	Value of test	Critical value (degrees of freedom)	Value of test	Critical value (degrees of freedom)
Electricity	102,403	82.72 (47)	239,642	82.72 (47)
Natural Gas	137,193	85.35 (49)	240,400	85.35 (49)
Liquid Fuels	92,275	84.04 (48)	221,560	84.04 (48)

Source: Own calculations.

Following the Tobit type II approach, we have the demand function for energy source for heating k for household i

$$x_{ik}^* = f_1(y_i, p^k, z_i, \eta_i) \tag{4}$$

However, x_{ik}^* is only observed when household i decided to use energy source k for heating, so the consumption of energy good k by household i is

$$x_{ik} = \begin{cases} x_{ik}^* & if \quad s_{ik}^* > 0 \\ 0 & if \quad s_{ik}^* \leq 0 \end{cases} \tag{5}$$

where $s_{ik}^* = f_2(H_i)$ is the household choice function for energy source k that depends of a number of variables H. Note that only the sign s_{ik}^* is observable, being positive if the household decides to use energy source k and negative otherwise. In this sense, it is possible to define a binary variable such as

$$s_{ik} = \begin{cases} 1 & if \quad s_{ik}^* > 0 \\ 0 & if \quad s_{ik}^* \leq 0 \end{cases} \tag{6}$$

This way, $\{x_{ik}, s_{ik}\}$ are the observed dependent variables of the model.

In order to estimate the model, a functional form must be specified. Firstly, we use the following specification of the functional form of the non-observable variable s^* for each source of energy k

$$s^*_{itk} = \alpha_k + \beta^e_k \log p^e_{it} + \beta^g_k \log p^g_{it} + \beta^l_k \log p^l_{it} + \phi^1_k \log g^t_{it} + \phi^2_k (\log g^t_{it})^2 +$$

$$+ \tau_k nmie_{it} + \varpi_k spf_{it} + \sum_{j=1}^{17} \varsigma^1_{jk} duca_{jit} + + \sum_{j=1}^{3} \varsigma^2_{jk} duth_{jit} + \sum_{j=1}^{4} \varsigma^3_{jk} dunoc_{jit} +$$

$$+ \sum_{j=1}^{3} \varsigma^4_{jk} duocu_{jit} + \sum_{j=1}^{2} \varsigma^5_{jk} dues_{jit} + \sum_{j=1}^{3} \varsigma^6_{jk} dusta_{jit} + \sum_{j=1}^{2} \varsigma^7_{jk} durgt_{jit} + \qquad (7)$$

$$+ \sum_{j=1}^{2} \varsigma^8_{jk} duted_{jit} + \varsigma^9_k duzrs_{it} + \varsigma^e_k duzrs_{it} * \log p^e_{it} + \varsigma^g_k duzrs_{it} * \log p^g_{it} +$$

$$+ \varsigma^l_k duzrs_{it} * \log p^l_{it} + \varsigma^{10}_{jk} duanco_{jit} + \theta_{ik} + \upsilon_{itk} = \sum_j \zeta_{jk} w_{jit} + \theta_{ik} + \upsilon_{itk}$$

where i indicates household, t time (year), g^t total household expenditure (income variable), $nmie$ the number of household members, spf the housing floor area, θ the unobservable heterogeneity and υ the idiosyncratic error term. Moreover, a complete set of dummies for household and housing characteristics are included (see Annex C for a description of these variables).

Secondly, a double logarithmic specification is used to model the continuous decision on energy consumption[7],

$$\log x^*_{itk} = \psi_k + \delta_k \log p^k_{it} + \gamma^1_k \log g^t_{it} + \gamma^2_k (\log g^t_{it})^2 + + \pi_k nmie_{it} + \iota_k spf_{it} +$$

$$+ \sum_{j=1}^{17} \omega^1_{jk} duca_{jit} + + \sum_{j=1}^{3} \omega^2_{jk} duth_{jit} + \sum_{j=1}^{4} \omega^3_{jk} dunoc_{jit} + \sum_{j=1}^{3} \omega^4_{jk} duocu_{jit} +$$

$$+ \sum_{j=1}^{2} \omega^5_{jk} dues_{jit} + \sum_{j=1}^{3} \omega^6_{jk} dusta_{jit} + \sum_{j=1}^{2} \omega^7_{jk} durgt_{jit} + \sum_{j=1}^{2} \omega^8_{jk} duted_{jit} + \qquad (8)$$

$$+ \omega^9_k duzrs_{it} + \omega^{10}_k duzrs_{it} * \log p^k_{it} + \omega^{11}_{jk} duanco_{jit} + \eta_{ik} + \varepsilon_{itk}$$

where η is the unobservable heterogeneity and ε the idiosyncratic error term. In this case only the price of the chosen energy source is included, as the decision on the amount of energy source to consume to provide heating is contingent on the type of energy source previously selected by the household[8]. This relates to the short-term nature of the decision on the level of energy consumption, and also to the existing household data (as in the SHS each household has a single source of energy for heating in each period). As indicated before, changes in the relative prices of energy sources for heating may influence medium/long-term choices on the type of

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[7] We use a double logarithmic specification to simplify the estimation and to be able to obtain directly the elasticities. We do not follow any theoretical demand model as the specification for each energy source is estimated without considering a complete demand model for energy products and, in this way, we do not need to impose any cross-equation restriction. Moreover, we use the logs of total expenditure and of its square to try to capture non-linear profiles of consumption as those depicted in Figure 1.

[8] This assumption is obviously tested in the empirical implementation below.

energy source used in household heating, but they do not affect the amount of consumption of the chosen energy source in the short term.

As s^* and x^* are not observable, estimation is carried out through a Tobit type II model for panel data, as previously discussed. Thus, assuming that the idiosyncratic error term υ is normal i.i.d., the probability that the household chooses the energy source k is estimated through a Probit model for panel data[9].

$$\Pr(s_{itk} = 1 \mid w_{it}, \theta_{ik}) = \Phi\left(\frac{\sum_j \zeta_{jk} w_{jit} + \theta_{ik}}{\sigma_\upsilon} \right) \tag{9}$$

where Φ is the standard normal distribution function and σ_v is the standard deviation of the idiosyncratic error term, which in this case is equal to one as we only identify the parameters up to this scaling vector. Yet this lack of identification does not have any influence on the consistency of the parameter estimates of the continuous equation. The results from this estimation allow the calculation of Heckman's (1979) lambda, which is introduced as an additional regressor in the consumption equation. Energy consumption is estimated through generalized least squares, given the presence of unobservable heterogeneity in the composite error term.

4. Results

The detailed results of the estimation of the household discrete decision on energy sources for heating are provided in Annex D. In all cases (natural gas, liquid fuels and electricity) the price of the energy source has a negative and significant influence on the probability of choosing that energy source, whereas the price of alternative sources of energy for heating shows a positive influence on that probability. Moreover, the results show that the probability of having heating always increases with household income, whereas the probability of having electric heating diminishes with housing floor area (the opposite for natural gas and liquid fuels).

It is thus clear from Spanish data that changes in the relative prices of energy sources for heating would lead households, in the medium and long terms, to select the cheapest energy alternative for heating. This is seen in Table 4, which reports the average own and cross price elasticities of

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[9] We are assuming random unobserved effects, being aware that this may constitute a restriction. In the section describing the data we have used a Logit model with fixed effects to adjust cross-price effects among different energy sources, which could be employed again. However, the estimation of this kind of model is based only on the data from households with observed changes in the source of energy for heating, so now it would be necessary to build a selection term (the inverse of Mill´s ratio) for the whole sample. Given these considerations, we have to opt for an alternative and we have chosen the Probit model.

the probability of choosing different energy sources for heating[10]. In this sense, the highest own-price impact is observed in liquid fuels, with a higher-than proportional reduction in the probability of using that energy source for heating. On the contrary, electricity would have the lowest own-price effect[11]. Cross-price elasticities show that a rise in electricity prices would have a higher influence in the probability of using natural gas for heating; higher natural gas prices would preferably promote changes to electricity powered heating; and rising prices of liquid fuels show a larger influence on the probability of using heating with natural gas.

Table 4. Price elasticities in the discrete choice

	Own-price elasticity	Cross-price elasticity
Electricity (E)	-0.0690	0.1546 (NG price) 0.0954 (LF price)
Natural Gas (NG)	-0.4170	0.1542 (E price) 0.4274 (LF price)
Liquid Fuels (LF)	-1.1255	0.0489 (E Price) 0.1226 (NG price)

Source: Own calculations.

Regarding the results on the continuous household decision on energy consumption for heating, Table 5 depicts the income and price elasticities of household demand obtained from the estimation (see again Annex D for a full report of the estimated parameters used for the calculation). As expected, energy demand for heating is inelastic with respect to its price for all energy sources so, *ceteris paribus,* an increase in the price of the energy source will lead to a less than proportional short-term reduction in the demand for that energy source. The results indicate larger short-term reactions to prices by households that use liquid fossil fuels for heating, in contrast to a rather rigid electricity demand for heating. There is a significant difference (for a 10% significance level) between the price elasticity calculated for urban and rural areas for households that use electricity as source for heating, which is probably due to the higher per-capita income in the former. As indicated in the preceding section, the prices of alternative energy sources do not influence the demand of the chosen energy good in the short term as this is conditional to the energy source for heating decided in the discrete choice.

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[10] The own-price elasticities were calculated from equation (9), following the expression

$$\frac{\partial \Pr(s_{ik}=1|w_{it},\theta_{ik})}{\partial p^k} = (\beta_k^k + \varsigma_k^k duzrs_{it})\frac{1}{p^k}\phi\left(\sum_j \zeta_{jk}w_{jit}\right) \Rightarrow \frac{\frac{\partial \Pr(s_{ik}=1|w_{it},\theta_{ik})}{\Pr(s_{ik}=1|w_{it},\theta_{ik})}}{\frac{\partial p^k}{p^k}} = \frac{(\beta_k^k + \varsigma_k^k duzrs_{it})\phi\left(\sum_j \zeta_{jk}w_{jit}\right)}{\Pr(s_{ik}=1|w_{it},\theta_{ik})}$$

where Φ is the standard normal density function. Cross-price elasticities are calculated in the same manner but using the price of other energy sources instead of the own price.

[11] We must note that this result is strongly influenced by the time span of our sample.

Table 5. Price and income elasticities of household demand of energy for heating

	Price elasticity		Income elasticity
	Urban	**Rural**	
Electricity	-0.1176	-0.2012	0.2976
Natural Gas	-0.2173	-0.2203	0.2301
Liquid Fuels	-0.3339	-0.3404	0.3102

Source: Own calculations.

Besides, the estimation of the continuous model shows that the level of income has always a positive influence on the demand of the energy source for heating, again with a less than proportional *ceteris paribus* increase of demand due to income growth. Other household and housing characteristics also show some influence on the demand of energy sources for heating (see Annex D). For instance, the demand of energy for heating is always higher when the main contributor to household income works is highly placed in a firm or public administration, especially in the case of households using liquid fuels for heating. On the contrary, the demand for electricity and, particularly, liquid fuels for heating is significantly lower when the main contributor to household income is unemployed, being significantly higher (especially for electricity) in households living in housing owned by them. As expected, demand is higher for all energy sources when households have more members or inhabit houses/flats with large floor areas. Moreover, there are significant variations in household energy consumption for heating across regions (*Comunidades Autónomas*) that are probably related to the remarkable climatic differences that exist in Spain[12].

Table 6 provides a compilation of price and income elasticities of energy demand from the academic literature. Note that the results from comparable pieces of research (i.e. those using a similar discrete-continuous methodological approximation) are quite heterogeneous in time frame, geographical setting, and regarding the modelled decision. With this caution, the numbers indicate that the Spanish price and income elasticities reported by this paper are within the usual range set by the existing international literature for the developed world.

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[12] Regional dummies can constitute proxies for climatic variables although we are aware that the aggregation to regions is very wide to capture the effects of weather conditions on consumption.

Table 6. Elasticities of household energy demand with discrete-continuous modeling

Paper	Country	Energy good	Price elasticity	Income elasticity
Hausman (1979)	U.S	Electricity	0.04	--
Dubin and McFadden (1984)	U.S	Electricity	[-0.26,-0.22]	[0.02, 0.06]
Baker and Blundell (1991)	U.K	Electricity Natural gas	-0.67 (winter) -0.98 (spring/fall) -1.03 (summer) -0.41 (winter) -0.62 (spring/fall) -0.47 (summer)	0.18 0.25 0.20 0.17 0.31 0.27
Bernard et al. (1996)	Canada	Electricity	[-1.29, -0.05]	[0.08, 0.09]
Vaage (2000)	Norway	Average*	[-1.29, -1.24]	[-0.07, 0.0]
Nesbakken (2001)	Norway	Electricity Electricity+fuel-oil Electricity+wood Electricity+fuel-oil+wood	-0.43 -0.23 -0.22 -0.17	0.08 0.04 0.04 0.03
Halvorsen and Larsen (2001)	Norway	Electricity	-0.43	[0.06, -0.13]
Asadoorian et al. (2008)	China	Electricity	-0.19 (urban) -0.28 (rural)	0.80 0.04

Note: * Four different sources of energy for heating are considered (electricity, electricity and wood, electricity and fuel-oil, wood and fuel-oil), although the paper calculates an average price elasticity in the continuous decision.
Source: Compilation from academic literature by the authors.

Table 7 summarizes the existing evidence on income and price elasticity of electricity for Spain, as this is the only energy input for heating whose price and income responses have been addressed by academic research. The elasticity price results of this paper are slightly lower than those reported by Labandeira et al. (2011), who use high-quality data on electricity consumption by Spanish households for a similar time span. Larger discrepancies with Labandeira et al. (2006) which, as before, only deals with the continuous decision on energy consumption but also provides income elasticities, are probably due to a very different socio-economic and energy setting as data for estimation refers to the 1970s-1990s. In both cases, however, the differences are consistent with the fact that the elasticities reported in this paper only incorporate the short-term or impact reaction to price changes, as the long-term effect is embedded in the discrete choice on energy sources. In any case, the divergences between this and previous approaches vindicate our choice, which provides a more accurate depiction of the likely effects of price and income changes on Spanish household demand of energy for heating.

Table 7. Other academic evidence on Spanish income and price elasticity of electricity

Paper	Price elasticity	Income elasticity
Labandeira et al. (2006)	-0.78	0.81
Labandeira et al. (2011)	-0.25	--
Bernstein and Madlener (2011)	[-0.14, 0.01] (short term) [-0.35, -0.30] (long term)	[0.14, 0.30] (short term) [1.21, 1.24] (long term)

Source: Compilation from academic literature by the authors.

6. Conclusions and implications

The main objective of this paper has been to provide rigorous and accurate results regarding the price and income effects on Spanish household demand of energy for heating. There are two main reasons behind this goal: household heating constitutes a significant part of total energy demand in a developed country such as Spain, and (because of that) public policies aimed at reducing energy consumption for environmental or energy security concerns are likely to be directed to this sector. Therefore, high-quality empirical evidence that, *ex-ante*, can guide and assess public and private strategies and policies, is especially necessary in this area.

The paper adjusts a micro econometric model on the high-quality micro data provided by the SHS. The model defines heating as a service that is associated to the purchase of durable goods that consume energy to produce the services. By considering that a reliable estimation of household energy demand for heating requires the use of discrete and continuous approaches that contemplate the previous two households decisions, on the type of energy source and on the amount of energy, the paper employs a methodological strategy that has been successfully applied for this and other purposes in the academic literature.

The paper focuses in the three main energy sources for household heating (natural gas, liquid fuels and electricity) and shows that the price of the energy source has a negative and significant influence on the probability of choosing that energy source (discrete approach). This means that changes in the relative prices of energy sources for heating would lead households, in the medium and long terms, to select the cheapest energy alternative. This result is consistent with the consistent time trend of relative prices for household heating, and also with the possibilities that Spanish households have to change their energy sources for heating: limited centralized heating facilities and a high access to natural gas, even in less populated areas.

Our research also provides short-term income and price elasticities that are contingent to the discrete decision on the energy source for heating. Energy demand for heating is found to be inelastic with respect to its price for all energy sources, although there are larger (lower) short-term reactions to prices by households that use liquid fossil fuels (electricity) for heating. The preceding results have been also justified by the time span of our sample. Regarding income elasticities, in all cases the level of income has a positive, but less than proportional, influence on the demand of the energy source for heating.

The paper contributes to the international literature in the field by providing new evidence on household energy demand for a rather active country in the energy domain, which can be applied for policy design and evaluation, and by tailoring demand modelling to the availability of a rich data set. The reported results are similar to those obtained for similar developed countries by papers using this approach but, due to the methodological improvements, they show some differences with respect to the (scarce) existing empirical evidence for Spain. As we feel that these new estimates are more accurate than previous empirical evidence, it is obvious that policy design and assessment can benefit from this piece of research.

The results of the paper allow for a number of policy-related reflections. First of all they show the limitation of pricing policies to control energy demand in the short term. However, changes in relative prices may have strong influences on the choice of heating technology and thus on energy consumption for heating in this sequential process. A combination of those two effects produces a richer and more accurate set of results, as illustrated by Table 8. The table simulates the effects of different price changes on household energy demand for heating with the set of elasticities estimated by this paper and Spanish data. The procedure assumes a 10% increase in the price of the energy source *k* and then uses the price elasticity provided by the continuous model and the average consumption of *k* before the price change to calculate the short-term demand reduction in *k*. Moreover, as the change in relative prices would induce households to modify their energy source for heating, we employ the discrete elasticities to determine the effect of the price increase of *k* in the probability of choosing each source of energy. The new energy demands and reported changes are calculated by using the new proportion of users as a second source for demand changes (now affecting all energy goods), which are then added to the preceding demand change.

As observed in Table 8, changes in the relative prices of the energy sources for heating have remarkably different effects depending on the fuel that is targeted with the price increase. For instance, for a discretionary 10% rise only in the price of electricity (that may be related to regulatory practices or market evolution), there is a much lower own reduction in demand than in the other two other cases. A general reduction in household energy consumption for heating is just observed when the price of natural gas is selectively increased in that amount, or when the

prices of all energy sources simultaneously increase. However, natural gas is the benefitted energy source when liquid fuels or electricity prices are selectively increased. This is not the case when there is a general price increase, as electricity is then the benefitted energy source.

Table 8. Effects of different energy price increases on Spanish household consumption

Price \\ Demand	+10% Electricity	+10% Natural Gas	+10% Liquid Fuels	+10% General
Electricity	*-2.00%*	1.55%	0.95%	0.47%
Natural Gas	1.54%	*-6.25%*	4.27%	*-0.56%*
Liquid Fuels	0.49%	1.23%	*-14.22%*	*-12.56%*
Total	0.82%	*-3.70%*	0.32%	*-2.66%*

Source: Own calculations.

The preceding results justify 'setting prices right' in each of the energy sources for heating by internalizing environmental negative effects and energy security concerns, but it also supports the use of design and/or performance standards on appliances used for heating. Assuming that discrete changes in energy sources for heating involve some relevant changes in heating systems, standards could reinforce the positive effects of prices. It is also clear from the paper that the evolution of household income is a very significant influence in energy demand for heating. Both distributional concerns and policy effectiveness should be informed by these results.

In sum, the results from this paper could be used not just for short-term policy assessment but also for prospective analysis. By combining the expected path of energy prices (including the impact of regulations) and economic (income) growth, it would be possible to obtain a clearer picture of the long-term effects of energy policies or, better, of the type and level of policies that should be introduced to attain the desired environmental and other energy or economic objectives.

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ANNEX A

FURTHER DATA ON SPANISH HOUSEHOLDS AND HEATING

Table A1. Main characteristics of Spanish households

	2006	2007	2008
Number of members			
1	14,20%	14,44%	14,43%
2	29,10%	29,18%	29,09%
[3-4]	47,75%	47,58%	48,19%
[5-7]	8,70%	8,54%	7,96%
>7	0,25%	0,26%	0,33%
Number of active workers			
0	24,25%	24,37%	23,30%
1	29,86%	29,30%	28,87%
2	35,88%	36,10%	38,02%
3	7,54%	7,59%	7,39%
≥4	2,47%	2,65%	2,42%
Number of workers			
0	28,01%	27,59%	27,59%
1	33,28%	32,57%	32,54%
2	31,44%	31,91%	32,89%
3	5,48%	6,18%	5,52%
≥4	1,79%	1,75%	1,46%
Situation of the main contributor to income			
Working	58,75%	59,69%	59,51%
Working, temporally absent	2,65%	2,33%	2,53%
Unemployed	3,12%	2,84%	4,04%
Retired	28,91%	29,09%	28,31%
Student	0,04%	0,10%	0,04%
House keeper	5,47%	4,84%	4,56%
Other situation	1,06%	1,12%	1,02%
Education level of the main contributor to income			
No education	2,57%	2,08%	1,88%
Basic school	34,78%	31,04%	28,16%
Secondary school	25,16%	27,57%	29,49%
High school	9,24%	9,54%	9,53%
Professional training, initial	5,12%	5,57%	5,86%
Professional training, superior	6,64%	6,82%	7,27%
University studies, short degree	6,97%	7,08%	7,35%
University studies, long and doctoral degrees	9,51%	10,30%	10,45%
Annual household expenditure			
< 10000 €	18,62%	17,47%	16,73%
[10000-20000) €	28,78%	28,14%	30,39%
[20000-30000) €	22,65%	23,17%	23,78%
[30000-40000) €	13,50%	13,75%	14,22%
[40000-50000) €	7,50%	8,15%	7,38%
[50000-60000) €	4,12%	4,28%	3,80%
≥ 60000 €	4,84%	5,04%	3,70%
Net annual household income			
< 10000 €	19,15%	18,79%	17,18%
[10000-20000) €	34,66%	29,29%	33,71%
[20000-30000) €	25,00%	26,73%	22,97%
[30000-40000) €	11,98%	13,68%	15,09%
[40000-50000) €	5,05%	6,29%	6,25%
[50000-60000) €	2,04%	2,35%	1,94%
≥ 60000 €	2,12%	2,87%	2,86%

Source: SHS and own calculations.

Table A2. Main characteristics of Spanish housing

	2006	2007	2008
Type of housing			
Independent house	13,85%	12,83%	12,01%
Semi-detached house	24,28%	24,66%	24,71%
Flat	61,87%	62,51%	63,27%
Date of construction			
< 25 years	38,71%	36,25%	35,87%
≥ 25 years	61,22%	63,70%	64,13%
Property regime			
Ownership without mortgage	56,15%	55,49%	53,55%
Ownership with mortgage	28,29%	29,80%	31,01%
Rental	9,07%	8,73%	9,21%
Reduced rental	1,31%	1,13%	1,15%
Partly free lease	2,15%	2,21%	2,44%
Free lease	3,03%	2,64%	2,65%
Gross floor area			
≤ 35 m²	0,45%	0,40%	0,39%
(35-100] m²	67,53%	66,59%	66,72%
(100-200] m²	28,04%	28,71%	28,68%
(200-300) m²	2,61%	2,82%	2,70%
≥ 300 m²	1,37%	1,49%	1,51%

Source: SHS and own calculations.

Table A3. Access to natural gas in Spanish municipalities (population), 2008

>100,000	95%
50,000-100,000	80%
25,000-50,000	77%
5,000-25,000	56%
1,000-5,000	24%
<1,000	4%
Total	72%

Source: CNE (2008).

Table A4. Energy consumption in SHS rural households

	2006	2007	2008
Electricity	18,6%	16,2%	17,4%
Natural gas	9,3%	11,7%	11,3%
Liquid fuels	56,3%	56,4%	56,0%

Source: SHS.

ANNEX B

PRICES AND DECISIONS ON ENERGY SOURCES FOR HEATING

To analyze if price changes influence the choice of the energy source for heating by households, we assume that the choice of each energy source is determined by a non-observable variable *s** with the functional form depicted below. The function includes energy prices and income as explanatory variables to see whether any of those variables has a significant influence on the household decision on energy sources for heating,

$$
\begin{aligned}
s_{itk}^{*} &= \varpi_k^e \log p_{it}^e + \varpi_k^g \log p_{it}^g + \varpi_k^l \log p_{it}^l + \chi_k^1 \log g_{it}^t + \chi_k^2 (\log g_{it}^t)^2 + \\
&+ \mu_{ik} + \pi_{itk} = \sum_j \rho_{jk} v_{jit} + \mu_{ik} + \pi_{itk}
\end{aligned}
\tag{B1}
$$

where μ is the unobservable heterogeneity and π the idiosyncratic error term. We only observe the sign of the dependent variable, being positive if the household chooses the source *k* and negative otherwise. In this context, we define a binary variable

$$
s_{ik} = \begin{cases} 1 & if \quad s_{ik}^* > 0 \\ 0 & if \quad s_{ik}^* \le 0 \end{cases}
\tag{B2}
$$

Assuming that the idiosyncratic error term is i.i.d. and assuming a standard logistic distribution for it, the probability of the household choosing energy source *k* is estimated through a Logit model for panel data.

$$
\Pr(s_{itk} = 1 \mid v_{it}, \mu_{ik}) = \frac{\exp\left(\sum_j \rho_{jk} v_{jit} + \mu_{ik}\right)}{1 + \exp\left(\sum_j \rho_{jk} v_{jit} + \mu_{ik}\right)}
\tag{B3}
$$

In order to be able to estimate consistently the parameters in (B3), we need a sufficient statistics to rule out the effects from the specification. The joint consistent estimation of the parameters of interest and the effects is not possible. Since the sum of the events is a sufficient statistic, we can estimate the parameters of interest in a specification that does not contain the effects, setting the

probability conditional to that sum. The contribution to the likelihood is null for those households that do not change the source of energy during the whole period (a great percent of our sample) or for households that change during the two observation periods (an unobserved event). So, the estimation is based on the subsample of households with changes in the source of energy. Since the number of observations per household is $T=2$, the possible events are: (1, 1), (1, 0), (0, 1) and (0, 0), but only (1, 0) and (0, 1) are used in the estimation process because they contribute to the likelihood. Once we express the conditional probabilities, the model is transformed to rule out the $\mu's$ and, as a consequence, the only variables entering the specification are those that show time variation.

Table B1 shows the results of the estimation. As indicated in section 2 of the article, the price of liquid fuels is significant in the three cases, so the sizable price increase of these products seen during the 2006-2008 period is the main determinant inducing households to substitute heating systems based on these fuels for others using natural gas and electricity. This means that it is necessary to consider the influence of the relative change in energy prices to study Spanish household demand for heating in a proper manner.

Table B1. Results from the Logit model on choice of energy source for heating

	Coefficient	t-ratio
Electricity		
Log (electricity price)	0.2813	1.23
Log (natural gas price)	-0.0461	-0.18
Log (liquid fuels price)	0.2306	2.98
Log (income)	2.8527	1.02
(Log (income))²	-0.1289	-0.94
Natural Gas		
Log (electricity price)	0.6646	1.82
Log (natural gas price)	-0.0712	-0.32
Log (liquid fuels price)	0.9924	8.76
Log (income)	0.3041	0.06
(Log (income))²	-0.0207	-0.08
Liquid Fuels		
Log (electricity price)	0.3982	0.74
Log (natural gas price)	0.1847	0.33
Log (liquid fuels price)	-2.1914	-10.49
Log (income)	0.7136	0.13
(Log (income))²	-0.0269	-0.10

Source: Own calculations.

ANNEX C

DUMMIES INCLUDED IN THE ESTIMATIONS

A. Geographical dummies

- *duca*: Region (autonomous community: CC.AA) of household residence

B. Dummies for household characteristics

- *duth*: Type of household
    1. Single
    2. Couple without children
    3. Couple with children
    4. Other

- *dunoc*: Number of workers in the household
    1. None
    2. One
    3. Two
    4. Three
    5. Four or more

C. Dummies for characteristics of main contributor to income

- *duocu*: Occupation
    1. Directive of firms or public administration, technicians and scientific and intellectual professionals.
    2. Administration, workers in services and shops.
    3. Qualified workers in agriculture, fishing, manufacturing, construction and mining industry
    4. Others

- *dues*: Level of studies of the main contributor to income
    1. Basic school
    2. High School
    3. University

- *dusta*: Working condition of the main contributor to income
    1. Working for at least one hour
    2. Unemployed
    3. Retired
    4. Other

D. Dummies for housing characteristics

- *durgt*: Type of possession

    1. Property
    2. Rent
    3. Other

- *duted*: Type of building

    1. Independent house
    2. Building of flats
    3. No information

- *duzrs*: Area of residence

    1. Urban
    2. Rural

- *duanco*: Date of construction

    1. Less than 25 years
    2. More than 25 years

ANNEX D

RESULTS FROM THE ESTIMATIONS

Table D1. Estimated parameters. Conditional demand for electricity for heating

Regressor	Coefficient	t-ratio
Log (electricity price)	-0.2012	-4.52
$\hat{\psi}$	-2.8742	-1.79
Number of household members	0.0552	4.93
Floor area	0.0018	8.91
Log (income)	1.1456	3.83
(Log (income))^2	-0.0415	-2.83
Dummy (duca) C.A. Andalucía	0.3532	4.14
Dummy (duca) C.A. Aragón	0.4003	4.29
Dummy (duca) C.A. Asturias	0.3714	4.12
Dummy (duca) C.A. Baleares	0.3355	3.70
Dummy (duca) C.A. Canarias	-0.1716	-1.51
Dummy (duca) C.A. Cantabria	0.2744	2.68
Dummy (duca) C.A. Castilla y León	0.5543	6.18
Dummy (duca) C.A. Castilla-La Mancha	0.5349	6.06
Dummy (duca) C.A. Catalunya	0.3624	4.22
Dummy (duca) C.A. Comunitat Valenciana	0.3077	3.58
Dummy (duca) C.A. Extremadura	0.3821	4.21
Dummy (duca) C.A. Galicia	0.3166	3.66
Dummy (duca) C.A. Madrid	0.4280	4.90
Dummy (duca) C.A. Murcia	0.2746	3.08
Dummy (duca) C.A. Nafarroa	0.4179	4.26
Dummy (duca) C.A. Euskadi	0.2229	2.61
Dummy (duca) C.A. La Rioja	0.4355	4.41
Dummy (duth) type of household 1	-0.0714	-1.87
Dummy (duth) type of household 2	0.0054	0.18
Dummy (duth) type of household 3	0.0523	2.31
Dummy number of workers 1	0.0173	0.25
Dummy number of workers 2	-0.0449	-0.72
Dummy number of workers 3	-0.0432	-0.70
Dummy number of workers 4	-0.0590	-0.91
Dummy (dunoc) occupation 1	0.0782	2.63
Dummy (dunoc) occupation 2	0.0155	0.58
Dummy (dunoc) occupation 3	0.0114	0.45
Dummy (dues) level of education 1	0.0425	1.72
Dummy (dues) level of education 2	0.0356	1.41
Dummy (dusta) working condition 1	0.0036	0.12
Dummy (dusta) working condition 2	-0.1103	-2.34
Dummy (dusta) working condition 3	0.0114	0.35
Dummy (durgt) possession 1	0.1039	2.86
Dummy (durgt) possession 2	0.0202	0.45
Dummy (duted) type of building 1	0.0160	0.04
Dummy (duted) type of building 2	-0.0039	-0.01
Dummy (duzrs) residential area	0.1897	1.85
Dummy residential area*log (electricity price)	0.0836	1.66
Dummy (duanco) date of construction	0.0011	0.06
Heckman's lambda	0.1333	1.01
R^2=0.2032	**Wald χ^2(45)**=1666.22 (p-value=0.0000)	

Source: Own calculations.

Table D2. Estimated parameters. Discrete choice of the type of energy source. Electricity

Regressor	Coefficiente	t-ratio
Log (electricity price)	-0.5197	-3.50
Log (natural gas price)	2.0677	5.72
Log (liquid fuels price)	1.0305	16.87
$\hat{\alpha}$	-4.1532	-1.00
Number of members in household	-0.0717	-2.65
Floor area	-0.0030	-5.90
Log (income)	1.5689	2.14
(Log (income))^2	-0.0659	-1.84
Dummy (duca) C.A. Andalucía	0.4901	2.27
Dummy (duca) C.A. Aragón	-0.3167	-1.38
Dummy (duca) C.A. Asturias	0.4565	2.00
Dummy (duca) C.A. Baleares	1.5359	6.79
Dummy (duca) C.A. Canarias	-1.7186	-6.53
Dummy (duca) C.A. Cantabria	-0.8640	-3.55
Dummy (duca) C.A. Castilla y León	-0.3094	-1.39
Dummy (duca) C.A. Castilla-La Mancha	0.5902	2.65
Dummy (duca) C.A. Catalunya	0.0016	0.01
Dummy (duca) C.A. Comunitat Valenciana	1.0013	4.59
Dummy (duca) C.A. Extremadura	0.4416	1.93
Dummy (duca) C.A. Galicia	0.8661	3.95
Dummy (duca) C.A. Madrid	0.0555	0.25
Dummy (duca) C.A. Murcia	0.8004	3.53
Dummy (duca) C.A. Nafarroa	-1.4691	-6.19
Dummy (duca) C.A. Euskadi	0.1931	0.90
Dummy (duca) C.A. La Rioja	-0.6984	-2.93
Dummy (duth) type of household 1	0.0306	0.33
Dummy (duth) type of household 2	0.2321	3.23
Dummy (duth) type of household 3	0.1598	2.82
Dummy number of workers 1	0.2357	1.37
Dummy number of workers 2	0.2350	1.52
Dummy number of workers 3	0.1542	1.02
Dummy number of workers 4	0.2051	1.29
Dummy (dunoc) occupation 1	0.2030	2.70
Dummy (dunoc) occupation 2	0.1575	2.35
Dummy (dunoc) occupation 3	0.1428	2.31
Dummy (dues) level of education 1	0.0308	0.48
Dummy (dues) level of education 2	0.1573	2.41
Dummy (dusta) working condition 1	-0.0281	-0.36
Dummy (dusta) working condition 2	-0.2113	-1.77
Dummy (dusta) working condition 3	-0.2228	-2.78
Dummy (durgt) possession 1	0.0700	0.80
Dummy (durgt) possession 2	-0.2119	-1.99
Dummy (duted) type of building 1	-2.3726	-1.56
Dummy (duted) type of building 2	-2.0046	-1.32
Dummy (duzrs) residential area	-4.0739	-4.32
Dummy residential area*log (electricity price)	0.1028	0.62
Dummy residential area*log (natural gas price)	-1.3239	-3.59
Dummy residential area*log (liquid fuels price)	-0.5197	-7.72
Dummy (duanco) date of construction	0.1178	2.84

Source: Own calculations.

Table D3. Estimated parameters. Conditional demand for natural gas for heating

Regressor	Coefficient	t-ratio
Log (natural gas price)	-0.2203	-5.80
$\hat{\psi}$	0.5372	0.48
Number of members in household	0.0555	9.41
Floor area	0.0020	15.07
Log (income)	0.6060	3.03
(Log (income))^2	-0.0182	1.88
Dummy (duca) C.A. Andalucía	-0.0078	-0.13
Dummy (duca) C.A. Aragón	-0.0362	-1.41
Dummy (duca) C.A. Asturias	-0.2034	-7.62
Dummy (duca) C.A. Baleares	-0.0684	-1.27
Dummy (duca) C.A. Cantabria	-0.1793	-6.80
Dummy (duca) C.A. Castilla y León	-0.0371	-1.58
Dummy (duca) C.A. Castilla-La Mancha	-0.0740	-2.37
Dummy (duca) C.A. Catalunya	-0.0471	-2.24
Dummy (duca) C.A. Comunitat Valenciana	-0.1137	-3.45
Dummy (duca) C.A. Extremadura	-0.0936	-2.13
Dummy (duca) C.A. Galicia	-0.0921	-2.81
Dummy (duca) C.A. Madrid	-0.0440	-2.05
Dummy (duca) C.A. Murcia	-0.0865	-2.08
Dummy (duca) C.A. Nafarroa	-0.0812	-3.59
Dummy (duca) C.A. Euskadi	-0.0938	-4.56
Dummy (duth) type of household 1	-0.1441	-7.18
Dummy (duth) type of household 2	-0.0639	-4.17
Dummy (duth) type of household 3	0.0003	0.02
Dummy number of workers 1	0.1049	2.91
Dummy number of workers 2	0.0180	0.56
Dummy number of workers 3	-0.0033	-0.11
Dummy number of workers 4	0.0088	0.27
Dummy (dunoc) occupation 1	0.0526	3.07
Dummy (dunoc) occupation 2	0.0059	0.38
Dummy (dunoc) occupation 3	-0.0049	-0.33
Dummy (dues) level of education 1	0.0265	1.97
Dummy (dues) level of education 2	0.0097	0.75
Dummy (dusta) working condition 1	0.0214	1.27
Dummy (dusta) working condition 2	-0.0401	-1.37
Dummy (dusta) working condition 3	0.0172	0.95
Dummy (durgt) possession 1	0.0146	0.60
Dummy (durgt) possession 2	-0.0350	-1.24
Dummy (duted) type of building 1	0.4035	1.01
Dummy (duted) type of building 2	0.3145	0.79
Dummy (duzrs) residential area	-0.0369	-0.38
Dummy residential area*log (natural gas price)	0.0031	0.08
Dummy (duanco) date of construction	0.0004	0.04
Heckman's lambda	-0.0161	-3.75
R²=0.2460	**Wald χ²(43)=4316.85 (p-value=0.0000)**	

Source: Own calculations.

Table D4. Estimated parameters. Discrete choice of the type of energy source. Natural gas

Regresor	Coeficiente	t-ratio
Log (electricity price)	0.6247	2.38
Log (natural gas price)	-1.9723	-5.52
Log (liquid fuels price)	1.8922	14.73
$\hat{\alpha}$	-70.3206	-0.17
Number of household members	-0.1183	-2.66
Floor area	0.0033	3.75
Log (income)	7.7451	5.91
(Log (income))^2	-0.3523	-5.54
Dummy (duca) C.A. Andalucía	17.9349	0.04
Dummy (duca) C.A. Aragón	26.7533	0.06
Dummy (duca) C.A. Asturias	26.5554	0.06
Dummy (duca) C.A. Baleares	20.3712	0.05
Dummy (duca) C.A. Canarias	0.1204	0.00
Dummy (duca) C.A. Cantabria	27.5656	0.07
Dummy (duca) C.A. Castilla y León	27.1489	0.07
Dummy (duca) C.A. Castilla-La Mancha	24.7795	0.06
Dummy (duca) C.A. Catalunya	27.5731	0.07
Dummy (duca) C.A. Comunitat Valenciana	21.6769	0.05
Dummy (duca) C.A. Extremadura	22.7192	0.05
Dummy (duca) C.A. Galicia	22.8155	0.05
Dummy (duca) C.A. Madrid	28.3234	0.07
Dummy (duca) C.A. Murcia	21.9796	0.05
Dummy (duca) C.A. Nafarroa	28.5161	0.07
Dummy (duca) C.A. Euskadi	27.8247	0.07
Dummy (duca) C.A. La Rioja	27.7668	0.07
Dummy (duth) type of household 1	-0.0425	-0.28
Dummy (duth) type of household 2	0.1287	1.10
Dummy (duth) type of household 3	0.3151	3.39
Dummy number of workers 1	-0.7212	-2.67
Dummy number of workers 2	-0.7478	-3.09
Dummy number of workers 3	-0.5109	-2.16
Dummy number of workers 4	-0.5860	-2.36
Dummy (dunoc) occupation 1	0.1871	1.49
Dummy (dunoc) occupation 2	0.4265	3.75
Dummy (dunoc) occupation 3	0.1527	1.42
Dummy (dues) level of education 1	-0.9480	-9.47
Dummy (dues) level of education 2	-0.5039	-5.12
Dummy (dusta) working condition 1	0.1170	0.94
Dummy (dusta) working condition 2	-0.3720	-1.81
Dummy (dusta) working condition 3	-0.0492	-0.37
Dummy (durgt) possession 1	1.1994	7.09
Dummy (durgt) possession 2	-0.7380	-3.77
Dummy (duted) type of building 1	-5.8261	-2.50
Dummy (duted) type of building 2	-3.0395	-1.30
Dummy (duzrs) residential area	4.0853	3.83
Dummy residential area*log (electricity price)	0.0075	0.03
Dummy residential area*log (natural gas price)	0.2772	0.75
Dummy residential area*log (liquid fuels price)	-0.1480	-1.11
Dummy (duanco) date of construction	1.7949	25.22

Source: Own calculations.

Table D5. Estimated parameters. Conditional demand for liquid fuels for heating

Regressor	Coefficient	t-ratio
Log (liquid fuels price)	-0.3404	-15.26
$\hat{\psi}$	-6.1150	-5.11
Number of members in household	0.0453	6.57
Floor area	0.0015	11.36
Log (income)	1.9232	8.98
(Log (income))^2	-0.0785	-7.56
Dummy (duca) C.A. Andalucía	-0.1616	-3.66
Dummy (duca) C.A. Aragón	-0.0013	-0.05
Dummy (duca) C.A. Asturias	-0.2191	-6.77
Dummy (duca) C.A. Baleares	-0.0502	-1.01
Dummy (duca) C.A. Canarias	-0.2038	-0.72
Dummy (duca) C.A. Cantabria	-0.2891	-7.98
Dummy (duca) C.A. Castilla y León	-0.0506	-2.15
Dummy (duca) C.A. Castilla-La Mancha	-0.0272	-1.13
Dummy (duca) C.A. Catalunya	-0.0647	-1.89
Dummy (duca) C.A. Comunitat Valenciana	-0.2122	-4.61
Dummy (duca) C.A. Extremadura	-0.3199	-7.49
Dummy (duca) C.A. Galicia	-0.2138	-8.51
Dummy (duca) C.A. Madrid	-0.1291	-3.77
Dummy (duca) C.A. Murcia	-0.2642	-4.95
Dummy (duca) C.A. Nafarroa	-0.0379	-1.61
Dummy (duca) C.A. Euskadi	-0.2569	-8.14
Dummy (duth) type of household 1	-0.0589	-2.29
Dummy (duth) type of household 2	0.0023	0.12
Dummy (duth) type of household 3	0.0005	0.03
Dummy number of workers 1	0.1661	3.86
Dummy number of workers 2	0.0830	2.16
Dummy number of workers 3	0.0479	1.28
Dummy number of workers 4	0.0536	1.35
Dummy (dunoc) occupation 1	0.0926	4.45
Dummy (dunoc) occupation 2	0.0102	0.51
Dummy (dunoc) occupation 3	0.0328	1.84
Dummy (dues) level of education 1	-0.0086	-0.52
Dummy (dues) level of education 2	-0.0141	-0.81
Dummy (dusta) working condition 1	-0.0146	-0.65
Dummy (dusta) working condition 2	-0.1324	-3.12
Dummy (dusta) working condition 3	-0.0189	-0.85
Dummy (durgt) possession 1	0.0619	2.55
Dummy (durgt) possession 2	0.0337	0.98
Dummy (duted) type of building 1	0.0094	0.02
Dummy (duted) type of building 2	-0.3426	-0.75
Dummy (duzrs) residential area	-0.1005	-1.63
Dummy residential area*log (liquid fuels price)	0.0065	0.28
Dummy (duanco) date of construction	-0.0388	-3.49
Heckman's lambda	-0.0522	-4.79
R^2=0.3443	**Wald χ^2(44)**=5051.55 (p-value=0.0000)	

Source: Own calculations.

Table D6. Estimated parameters. Discrete choice of the type of energy source. Liquid fuels

Regressor	Coefficient	t-ratio
Log (electricity price)	0.2379	1.72
Log (natural gas price)	0.0356	0.12
Log (liquid fuels price)	-3.2781	-32.09
$\hat{\alpha}$	-308.8528	-60.39
Number of household members	-0.1134	-3.56
Floor area	0.0101	17.04
Log (income)	2.5414	2.84
(Log (income))^2	-0.1089	-2.49
Dummy (duca) C.A. Andalucía	284.9426	514.28
Dummy (duca) C.A. Aragón	288.7501	500.65
Dummy (duca) C.A. Asturias	287.6611	502.58
Dummy (duca) C.A. Baleares	285.6892	504.92
Dummy (duca) C.A. Canarias	281.3591	-
Dummy (duca) C.A. Cantabria	287.1409	502.65
Dummy (duca) C.A. Castilla y León	288.4393	504.59
Dummy (duca) C.A. Castilla-La Mancha	288.4436	504.19
Dummy (duca) C.A. Catalunya	286.3525	512.59
Dummy (duca) C.A. Comunitat Valenciana	285.3687	510.31
Dummy (duca) C.A. Extremadura	285.7875	508.81
Dummy (duca) C.A. Galicia	288.1901	505.83
Dummy (duca) C.A. Madrid	286.8136	508.68
Dummy (duca) C.A. Murcia	285.0813	505.73
Dummy (duca) C.A. Nafarroa	288.8983	500.86
Dummy (duca) C.A. Euskadi	286.8898	509.70
Dummy (duca) C.A. La Rioja	289.1061	496.77
Dummy (duth) type of household 1	-0.1567	-1.37
Dummy (duth) type of household 2	0.0667	0.77
Dummy (duth) type of household 3	0.0965	1.44
Dummy number of workers 1	0.1756	0.88
Dummy number of workers 2	-0.0212	-0.12
Dummy number of workers 3	-0.1125	-0.64
Dummy number of workers 4	0.0666	0.36
Dummy (dunoc) occupation 1	0.5561	5.94
Dummy (dunoc) occupation 2	0.2959	3.40
Dummy (dunoc) occupation 3	0.0307	0.39
Dummy (dues) level of education 1	-0.0992	-1.28
Dummy (dues) level of education 2	0.0175	0.22
Dummy (dusta) working condition 1	-0.0742	-0.75
Dummy (dusta) working condition 2	-0.5083	-2.93
Dummy (dusta) working condition 3	-0.0740	-0.74
Dummy (durgt) possession 1	-0.5420	-5.24
Dummy (durgt) possession 2	-0.9460	-6.96
Dummy (duted) type of building 1	-0.7238	-0.34
Dummy (duted) type of building 2	-1.9500	-0.91
Dummy (duzrs) residential area	-0.3808	-0.47
Dummy residential area*log (electricity price)	-0.1419	-0.81
Dummy zona residencia*log (natural gas price)	0.5931	1.98
Dummy zona residencia*log (liquid fuels price)	-0.4531	-4.95
Dummy (duanco) date of construction	-0.3363	-6.60

Source: Own calculations.