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Abstract

Residential 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 Spanish household micro data to estimate a discrete-continuous model of residential energy demand for heating covering both the choice of energy source and the amount of energy used for heating. Relative fuel prices for heating influence the discrete decision on the type of energy source as a long-run effect. The short-run demand response to energy price changes is found to be limited but variable across the different energy sources for heating in Spain. Moreover, household demand responses consistently differ across rich and poor regions. A simple policy simulation illustrates the practical relevance of this empirical approach.

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

JEL Classification: C13, C14, C23, Q41

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1. Introduction

Energy consumption is increasingly on the agendas of policy makers in many countries due to environmental concerns, relating to both climate change and air quality, and also to energy security concerns in countries with a high dependence on foreign energy sources. Household energy use constitutes a major share of total energy use in developed countries and, within this, heating is a major component. Therefore, any policy intended to reduce energy consumption should target residential space heating. There are many possibilities to achieve this objective, ranging from building standards to other conventional energy efficiency instruments such as energy taxes (see Linares and Labandeira, 2010). However, before applying such instruments, it is desirable to have an indication of their effectiveness and also their cost (including the distributional impact). This requires a proper modelling of the demand for heating that can provide accurate estimates of the household response to policy instruments.

This is the general context for the paper: we are interested in providing precise and accurate results regarding demand of household heating, both at the extensive and intensive margins, so that future public policies in the field can be properly designed and assessed. To do so, we use a high-quality household survey that allows us to estimate 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 with 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 modeling 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 growth in interest (see e.g. Nelson, 1975). Many of the earlier papers employ aggregate data (see, for a recent application, Narayan and Smyth, 2005), but this entails an important loss in terms of understanding individual behavior. When using micro data, a first option is to estimate energy demand through standard econometric techniques with different variables such as energy prices, income or weather conditions (see e.g. Barnes et al. 1981; Branch, 1993; Filippini and Pachauri, 2004). However, this does not account for the 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) or to employ market values to estimate a hedonic pricing function of housing attributes that would be subsequently used in a household production and utility maximization model (Quingley and Rubenfeld, 1989), it is more common to use sequential discrete-continuous models. The sequential nature of the model reflects the household decision process. The household first makes the discrete decision on the purchase of durables that consume energy and, constrained by that, in a second stage makes 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 of Dubin and McFadden's methodology to energy demand.[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-run 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 no applications that incorporate the relationship between purchases of certain durables and energy consumption (see e.g. Labandeira et al., 2006).

This paper focuses on heating, using a detailed database on Spanish household consumption.[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 amount of energy used. In section 3 we introduce the models that are applied to the detailed Spanish household data.

[1] Many papers have also applied this methodology for discrete-continuous decisions to the specific case of transportation. 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.

In section 4 we present and interpret the results of the empirical estimation, comparing them to empirical estimates in the existing literature, and we also report some robustness checks. Section 5 provides some general conclusions and a discussion of policy implications, both in terms of effectiveness and equity. Several annexes yield some further detail on the empirical estimates and information on the data used.

2. Description of household energy 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 survey provides information on the amount and sources of households' incomes, their expenditures on goods and services, and other socio-demographic information. The SHS is the main public source of micro data on the behavior of Spanish households. It is used to obtain the national accounting aggregate for private consumption and also to calculate, from the distribution of expenditures, the retail price index for Spain.

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.[3] The survey does not provide information on weather variables and the identification of residential location is too vague to permit matching it to weather information in any meaningful way, so weather variables cannot be included in the estimation. In any case, we try to control the effect of outside temperatures on energy demand with the use of spatial and temporal dummies. Annex A provides summary information on Spanish households, housing and access to energy.

Table 1 shows the average household expenditure on energy by Spanish households in 2006, 2007 and 2008, and the breakdown by fuel sources. A majority of Spanish families (around 60%) use energy for space heating their home. Average household energy consumption for all purposes was around 8 Euro/m^2 in this period. Electricity, natural gas and liquid fuels (diesel, fuel-oil, etc.) are the main sources of energy for heating and 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 each of the main energy sources). Figure 2 shows the breakdown of household energy

[3] All monetary variables are deflated using the INE retail price index.

consumption by end use, with space heating being the largest use followed by water heating and appliances.[4]

Table 1. Energy and heating in Spanish households

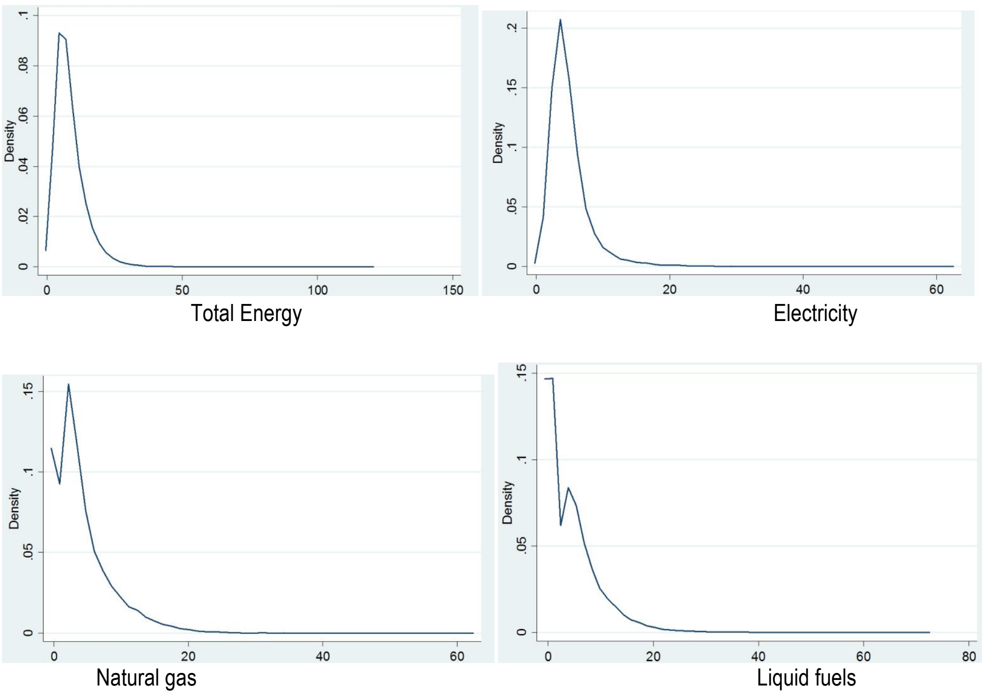
	2006	2007	2008
Average household energy consumption (€/m²)			
Total	8.39	8.32	8.55
Electricity	4.77	4.81	4.89
Natural gas	4.55	3.93	4.20
GLP	2.71	2.24	2.47
Liquid fuels	5.33	4.03	4.40
Solid fuels (coal, wood, etc.)	1.42	0.81	0.88
Heating availability			
Yes	59.64%	62.09%	63.75%
No	40.35%	37.91%	36.25%
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%

Note: To calculate average energy consumption, housing with less than 35 m^2 or more than 300 m^2 were excluded, as no information on their exact size was available.
Source: Own calculations from SHS.

As noted in the introduction, when studying household energy demand for heating it is crucial to consider the prior decision on the energy source for heating. Table 2 shows that during the 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).

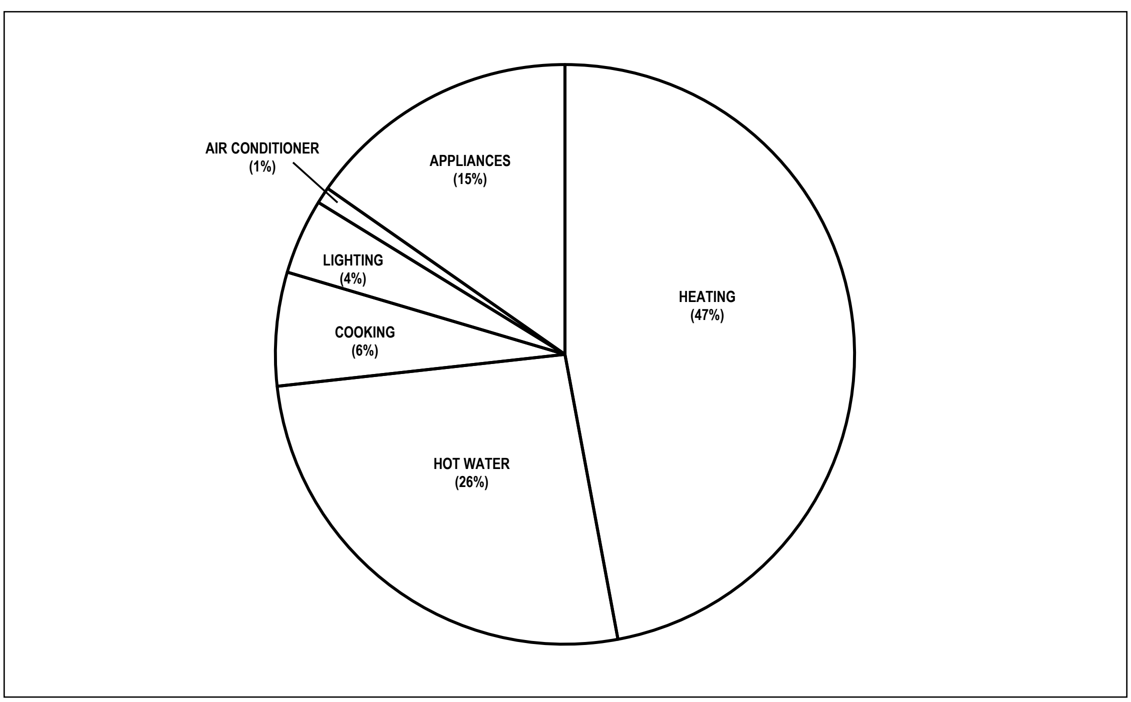
[4] Although the large number of households without residential heating may be surprising when compared to other developed countries, the regions of Spain that do not use energy for space heating are along the Mediterranean coast where winters are mild (for instance, the SHS indicates that in Andalusia only 20% of households had central heating in 2008). This explains the lower heating share with respect to the EU average of 70% (EEA, 2012), although quite above the U.S. average of 26% (EIA, 2012). Moreover, despite the high temperatures during summers in large areas of the country, only around 2.7% of Spanish household electricity consumption in 2008 was due to air conditioning (MITyC, 2010), representing around 1% of total household energy consumption (Figure 2). In any case, the SHS does not break out the air conditioning component of household energy use.

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.

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

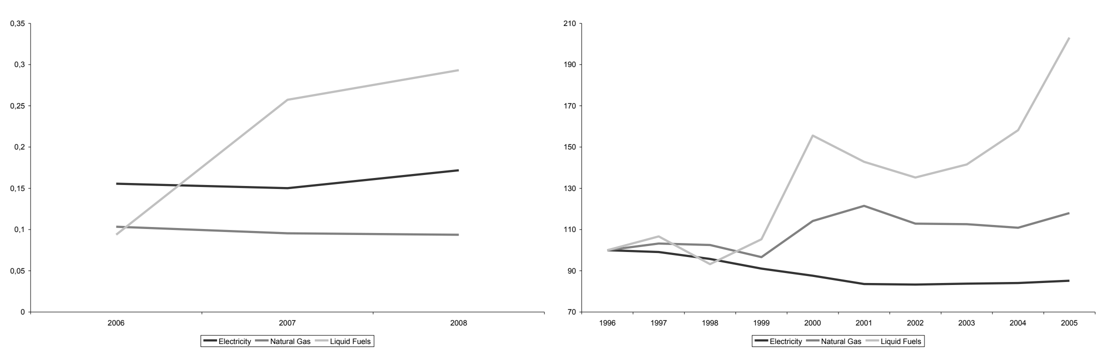
2006 \ 2007	Electricity	Natural Gas	Liquid Fuels	Others
Electricity	92.59% (612)	4.39% (29)	1.97% (13)	1.06% (7)
Natural Gas	1.24% (22)	95.16% (1,690)	2.08% (37)	1.52% (27)
Liquid Fuels	1.25% (15)	3.57% (43)	92.77% (1,117)	2.41% (29)
2007 \ 2008	**Electricity**	**Natural Gas**	**Liquid Fuels**	**Others**
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)

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

Figure 3 (left) depicts the evolution, in real terms, of the average prices of these fuels over the period 2006-8. These prices were calculated from information provided by the SHS and thus are specific to residential energy use. Whereas natural gas and electricity prices remained rather stable in Spain, the average price of liquid fuels rose quite drastically, reflecting the spike in oil prices during those years. This evolution is consistent with the observed trends for Spanish households in the previous ten years (see Figure 3, right, with IEA data).

Figure 3. Evolution of the prices of electricity, natural gas and liquid fuels

(left: €/kWh; right: 1996=100)



Source: SHS (left) and IEA (2006) (right)

Given this sharp increase in the price of liquid fuels, we would expect more fuel switching by households who use liquid fuels than by other households. However, Table 2 does not show this pattern of behavior. We performed a t-test of difference of means (see Table A5, in Annex A), comparing the changes in the proportion of households that use a particular fuel source for heating. The results show that, in most cases, there are no differences between the rates of change of different fuels. This suggests that, in addition to prices, other factors may influence fuel switching. Table A6, in Annex A, depicts the main characteristics of both households that changed their energy source for heating and those that continue to use the same source during the period considered. Comparing both sets of households, we see differences in household characteristics that may be influencing the fuel-switching decision, such as the place of residence, occupation or educational level of the main contributor to income, type of building or area of residence. There may also be impediments that hinder the change of fuel, such as the cost of installation of new heating systems. The question is how much the fuel prices themselves also influence fuel switching for space heating.

3. Modeling residential energy demand for heating

3.1. Choice of fuel source as an isolated choice

In this section we investigate whether fuel prices affect the choice of energy source for heating considered independently of the level of fuel consumption. After checking this, in section 3.2 we present a theoretical framework for analyzing energy demand for heating in Spain that integrates fuel choice with level of consumption.

To determine whether fuel prices affect the choice of energy source for space heating, we use a discrete choice model to examine the influence of price on the choice of energy inputs for residential heating. We estimate a panel data logit model to control for unobserved heterogeneity, and we include energy prices and household expenditures during the 2006-2008 period as the explanatory variables (for more, see Annex B). We chose this model in order to control for 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 as description of the substitution among energy sources at the extensive margin.

The results show that liquid fuels have significant own-price elasticity and cross-price elasticities in the choice of electricity and natural gas. The other own price elasticities (electricity and natural gas) are not significant. Of the other cross-price elasticities only the price of electricity for the choice of natural gas is significant. Thus, the remarkable price increase in liquid fuels in 2006-2008 led households to reduce their use as source of heating and to switch to electricity and natural gas (see also Figure 3, left). This result is reinforced by the fact that the energy price signals show a consistent pattern since the mid 1990s (Figure 3, right), and also that only 10% of Spanish households are under centralized heating (IDAE, 2010) which, otherwise, would largely impede fuel switching for heating. Moreover, energy-heating choices were available to a large share of households because access to natural gas was quite widespread in 2008, even in sparsely populated areas (see Tables A3 and A4 in Annex A).

The implication is that energy prices influence the discrete decision on the type of fuel used for residential energy heating. If this were overlooked, the price elasticities estimated just from the continuous decision on level of energy use would be biased and inconsistent. 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 choice of energy source.

3.2. Theoretical framework

In contrast to the previous section, here we employ a discrete-continuous model of energy demand that accounts for both dimensions of residential energy demand for heating: the type of fuel used (electricity, liquid fuels or natural gas), and the amount of fuel used. We follow Hanemann's (1984) framework, using as the discrete decision the choice of the source of energy for heating and as the continuous decision the amount of energy used for residential heating. Households have a utility function,

$$u(x,b,d,z,\eta) \tag{1}$$

where $x=(x_0,x_1,x_2,x_3)$ is a vector of consumption levels for the various energy sources for residential heating, b is a vector of characteristics of x, d is a composite *numéraire* good, z are the observable characteristics of the household and the home, and η represents unobservable characteristics of the household. As in Hanemann (1984), we assume that each household chooses only one energy source for heating, so

$$x_m x_k = 0 \quad \forall m \neq k \quad k = 0,\ldots,3 \tag{2}$$

The household decides first on the type of energy used for heating; conditional on that choice, it has an indirect utility function

$$V(sh, p^k, y, z, \eta) \tag{3}$$

where *sh* is *k* (*k*=0,…,3) if the household decides to have *k* as energy source, p^k is the price of fuel *k*, *y* is household total expenditure. In this setting the probability of the household *i* deciding to use *k* as its energy source for heating is

$$P(sh_i = k) = \Pr\{V(k, p^k, y_i, z_i, \eta_i) > V(m, p^k, y_i, z_i, \eta_i); \forall m \neq k\} \equiv f_k(y_i, p^e, p^g, p^l, c_i, \theta_i) \tag{4}$$

where p^e is the price of electricity, p^g the price of natural gas, p^l the price of liquid fuels, and *c* and *θ* are respectively observable and unobservable characteristics of the household that influence this decision. If the household decides to use fuel *k* as the energy source for heating, the household's conditional demand for the quantity of that fuel (the continuous choice) is given by Roy's identity,

$$x_{ik} = \frac{-\partial V(k, p^k, y_i, z_i, \eta_i) / \partial p^k}{\partial V(1, p^k, y_i, z_i, \eta_i) / \partial y_i} = g_k(y_i, p^k, z_i, \eta_i \mid sh_i = k) \tag{5}$$

Therefore, we are interested in estimating the conditional demand function (5) conditioned on the prior choice 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.[5]

3.3. Empirical implementation

The choice of energy source for heating is a medium/long-run decision, whereas the decision on the level of energy use is a short-run decision. Therefore, we are dealing with linked but sequential choices: first the household decides the energy source to be used for heating and subsequently,

[5] Here we are assuming that the stock of durables providing energy services for heating are homogeneous across households, although we are aware that it could be the case that more environmentally-conscious households own more efficient appliances. In this case, price and income responsiveness by households could differ (see Reiss and White, 2005). However, our database does not contain information to take into account this kind of considerations.

conditioned on that choice, decides the amount of energy to provide the desired level of heating. We therefore perform the estimation in two steps, following the procedure suggested by Heckman (1979).

Following this approach, household *i*'s demand function for energy source *k* for residential heating is[6]

$$x_{ik}^{*} = g_k(y_i, p^k, z_i, \eta_i). \tag{6}$$

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

$$x_{ik} = \begin{cases} x_{ik}^{*} & if \quad s_{ik}^{*} > 0 \\ 0 & if \quad s_{ik}^{*} \le 0 \end{cases} \tag{7}$$

where $s_{ik}^{*} = h_k(y_i, p^e, p^g, p^l, c_i, \theta_i)$ is the household choice function for energy source *k*. Note that only the sign s_{ik}^{*} is observable, being positive if the household decides to use energy source *k* and non-positive otherwise. In this sense, it is possible to define a choice variable,

$$s_i = \begin{cases} 1 \quad if \quad s_{i1}^{*} > 0 & \left(V_i(1, y_i, p^k, z_i, \eta_i) > V_i(m, y_i, p^k, z_i, \eta_i); \forall m \ne 1\right) \\ 2 \quad if \quad s_{i2}^{*} > 0 & \left(V_i(2, y_i, p^k, z_i, \eta_i) > V_i(m, y_i, p^k, z_i, \eta_i); \forall m \ne 2\right) \\ 3 \quad if \quad s_{i3}^{*} > 0 & \left(V_i(3, y_i, p^k, z_i, \eta_i) > V_i(m, y_i, p^k, z_i, \eta_i); \forall m \ne 3\right) \\ 0 \quad otherwise & \end{cases} \tag{8}$$

Then, $\{x_{ik}, s_i\}$ are the observed dependent variables in 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 unobservable variables *s**

$$s_{ik}^{*} = A_i \beta_k + \theta_{ik} + \upsilon_{ik} \tag{9}$$

where β is the parameter vector to be estimated, θ is the unobservable heterogeneity, υ is the idiosyncratic error term and *A* is a matrix of independent variables that includes the natural logarithm of fuel prices (electricity, natural gas, and liquid fuels), the natural logarithm of total household expenditure (i.e., the income variable) and its square, the number of household members, housing

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[6] We omit time subscripts for convenience.

floor area and a complete set of dummies for household and house characteristics (see Annex C for a description of these variables). Furthermore, since (9) is non-linear we try some interaction terms in *A*.

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

$$\log(x_{ik}^{*}) = E_i \gamma_k + \eta_{ik} + \vartheta_{ik} \tag{10}$$

where γ is a parameter vector to be estimated, η is the unobservable heterogeneity, ϑ is the idiosyncratic error term and *E* is a matrix of independent variables that includes the natural logarithm of the price of fuel *k*, the natural logarithm of total household expenditure and its square, the number of household members, housing floor area and a complete set of dummies for household and housing characteristics (see Annex C for a description of these variables). Moreover, we include in *E* the interaction between the natural logarithm of fuel *k* price and the dummy for home area. In this case only the price of the chosen energy source is included, as the decision on the amount of energy to consume for heating is contingent on the type of energy source previously selected by the household.[8] This reflects the short-run nature of the decision on the level of energy consumption, as each household reports in SHS just one energy source for heating in each period. As indicated above, changes in the relative prices of energy sources may influence medium/long-run choices on the type of energy source used in household heating, but if an energy source is not used its price does not affect the level of consumption of the chosen energy source in the short run.

As s^* and x^* are not observable (although when the sign of s^* is observed, x^* is observable), we carried out estimation in two steps. 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 multinomial probit model for panel data.[9,10] The results from this estimation allow the calculation of Heckman's (1979)

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[7] Since this is a sequential process, once the household chooses the fuel, *x* does not take the value zero. We use a double logarithmic specification to simplify the estimation and to provide a direct estimate of the elasticities. The demand for each energy source is specified without considering a complete demand model for energy products and, in this way, we do not need to impose any cross-equation restrictions. This is because the demand for energy services is conditional to the choice of the source of energy in a way such that in the short run cross-price effects are not possible, although we test this assumption. Moreover, we use the logs of total expenditure and of its square to try to capture non-linear profiles of consumption such as those depicted in Figure 1.

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

[9] We are assuming random unobserved effects, and recognize that this is a restriction. We also use a logit model with fixed effects but the identification of parameters in that model is based only on households who changed their source of energy for heating. Therefore, it would now 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 modeling strategy and use a probit model.

lambda, which is included 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 and diagnostics

4.1. Empirical results

Table 3 presents the estimated price and income coefficients and t-statistics for the discrete choice. The detailed results of the estimation of the household discrete decision on energy sources for heating are provided in Annex D. With all fuels, the price of the energy source has a negative and significant influence on the probability of choosing that energy source, whereas the prices of the alternative sources have a positive though not always significant impact on that probability. Moreover, the results show that the probability of having home heating always increases with household income.

It is thus clear from our dataset that an increase in the relative prices of energy sources for heating would lead households, in the medium and long runs, to switch to a cheaper energy alternative. This is seen in Table 4, which reports the average own and cross price elasticities of the probability of choosing different energy sources for heating.[11] In all cases the probability of choosing a given source of energy for heating is inelastic with respect to own- and cross-price effects, so that an increase in the own (cross) price will lead to a negative (positive), but less than proportional, variation in the probability of choosing the considered energy source for heating. The highest own-price elasticity is observed for liquid fuels, while natural gas has the lowest.[12] The cross-price elasticities of liquid fuels and natural gas on the choice of electricity for home heating are not statistically significant, nor are the cross-price elasticities of electricity on the choices of those fuels. But the

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[10] When estimating the discrete model, we impose the constraint that, for each pair of energy sources for heating, the cross-price parameters have to be the same (we check these constraints in Annex D).

[11] Own-price elasticities were calculated from multinomial probit, $\frac{\Pr(s_{it}=k \mid A_i,\theta_i)}{\Pr(s_{it}=0 \mid A_i,\theta_i)}=\Phi(A_i\beta_k)$, by using the formula

$$\frac{\partial \Pr(s_{it}=k \mid w_{it},\theta_i)}{\partial p^k}=(\delta_k^k+\varsigma_k^k duzrs_{it})\frac{1}{p^k}\phi(A_i\beta_k)\Pr(s_{it}=0 \mid A_i,\theta_i) \Rightarrow \frac{\frac{\partial \Pr(s_{it}=k \mid A_i,\theta_i)}{\Pr(s_{it}=k \mid A_i,\theta_i)}}{\frac{\partial p^k}{p^k}}=\frac{(\delta_k^k+\varsigma_k^k duzrs_{it})\phi(A_i\beta_k)\Pr(s_{it}=0 \mid A_i,\theta_i)}{\Pr(s_{it}=1 \mid A_i,\theta_i)}$$

where Φ is the standard normal density function, δ_k^k is the estimated parameter of the natural logarithm of fuel *k* price and ς_k^k is the estimated parameter of dummy of area for residence (*duzrs*). Cross-price elasticities are calculated in the same manner but using the price of the other energy source instead of the own price.

[12] This result is strongly influenced by the time span of our data.

cross-price elasticities of liquid fuels on the choice of natural gas and conversely of natural gas on the choice of liquid fuels are statistically significant.

Table 3. Estimates of price and income parameters. Discrete choice

	Regresor	Coefficient	t-ratio
Electricity (E)	Log (electricity price)	-0.3037	-2.29
	Log (natural gas price)	-0.2075	-1.30
	Log (liquid fuels price)	-0.0099	-0.14
	Log (income)	0.8881	0.72
	$(\text{Log (income)})^2$	-0.0361	-0.60
	duzrs*log(electricity price)	-0.0942	-0.52
	duzrs*log(natural gas price)	0.4295	2.35
	duzrs*log(liquid fuels price)	0.1015	1.01
Natural Gas (NG)	Log (electricity price)	-0.2075	-1.30
	Log (natural gas price)	-2.5235	-8.41
	Log (liquid fuels price)	-0.2320	-2.51
	Log (income)	4.3643	3.39
	$(\text{Log (income)})^2$	-0.2013	-3.21
	duzrs*log(electricity price)	0.4295	2.35
	duzrs*log(natural gas price)	1.8672	5.97
	duzrs*log(liquid fuels price)	0.5886	5.25
Liquid Fuels (LF)	Log (electricity price)	-0.0099	-0.14
	Log (natural gas price)	-0.2320	-2.51
	Log (liquid fuels price)	-1.6594	-22.62
	Log (income)	2.3045	1.51
	$(\text{Log (income)})^2$	-0.1145	-1.54
	duzrs*log(electricity price)	0.1015	1.01
	duzrs*log(natural gas price)	0.5886	5.25
	duzrs*log(liquid fuels price)	-0.6783	-6.65

Source: Own calculations.

Table 4. Price elasticities in the discrete choice

	Own-price elasticity	Cross-price elasticity
Electricity (E)	-0.2695	0.1041 (NG price) 0.0523 (LF price)
Natural Gas (NG)	-0.1433	0.0382 (E price) 0.0624 (LF price)
Liquid Fuels (LF)	-0.4281	0.0104 (E Price) 0.0241 (NG price)

Source: Own calculations.

With regard to the continuous decision on residential energy consumption, Table 5 presents the price and income coefficient estimates and t-statistics, whereas Table 6 depicts the resulting income and price elasticities (see Annex D for a full report of the estimated parameters used for the calculation).[13] As expected, energy demand for heating is inelastic with respect to its own price for each source of energy so, *ceteris paribus,* an increase in the price of an energy source will lead to a less than proportional short-run reduction in the demand for that energy source. The results indicate larger short-run 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 (at 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 run as this demand is conditioned on the prior choice of energy source through the discrete choice component of the model.

Table 5. Estimated price and income parameters. Conditional demand

	Regresor	Coefficient	t-ratio
Electricity (E)	Log (electricity price)	-0.2054	-4.62
	Log (income)	1.1572	3.86
	$(\text{Log (income)})^2$	-0.0419	-2.87
	duzrs*log (electricity price)	0.0849	1.68
Natural Gas (NG)	Log (natural gas price)	-0.2088	-5.50
	Log (income)	0.5146	2.60
	$(\text{Log (income)})^2$	-0.0140	-1.46
	duzrs*log (natural gas price)	0.0263	0.68
Liquid Fuels (LF)	Log (liquid fuels price)	-0.2660	-15.08
	Log (income)	1.7980	8.44
	$(\text{Log (income)})^2$	-0.0728	-7.05
	duzrs*log (liquid fuels price)	-0.0118	-0.51

Source: Own calculations.

Table 6. Price and income elasticities of residential energy demand for heating

	Price elasticity			Income elasticity
	Urban	Rural	Average	
Electricity	-0.1205	-0.2054	-0.1352	0.2998
Natural Gas	-0.1824	-0.2088	-0.1838	0.2253
Liquid Fuels	-0.2779	-0.2660	-0.2730	0.3009

Source: Own calculations.

The continuous choice model results show that the level of income has a positive influence on energy demand for residential heating, again with a less than proportional *ceteris paribus* increase of demand due to income growth. Other household and housing characteristics also have some

[13] Since we estimate conditional demands, each equation is estimated on a different sample and theoretical restrictions across equations cannot be imposed.

influence on energy demand (see Annex D). For instance, energy demand for residential heating is higher when the main income earner is highly placed in a firm or public administration, especially in the case of households using electricity for heating. Energy demand for electricity and liquid fuels is significantly lower when the main income earner is unemployed; it is significantly higher (especially for electricity) in owner-occupied housing. Energy demand is higher for larger households and for households occupying larger residences. Moreover, there is significant regional variation in household energy demand for heating that is related to the remarkable climatic variation that exists in Spain.[14]

Table 7 depicts the price and income elasticities of demand in rich and poor Spanish regions.[15] For discrete choice, as expected, price elasticities are lower in rich regions, where fuel prices have less influence on fuel choice, especially in the case of households with natural gas heating (the main energy source for residential heating in rich regions: used by 54.1% of households, vs. 23.4% in poor regions). In households with natural gas heating in rich regions, natural gas price hardly affects the fuel choice, whereas in households with natural gas heating in poor regions, natural gas price has a much larger (fifty-times larger) impact. In the case of continuous choice, households from poor regions are more sensitive to electricity price, and less sensitive to natural gas price, while the sensitivity is about the same in the case of liquid fuels. The income elasticity is higher in poor regions, so that an increase in household income in these regions generates a larger increase in energy demand than for rich regions, except in the case of natural gas.

Table 7. Elasticities in discrete and continuous choice. Rich vs. poor regions

	Discrete choice		**Continuous choice**			
	Price elasticity		Price elasticity		Income elasticity	
	Rich	**Poor**	**Rich**	**Poor**	**Rich**	**Poor**
Electricity	-0.2574	-0.3553	-0.0813	-0.1583	0.2983	0.2993
Natural Gas	-0.0304	-1.5268	-0.1925	-0.1615	0.2284	0.2159
Liquid Fuels	-0.2842	-0.5684	-0.2770	-0.2739	0.2627	0.3443

Source: Own calculations.

In order to compare our results with the existing literature, Table 8 provides a compilation of price and income elasticities of energy demand from other studies. Note that the results from studies using a

[14] Regional and temporal dummies can constitute proxies for climatic variables, although we are aware that the aggregation into regions is wider than optimal to capture the effects of climate conditions on consumption.

[15] To classify regions as rich or poor, we used 2007 INE's per-capita gross household disposable. Thus, the nine rich regions are Basque country, Navarra, Madrid, Catalonia, Aragón, Balearic Islands, La Rioja, Cantabria and Asturias; and the nine poor regions are Extremadura, Andalusia, Murcia, Castille-La Mancha, Castille-León, Canarias, Valencia, Galicia, and Ceuta and Melilla.

similar discrete-continuous approach are quite heterogeneous with regard to time frame, geographical setting, and energy demand modeling. With this caveat, the numbers indicate that the Spanish price and income elasticities reported here lie within the range spanned by the existing literature on residential energy demand in the developed world.

Table 8. 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]
Reiss and White (2005)	U.S	Electricity	-0.39	-0.00
Asadoorian et al. (2008)	China	Electricity	-0.19 (urban) -0.28 (rural)	0.80 0.04
Labandeira et al. (2006)	Spain	Electricity	-0.78	0.81
Labandeira et al. (2012)	Spain	Electricity	-0.25	--
Bernstein and Madlener (2011)	Spain	Electricity	[-0.14, 0.01] SR [-0.35, -0.30] LR	[0.14, 0.30] SR [1.21, 1.24] LR

Notes: * Four different sources of energy for heating are considered, although the paper calculates an average price elasticity in the continuous decision; SR: short run; LR: long run.
Source: Compilation from the literature by the authors.

Table 8 also summarizes the existing evidence on income and price elasticity of electricity for Spain, the only heating energy source addressed by the academic literature for Spain. The price elasticity estimates reported in this paper are slightly lower than those reported by Labandeira et al. (2012), who use high-quality data on electricity consumption by Spanish households for a similar time span. There are larger differences with the results in Labandeira et al. (2006), but that paper deals only with the continuous choice of energy consumption, and it covers a very different socio-economic and energy setting of the 1970s-1990s. In both cases, the differences with this paper are consistent with the fact that the elasticities reported in this paper incorporate only the short-run response to price changes, as the long-run effect is embedded in the discrete choice of energy source.

4.2. Robustness checks

Besides the measures of goodness of fit and tests of significance reported in the tables in Annex D, we provide some additional tests as a check on the robustness of our results. In deriving the estimates of income and price elasticities for the three sources of energy, we made several assumptions. First of all, we assumed that individuals decide through a two-stage process first choosing their source of energy source and, conditional on that choice, then choosing how much energy to consume. Since the three equations are estimated on the subsample of households once they made their choice of an energy source, we cannot apply a seemingly unrelated regression (SURE) method to three different subsamples. A concern here is that there could be potential correlation among the unobservables of the three equations. Since they pertain to different subsamples we believe that the sampling scheme guarantees independence. However, we also estimated a SURE model on the whole sample with and without random effects. We find that own-price and income elasticities are completely different from those estimated in the two-stage sequential process after correcting for sample selection. The own-price elasticities at mean values are -0.36, -1.38 and -2.25 for electricity, natural gas and liquid fuels, respectively. While it is possible to argue that they incorporate both the discrete and continuous choice responses, they do differ from the sum of the two response elasticities estimated separately. Our view is that the zero consumption contaminates the estimates because, when a change is observed in any source of energy, the impact on the elasticity is large enough to produce an upward bias. The income elasticities are different from, but closer to, the values estimated in our preferred 2SLS model with selectivity corrections (in particular they take the values 0.21, 0.27 and 0.18 for electricity, natural gas and liquid fuels, respectively). We believe that since income has only a marginal effect on the choice of energy source, its effects on the conditional and unconditional demands for energy services should be similar.

Our theoretical model assumes an initial choice of energy source which necessarily precedes the demand for the amount of energy used. It is also possible that households could take these decisions simultaneously (although the notion of frequent changes in energy source from one year to the next seems less likely than changes in the amount of energy used). In that case, if we assume that the same specification governs the decision about the source of energy and the decision about the amount of services demanded, the estimation of a tobit type I (or a system of tobit type I models) should be enough to capture household behavior. We have estimated three tobit equations (one for each source of energy) and we have computed the income and price elasticities.[16] Since tobit results could be affected by the normality assumptions (see Figure 1), we check them against Symmetrically Censored Least Squares (Powell, 1986), which maintain symmetry and also Censored Least Absolute Deviations (Powell, 1984). We again get very different values for income and price elasticities, which in our opinion are due not to distributional but to specification assumptions (see Annex E for a summary of the above-mentioned estimations).

In a sequential model like that proposed here, one can also face a problem of endogeneity of total expenditure dues to several factors such as errors in variables or two-stage budgeting. We have also estimated our preferred specification by 2SLS instrumenting total expenditure with its prediction obtained in an auxiliary reduced form equation, again available upon request, which include a wide range of socio-demographic variables, powers of some of them and interactions among them. The own-price elasticities obtained in this last experiment are -0.13, -0,18 and -0.29 for respectively electricity, natural gas and liquid fuels, and they are thus very similar to those reported in Table 6.

5. Discussion and implications

The main objective of this paper has been to provide improved empirical results regarding the price and income elasticities of residential energy demand in Spain for heating. Residential heating constitutes a significant part of total energy demand in any developed country, and policies targeted at reducing energy consumption whether for environmental or energy security reasons are likely to be directed towards this sector.

The paper estimates a micro-econometric model from detailed household level micro data provided by the SHS. The model defines heating as a service that is associated with the purchase of a durable good that consumes a particular energy source. The paper employs a discrete-continuous model of demand that accounts for the choice of energy source as well as the level of utilization of the chosen source, a methodology strategy that has been successfully applied for this similar purpose in the literature.

[16] Own-price elasticities are -1.02, -1.01 and -6.21 while income elasticities are 0.71, 0.49 and 0.84 for respectively electricity, natural gas and liquid fuels. These figures are much larger than those presented in Table 6. Our opinion is that tobit results incorporate the whole effect of the discrete and continuous processes in an erroneous way because while the determinants of the two decisions could be the same (we have checked that they are not the same), the effects of the variables could be different for each process.

Our research also provides short-run income and price elasticities that are conditioned on the prior discrete choice of an energy source for home heating. The short-run demand for energy for heating is found to be price-inelastic for all energy sources, although there is a larger short-run response to price by households that use liquid fossil fuels and a smaller short-response by those which use electricity. Regarding income elasticities, in all cases the level of income has a positive, but less than proportional, influence on the energy demand for heating.

The paper contributes to the international literature in the field by providing new evidence on household energy demand. The results obtained here are similar to those obtained for similar developed countries, but differ from previous results reported for Spain due to the use of a methodology that effectively distinguishes between the short- versus long-run response to changes in energy prices.

Our results may have several implications for the design of energy and climate policies. First, they show the limitations of pricing policy to control energy demand in the short run. However, changes in relative energy prices may have a strong influence on the choice of heating fuel in the longer-run. The combination of the short- and long-run responses produces a richer and more nuanced set of results, as illustrated by Table 10. The table simulates the effects of different price changes on residential energy demand for heating using the elasticities estimated in this paper. We assume a 10% increase in the price of each energy source in isolation, and then a 10% increase in all energy prices simultaneously. We use the price elasticity from the continuous choice model to capture the short-run impact on demand for that source combined with the discrete choice elasticity to capture potential fuel switching in the long run. The overall long-run change in in demand for each fuel when its own price increases by X% is given (*ceteris paribus*) by the following expression,[17]

$$X\left[\varepsilon_{cc} + \varepsilon_{dc}\left(1 + \varepsilon_{cc}\frac{X}{100}\right)\right] \tag{11}$$

where ε_{cc} is the price elasticity from the continuous choice model and ε_{dc} is the price elasticity from the discrete choice model.

[17] Since the price of a fuel only influences the demand for other fuels through the discrete choice, the effect on demand for other fuels is given by the cross-elasticities of the discrete model.

As shown in Table 9, changes in the relative prices of heating energy have different effects depending on which fuel price is increased. For a 10% increase in the price of electricity there is a smaller overall demand reduction than for the other two fuels. When all energy prices simultaneously increase by 10%, while overall energy demand falls, there is fuel switching, especially to natural gas. Also notice the significant differences of household reactions in rich and poor regions (see note 15), which should also inform policy making in this area to avoid undesired distributional effects. For instance, a simultaneous 10% price increase of fuel sources for heating would lead to a household reduction in consumption of almost 12% in poor region: 10 points above the average reduction in rich regions.

Table 9. Effects of energy price increases on Spanish household consumption

Demand \ Price	+10% Electricity Price	+10% Natural Gas Price	+10% Liquid Fuels Price	+10% All Prices
Electricity	-4.01%	1.04%	0.52%	-2.47%
Natural Gas	0.38%	-3.24%	0.62%	-2.26%
Liquid Fuels	0.10%	0.24%	-6.89%	-6.56%
Rich Regions	*0.31%*	*-1.54%*	*-0.81%*	*-2.06%*
Poor Regions	*-1.32%*	*-8.38%*	*-2.15%*	*-11.85%*
Total	**-0.32%**	**-1.96%**	**-0.80%**	**-3.09%**

Source: Own calculations.

With the above caveats, the results of this paper favor the notion of 'getting the price right' for heating fuel sources by internalizing environmental or energy security externalities. The results may also support the use of design standards and/or performance standards for heating appliances: assuming that switching energy sources requires some changes in heating equipment, standards could reinforce the effects of price changes. It is also clear that the evolution of household income is a very significant influence on residential energy demand for heating. This has implications for policy design and also for the distributional consequences of policy innovation.

In sum, the conclusions from this paper are useful not just for short-run policy assessment but also for prospective analysis. By combining the expected path of energy prices (including the impact of regulations) and economic growth (income growth), it would be possible to obtain a clearer picture of the long-run effects of various energy policies and to identify the type of instruments, and their levels, that would have to be introduced to attain certain desired environmental or other energy-related 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			
< 10,000 €	18.62%	17.47%	16.73%
[10,000-20,000) €	28.78%	28.14%	30.39%
[20,000-30,000) €	22.65%	23.17%	23.78%
[30,000-40,000) €	13.50%	13.75%	14.22%
[40,000-50,000) €	7.50%	8.15%	7.38%
[50,000-60,000) €	4.12%	4.28%	3.80%
≥ 60,000 €	4.84%	5.04%	3.70%
Net annual household income			
< 10000 €	19.15%	18.79%	17.18%
[10,000-20,000) €	34.66%	29.29%	33.71%
[20,000-30,000) €	25.00%	26.73%	22.97%
[30,000-40,000) €	11.98%	13.68%	15.09%
[40,000-50,000) €	5.05%	6.29%	6.25%
[50,000-60,000) €	2.04%	2.35%	1.94%
≥ 60,000 €	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 m^2	0.45%	0.40%	0.39%
(35-100] m^2	67.53%	66.59%	66.72%
(100-200] m^2	28.04%	28.71%	28.68%
(200-300) m^2	2.61%	2.82%	2.70%
≥ 300 m^2	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.

Table A5. t-test of difference of means (p-values).

	Electricity vs. Natural gas	Electricity vs. Liquid fuels	Natural gas vs. Liquid fuels
2006-2007	0.5934	0.1442	0.3312
2007-2008	0.0003	0.0016	0.4859

Source: Own calculations.

Table A6. Households that did or did not change their energy source for heating

	2006-2007		2007-2008	
	Households that did not change	Households that did change	Households that did not change	Households that did change
Average household expenditure	35,390.94	32,419.61	35,945.60	35,871.66
Average number of household members	2.95	2.93	2.91	2.79
Average housing floor area	107.35	105.58	107.11	108.03
Region of household residence				
Andalusia	2.60%	0.90%	2.37%	1.74%
Aragón	7.08%	4.95%	6.11%	3.04%
Asturias	4.97%	2.25%	5.01%	3.48%
Balearic Is.	2.19%	1.80%	2.42%	2.61%
Canarias	0.03%	0.00%	0.11%	0.00%
Cantabria	3.31%	6.31%	4.61%	3.04%
Castille-León	10.53%	7.66%	9.66%	16.52%
Castille-La Mancha	6.99%	4.05%	6.87%	3.04%
Catalonia	13.42%	8.11%	11.41%	9.13%
Valencia	3.86%	3.15%	3.60%	3.48%
Extremadura	2.05%	4.05%	2.01%	2.17%
Galicia	6.96%	7.21%	6.13%	10.43%
Madrid	9.36%	14.41%	8.97%	15.22%
Murcia	1.73%	3.60%	1.57%	2.61%
Navarra	5.97%	12.61%	12.89%	11.30%
Basque country	13.48%	11.26%	10.29%	5.22%
La Rioja	5.38%	7.66%	5.77%	6.96%
Ceuta and Melilla	0.09%	0.00%	0.20%	0.00%
Type of household				
Single	10.32%	10.36%	12.21%	17.39%
Couple without children	22.11%	22.97%	22.21%	22.61%
Couple with children	50.66%	50.45%	49.55%	44.78%
Other	16.91%	16.22%	16.02%	15.22%
Number of workers				
None	22.49%	26.58%	21.90%	27.39%
One	31.94%	31.98%	31.97%	28.26%
Two	37.41%	35.14%	38.37%	36.96%
Three	6.20%	5.86%	6.17%	6.52%
Four or more	1.96%	0.45%	1.59%	0.87%
Occupation of the main contributor to income				
Directive of firms	25.74%	30.63%	25.57%	35.22%
Administration	25.15%	23.87%	25.21%	22.17%
Qualified worker	37.99%	35.59%	37.07%	30.00%
Other	11.11%	9.91%	12.15%	12.61%
Level of studies of the main contributor to income				
Basic school	53.41%	51.80%	52.08%	43.91%
High school	25.45%	22.07%	25.23%	28.26%
University	21.15%	26.13%	22.68%	27.83%
Working condition of the main contributor to income				
Working	64.93%	51.80%	66.15%	61.74%
Unemployed	2.28%	22.07%	1.77%	2.17%
Retired	25.39%	26.13%	24.61%	28.70%
Other	7.40%	8.11%	7.47%	7.39%
Type of housing possession				
Property	91.93%	88.74%	90.87%	86.96%
Rent	4.59%	8.11%	4.97%	7.83%
Other	3.48%	3.15%	4.16%	5.22%
Type of building				
Independent house	32.47%	22.07%	32.06%	22.17%
Building of flats	67.51%	77.93%	67.92%	77.83%
Area of residence				
Urban	79.03%	83.78%	80.78%	85.22%
Rural	20.97%	16.22%	19.22%	14.78%
Date of building construction				
Less than 25 years	45.57%	43.24%	47.02%	42.61%
More than 25 years	54.43%	56.76%	52.98%	57.39%

Note: Only households staying for at least two periods in the sample were considered. See Annex C for a more detailed description of occupation of the main contributor to income categories.
Source: Own calculations.

ANNEX B

PRICES AND DECISION MAKING ON HEATING ENERGY SOURCE

To analyze whether prices influence the choice of energy source for residential heating, we assume that the choice of each energy source is determined by a unobserved variable *s** defined as specified below, with energy prices and income as explanatory variables:

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

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

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

Assuming that the idiosyncratic error term is i.i.d. with a standard logistic distribution for it, the probability of the household choosing energy source *k* is given by a panel data logit model:

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

Because of the incidental parameters problem, maximum likelihood estimation of this fixed-effects logit model yields inconsistent estimates of the coefficients on the explanatory variables. A standard solution uses the conditional maximum likelihood estimator, conditioned on a sufficient statistic, to eliminate the nuisance parameters (the fixed effects). Consistent estimation of this logit model is obtained by conditioning on $\sum_t s_{itk} = 1$ (Chamberlain, 1980). The contribution to the likelihood is zero for those households which do not switch their energy source during the period observed (the vast majority of households). Thus, the estimation of the logit parameters is based on the subset of households which did change their energy source. Since there are *T*=2 observations per household, the only combinations of outcomes that contribute to the likelihood are (1, 0) and (0, 1). With this conditioning, the model is transformed to eliminate the μ´*s* and, as a consequence, the only variables entering the specification are those that show some time variation.

Table B1. Results from the logit model for 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
$(\text{Log (income)})^2$	-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
$(\text{Log (income)})^2$	-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
$(\text{Log (income)})^2$	-0.0269	-0.10

Source: Own calculations.

Table B1 shows the results of the estimation. As indicated in section 2, the price of liquid fuels is significant in each case; the sizable price increase in this fuel source during the 2006-2008 period was the main factor inducing households to switch their energy source for heating, highlighting the significance of changes in relative energy prices for residential energy demand for heating in Spain.

ANNEX C

DUMMIES INCLUDED IN THE ESTIMATION

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

ESTIMATION RESULTS

Table D1. Parameter estimates. Conditional demand for electricity for heating

Regressor	Coefficient	t-ratio
Log (electricity price)	-0.2054	-4.62
$\hat{\psi}$	2.8643	-1.79
Number of household members	0.0522	4.85
Floor area	0.0018	8.81
Log (income)	1.1572	3.86
$(\text{Log (income)})^2$	-0.0420	-2.87
Dummy (duca) C.A. Andalusia	0.3591	4.20
Dummy (duca) C.A. Aragón	0.3993	4.28
Dummy (duca) C.A. Asturias	0.3750	4.16
Dummy (duca) C.A. Balearic Is.	0.3626	4.18
Dummy (duca) C.A. Canarias	-0.1718	-1.52
Dummy (duca) C.A. Cantabria	0.2732	2.67
Dummy (duca) C.A. Castille-León	0.5528	6.16
Dummy (duca) C.A. Castille-La Mancha	0.5410	6.14
Dummy (duca) C.A. Catalonia	0.3633	4.23
Dummy (duca) C.A. Valencia	0.3200	3.75
Dummy (duca) C.A. Extremadura	0.3855	4.25
Dummy (duca) C.A. Galicia	0.3258	3.79
Dummy (duca) C.A. Madrid	0.4282	4.90
Dummy (duca) C.A. Murcia	0.2812	3.16
Dummy (duca) C.A. Navarra	0.4169	4.25
Dummy (duca) C.A. Basque country	0.2239	2.62
Dummy (duca) C.A. La Rioja	0.4346	4.40
Dummy (duth) type of household 1	-0.0708	-1.85
Dummy (duth) type of household 2	0.0075	0.26
Dummy (duth) type of household 3	0.0538	2.37
Dummy number of workers 1	0.0199	0.29
Dummy number of workers 2	-0.0418	-0.67
Dummy number of workers 3	-0.0410	-0.67
Dummy number of workers 4	-0.0555	-0.85
Dummy (dunoc) occupation 1	0.0802	2.70
Dummy (dunoc) occupation 2	0.0173	0.65
Dummy (dunoc) occupation 3	0.0126	0.50
Dummy (dues) level of education 1	0.0420	1.70
Dummy (dues) level of education 2	0.0373	1.49
Dummy (dusta) working condition 1	0.0033	0.11
Dummy (dusta) working condition 2	-0.1124	-2.39
Dummy (dusta) working condition 3	0.0091	0.28
Dummy (durgt) possession 1	0.1058	2.91
Dummy (durgt) possession 2	0.0192	0.43
Dummy (duted) type of building 1	-0.0604	-0.14
Dummy (duted) type of building 2	-0.0751	-0.17
Dummy (duzrs) residential area	0.1881	1.83
Dummy residential area*log (electricity price)	0.0849	1.68
Dummy (duanco) date of construction	0.0021	0.13
Heckman's lambda	-0.0123	-0.37
Test of joint significance: Wald χ^2(45)=1665.15 (p-value=0.0000)		
R^2=0.2031	**Significance of Heckman's lambda parameter: Wald χ^2(1)**=0.14 (p-value=0.7092)	

Source: Own calculations.

Table D2. Parameter estimates. Discrete choice of energy source. Electricity

Regressor	Coefficient	t-ratio
Log (electricity price)	-0.3037	-2.29
Log (natural gas price)	-0.2075	-1.30
Log (liquid fuels price)	-0.0099	-0.14
$\hat{\alpha}$	0.1329	0.00
Number of members in household	-0.0625	-0.76
Floor area	-0.0112	-1.98
Log (income)	0.8881	0.72
$(\text{Log (income)})^2$	-0.0361	-0.60
Dummy (duca) C.A. Andalusia	-6.7105	-4.65
Dummy (duca) C.A. Aragón	-7.4144	-5.12
Dummy (duca) C.A. Asturias	-7.2495	-5.01
Dummy (duca) C.A. Balearic Is.	-7.1365	-4.94
Dummy (duca) C.A. Canarias	-7.4607	-5.06
Dummy (duca) C.A. Cantabria	-8.2864	-5.72
Dummy (duca) C.A. Castille-León	-7.8462	-5.43
Dummy (duca) C.A. Castille-La Mancha	-6.9175	-4.79
Dummy (duca) C.A. Catalonia	-6.9955	-4.84
Dummy (duca) C.A. Valencia	-7.0690	-4.90
Dummy (duca) C.A. Extremadura	-6.9513	-4.81
Dummy (duca) C.A. Galicia	-7.2791	-5.04
Dummy (duca) C.A. Madrid	-7.2606	-5.03
Dummy (duca) C.A. Murcia	-7.0236	-4.85
Dummy (duca) C.A. Navarra	-7.5650	-5.22
Dummy (duca) C.A. Basque country	-7.2166	-5.00
Dummy (duca) C.A. La Rioja	-7.2459	-5.00
Dummy (duth) type of household 1	-0.0645	-0.13
Dummy (duth) type of household 2	0.0285	0.07
Dummy (duth) type of household 3	0.3027	1.03
Dummy number of workers 1	0.7008	1.19
Dummy number of workers 2	0.6463	1.27
Dummy number of workers 3	0.4899	1.02
Dummy number of workers 4	1.001	2.24
Dummy (dunoc) occupation 1	0.4544	1.35
Dummy (dunoc) occupation 2	0.5091	1.62
Dummy (dunoc) occupation 3	0.0228	0.08
Dummy (dues) level of education 1	-0.4080	-0.94
Dummy (dues) level of education 2	-0.3522	-0.90
Dummy (dusta) working condition 1	-0.0359	-0.15
Dummy (dusta) working condition 2	-0.5578	-1.55
Dummy (dusta) working condition 3	0.1613	0.52
Dummy (durgt) possession 1	0.4880	1.07
Dummy (durgt) possession 2	-1.6425	-1.73
Dummy (duted) type of building 1	1.8909	0.02
Dummy (duzrs) residential area	1.1495	1.69
Dummy residential area*log (electricity price)	-0.0942	-0.52
Dummy residential area*log (natural gas price)	0.4295	2.35
Dummy residential area*log (liquid fuels price)	0.1015	1.01
Dummy (duanco) date of construction	-0.1209	-0.57
Log (electricity price in *t-1*)	-0.3132	-2.87
Log (natural gas price in *t-1*)	-0.0295	-0.27
Log (liquid fuels price in *t-1*)	0.1575	3.57

Log (income in *t-1*)	0.0917	1.21
Number of members in household in *t-1*	-0.0830	-1.02
Mean (floor area)	-0.0003	-0.05
(Mean (floor area))^2	0.0000	3.66
Mean *(dummy* type of household 1)	0.0566	0.11
Mean *(dummy* type of household 2)	-0.0725	-0.18
Mean *(dummy* type of household 3)	-0.2736	-0.90
Mean (*dummy* number of workers 1)	-0.4947	-0.76
Mean (*dummy* number of workers 2)	-0.4621	-0.82
Mean (*dummy* number of workers 3)	-0.3169	-0.59
Mean (*dummy* number of workers 4)	-0.9333	-1.78
Mean (*dummy* occupation 1)	-0.4045	-1.13
Mean (*dummy* occupation 2)	-0.4305	-1.29
Mean (*dummy* occupation 3)	-0.0338	-0.11
Mean (*dummy* level of education 1)	0.3466	0.78
Mean (*dummy* level of education 2)	0.4138	1.02
Mean (*dummy* working condition 1)	-0.0290	-0.11
Mean (*dummy* working condition 2)	0.4801	1.08
Mean (*dummy* working condition 3)	-0.3667	-1.09
Mean (*dummy* possession 1)	-0.1564	-0.33
Mean (*dummy* possession 2)	1.6000	1.66
Mean (*dummy* type of building 1)	-1.5885	-0.02
Mean (*dummy* type of building 2)	0.5328	0.01
Mean (*dummy* date of construction)	0.1676	0.78
Test of joint significance: Wald χ^2(75)=577.78 (p-value=0.0000)		
Test of joint significance of price parameters: Wald χ^2(9)=56.45 (p-value=0.0000)		

Source: Own calculations.

Table D3. Parameter estimates. Conditional demand for natural gas for heating

Regressor	Coefficient	t-ratio
Log (natural gas price)	-0.2088	-5.50
$\hat{\psi}$	1.0448	0.95
Number of members in household	0.0562	9.60
Floor area	0.0020	15.30
Log (income)	0.5146	2.60
(Log (income))^2	-0.0140	-1.46
Dummy (duca) C.A. Andalusia	0.0465	0.80
Dummy (duca) C.A. Aragón	-0.0194	-0.76
Dummy (duca) C.A. Asturias	-0.1831	-6.93
Dummy (duca) C.A. Balearic Is.	-0.0242	-0.46
Dummy (duca) C.A. Cantabria	-0.1714	-6.52
Dummy (duca) C.A. Castille-León	-0.0206	-0.88
Dummy (duca) C.A. Castille-La Mancha	-0.0345	-1.14
Dummy (duca) C.A. Catalonia	-0.0417	-1.99
Dummy (duca) C.A. Valencia	-0.0675	-2.14
Dummy (duca) C.A. Extremadura	-0.0483	-1.14
Dummy (duca) C.A. Galicia	-0.0460	-1.46
Dummy (duca) C.A. Madrid	-0.0372	-1.76
Dummy (duca) C.A. Murcia	-0.0374	-0.92
Dummy (duca) C.A. Navarra	-0.0888	-4.01
Dummy (duca) C.A. Basque country	-0.0922	-4.50
Dummy (duth) type of household 1	-0.1424	-7.14
Dummy (duth) type of household 2	-0.0632	-4.15
Dummy (duth) type of household 3	-0.0019	-0.15
Dummy number of workers 1	0.1052	2.95
Dummy number of workers 2	0.0213	0.67
Dummy number of workers 3	-0.0034	-0.11
Dummy number of workers 4	0.0134	0.41
Dummy (dunoc) occupation 1	0.0455	2.67
Dummy (dunoc) occupation 2	-0.0011	-0.07
Dummy (dunoc) occupation 3	-0.0055	-0.37
Dummy (dues) level of education 1	0.0352	2.69
Dummy (dues) level of education 2	0.0128	1.01
Dummy (dusta) working condition 1	0.0206	1.24
Dummy (dusta) working condition 2	-0.0281	-0.96
Dummy (dusta) working condition 3	0.0183	1.01
Dummy (durgt) possession 1	0.0029	0.12
Dummy (durgt) possession 2	-0.0253	-0.90
Dummy (duted) type of building 1	0.3866	0.97
Dummy (duted) type of building 2	0.2739	0.69
Dummy (duzrs) residential area	-0.0082	-0.08
Dummy residential area*log (natural gas price)	0.0263	0.68
Dummy (duanco) date of construction	-0.0187	2.15
Heckman's lambda	0.0336	5.31
Test of joint significance: Wald χ^2(43)=4353.39 (p-value=0.0000)		
R^2=0.2446	**Significance of Heckman's lambda parameter: Wald χ^2(1)**=28.19 (p-value=0.0000)	

Source: Own calculations.

Table D4. Parameter estimates. Discrete choice of energy source. Natural gas

Regressor	Coeficient	t-ratio
Log (electricity price)	-0.2075	-1.30
Log (natural gas price)	-2.5234	-8.41
Log (liquid fuels price)	-0.2320	-2.51
$\hat{\alpha}$	-36.6742	-0.72
Number of household members	0.0094	0.12
Floor area	-0.0040	-0.75
Log (income)	4.3643	3.39
$(\text{Log (income)})^2$	-0.2013	-3.21
Dummy (duca) C.A. Andalusia	5.6030	23.43
Dummy (duca) C.A. Aragón	7.8811	38.80
Dummy (duca) C.A. Asturias	7.6775	38.25
Dummy (duca) C.A. Balearic Is.	6.1179	27.92
Dummy (duca) C.A. Cantabria	8.0076	40.39
Dummy (duca) C.A. Castille-León	7.5018	41.46
Dummy (duca) C.A. Castille-La Mancha	7.5711	37.25
Dummy (duca) C.A. Catalonia	8.3241	45.65
Dummy (duca) C.A. Valencia	6.6058	34.79
Dummy (duca) C.A. Galicia	6.7420	35.37
Dummy (duca) C.A. Madrid	8.0953	43.06
Dummy (duca) C.A. Murcia	6.7486	30.84
Dummy (duca) C.A. Navarra	8.7571	42.97
Dummy (duca) C.A. Basque country	8.2494	45.25
Dummy (duca) C.A. La Rioja	8.7677	39.79
Dummy (duth) type of household 1	0.2601	0.52
Dummy (duth) type of household 2	-0.0383	-0.10
Dummy (duth) type of household 3	0.2985	1.02
Dummy number of workers 1	0.4814	0.85
Dummy number of workers 2	0.2682	0.56
Dummy number of workers 3	0.2551	0.56
Dummy number of workers 4	0.1659	0.39
Dummy (dunoc) occupation 1	0.8814	2.58
Dummy (dunoc) occupation 2	0.9511	2.96
Dummy (dunoc) occupation 3	0.1863	0.64
Dummy (dues) level of education 1	-0.2385	-0.56
Dummy (dues) level of education 2	-0.3665	-0.95
Dummy (dusta) working condition 1	-0.0966	-0.41
Dummy (dusta) working condition 2	-0.9776	-2.63
Dummy (dusta) working condition 3	0.0200	0.06
Dummy (durgt) possession 1	0.3666	0.77
Dummy (durgt) possession 2	-2.1958	-2.30
Dummy (duted) type of building 1	-1.5588	-0.02
Dummy (duzrs) residential area	7.4008	7.95
Dummy residential area*log (electricity price)	0.4295	2.35
Dummy residential area*log (natural gas price)	1.8672	5.97
Dummy residential area*log (liquid fuels price)	0.5886	5.25
Dummy (duanco) date of construction	0.1621	2.13
Log (electricity price in *t-1*)	0.1741	1.61
Log (natural gas price in *t-1*)	-0.8691	-8.66
Log (liquid fuels price in *t-1*)	0.0622	1.45
Log (income in *t-1*)	0.1621	2.13
Number of members in household in *t-1*	-0.1018	-1.29

Mean (floor area)	0.0056	0.98
(Mean (floor area))^2	-6.40e-06	-0.82
Mean *(dummy* type of household 1)	-0.1644	-0.32
Mean *(dummy* type of household 2)	-0.0604	-0.15
Mean *(dummy* type of household 3)	-0.3105	-1.02
Mean (*dummy* number of workers 1)	-0.1871	-0.29
Mean (*dummy* number of workers 2)	-0.0555	-0.10
Mean (*dummy* number of workers 3)	-0.0045	-0.01
Mean (*dummy* number of workers 4)	0.0025	0.00
Mean (*dummy* occupation 1)	-0.8194	-2.26
Mean (*dummy* occupation 2)	-0.7777	-2.29
Mean (*dummy* occupation 3)	-0.2602	-0.85
Mean (*dummy* level of education 1)	0.0150	0.03
Mean (*dummy* level of education 2)	0.2311	0.58
Mean (*dummy* working condition 1)	0.1340	0.49
Mean (*dummy* working condition 2)	0.5176	1.12
Mean (*dummy* working condition 3)	-0.1595	-0.47
Mean (*dummy* possession 1)	-0.0567	-0.12
Mean (*dummy* possession 2)	1.9230	1.99
Mean (*dummy* type of building 1)	-3.9930	-0.06
Mean (*dummy* type of building 2)	-4.9554	-0.10
Mean (*dummy* date of construction)	-0.4251	-1.89
Test of joint significance: Wald χ^2(73)=4475.01 (p-value=0.0000)		
Test of joint significance of price parameters: Wald χ^2(9)=303.89 (p-value=0.0000)		

Source: Own calculations.

Table D5. Parameter estimates. Conditional demand for liquid fuels for heating

Regressor	Coefficient	t-ratio
Log (liquid fuels price)	-0.2660	-15.08
$\hat{\psi}$	-5.4133	-4.54
Number of members in household	0.0497	7.25
Floor area	0.0011	10.25
Log (income)	1.7980	8.44
$(\text{Log (income)})^2$	-0.0728	-7.05
Dummy (duca) C.A. Andalusia	-0.0449	-1.19
Dummy (duca) C.A. Aragón	0.0114	0.46
Dummy (duca) C.A. Asturias	-0.1647	-5.40
Dummy (duca) C.A. Balearic Is.	0.0707	1.61
Dummy (duca) C.A. Canarias	-0.0976	-0.35
Dummy (duca) C.A. Cantabria	-0.2148	-6.48
Dummy (duca) C.A. Castille-León	-0.0243	-1.06
Dummy (duca) C.A. Castille-La Mancha	-0.0025	-0.11
Dummy (duca) C.A. Catalonia	0.0311	1.10
Dummy (duca) C.A. Valencia	-0.0902	-2.31
Dummy (duca) C.A. Extremadura	-0.2108	-5.71
Dummy (duca) C.A. Galicia	-0.1816	-7.48
Dummy (duca) C.A. Madrid	-0.0536	-1.74
Dummy (duca) C.A. Murcia	-0.1454	-3.02
Dummy (duca) C.A. Navarra	-0.0352	-1.49
Dummy (duca) C.A. Basque country	-0.1803	-6.51
Dummy (duth) type of household 1	-0.0544	-2.12
Dummy (duth) type of household 2	-0.0011	-0.06
Dummy (duth) type of household 3	-0.0037	-0.26
Dummy number of workers 1	0.1569	3.65
Dummy number of workers 2	0.0818	2.13
Dummy number of workers 3	0.0505	1.35
Dummy number of workers 4	0.0493	1.24
Dummy (dunoc) occupation 1	0.0732	3.58
Dummy (dunoc) occupation 2	-0.0002	-0.01
Dummy (dunoc) occupation 3	0.0315	1.77
Dummy (dues) level of education 1	-0.0047	-0.29
Dummy (dues) level of education 2	-0.0150	-0.86
Dummy (dusta) working condition 1	-0.0127	-0.57
Dummy (dusta) working condition 2	-0.1124	-2.65
Dummy (dusta) working condition 3	-0.0149	-0.67
Dummy (durgt) possession 1	0.0820	3.42
Dummy (durgt) possession 2	0.0624	1.84
Dummy (duted) type of building 1	0.0404	0.09
Dummy (duted) type of building 2	-0.2690	-0.58
Dummy (duzrs) residential area	-0.1368	2.24
Dummy residential area*log (liquid fuels price)	-0.0118	-0.51
Dummy (duanco) date of construction	-0.0227	-2.09
Heckman's lambda	0.0178	4.03
Test of joint significance: Wald $\chi^2(44)$= 5036.52 (p-value=0.0000)		
R^2=0.3429	**Significance of Heckman's lambda parameter: Wald $\chi^2(1)$**=16.22 (p-value=0.0001)	

Source: Own calculations.

Table D6. Parameter estimates. Discrete choice of energy source. Liquid fuels

Regressor	Coefficient	t-ratio
Log (electricity price)	-0.0099	-0.14
Log (natural gas price)	-0.2320	-2.51
Log (liquid fuels price)	-1.6594	-22.62
$\hat{\alpha}$	-16.5386	-
Number of household members	-0.2005	-2.01
Floor area	0.0038	0.70
Log (income)	2.3045	1.51
$(\text{Log (income)})^2$	-0.1145	-1.54
Dummy (duca) C.A. Andalusia	4.5665	0.08
Dummy (duca) C.A. Aragón	5.5322	0.10
Dummy (duca) C.A. Asturias	5.1745	0.10
Dummy (duca) C.A. Balearic Is.	4.5377	0.08
Dummy (duca) C.A. Canarias	3.2562	0.06
Dummy (duca) C.A. Cantabria	4.8620	0.09
Dummy (duca) C.A. Castille-León	5.2977	0.10
Dummy (duca) C.A. Castille-La Mancha	5.6535	0.10
Dummy (duca) C.A. Catalonia	5.3454	0.10
Dummy (duca) C.A. Valencia	4.8579	0.09
Dummy (duca) C.A. Extremadura	4.6093	0.09
Dummy (duca) C.A. Galicia	5.5929	0.10
Dummy (duca) C.A. Madrid	4.9961	0.09
Dummy (duca) C.A. Murcia	3.8199	0.07
Dummy (duca) C.A. Navarra	6.1868	0.11
Dummy (duca) C.A. Basque Country	5.3512	0.10
Dummy (duca) C.A. La Rioja	6.1688	0.11
Dummy (duth) type of household 1	0.1120	0.17
Dummy (duth) type of household 2	-0.1284	-0.27
Dummy (duth) type of household 3	0.0971	0.27
Dummy number of workers 1	-0.2352	-0.33
Dummy number of workers 2	-0.1076	-0.18
Dummy number of workers 3	-0.0681	-0.12
Dummy number of workers 4	0.2424	0.47
Dummy (dunoc) occupation 1	0.6394	1.50
Dummy (dunoc) occupation 2	0.4883	1.18
Dummy (dunoc) occupation 3	0.0192	0.05
Dummy (dues) level of education 1	0.1122	0.21
Dummy (dues) level of education 2	0.3831	0.78
Dummy (dusta) working condition 1	-0.1155	-0.37
Dummy (dusta) working condition 2	-1.2044	-2.42
Dummy (dusta) working condition 3	-0.6413	-1.66
Dummy (durgt) possession 1	-0.8541	-1.55
Dummy (durgt) possession 2	-0.4898	-0.34
Dummy (duted) type of building 1	-2.2171	-0.03
Dummy (duzrs) residential area	0.5290	1.05
Dummy residential area*log (electricity price)	0.1015	1.01
Dummy zona residencia*log (natural gas price)	0.5886	5.25
Dummy zona residencia*log (liquid fuels price)	-0.6783	-6.65
Dummy (duanco) date of construction	0.0151	0.06
Log (electricity price in *t-1*)	0.1379	1.04
Log (natural gas price in *t-1*)	0.0761	0.50
Log (liquid fuels price in *t-1*)	-1.1380	-19.48

Log (income in *t-1*)	0.2085	2.19
Number of members in household in *t-1*	0.0726	0.73
Mean (floor area)	0.0058	1.00
(Mean (floor area))^2	-0.0000	-2.55
Mean *(dummy* type of household 1)	0.0261	0.04
Mean *(dummy* type of household 2)	0.1393	0.27
Mean *(dummy* type of household 3)	-0.0804	-0.21
Mean (*dummy* number of workers 1)	0.3933	0.50
Mean (*dummy* number of workers 2)	0.2187	0.32
Mean (*dummy* number of workers 3)	0.0860	0.13
Mean (*dummy* number of workers 4)	-0.4073	-0.66
Mean (*dummy* occupation 1)	-0.3721	-0.82
Mean (*dummy* occupation 2)	-0.2192	-0.50
Mean (*dummy* occupation 3)	-0.0030	-0.01
Mean (*dummy* level of education 1)	-0.0839	-0.15
Mean (*dummy* level of education 2)	-0.3764	-0.74
Mean (*dummy* working condition 1)	-0.3159	-0.89
Mean (*dummy* working condition 2)	0.3962	0.68
Mean (*dummy* working condition 3)	0.1820	0.44
Mean (*dummy* possession 1)	-0.0915	-0.16
Mean (*dummy* possession 2)	-0.5202	-0.36
Mean (*dummy* type of building 1)	-4.7762	-0.08
Mean (*dummy* type of building 2)	-7.1227	-0.13
Mean (*dummy* date of construction)	0.0570	0.22
Test of joint significance: Wald χ^2(74)=2.3x10^5 (p-value=0.0000)		
Test of joint significance of price parameters: Wald χ^2(9)=2833.46 (p-value=0.0000)		

Source: Own calculations.

Table D7. Tests of cross-price parameters constraints

	Test results
H_0: NG price parameter (E equation)=E price parameter (NG equation)	Wald χ^2(1)=0.27 (p-value=0.7092)
H_0: LF price parameter (E equation)=E price parameter (LF equation)	Wald χ^2(1)=5.51 (p-value=0.0189)
H_0: LF price parameter (NG equation)=NG price parameter (LF equation)	Wald χ^2(1)=1.14 (p-value=0.2867)
H_0: (duzrs*NG price) parameter (E equation)= (duzrs*E price) parameter (NG equation)	Wald χ^2(1)=0.01 (p-value=0.9160)
H_0: (duzrs*LF price) parameter (E equation)= (duzrs*E price) parameter (LF equation)	Wald χ^2(1)=0.49 (p-value=0.4861)
H_0: (duzrs*LF price) parameter (NG equation)= (duzrs*NG price) parameter (LF equation)	Wald χ^2(1)=0.42 (p-value=0.5172)

Source: Own calculations.