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Xavier Labandeira, José M. Labeaga** and Miguel Rodríguez**

Sharp price fluctuations and increasing environmental and distributional concerns, among other issues, have led to a renewed academic interest in energy demand. In this paper we estimate, for the first time in Spain, an energy demand system with household microdata. In doing so, we tackle several econometric and data problems that are generally recognized to bias parameter estimates. This is obviously relevant, as obtaining correct price and income responses is essential if they may be used for assessing the economic consequences of hypothetical or real changes. With this objective, we combine data sources for a long time period and choose a demand system with flexible income and price responses. We also estimate the model in different sub-samples to capture varying responses to energy price changes by households living in rural, intermediate and urban areas. This constitutes a first attempt in the literature and it proved to be a very successful choice.

1. INTRODUCTION

The self-evident importance of energy in contemporary developed societies and economies constitutes a first reason for deep academic analysis in the field. There are also other issues and facts, most of them quite recent, which reinforce research needs and interests. Indeed, growing price fluctuations of primary energy goods, increasing shares in public receipts from energy taxes, correction of increasing environmentally-related damages, and the widespread

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application of de-regulatory packages have all led to significant economic effects through energy price changes.

Due either to oscillations in primary sources or to the application of public policies, energy price modifications have sizeable consequences on welfare. Questions of efficiency and distribution must both be addressed to provide a complete evaluation of price shocks, which could be used to define compensatory measures or for policy design and reform. Obviously, such a comprehensive assessment requires a full and detailed understanding of energy demand. This is the context for this paper, which, for the first time, estimates a household energy demand system for Spain.

Households are important contributors to total Spanish energy demand, representing approximately 30% of final consumption as in other developed countries. Yet household consumption shares lie between 20% and 35% in the most important energy goods, raising variations even with EU neighbors because of variable energy endowments, climate and institutional settings. A significant difference with most developed countries relates to the importance of household consumption of liquefied petroleum gases (LPG), which of course has relevant effects on demand modelling and results.

Spanish energy institutional and policy contexts also show some differential characteristics. In a context of extreme dependence on foreign energy stocks, strong price hikes have been felt and could be accentuated from the effects of new regulations and developments in some Spanish energy sectors. Actually, the lax application of tax, savings and environmental policies to the energy domain has resulted in a fast growth of total and household energy demand since the 1980s, with energy efficiency and environmental indicators (especially greenhouse gas emissions) performing very poorly in Spain. This policy setting will have to change in the short term, e.g., due to the commitments derived from the Kyoto Protocol, leading to further energy price effects and to an extra vindication of this study.

There is extensive empirical literature on household energy demand estimation (see Madlener, 1996). Most papers use econometric single equation models for household demand of electricity, gas and car fuels through diverse methodologies. A first general approach consists of estimating the demand for one or several energy goods based on an aggregate household model conditional on prices, income (or GDP) and climatic conditions (e.g. Narayan and Smyth, 2005; Hondroyiannis, 2004; Holtedahl and Joutz, 2004; Kamerschen and Porter, 2004; Considine, 2000 and García, 2000). A second group of papers uses microeconomic data to estimate the demand for energy goods at the household level (e.g., Larsen and Nesbakken, 2004; Filippini and Pachauri, 2004; Oladosu, 2003; Leth-Petersen, 2002; Halvorsen and Larsen, 2001; Yatchew and No, 2001; Kayser, 2000; Vaage, 2000; Schmalensee and Stoker, 1999; Puller and Greening, 1999 and Baker et al., 1989) allowing for some additional explanatory variables as the stock of durable goods (heating systems, stock of electric appliances, etc.), housing (size, age of house, insulation, etc.) and household characteristics (number of members, age, income, etc.). More sophisticated models, such as Nesbakken (2001), simultaneously estimate a discrete model for stocks of appliances and a continuous model of energy consumption (e.g. for space heating in Norway).[1]

A major inconvenience of single-equation models is their imposition of implausible separability restrictions, and thus their inability to estimate cross-price effects between different energy goods. One exception is Baker et al. (1989), who use a quadratic model to estimate gas and electricity expenditure in the UK, including several energy prices as regressors in each single equation.[2] However, relatively little attention has been devoted to the estimation of household energy demand through multiple-equation modelling. Baker et al. (1990) estimate a demand model for eleven goods in the UK that incorporates household energy, car fuels and public transport. A similar approach is found in one of the few applications to Spain, Labandeira and Labeaga (1999), where a quadratic household demand model with eight non-durable goods includes electricity, gas, car fuels and public transport. Also using a quadratic model, Nicol (2003) estimates the demand for car fuels, public transport, and four other goods for Canada and the USA. More recently, Tiezzi (2005) estimates an Italian household demand model for domestic fuels, transport fuels, public transport, and four other goods.

In this paper, we estimate a demand model especially designed for a simultaneous analysis of energy goods, dealing with the main issues arising in the estimation of complete equation systems. Our ultimate objective is to provide reliable income and price responses, useful for the economic assessment of real or hypothetical changes. Therefore we first combine data sources for a long time period to have enough price variation, using microdata from standard and rather detailed cross-section Spanish household expenditure surveys between 1973 and 1995. We also choose a demand system, the quadratic extension to the Almost Ideal Model of Deaton and Muellbauer (1980), with a solid theoretical foundation and capable of yielding a realistic picture of the substitution, own price and income effects.

Through the most disaggregated energy demand model estimated so far in scientific literature, the article explores consumer choices in electricity, natural gas, LPG, and car fuels for private transport. The demand system also incorporates public transport, food and other non-durable goods, given their relevance in household consumption. Explanatory variables include those found as significant by the literature, such as place of residence, household size, age, education or labor force participation. This way, we can control for observed heterogeneity in the energy profiles of different households.

1. This approximation was pioneered by Dubin and McFadden (1984), who estimated both the choice of heating technology (discrete choice) and energy consumption (continuous choice).

2. García-Cerruti (2000) used aggregated data for 44 counties in California with a dynamic random variable model.

A noteworthy contribution of the paper is the estimation of the model with different sub-samples for capturing varying responses to energy price changes by households living in rural, intermediate and urban areas. This is quite relevant for our purposes because, depending on location, many households do not have the possibility of accessing some energy goods, also seeing a considerable variation in housing characteristics or in transport needs and means. We found this approach very successful in empirical terms, representing a first development in this direction within such a disaggregated energy demand system.

We report several interesting results in our exercise. Firstly, a significant relationship was found between spending on different energy goods and place of residence, household composition and head status. In addition, all but one of the demand equations require quadratic expenditure terms, probably due to the presence of substantial heterogeneity. Moreover, we find it easier to fail to reject the theoretical assumptions in homogeneous rather than in heterogeneous models. These two facts point towards misspecification of linear demand models (the need for a complete profile of observed heterogeneity) or misspecification of unobserved heterogeneity, potentially correlated with observables.

Concerning price elasticities, we show that energy products are rather inelastic in Spain. Electricity is the most elastic good, in contrast to the price independence of natural gas. If we move to income elasticities, food, electricity and LPG are normal goods, and natural gas, car fuels and public transport are luxuries, whereas LPG are clearly income inelastic. Income and price elasticities vary with different types of households grouped by their place of residence, which has important implications for efficiency and distribution because some households have limited possibilities to substitute energy goods. Of course, all these results have important implications for the reform or design of future Spanish energy and environmental policies.

The paper is structured in five sections, including this introduction. Section 2 presents the general theoretical framework for our demand analysis. The following section deals with data, empirical specification and methods used in our estimation. The results (parameters and elasticities) are shown in Section 4, based both on estimations with the whole sample and with sub-samples by household location. Finally, we conclude the paper with a summary of the main findings and some derived policy implications.

2. TWO IMPORTANT CHOICES IN ESTIMATING DEMAND MODELS

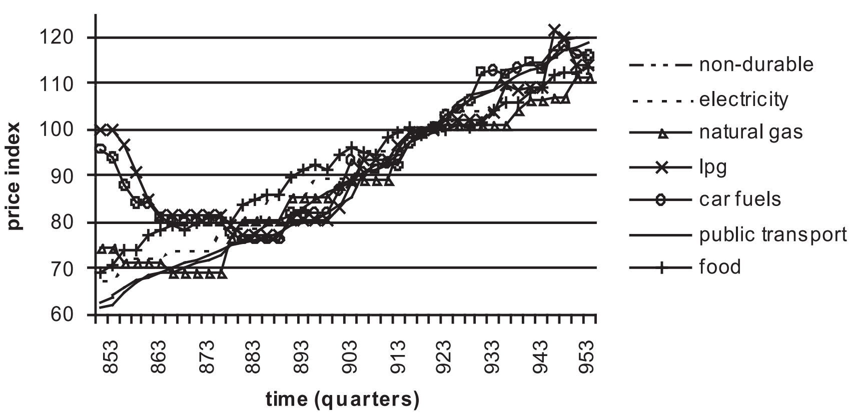
There are several relevant matters when adjusting demands. A fundamental reason for concern is the use of the estimated parameters with purposes of prediction, welfare evaluation or revenue simulation of policy packages. That is why empirical models intend to provide adequate price and total expenditure responses, which request two primary and important decisions on: i) the use of a suitable data set and ii) the choice of a sufficiently flexible demand system.

2.1. The data

Concerning the choice of the data, one ideally would like to have panel data for long time periods, but this is not common. Instead, it is more usual to have aggregated data, repeated cross-sections or short-time panel databases. In the case of demand system estimation from aggregated data, the problems are well known (see, e.g., Deaton and Muellbauer, 1980 or Blundell et al., 1993). In all but aggregated data surveys, income, price and demographic characteristics are reported but with the usual problem of having short-time series for prices. This generates the potential for under-identification of price effects, which is normally worsened by price aggregation due to the inexistence of regional or other type of potential variations.[3] Even when panel data is available for rather long periods, multicollinearity among price series does not allow for precise estimates of own or cross price effects for most goods (Labeaga and López, 1997). As an illustration, Figure 1 reports the evolution of different energy prices in Spain between the third quarter of 1985 (853) and the forth quarter of 1995 (954).

To alleviate multicollinearity problems, several alternatives have been proposed: Labeaga and López (1994) combine different surveys, Nichèle and Robin (1995) simultaneously use aggregated and micro data, and Blundell and Robin (2000) and Labeaga and Puig (2006) estimate a latent separable demand system instead of a weakly separable one. In this paper we opt for combining

Figure 1. Price indexes for different goods between 1985 and 1995



Source: Own calculations from Spanish Institute for Statistics.
Notes: i) Average price in 1992 represents the base year (100) for the calculation of price indexes for each good. ii) 853 refers to the third quarter of 1985 and so on.

3. Prices can also be measured with errors as in Nicol (2001), although the discussion about the implications of this problem lies beyond the scope of this paper.

microdata for a sufficiently long time period.[4] Proceeding this way we are able to obtain long-run and significant responses to price changes, which is especially important when the final objective is simulating policy impacts.

2.2. The demand system

Recently, there has been renewed academic interest in estimating demand models for several reasons. Firstly, normal demand models (up to rank two) have resulted in rejecting the theoretical assumptions or have provided elasticity figures not rich enough to represent all the heterogeneity in consumer behavior. Thus, many applications use demand systems with at least rank three (Banks et al., 1997; Lissyotou et al., 1999 or Nicol, 2001) or even rank four (Lewbel, 2003). Secondly, there are several relevant theoretical and empirical aspects of demand models which should be taken into account in the empirical applications: *i)* the importance of observed (Blundell et al., 1993) and unobserved heterogeneity (Labeaga et al., 2001), and *ii)* the treatment of endogeneity (or separability) of some variables like labor supply (Browning and Meghir, 1991) or total expenditure (Keen, 1986; Hausman et al., 1995).

Our choice is the quadratic extension of Deaton and Muellbauer's (1980) Almost Ideal Demand Model, as proposed by Banks et al. (1997). This demand system allows for flexible income and price responses and it does not have constant elasticities, as they depend on the level of expenditure. In this sense, Nicol (2001, 2003) reveals the interest of rank-three models in demand systems using data from the US CEX or the Canadian FAMEX consumer expenditure surveys. Pashardes (1995) also shows the relevance of these models for the identification of equivalence scales. The option we chose enriches the demand model and leaves less space for misspecification.

As usual in microeconomic demand system estimation, we assume that consumers follow a two-stage budgeting process. They first decide their leisure, savings and investment (durable goods), distributing total expenditure in a number of non-durable commodities in the second stage. In this sense, we proceed with the usual separability assumptions.

To define the model, we start by a within-period indirect utility function that reflects the need for quadratic Engel curves

$$v_{ht}(x_{ht}, \vec{p}_t) = [b_{ht}/\ln(x_{ht}/a_{ht})+d_t]^{-1} \quad (1)$$

where $a_{ht} = a(\vec{p}_t)$ is a linear homogeneous price index, and $b_{ht} = b(\vec{p}_t)$ and $d_{ht} = d(\vec{p}_t)$ are zero homogeneous in prices. We derive the demand equations for goods $i, j = 1, 2, \ldots I$, by taking the Almost Ideal parameterization of Deaton and Muellbauer (1980) for a_{ht} and b_{ht}

4. We first attempted to use quarterly household data for the period 1985-1995 (see section 3.3). Unfortunately, there were few changes on most energy prices, which also varied collinearly during that time span. Therefore, we were unable to correctly identify price effects.

$$\ln a_{ht} = \alpha_0 + \sum_{j=1}^{I} \alpha_j \ln p_{jt} + \frac{1}{2} \sum_{j=1}^{I} \sum_{i=1}^{I} \gamma_{ij} \ln p_{it} \ln p_{jt} \tag{2}$$

$$\ln b_{ht} = \sum_{j=1}^{I} \beta_j \ln p_{jt} \tag{3}$$

and we define d_t as in Banks et al. (1997)

$$d_t = \sum_{j=1}^{I} d_j \ln p_{jt} \tag{4}$$

Applying Roy's identity we have the budget shares

$$w_{iht} = \alpha_i + \sum_{j=1}^{I} \gamma_{ij} \ln p_{jt} + \beta_i \ln (x_{ht}/a_{ht}) + \frac{\lambda_i}{b_{ht}} [\ln (x_{ht}/a_{ht})]^2 + u_{iht} \tag{5}$$

where w_{iht} is the participation of good i in total expenditure by household h at moment t. The price vector faced by households at each moment in time is $\vec{p}_t = (p_{1t},....,p_{It})$, whereas x_{ht} is total expenditure. Since we have several observed demographics, z_{ht}, the model is flexible enough to allow functions of the parameters in (5) to affect demand. They shift both the intercept and the slopes of the share equations, so we can express

$$\alpha_i = \alpha_i(z_{ht}),\ \beta_i = \beta_i(z_{ht}),\ \text{and}\ \lambda_i = \lambda_i(z_{ht}) \tag{6}$$

Differentiation of equation (5) with respect to total expenditure provides the following income elasticity for each good i and household h,

$$e_i^h = 1 + \frac{\mu_i^h}{w_i^h} \tag{7}$$

where

$$\mu_i^h = \beta_i + \left(2\lambda_i \ln \frac{x_h}{a(\vec{p})}\right) \frac{1}{b(\vec{p})} \tag{8}$$

Goods that exhibit income elasticity higher (lower) than one are luxuries (necessities). However, (8) implies that each good can be either a necessity or a luxury for different households, depending upon the distribution of total expenditure. The uncompensated elasticity of good i with respect to the price of good j for household h is again obtained by differentiating equation (5) with respect to the price of good j,

$$e_{ij}^{uh} = \frac{\mu_{ij}^h}{w_i^h} - \delta_{ij} \tag{9}$$

where

$$\mu_{ij}^{h} = \gamma_{ij} - \mu_{i}^{h} \left(\alpha_{j} + \sum_{k=1}^{N} \gamma_{jk} \ln p_{k}\right) - \beta_{j} \lambda_{i} \left[\ln\left(\frac{x_{h}}{a(\vec{p})}\right)^{2}\right] \frac{1}{b(\vec{p})} \tag{10}$$

δ_{ij} is the Kronecker delta equal to 1 if $i=j$ and zero otherwise. We can use the Slutsky conditions to derive the compensated price elasticities,

$$e_{ij}^{ch} = e_{ij}^{uh} + e_{i}^{h} w_{j}^{h} \tag{11}$$

3. DATA, EMPIRICAL SPECIFICATION AND METHODS

3.1. A first look at the data

We take data from three surveys managed by the Spanish Institute for Statistics (INE): two standard cross-sections of the Spanish Household Expenditure Survey (EPF) for 1973-74 and 1980-81, and cross-sectional time-series data from the Continuous Household Expenditure Survey (ECPF) for 1985-95. EPF is a very comprehensive microdata survey on household expenditure, income and characteristics, including information from approximately 24,000 households with 170 different goods in 1973-74 and 632 goods in 1980-81. Expenditure on these goods by each household is reported for a natural year, in some cases estimated by INE as information is collected on a weekly basis.[5] On the other hand, the ECPF 1985-95 is a rotating panel based on a comprehensive survey with 252 different goods and quarterly data for 3,200 households.

To estimate the model we only use energy expenditure referring to the first home, thus avoiding distortions due to contract overheads in second homes. Furthermore we exclude all households that report null expenditure on food and electricity, and those with income, total expenditure and expenditure on each good below 2% and over 98% of the distribution to rule out outliers.[6] Table A1, in the Appendix, presents some descriptive statistics on variables in the database prior to and following selection.

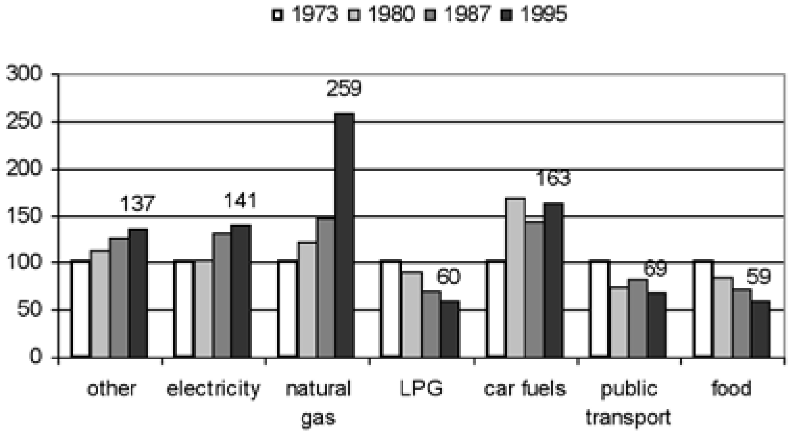
The demand model contains the following aggregation of goods: electricity, natural gas, LPG (butane and propane gases), car fuels, public transport, food and non-alcoholic drinks, and other non-durable goods.[7] Figure 2 summarizes the significant changes in the share of each good on total expenditure between 1973 and 1995. In this period there were important modifications in the

5. See, e.g., Baker et al. (1989) for some comments on data collection processes in this type of surveys and their implications.

6. Regarding the high number of households that report null expenditure on natural gas, LPG and car fuels, the 98% rule was applied to those households that reported positive expenditure, which is a more sensible approach for controlling outliers in the consumption of such goods.

7. Price of aggregate goods is the weighted sum of the original price indexes as published by the INE. We have used expenditure figures from the year 1992, the base year for the ECPF, to estimate the weight of each individual good in the corresponding aggregate good in the model.

Figure 2. Changes in share expenditure between 1973 and 1995



Source: Own calculations.
Note: The *y* axis corresponds to mean values of share expenditures for the whole sample of households. We report index numbers taking 1973 as the base year (1973=100).

structure of Spanish household consumption of the preceding goods, with a large number of households switching to LPG for electricity and natural gas.

During those years there was also a significant substitution of public for private transport as a result of the increasing number of vehicles in Spain.[8] Figure 2 depicts a sizeable decline in the expenditure on food and non-alcoholic drinks and a simultaneous increase in other non-durable goods, as expected from the large rise in the wealth of Spanish households.

The most common combination of energy goods in 1995 is electricity and LPG, consumed by 70.5% of Spanish households, followed by simultaneous consumption of electricity and natural gas (13.4% of households). The consumption of solid, liquid heating fuels and collective central heating do not, as expected, show significant values. The place of residence is clearly an important variable for explaining energy consumption by the household, mainly due to availability of connections and housing type.[9]

As further developed in section 3.3, the empirical application of the demand model must solve the existence of measurement errors for some goods, which also affects total expenditure. To analyze this problem we use the ECPF 1985-1995 in its panel form, which allows us to follow the same household over a maximum of eight consecutive quarters. Table 1 reports the percentage of

8. Between 1975 and 1995 the number of inhabitants per vehicle decreased by 75%, from 11 to 2.76 (Universidad Politécnica de Madrid, 2000). It is interesting to note that, unlike in other consumption categories, there are remarkable discontinuities in the observed expenditure trends on car fuels and public transport that are related to the effects of oil crises.

9. For a further description of theses issues see Labandeira et al. (2004).

null expenditures for those households that have at least one positive record and collaborated for more than three quarters. For example, fuels for heating purposes such as oil, coal or wood are typically bought twice a year, and the number of null expenditure records is around 55% for both solid and liquid fuels in households that report positive expenses. Therefore, this phenomenon may be related to both absence of consumption and infrequency of purchase, although we cannot identify the specific reason. We assume that we have wrongly measured household consumption during the different quarters of the sample, because considering the two reasons simultaneously makes the estimation process complex (see Wales and Woodland, 1983 or Lee and Pitt, 1986).

There are also some problems with observed expenditure on collective central heating. It was usual in the past for households sharing collective central heating means to spread the total cost on a per capita basis, so expenditure on this good is not directly related to individual household consumption but rather to the average for some households. That is why we decided not to estimate the demand for these goods separately, aggregating them to other non-durable goods.[10]

Table 1. Infrequency (%) of energy expenditure from households that report some positive spell in ECPF 1985-95

	Number of quarters				
Goods	**4**	**5**	**6**	**7**	**8**
Electricity	1.50	1.72	1.54	1.26	1.44
Natural gas	7.96	9.50	10.63	9.86	9.30
LPG	9.91	10.12	11.11	10.47	10.10
Liquid Fuels	53.46	53.41	54.50	57.82	59.30
Solid Fuels	50.00	57.35	62.10	52.71	59.12
Collective Central Heating	10.77	15.09	13.75	11.99	11.66
Car fuels	14.72	15.26	17.08	18.89	17.29

Source: Own calculations.
Note: We define infrequency as the ratio between the number of quarters with null expenditure and the number of quarters with household collaboration.

3.2. Empirical specification

We are interested in estimating equation (5), allowing for heterogeneity in intercepts and slopes in the form defined by equation (6). Therefore, shares of expenditure on each of the seven non-durable goods are dependent on prices,[11]

10. Problems of infrequency in expenditure reported by households for the aggregated goods considered are, however, of little importance because we use annual data for estimation.

11. Note that all households faced the same vector of energy prices in the period of analysis, as residential energy prices were regulated by the Spanish government in this fashion. See the Appendix for more details on price and tax rate data.

expenditure and a range of other explanatory variables. However, both the definition of the variables used and the inclusion of some determinants of demand are restricted by the combination of different surveys.

Prior to any econometric analysis, some data manipulation was needed to obtain the same information from the three different but compatible surveys (mainly differences in the aggregation of goods).[12] We proceeded by aggregating expenditures in homogeneous goods following survey definitions, and used the same methodology for demographics by defining new variables containing the same household characteristics in the three surveys. Moreover, we calculated annual expenditures for each household in the ECPF as the sum of quarterly expenditures by selecting only those households that collaborated the whole year.

The empirical model considers several dummy variables that modify the intercept and try to capture heterogeneity in the range of energy sources consumed by Spanish households. We thus include dummies for the educational level of household heads (no education, secondary level, higher education), geographical location of the home (rural, village), ownership of the main dwelling, whether the head of the household is retired from work, and the number of household members by age (15 or under, older than 15). Moreover, we use a trend variable to control possible tendencies in any of the expenditure groups or technical progress in domestic appliances or vehicles that consume different energy goods.[13] Most of those variables are also included as interactions of total expenditure.[14]

The preceding variables were usually found to be significant by the empirical literature (Baker et al., 1989; Blundell et al., 1993, Labandeira and Labeaga, 1999 or Nicol, 2003). Indeed, household size is an important explanatory variable as consumption of food and non-durable goods should be a function of the number of household members. The same may apply for car fuel and energy for home consumption as: i) the number of household members could give some insight into the size of the house and thus energy consumption, and ii) the number of household members by age is also important for the consumption of transport services.

Consumption of energy goods could also be related to the age of the head of the household in two ways: preferences may be different because of cultural reasons, and age could provide some insight into the characteristics of the house and the stock of appliances (age of the house, heating system, etc). For instance,

12. Indeed, the quarterly ECPF ended up replacing the annual EPF in Spanish national statistics.

13. This is a reasonable approach as our sole interest is on the overall impact of technological change (Popp, 2001). Moreover, this variable could be used as a proxy of irreversible efficiency improvements (Haas and Schipper, 1998).

14. To avoid perfect collinearity we dropped a variable from each set of dummies, primary schooling in the case of education. Rural corresponds to those households living in municipalities with fewer than 10,001 inhabitants. Village corresponds to those households living in municipalities with more than 10,000 inhabitants but fewer than 50,001. We dropped the dummy corresponding to households living in municipalities with more than 50,000 inhabitants (cities). Characteristics of the baseline household are reported in the Appendix (Table A1).

Baker et al. (1989) and Leth-Petersen (2002) found that house characteristics are important variables in explaining energy expenditures.

Moreover, it should be taken into account that energy expenditure is the result of the joint demand of a stock of appliances and their level of usage. The preceding data analysis hinted at how to face the empirical exercise without information about the stock of household appliances, which is not provided by the surveys. In its absence, some of the variables included in the empirical model attempted to proxy these effects. For example, higher income households, probably with a better educational level, are likely to have more expensive and efficient appliances and better insulated houses. Furthermore, the type of durable goods in the house could be subject to heavy restrictions by, for example, the type of tenancy on the property (rental, owned), as Baker et al. (1989) find for electricity and gas.

3.3. Econometric methods

The econometric methods we use to estimate the system in equation (5) are guided by an adequate treatment of measurement errors in total expenditure as well as by the imposition of the theoretical restrictions. The presence of dependent variables with measurement errors makes it necessary to use estimation methods alternative to Ordinary Least Squares (OLS). OLS provides inconsistent estimates due to the existence of contemporaneous correlation between the error term and total expenditure. This can be solved by instrumenting total expenditure with total income, which under separability conditions must be uncorrelated with the error term (Keen, 1986).

We use an instrumental variable (IV) method, employing as identifying assumption the exogeneity of prices and demographic characteristics. As the demand model is non-linear in parameters, we employ a non-linear IV method through an iterative procedure with starting values taken from a first stage estimation of a linear version of the model. In this sense, we estimate a linear model in a first stage by substituting $a(\vec{p})$ for a Stone index, $\ln p_{ht} = \sum_{j=1}^{I} w_{jht} \ln p_{jt}$ and assuming that $b(\vec{p})$ is equal to unity. Once this has been done, we use these initial estimates to obtain the non-linear estimates through an iterative method until convergence is achieved (for additional details see Blundell and Robin, 1999).

A second issue refers to identification of α_0 in equation (2). We use the value just below the minimum of log of real total expenditure as a guess estimate for α_0, following the suggestions by Deaton and Muellbauer (1980) and Banks et al. (1997). There are alternatives, however, such as providing a grid of values and choosing the estimate that maximizes some criteria. We can also estimate α_0 jointly with the rest of the parameters in the system (2)-(5), as in a simultaneous triangular equation system. In any case, we have tried with several values of α_0 and the results are robust to the chosen alternatives.

Concerning theoretical restrictions, it should be noted that each equation is a linear combination of the others. Therefore, to avoid singularity of the variance-covariance matrix of errors, one of the equations needs to be left out of the estimation. In our case, the demand equation of other non-durable goods is not estimated and its parameters are recovered through the additivity restriction.[15] Moreover, for the estimated demand system to be coherent with consumer theory, we impose symmetry and zero degree homogeneity conditions. The homogeneity restriction is imposed on the model by using prices relative to the good excluded in the estimation. It will be possible to test the homogeneity condition for each of the estimated equations, as well as for the system as a whole.[16] The symmetry condition ($\gamma_{ij} = \gamma_{ji}$) is imposed during estimation, and is tested jointly with homogeneity using a Chi-squared test. Negativity cannot be imposed, but it can be tested by looking at the sign of the Slustky matrix.

During estimation we also impose the condition that price indexes in equations (2)-(4) are common across goods. It must be noted that this modeling approach may result in price coefficients and elasticities that are biased upwards (Micklewright, 1989). Moreover, the structural parameters of the model will not be identified when, for instance, a rise in fuel prices leads to energy savings, substitution and investments in house insulation. However, reduced-form parameters will be appropriate as long as we are interested only in forecasting the effects of changes in market prices and not in the precise mechanism that takes place in each household.

4. RESULTS AND DISCUSSION

4.1. Estimates based on the whole sample

In Table 2 we present the most significant results obtained in the estimation of the demand system, leaving the comparison based on elasticity figures for the next section. As expected, home ownership is a relevant factor explaining energy expenditure in Spanish households. Being the home owner significantly reduces expenditure shares of natural gas, car fuels and public transport and increases those of LPG, electricity and food, also resembling the consumption patterns of households living in rural areas (where home ownership is common). We obtained the opposite results when including an interaction term between total expenditure and the dummy for ownership, showing that the weight of necessity expenditures is lower in high-income households, precisely those which can access home ownership under better conditions in financial markets.

On the contrary, once we account for both direct and indirect effects through an interaction term between income and the educational dummies, the educational level of the household head does not condition the choice of energy sources.[17] Moreover, a significant relationship between spending on different

15. This condition imposes that $\sum_{i=1}^{I} \alpha_i = 1$, $\sum_{i=1}^{I} \beta_i = 0$, $\sum_{i=1}^{I} \gamma_{ij} = 0$, and $\sum_{i=1}^{I} \lambda_i = 0$.

16. The homogeneity condition is satisfied if, and only if, $\sum_{i=1}^{I} \gamma_{ij} = 0$.

17. Although the demands for electricity and LPG are negatively related to the educational level of the household head, a positive relationship at all income levels dominates when including the interaction term. More importantly, the direct effect of education and its indirect effect through income cancel out for electricity and LPG.

Table 2. Parameter estimates from the pooled sample

Goods / Exp. Variables	Electricity	Natural Gas	LPG	Car fuels	Public transport	Food
Constant	-0.0068 (-2.842)	0.0064 (4.794)	0.0012 (0.466)	0.0022 (0.203)	0.0118 (2.177)	0.4237 (16.596)
No younger than 15 years	0.0061 (7.648)	-0.0008 (-2.303)	0.0095 (13.494)	-0.0146 (-4.156)	-0.0020 (-1.143)	0.1495 (16.213)
No older than 15 years	0.0139 (11.474)	-0.0005 (-0.911)	0.0163 (14.579)	-0.0399 (-7.363)	-0.0076 (-2.861)	0.3676 (27.046)
Home owner	0.0138 (6.905)	-0.0034 (-3.699)	0.0195 (10.887)	-0.0308 (-3.478)	-0.0092 (-2.110)	0.1803 (7.831)
Primary school	0.0117 (7.209)	-0.0004 (-0.556)	0.0136 (9.709)	-0.0169 (-2.370)	-0.0125 (-3.549)	0.0567 (2.958)
High school	0.0336 (9.872)	-0.0008 (-0.573)	0.0078 (2.649)	0.0576 (3.844)	0.0016 (0.222)	-0.0238 (-0.592)
Rural (<10,001 Inhabitants)	-0.0220 (-12.887)	0.0016 (2.140)	0.0058 (3.901)	-0.0549 (-7.287)	0.0095 (2.562)	0.2716 (13.518)
Village (10,000<lnh<50,001)	-0.0043 (-2.243)	0.0002 (0.318)	0.0086 (5.232)	-0.0240 (-2.870)	-0.0019 (-0.458)	0.2118 (9.418)
Principal retired work	0.0239 (11.345)	0.0003 (0.347)	0.0284 (14.949)	-0.0132 (-1.419)	-0.0239 (-5.166)	0.3006 (12.442)
Trend	0.0005 (8.295)	-0.0001 (-2.619)	-0.0001 (-1.625)	-0.0004 (-1.635)	0.0001 (0.464)	-0.0073 (-10.359)
Younger than 15 * expenditure	-0.0006 (-7.516)	0.0001 (1.967)	-0.0009 (-13.102)	0.0015 (4.171)	0.0001 (0.419)	-0.0135 (-14.270)
Older than 14 * expenditure	-0.001 (-11.565)	0.00003 (0.639)	-0.0016 (-14.134)	0.0039 (7.018)	0.0010 (3.630)	-0.0349 (-25.202)
Home owner * expenditure	-0.0015 (-7.277)	0.0003 (3.474)	-0.0021 (-11.305)	0.0030 (3.234)	0.0007 (1.595)	-0.0202 (-8.499)
Primary sch. * expenditure	-0.0013 (-8.223)	0.00001 (0.124)	-0.0013 (-9.213)	0.0015 (2.049)	0.0013 (3.598)	-0.0045 (-2.248)
High school * expenditure	-0.0033 (-9.756)	0.0001 (0.724)	-0.0008 (-2.932)	-0.0054 (-3.611)	-0.0002 (-0.272)	0.0004 (0.089)
Rural * expenditure	0.0020 (11.675)	-0.0003 (-3.662)	-0.0005 (-3.641)	0.0061 (7.909)	-0.0016 (-4.197)	-0.0252 (-12.143)
Village * expenditure	0.0003 (1.835)	-0.0001 (-1.511)	-0.0008 (-4.640)	0.0028 (3.221)	-0.0004 (-0.911)	-0.0203 (-8.820)
Retired * expenditure	-0.0024 (-11.183)	-0.00002 (-0.196)	-0.0029 (-14.66)	0.0001 (0.065)	0.0025 (5.180)	-0.0287 (-11.522)
Total expenditure	0.0067 (10.710)	-0.0012 (-4.231)	0.0008 (1.342)	0.0061 (2.200)	0.0049 (3.512)	-0.0448 (-6.264)
Square total expenditure	-0.0005 (-7.654)	0.0001 (4.388)	0.0001 (0.953)	0.00004 (0.138)	-0.0008 (-5.019)	0.0052 (6.170)
P Electricity	0,0066 (12,875)	0,0010 (4,044)	0,0071 (13,375)	-0,0062 (-4,793)	-0,0002 (-0,228)	-0.0052 (-6.069)
P Natural gas	0,0010 (4,044)	0,0037 (6,372)	-0,0048 (-6,855)	0,0043 (5,082)	0,0017 (2,153)	-0.0051 (-7.586)
P LPG	0,0070 (13,375)	-0,0048 (-6,855)	0,0080 (4,717)	0,0010 (0,608)	-0,0046 (-2,774)	-0.0114 (-9.799)
P Car fuels	-0,0062 (-4,793)	0,0043 (5,082)	0,0010 (0,608)	0,0405 (5,956)	-0,0013 (-0,404)	-0.0169 (-5.560)
P Public transport	-0,0002 (-0,228)	0,0017 (2,153)	-0,0046 (-2,774)	-0,0013 (-0,404)	0,0134 (3,831)	0.0017 (0.869)
P Food	-0,0052 (-6,069)	-0,0051 (-7,586)	-0,0114 (-9,799)	-0,0169 (-5,260)	0,0017 (0,869)	-0.0611 (-6.467)

Source: own calculations. Note: t-ratios in brackets.

energy goods and place of residence is found, with rural households spending more on electricity and less on food, and households living in smaller municipalities spending more in car fuels and less in public transport.[18]

Household composition is another important determinant of energy spending. Each household member increases the expenditure on private and public transport, with more intensive effects accounted for by older members as they can ride a motorcycle or drive a car. Household composition also affects the expenditure on energy for the house, as each additional member reduces the share of electricity and LPG, probably due to the indirect positive relationship between income levels and the number of household members. Besides, the expenditure on food is negatively affected by the number of members in the house, which, in accordance with Engel's law, is also indirectly linked to the income level.[19]

There is a positive relationship between retired household head and expenditure on energy goods for the house, which could be explained by senior citizens' longer stays at home. Some specific effects regarding food and transport expenditure shares also exist for this household group, as they spend less on private transport and more on public transport services, probably due to less transport needs and to the existence of low fares for older people.[20]

We did not find significant effects of the above variables on the consumption of natural gas, possibly because this type of energy is mainly consumed in big cities and by households with higher-than-average income that conform to a rather homogeneous group. Finally, we observed the need to introduce the quadratic term in the electricity, natural gas, public transport and food equations. However, there is no significant income effect on LPG and the quadratic term is not significant in car fuel consumption. This is to be expected with LPG, as they are mainly consumed by poorer households, whereas the result for car fuels simply indicates that the use of cars and the subsequent fuel consumption is generalized among the Spanish population.

4.2. Comparisons of results from the whole sample and from sub-samples by location of household

As an alternative to parameter estimates, in this section we present the elasticity figures for three sub-samples and a comparison with those obtained

18. Taking account of direct and indirect effects, households living in rural municipalities present a higher share of electricity on total expenditure (34% more than average) and car fuels (95% larger than households living in cities). Furthermore, rural households reduce their expenditure on food by 17.5%, probably due to consumption of own production.

19. Members under the age of 15 increase the share of expenditure in car fuels by 20%, whereas those over 15 increase that share by 43%. An analogous behavior is observed with public transport, with increases by 47% and 220% in the shares for the same ages. We find that each member over the age of 15 reduces the share of electricity and LPG on total expenditure by 32% and 50% respectively.

20. Expenditure shares of electricity, LPG, public transport and private transport for these households are, respectively, 53.5%, 62.0%, 77.7% and -46.0% over/below the average.

when using the whole sample. A major contribution of the paper consists of estimating the model with sub-samples constructed by place of residence of the household. A similar exercise has been carried out for different regions within a country (Blundell et al., 1993; Nicol, 2003), but to our knowledge this is the first application that differentiates between types of municipalities. We do this for at least two reasons: i) significant differences in consumption of the seven considered goods related to the place of residence have been already shown, and ii) household access to several energy goods and public transport is very limited in some cases.[21] Of course, this has important implications for the substitution possibilities among energy goods for the house and between private and public transport.

Elasticities are obtained by using equations (7)-(9) and are evaluated at sample means for all households as well as for those households which consume the good. We can provide a distribution of elasticities too, although to keep tables manageable we focus on the groups with different elasticities at different income values. It should first be noted that the reported figures provide short-run values, as we adjust the decision about distribution of total expenditure within groups in a given period. Nevertheless, the sample covers a time period of 22 years, so the figures can, to some extent, also be interpreted as long-run elasticities.

Panel A in Table 3 reports total expenditure elasticities calculated using the parameter estimates for the whole sample. It can be seen in the first column that food, electricity, natural gas and LPG are defined as normal goods, whereas car fuels and public transport are luxuries. Once we control for positive expenditure on the group (column 2), the size of the values are reduced for luxuries and increased for normal goods, except in food and electricity where all observations have been selected to be positive. The distribution of the income elasticity for electricity shifts from a luxury good for poor households (1.01) to a value of 0.53 for rich households. LPG are the most income-inelastic energy sources and the distribution of their elasticity is continuously decreasing, being a Giffen good for 25% of the richest households, although these negative values are not significatively different from zero. As regards public transport, the values run from a maximum of 1.74 for households in the bottom decile of income to 1.50 for households in the top decile. In the case of food, figures vary from 0.70 for the poorest decile to 0.33 for the richest decile. Natural gas and car fuels maintain roughly the same values across the distribution of total expenditure.

Table 4 shows uncompensated own-price elasticities, also evaluated for the whole sample and for different sub-samples.[22] The figures at mean values for the whole sample (panel A, columns 1 and 2) reflect that electricity shows

21. Although regional differentiation of households approximates the varying climatic conditions across a country, it does not necessarily inform on variable access to energy goods and services. Furthermore, rural municipalities show a larger proportion of single family homes with comparatively more heating and cooling requirements with respect to multi family homes.

22. Compensated elasticities are easy to calculate through equation (11). Given total expenditure elasticities and shares, compensated elasticities are slightly lower than their corresponding uncompensated figures. We do not provide these results, but they are available from the authors on request.

Table 3. Total expenditure elasticities

Goods	1	2	3	4	5
Panel A. Results with parameter estimates for the whole sample					
Electricity	0.811	0.811	0.891	0.784	0.783
Natural gas	0.899	0.990	---	0.584	1.016
LPG	0.343	0.420	0.363	0.328	0.337
Car fuels	1.798	1.360	2.051	1.850	1.668
Public transport	1.302	1.170	1.357	1.433	1.254
Food	0.600	0.600	0.592	0.576	0.615
Panel B. Results with parameter estimates in sub-samples					
Electricity			0.739	0.649	0.585
Natural gas			1.436	2.244	1.751
LPG			0.517	0.479	0.219
Car fuels			1.973	1.717	1.752
Public transport			0.904	1.082	0.977
Food			0.721	0.684	0.630

Source: Own calculations.

Notes: i) Panel A: in column 1 we present elasticities at mean values for the whole sample, in column 2 those for the sub-sample of positive expenditures on each good. Columns 3, 4 and 5 respectively report total expenditure elasticities for rural households, households living in villages and urban households. ii) Panel B: Figures in columns 3, 4 and 5 correspond to elasticities at mean values evaluated with parameter estimates obtained in sub-samples by location of the household. They respectively report elasticities for rural households, households living in villages and urban households.

the largest uncompensated responses to prices, which should be related to the multiple services provided by this good (lighting, cooking, heating, etc.). On the contrary, demand for natural gas can be considered price independent, probably because it was only introduced in cities during the sample period. For these two groups of goods, the Slutsky matrix does not fulfill negativity conditions for 1% of households. Elasticity for LPG is larger than that for natural gas but much lower than that for electricity, which could be explained because the LPG share is extremely small for a large number of households. These results are similar to those found by Filippini (1995) and Halvorsen and Larsen (2001), thus contradicting the null effects estimated by Considine (2000) and García-Cerruti (2000). In fact, our own-price elasticity for electricity is within the average interval of estimates reported by the literature (see Narayan and Smyth, 2005), while our results for car fuels are close to Nicol's (2003) findings for the US.

There are some differences both in total expenditure as well as own-price elasticities when they are computed taking into account the location of the household (panel A, columns 3 to 5). The most remarkable changes are seen in natural gas, which is more income-elastic for urban households and shows zero elasticity for rural households which have no access to this energy source. On the other hand, car fuels are significantly more income-elastic for rural households. However, public transport presents very similar income elasticity values, which

Table 4. Own-price elasticities

Good2	1	2	3	4	5
Panel A. Results with parameter estimates for the whole sample					
Electricity	-0.797	-0.783	-0.797	-0.795	-0.797
Natural gas	-0.047	-0.046	---	---	-0.445
LPG	-0.367	-0.249	-0.320	-0.325	-0.416
Car fuels	-0.110	-0.058	0.049	-0.087	-0.187
Public transport	-0.106	-0.091	---	0.165	-0.274
Food	-0.422	-0.190	-0.324	-0.310	-0.525
Panel B. Results with parameter estimates in sub-samples					
Electricity			-0.447	-0.749	-0.962
Natural gas			-13.050	-9.997	-0.439
LPG			-0.154	-0.325	-0.630
Car fuels			-0.300	-0.272	0.010
Public transport			-1.490	-0.777	-0.558
Food			-0.716	-0.420	-0.286

Source: Own calculations.

Notes: i) Panel A: in column 1 we present uncompensated price elasticities at mean values for the whole sample, in column 2 those for the sub-sample of positive expenditures on each good. Columns 3, 4 and 5 respectively report own price elasticities for rural households, households living in villages and urban households. ii) Panel B: Figures in columns 3, 4 and 5 correspond to elasticities at mean values evaluated with parameter estimates obtained in sub-samples by location of the household. They respectively report elasticities for rural households, households living in villages and urban households.

has to be related to the low use of public transport by Spanish households (mainly at median and high-income values) irrespective of the place of residence.

Regarding own-price uncompensated elasticities, natural gas is more price-elastic for urban households, as the other households had no access to it during most of the sample period. Actually, Table 4 shows that price elasticities for natural gas and LPG are almost identical for those households which are connected to the grid and therefore can choose between both energies, which reinforces our conclusions about the importance of heterogeneity (panel A, column 5).

On the other hand, rural and urban households hardly react to changes in the price of car fuels because, in many cases, they cannot substitute private for public transport. Yet the elasticity of car fuels for urban households almost doubles that for the whole sample, while the elasticity of public transport is almost triple. Electricity roughly shows the same figure for all sub-samples, which means all households use this energy for the same purposes irrespectively of the place of residence. Finally, food is more price elastic for urban households.

Given the differences detected in the values of the elasticities for some energy goods for the house, car fuels and public transport among households located in different areas, we re-estimate the model in three sub-samples: rural households, households living in towns, and urban households. Although interactions of dummy variables and total expenditure included in the estimation of the whole sample give us more flexibility in income responses, the re-estimation looks for more price flexibility. In panel B of Tables 3 and 4, we report total expenditure and own-price elasticities for those sub-samples, showing how income and price elasticities vary when considering different sub-samples. This is quite relevant, as it vindicates the need to introduce observed heterogeneity in the demand models (see Blundell et al., 1993 or Nicol, 2003). Moreover, these differences also underlie the need to consider unobserved heterogeneity, which we could not take into account because of the need to combine different databases. This issue is, of course, in our future research agenda.

The most striking differences between panels A and B of Tables 3 and 4 are seen in natural gas and public transport. These results should be expected, as households living in rural areas find it very difficult to consume those goods. As a consequence, estimation with the whole sample (which results in mean value-adjusted regressions) masks the true parameters for population sub-samples that exhibit different behaviors. For instance, natural gas is expected to be a luxury good, which is corroborated by panel B but denied by panel A. Furthermore, some anomalies are found in the own-price elasticities of public transport and food in panel A, which are corrected in panel B because rural households are less dependent on this type of transport and they usually produce food for own consumption.

Although we do not report all cross-price elasticities due to lack of space, some information is provided on the main and most interesting results. Electricity and natural gas are found to be substitutes in urban areas with a small value for the cross-price elasticity (0.04). Moreover, LPG are substitutes for natural gas and electricity in all areas. Rural households cannot substitute car fuels for public transport, as shown by a cross-price elasticity significantly equal to zero. Finally, given the already mentioned importance of food in Spanish household demand, this group appears to be a substitute for the other consumption categories.

Concerning the theoretical restrictions, we provide an example of the importance of estimating demand models in homogeneous samples or properly controlling observed and unobserved heterogeneity. Although we reject symmetry and symmetry and homogeneity jointly, the value of the test varies from 316.40 in the whole sample to 80.48 in the subsample of households living in villages. These tests have to be compared with a χ^2 with 21 degrees of freedom.

5. CONCLUSIONS

In this paper we have estimated a seven-equation demand system that includes six energy-related products for Spain. There are two main reasons to examine this issue: the rather different characteristics of Spanish household energy demand with respect to other developed countries and the sizeable price effects that are to be expected in the short term from a high dependence on foreign energy sources and from new and more intensive public policies in the field. Both issues involve important efficiency and distributional concerns on which this piece of research can provide information.

Our contribution to the scientific literature is threefold as: i) this paper constitutes the most disaggregated empirical application in terms of energy goods so far; ii) an in-depth analysis of the role of household location in rural vs. urban areas is performed for the first time, and iii) the paper is the first household energy demand system estimated for Spain.

Before estimation, we made several important decisions to have reliable price and income responses for Spanish households. We first chose the data on which to estimate the model by combining several surveys for a long time period, thus allowing for more price variation and fewer multicollinearity problems. Secondly, we proposed a rank-three demand model based on state-of-the-art empirical methods and evidence. Thirdly, as the database combination did not allow us to use the panel structure of our data (ECPF) and to minimize the presence of heterogeneity on price and income elasticities, we selected several sub-samples based on a crucial variable for the demand of energy goods: household location in rural, intermediate and urban regions.

Our estimation strategy provided several findings. First, all but one of the demand equations required quadratic expenditure terms, demonstrating their importance as heterogeneity increases. In addition, we found that it is easier to fail to reject the theoretical assumptions in more homogeneous models (pooled sample), pointing out misspecification of linear demand models (the need for a complete profile of observed heterogeneity) or misspecification of unobserved heterogeneity potentially correlated with observables. The results also showed the relevance of including explanatory variables capable of taking heterogeneity into account. In particular, a significant relationship was found between spending on different energy goods and place of residence, household composition and head work status (active or retired). As rural, intermediate and urban households do not have the same opportunities to consume energy goods and transport services, when the population size of the municipality increased, we reported a progressive substitution of car fuels and LPG for public transport and natural gas, respectively.

Concerning own-price elasticities, we found that energy products are rather inelastic in Spain, with electricity the most elastic energy good and natural gas price-independent. Cross-price effects exist in some cases, indicating limited substitution between electricity and natural gas in urban areas and LPG and electricity in all locations. When referring to income elasticities, food, electricity and LPG are normal goods, natural gas, car fuels and public transport are luxuries, and LPG are the most income-inelastic energy sources. Poorer households are more responsive to changes in energy prices, which is obviously related to a larger share of energy on total expenditure. Again, in some goods, we observed significant differences related to place of residence; these differences have an important impact on efficiency and distribution.

Policy implications are rather straightforward and directly connected to many of the issues currently faced by Spanish regulators. In fact, the unavoidable policies to reduce an increasing dependence on foreign stocks and growing environmental problems associated with energy consumption could be partially informed by our results. This is the approach followed by Labandeira et al. (2004) to calculate the effects of a substantial energy tax-induced price rise through a microsimulation procedure based on our estimates. However, as our reported price elasticities indicate only a limited short-term effectiveness of pricing policies to restrict Spanish energy household consumption, other regulatory approaches should be contemplated, too. Only electricity consumption seems to be fairly price-sensitive, which is simultaneous to more than seven consecutive years of falling real prices in Spain due to the liberalization of the sector. Given that electricity generators are also dependent on energy imports and cause a myriad of serious environmental problems, that price evolution is probably undesirable. This is even clearer in Labandeira et al. (2006) who integrate a microeconomic model, also constructed with information from this estimation, and a macroeconomic model that incorporates the supply responses from higher energy inputs, concluding that control policies on this sector are cost-effective and thus recommendable.

On the contrary, car fuel demand was found to be particularly price inelastic. This presents a formidable challenge for public regulators due to the uncontrolled and unsustainable pattern of increasing consumption seen in the last decades. It is nevertheless true that price policies may be effective in the medium and long terms, as the preferential tax treatment of diesel has led to a remarkably declining Spanish share of petrol fuelled cars in less than fifteen years. This raises two relevant questions when using prices with corrective purposes: i) the need for specific compensation packages to rural households, as stated in our results, and ii) the need to explicitly include durable goods linked to non-durable energy modelling. As the new Spanish household survey (ECPF-98) provides detailed information on the latter, that interesting and rather unexplored issue demands intensive research.

REFERENCES

Baker, P., Blundell, R.W. and J. Micklewright (1989). "Modelling Household Energy Expenditures Using Micro-Data." *Economic Journal* 99: 720-738.

Baker, P., McKay, S. and E. Symons (1990). "The Simulations of Indirect Tax Reforms: The IFS Simulation Program for Indirect Taxation." Institute for Fiscal Studies, Working Paper # 90-11.

Banks, J., Blundell, R.W. and A. Lewbel (1997). "Quadratic Engel Curves and Consumer Demand." *Review of Economics and Statistics* 79: 527-539.

Blundell, R.W., Pashardes, P. and G. Weber (1993). "What Do We Learn about Consumer Demand Patterns from Micro-Data?." *American Economic Review* 70: 312-326.

Blundell, R.W. and J.M. Robin (1999). "Estimation in Large and Disaggregated Demand Systems: An Estimator for Conditionally Linear Systems." *Journal of Applied Econometrics* 14: 209-232.

Blundell, R.W. and J.M. Robin (2000). "Latent Separability: Grouping Goods without Weak Separability." *Econometrica* 68: 53-84.

Browning, M. and C. Meghir (1991). "The Effects of Male and Female Labor Supply on Commodity Demands." *Econometrica* 59: 925-951.

Considine, T. (2000). "The Impacts of Weather Variations on Energy Demand and Carbon Emissions." *Resource and Energy Economics* 22: 295-314.

Deaton, A.S. and J.N. Muellbauer (1980). "An Almost Ideal Demand System." *American Economic Review* 83: 570-597.

Dubin, J. and D. Mcfadden (1984). "An Econometric Analysis of Residential Electric Appliance Holdings and Consumption." *Econometrica* 52: 345-362.

Filippini, M. (1995). "Swiss Residential Demand for Electricity by Time-of-use." *Resource and Energy Economics* 17: 281-290.

Filippini, M. and S. Pachauri (2004). "Elasticities of Electricity Demand in Urban Indian Households." *Energy Policy* 32: 429-436.

García-Cerruti, L. (2000). "Estimating Elasticities of Residential Energy Demand from Panel County Data Using Dynamic Random Variables Models with Heteroskedastic and Correlated Error Terms." *Resource and Energy Economics* 22: 355-366.

Haas, R. and L. Schipper (1998). "Residential Energy Demand in OECD Countries and the Role of Irreversible Efficiency Improvements." *Energy Economics* 20: 421-442.

Halvorsen, B. and B. Larsen (2001). "The Flexibility of Household Electricity Demand over Time." *Resource and Energy Economics* 23: 1-18.

Hausman, J.A., Newey, W.K. and J.L. Powell (1995). "Nonlinear Errors in Variables. Estimation of Some Engel Curves." *Journal of Econometrics* 65: 205-233.

Holtedahl, P. and F. Joutz (2004). "Residential Electricity Demand in Taiwan." *Energy Economics,* 26: 201-224.

Hondroyiannis, G. (2004). "Estimating Residential Demand for Electricity in Greece." *Energy Economics* 26: 319-334.

International Energy Agency (2003). *Energy Prices and Taxes.* OECD, Paris.

Kamerschen, D. and D. Porter (2004). "The Demand for Residential, Industrial and Total Electricity 1973-1998." *Energy Economics* 26: 87-100.

Kayser, H. (2000). "Gasoline Demand and Car Choice: Estimating Gasoline Demand Using Household Information." *Energy Economics* 22: 331-348.

Keen, M. (1986). "Zero Expenditures and the Estimation of Engel Curves." *Journal of Applied Econometrics* 1: 277-286.

Labandeira, X. and J.M. Labeaga (1999). "Combining Input-Output and Microsimulation to Asses the Effects of Carbon Taxation on Spanish Households." *Fiscal Studies* 20: 303-318.

Labandeira, X., Labeaga, J.M. and M. Rodríguez (2004). "Microsimulating The Effects of Household Energy Price Changes in Spain." Fondazione Eni Enrico Mattei, Working Paper # 161 (nota di lavoro).

Labandeira, X., Labeaga, J.M. and M. Rodríguez (2006). "A Macro and Microeconomic Integrated Approach to Assess the Effects of Public Policies." FEDEA, Working Paper # 2006-02 (documento de trabajo).

Labeaga, J.M. and A. López (1994). "Estimation of the Welfare Effects of Indirect Tax Changes on Spanish Households." *Investigaciones Económicas* 18: 289-311.

Labeaga, J.M. and A. López (1997). "A Study of Petrol Consumption Using Spanish Panel Data." *Applied Economics* 29: 795-802.

Labeaga, J.M., Preston, I. and J. Sanchis (2001). "Children and Demand Patterns: Evidence from Spanish Panel Data." Departamento de Análisis Económico UNED, Working Paper # 02 (documento de trabajo).

Labeaga, J.M. and J. Puig (2006). "Some Practical Implications of Latent Separability with Application to Spanish Data." FEDEA, Working Paper (documento de trabajo), forthcoming.

Larsen, B. and R. Nesbakken (2004). "Household Electricity End-use Consumption: Results from Econometric and Engineering Models." *Energy Economics* 26: 179-200.

Lee, L.F. and M. Pitt (1986). "Microeconometric Demand Systems with Binding Non-negativity Constraints: the Dual Approach." *Econometrica* 54: 1237-1242

Leth-Petersen, S. (2002). "Microeconometric Modelling of Household Energy Use: Testing for Dependence between Demand for Electricity and Natural Gas." *Energy Journal* 23: 57-84.

Lewbel, A. (2003). "A Rational Rank Four Demand System." *Journal of Applied Econometrics* 18: 127-135.

Lissyotou, P., Pashardes, P. and T. Stengos (1999). "Testing the Rank of Engel Curves with Endogenous Expenditure." *Economic Letters* 64: 61-65.

Madlener, R. (1996). "Econometric Analysis of Residential Energy Demand: A Survey." *Journal of Energy Literature II* 2: 3-32.

Micklewright, J. (1989). "Towards a Household Model of UK Domestic Energy Demand." *Energy Policy* 6: 264-276.

Narayan, P. and R. Smyth (2005). "The Residential Demand for Electricity in Australia: An Application of the Bounds Testing Approach to Cointegration." *Energy Policy* 33: 467-474.

Nesbakken, R. (2001). "Energy Consumption for Space Heating: A Discrete-Continuous Approach." *Scandinavian Journal of Economics* 103: 165-184.

Nichèle, V. and J.M. Robin (1995). "Simulation of Indirect Tax Reforms Using Pooled Micro and Macro French Data." *Journal of Public Economics* 56: 225-244.

Nicol, C. (2001). "The Rank and Model Specification of Demand Systems; An Empirical Analysis Using United States Microdata." *Canadian Journal of Economics* 34: 259-289.

Nicol, C. (2003). "Elasticities of Demand for Gasoline in Canada and the United States." *Energy Economics* 25: 201-214.

Oilgas (2002). *Enciclopedia* 2001. Madrid: Oilgas.

Oladosu, G. (2003). "An Almost Ideal Demand System Model of Household Vehicle Fuel Expenditure Allocation in the United States." *Energy Journal* 24: 1-21.

Pashardes, P. (1995). "Equivalence Scales in a Rank-3 Demand System." *Journal of Public Economics* 58: 143-158.

Popp, D. (2001). "The Effect of New Technology on Energy Consumption." *Resource and Energy Economics* 23, 215-239.

Puller, S.L. and L.A. Greening (1999). "Household Adjustment to Gasoline Price Change: An Analysis Using Nine Years of US Survey Data." *Energy Economics* 21: 37-52.

Schmalensee, R. and T.M. Stoker (1999). "Household Gasoline Demand in the United States." *Econometrica* 67: 645-662.

Tiezzi, S. (2005). "The Welfare Effects and the Distributive Impact of Carbon Taxation on Italian Households." *Energy Policy* 33: 1597-1612.

Universidad Politécnica de Madrid (2000). Estudio del sector del transporte en España. Primeros datos y conclusiones. Madrid: Servicio de Publicaciones de UPM.

Vaage, K. (2000). "Heating Technology and Energy Use: A Discrete/Continuous Choice Approach to Norwegian Household Energy Demand." *Energy Economics* 22: 649-666.

Wales, T.J., and A.D. Woodland (1983). "Estimation of Consumer Demand Systems with Binding Non-negativity Constraints." *Journal of Econometrics* 21: 263-285.

Yatchew, A. and J. No (2001). "Household Gasoline Demand in Canada." *Econometrica* 69: 1697-1709.

APPENDIX

· Price and tax rate data

Neither EPF nor ECPF provide information on prices, so they were obtained from INE in the form of indexes on a monthly basis. We aggregated goods for those indexes so as to make them compatible with our cross-section data and expressed them on base 1992. For the years 1973-74 we used as a proxy the price index for January 1976, since the INE did not provide prices for most goods in the model. For the 1980 EPF we used prices referring to the quarter in which each household was interviewed, although the data refer to individual annual expenditure. Finally, we adjusted the annual price index for each good between 1985 and 1995 as an arithmetic mean of quarterly prices.

Data referring to prices available on the INE web site (www.ine.es) in the form of indexes, do not offer enough degree of disaggregation for the objectives of this research. For this reason, we have resorted to various sources to obtain prices for energy goods. Firstly, the International Energy Agency (IEA) regularly publishes *Energy Prices and Taxes,* with current prices and taxes for electricity, heating oil, and natural gas (see, for example, IEA, 2003). Secondly, the Spanish Ministry of Economy has supplied us with current prices and taxes for natural gas and LPG. Finally, the *Enciclopedia* 2001 (Oilgas, 2002) provides the prices of various energy goods since the 1970s, with a considerable degree of disaggregation.

The Oilgas 2001 Encyclopedia has been used to obtain price indices for LPG and natural gas, whereas the electrical energy price index has been obtained from *Energy Prices and Taxes*. For the other goods considered in the model, we have used data obtained from the INE.

VAT rates born by the various goods groups have been calculated by weighting the corresponding legal rates to each type of expenditure by their relative weight within each group. For the excise duties born by transport fuel, the same procedure has been followed, using data published by the Spanish Tax Agency (AEAT) as our source.

· Descriptive statistics

Table A1. Descriptive statistics of variables

	1973-95 original sample (annual data)		**1973-95 estimation sample (annual data)**	
Number of observations	**63,706**		**51,691**	
Variables	**Mean**	**Standard Dev.**	**Mean**	**Standard Dev.**
Income[a]	5,365	6,480	5,199	5,677
Total expenditure[a]	5,374	6,184	5,223	5,449
Electricity[a]	86	113	86	106
Natural gas[a]	7	43	6	36
LPG[a]	40	47	40	42
Car fuels[a]	201	380	191	340
Public transport[a]	69	214	58	130
Food[a]	1,584	1,449	1,626	1,398
Other non-durable[a]	3,387	4,632	3,214	3,893
Electricity[b]	0.0172	0.0140	0.0166	0.0096
Natural gas[b]	0.0009	0.0046	0.0008	0.0037
LPG[b]	0.0116	0.0121	0.0109	0.0087
Car fuels[b]	0.0290	0.0448	0.0287	0.0415

Table A1. Descriptive statistics of variables (continued)

Public transport[b]	0.0135	0.0266	0.0121	0.0197
Food[b]	0.3859	0.1617	0.3885	0.1406
Other non-durable[b]	0.5419	0.1569	0.5423	0.1356
No members younger than 15[c]	0.90	1.22	0.94	1.22
No members older than 15[c]	2.77	1.23	2.83	1.18
Home owner[d]	0.68	--	0.70	--
Unskilled[d]	0.29	--	0.27	--
High school[d]	0.10	--	0.10	--
University[d]	0.06	--	0.05	--
Rural (inhab.<10,001)[d]	0.28	--	0.27	--
Village (10,000 <inhab.<50,001)[d]	0.20	--	0.20	--
City (inhab.>50,000)[d]	0.52	--	0.53	--
Retired head[d]	0.25	--	0.23	--

Source: Own calculations.
Notes: i) [a]Euros; [b]Share (%); [c]Integer number; [d]Dummy. ii) Data statistics are for the original sample so they include households that do not consume some of the goods. iii) Share refers to the share of each good on total expenditure. iv) All dummies take the value 1 when the event is true and 0 otherwise.

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199 Lessons Learned from the Electricity Market Liberalization, Paul L. Joskow, The Energy Journal, David Newbery Special Edition, (2008)

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