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A meta-analysis on the price elasticity of energy demand[☆]

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ABSTRACT

Price elasticities of energy demand have become increasingly relevant in estimating the socio-economic and environmental effects of energy policies or other events that influence the price of energy goods. Since the 1970s, a large number of academic papers have provided both short and long-term price elasticity estimates for different countries using several models, data and estimation techniques. Yet the literature offers a rather wide range of estimates for the price elasticities of demand for energy. This paper quantitatively summarizes the recent, but sizeable, empirical evidence to facilitate a sounder economic assessment of (in some cases policy-related) energy price changes. It uses meta-analysis to identify the main factors affecting short and long term elasticity results for energy, in general, as well as for specific products, i.e., electricity, natural gas, gasoline, diesel and heating oil.

1. Introduction

In contemporary economies, energy is a key element for the production of goods and services; but it is also a direct source of welfare for individuals. It is therefore crucial to know how price changes, given by market dynamics and/or energy-related public policies, affect producer and consumer energy demand. Over the last few years energy deregulation and sharp movements in the price of primary energy goods, together with policies related to climate change and energy security concerns, have actually fostered renewed interest in this area. Energy savings are likely to play a crucial role in attaining climate objectives (see e.g. IPCC, 2014), thus the need to correctly quantify actual mitigation potentials within energy demands. Robust evidence on price elasticities of energy demand could facilitate a better understanding of the environmental, economic and distributional[1] consequences of varying energy prices and enable societies to make *ex-ante* decisions on energy and environmental matters.

Although the economic literature on energy demand dates back to the last century (it began with Houthakker (1951)), a large number of recent academic studies have used several techniques to estimate (both short and long-term) price elasticity demand for different energy products in various countries, thus yielding rather sizeable empirical evidence. Given the practical relevance of price elasticities of energy demand within this context, it is particularly interesting to develop methods that summarize (qualitatively and quantitatively) existing evidence and identify the main factors systematically affecting the results. Meta-analysis, or the statistical analysis of studies in an area, first proposed by Glass (1976) in the field of education but subsequently extended to many other disciplines, seems to be an appropriate and useful approach for this purpose. After the work of Stanley and Jarrell (1989), multiple meta-analyses have been conducted in economics; at least one third of these studies relate to environmental and resource economics (Nelson and Kennedy, 2009).

Unfortunately the use of meta-analysis has been rather limited in the field of energy demand. The few existing exercises focus almost exclusively on price elasticities of gasoline demand. So the first objective of this paper is to incorporate other energy goods, i.e., electricity, natural gas, diesel, heating oil and energy in general, and provide a more profuse analysis and improved conclusions concerning growing empirical evidence on price elasticities in the energy domain.

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[1] In this context, energy goods may be particularly exposed to price increases and collateral distributive effects from post-Paris climate policies (see Sterner (2007)). However, the analysis of the distributive impacts of energy price variations is beyond the scope and capabilities of this article. For a detailed discussion on this matter see Sterner (2012).

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Table 1
Selected surveys on price elasticity of energy demand.

Study	Energy Product	Elasticity range	
		Short-term	Long-term
Taylor (1975)	Electricity	[−0.90; −0.13]	[−2.00; 0]
Kouris (1983)	Car fuels	[−0.26; −0.05]	[−1.77; −0.18]
	Energy	[−0.79; 0.30]	[−1.75; 1.03]
Bohi and Zimmerman (1984)	Electricity	[−0.88; −0.07]	[−4.56; −0.18]
	Gasoline	[−0.77; −0.07]	[−1.59; −0.14]
	Heating oil	[−0.19; −0.18]	[−0.67; −0.62]
	Natural Gas	[−0.63; −0.03]	[−3.44; −0.26]
Drollas (1984)	Gasoline	[−0.78; −0.07]	[−1.37; −0.23]
Dahl (1986)	Gasoline	[−0.52; −0.01]	[−1.61; −0.05]
Al-Sahlawi (1989)	Natural Gas	[−0.95; −0.05]	[−4.60; −0.12]
Dahl and Sterner (1991a)	Gasoline	[−0.77; 0.28]	[−2.72; −0.29]
Dahl (1995)	Gasoline	[−0.8; 0]	[−1.6; 0]
Graham and Glaister (2004)	Car fuels	[−2.13; 0.59]	[−22.00; 0.85]
Basso and Oum (2007)	Car fuels	[−0.37; −0.04]	[−1.12; −0.12]
Dahl (2012)	Diesel	[−0.94; 2.13]	[−6.18; 2.29]
	Gasoline	[−1.65; 0.63]	[−61.11; 5.89]

It also contemplates aggregated as well as residential, industrial and commercial energy demand. However, it only deals with the latest evidence available (papers published as of 1990) for two reasons: the need to update and relate a scarce number of academic contributions that previously considered these matters through comparable methodologies, and the remarkable increase in the quality and reliability of recent results given the significant technical advances in data collection and processing witnessed throughout the last two decades.

This research carries out a meta-analysis following the procedure outlined by Nelson and Kennedy (2009), using a regression analysis (see also Stanley and Jarrell (1989)). That is to say, it performs a regression analysis employing the entire set of results selected from the literature and an extensive specification of the factors determining these elasticities. Thus, the paper addresses the need to determine, as accurately as possible, the value of price elasticities of energy demand in general as well as the price elasticities of the demand for the aforementioned energy goods. As a secondary outcome, it identifies the variables that explain the heterogeneity of price elasticities reported in the literature.

The article is divided into five sections, including this introduction. The second section describes existing academic literature using meta-analysis to summarize and analyze price elasticities of energy demand. The subsequent part provides details on the implemented empirical application and also describes the factors that influence the estimation of price elasticities for energy demand. Section 4 presents the empirical results obtained by applying the meta-analysis to the updated literature review, and Section 5 concludes. The paper also includes two annexes with full estimation results and a list of the papers employed in the meta-analysis, respectively.

2. Meta-analyses of price elasticities of energy demand

A number of papers have used a variety of studies, methodologies, time spans and geographical areas to summarize the empirical literature on price elasticities of energy demand. Table 1 presents a selection of surveys that depict a large variability in the estimated short and long-term elasticities. Most surveys attempt to identify the factors behind such dispersion; in some cases they also try to approach the true elasticity value (see e.g. Dahl and Sterner, 1991b; Goodwin, 1992).

At any rate, the large number of surveys on price elasticities of energy demand contrasts with scarce attempts by the literature to summarize these elasticities in a single value through meta-analysis. What is more, as we may see in Table 2, most of these existing meta-analyses have been applied to the literature on price elasticities of gasoline demand.

In particular, Espey (1996) carried out the first meta-analysis that included the characteristics of the data, the model structure and the estimation technique as explanatory variables to examine the existence of factors systematically affecting gasoline price (and income) elasticity estimates in the United States. An extension of this work is provided in Espey (1998), with the use of existing empirical evidence on gasoline demand across the globe and the separate analysis of long-term and

Table 2
Meta-analyses for price elasticity of energy demand.
Source: Brons et al. (2008) and the cited literature.

Study	Period	Considered papers	Observations	Energy Product	Elasticities
Espey (1996)	1936–1990	41	70	Gasoline	−0.65 (LT)
Espey (1998)	1929–1993	101	640	Gasoline	−0.16 (ST) −0.81 (LT)
Hanly et al. (2002)	1929–1991	69	491	Car fuels	−0.76 (ST) −1.16 (LT) −0.54 (STA)
Graham and Glaister (2002)	1966–2000	113	600	Car fuels	−0.25 (ST) −0.77 (LT)
Espey and Espey (2004)	1947–1997	36	248	Electricity	−0.35 (ST) −0.85 (LT)
Brons et al. (2008)	1949–2003	43	312	Gasoline	−0.36 (ST) −0.81 (LT)
Havranek et al. (2012)	1974–2011	41	202	Gasoline	−0.09 (ST) −0.31 (LT)

Note: LT, long term; ST, short term; STA, result obtained by using only papers that employ statistical models.

short or medium-term elasticities. It employs the functional form, the structure of delays, the sampling period, the country, the estimation technique and other structural characteristics of the model as explanatory variables. Subsequently, the UK Department of Transport commissioned two reports (Hanly et al., 2002; Graham and Glaister, 2002) that aimed to identify the magnitude and ranges of road transport elasticities provided by the existing literature, and distinguish price elasticities by type of traffic and different definitions of costs and prices. Within this context, the reports also conducted a meta-analysis, akin to that of Espey (1998), on price elasticities of car fuel demand.

Regarding price elasticities of other energy sources, Espey and Espey (2004) carried out the only meta-analysis of studies on residential electricity demand. This paper examines how the values of short and long-term price elasticities are affected by the specification of the demand model, the characteristics of the data used, the country for which the exercise is conducted, the period of analysis and the estimation technique.

The latest contributions to the literature of meta-price elasticities of energy demand are those of Brons et al. (2008) and Havranek et al. (2012). In the first case, the authors perform a meta-analysis to enquire on the variation in empirical estimates of price elasticity of gasoline demand. They develop an estimation method based on the Seemingly Unrelated Regression (SUR) model assuming that gasoline demand may be expressed as a multiplicative function of car fuel efficiency, mileage per vehicle and vehicle ownership. This implies a linear relationship between the price elasticity of the total demand for gasoline and the price elasticities of each of these variables. The combination of information on different types of elasticities allowed Brons et al. (2008) to obtain more precise estimates. Havranek et al. (2012), on the other hand, approached this issue through a meta-analysis of the estimates of gasoline demand elasticities across different countries. This study considered that the distribution of estimated elasticities might be explained by the type of data used, the date of publication of the study and an indicator of whether the data are for the US. The paper employed the so-called Heckman meta-regression (see Stanley and Doucouliagos (2007)), for the first time within this field, to correct selection bias in existing publications on these price elasticities.

The results of these studies show a price elasticity of energy products in the short term ranging between −0.09 and −0.76, while they report long-term elasticities between −0.31 and −1.16. The preceding papers also show that elasticities have a tendency to decrease over time in absolute values. This phenomenon may reflect income effects as well as the influence of energy-efficiency improvements that could make consumers less sensitive to price changes.

3. Meta-analysis

Following Nelson and Kennedy (2009), we perform a meta-regression analysis (Stanley and Jarrell, 1989). That is to say, we carry out a regression analysis for the whole set of coefficients included in the papers selected for this study (see Annex B). The paper therefore intends to adjust the value of price elasticities of demand for energy as precisely as possible, and identify the factors that explain the differences between the results of the various studies.[2] To this end, it estimates the following model,

$$b_j = \beta + \sum_{k=1}^{k} \alpha_k Z_{jk} + e_j (j = 1, 2, \ldots, L) \tag{1}$$

where b_j is the estimation carried out in the j-nth study using the real value of the price elasticity of demand for energy; Z are the K explanatory variables that measure the relevant characteristics of the empirical study that influence estimated elasticities; α_k are the coefficients of these attributes in the meta-regressions that reflect the bias introduced by the particular characteristics of the study; e_j is the error term of the meta-regression; and L is the number of studies employed in the analysis. The parameter of particular interest is the intercept β, which collects the average value of the elasticity when the rest of the explanatory variables are set to zero. As in previous meta-analyses in this field, different models are estimated for short and long-term elasticities of energy demand.

The results we used to conduct the meta-analysis were taken from papers selected from a fully updated, comprehensive and detailed review of existing empirical literature on price elasticities of energy demand. Even though we used extensive internet search tools (including *Google Scholar* and *ScienceDirect*), we actually located most of the papers by consulting previous surveys and meta-analyses on this issue. Among the sources used to identify and compile the studies contained herewith, *Dahl Energy Demand Database* (Dahl, 2010) deserves a special mention. In total, we collected 428 papers produced between 1990 and 2016 providing 966 short-term price elasticities and 1010 long-term price elasticities of energy demand[3] (see Table 2 in the preceding section to compare it to previous meta-analyses in the field). Table 3 shows a statistical summary of the elasticities that served as the basis for the meta-analysis: estimates of the long-term elasticity range between −22 and 4.189, with an average of −0.596, while short-term elasticity estimates range between −24 and 2.908, with an average of −0.236. The upper panel in Fig. 1 shows the density of the total sample of estimated short and long-term elasticities.

As some of the estimated values of elasticities are very extreme and statistically non-significant, usually due to small sample sizes, we decided to exclude 5% of the sample from the meta-analysis (2.5% of values in the upper tail and 2.5% of the values in the lower tail of the distribution) to eliminate outliers that could strongly affect the results of the estimation of Eq. (1). Table 3 summarizes, under the heading *selected sample*, the statistics that describe the elasticities used, with short-term price elasticities ranging between −0.803 and 0.066 and long-term elasticities ranging between −1.809 and 0.154; the lower panel of Fig. 1 shows the density of the elasticities actually considered in this paper.

Heterogeneity of the selected empirical studies generates an important variation in estimated elasticities; so we introduced a number of indicators (constructed as variables 0–1) to capture its various sources. We considered eight main factors or determinants that could affect the estimation of elasticities, as listed below and summarized in Table 4:

- *Type of energy product*. Since the reaction of consumers to price changes may be different in function of the energy product consumed, this exercise distinguishes between the studies estimating the price elasticity of demand for energy in general and the ones estimating the price elasticities of demand for each of the main energy products, i.e., electricity, natural gas, gasoline, diesel and heating oil.
- *Type of consumer*: Energy is used for different purposes in function of the general type of consumer demanding it, which itself influences the effect of prices on demand. The exercise therefore distinguishes between studies estimating residential, industrial, commercial, and total energy consumption.
- *Country (geographical area)*. The behavior of energy consumers can vary depending on the country under analysis. In this case, the exercise considers two factors that may affect estimated elasticities: stage of economic development (developed and developing coun-

[2] Although the paper employs standard approaches in the field of meta-analysis, its use of panel data procedures to control for unobservables (fixed effects) is uncommon in previous applications.

[3] Short term refers to the immediate reaction by agents (up to one year), while long term contemplates a much larger adaptation of agents (more than one year).

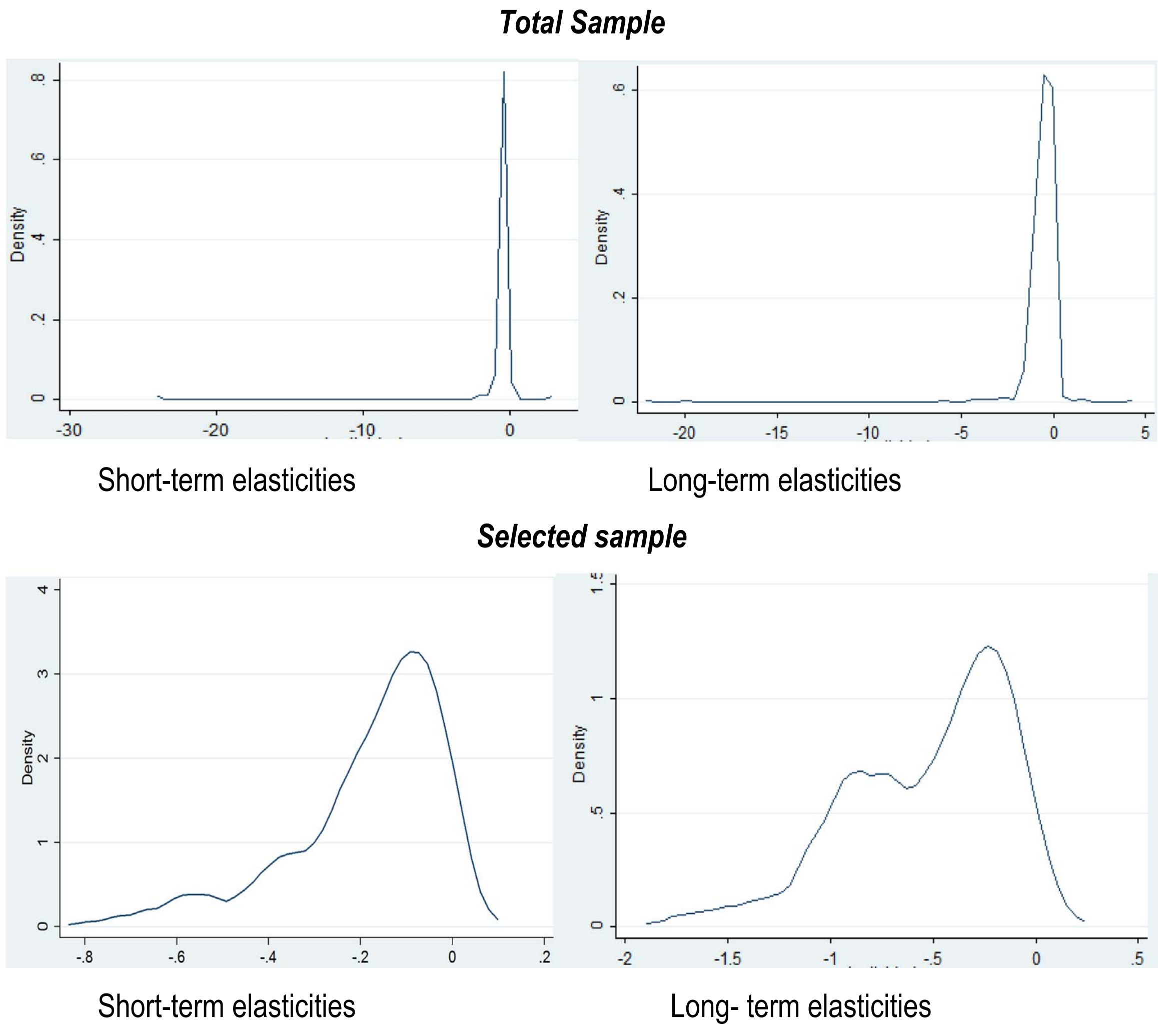

Fig. 1. Density of the price elasticities. Total and selected samples.

Table 3
Statistics of price elasticities of demand. Total and selected samples.

Variable	Observations	Average	Median	Standard Deviation	Minimum	Maximum
Total sample						
ST Elasticity	966	−0.236	−0.140	0.880	−24.0	2.908
LT Elasticity	1010	−0.596	−0.428	1.120	−22.0	4.189
Selected sample						
ST Elasticity	917	−0.186	−0.140	0.168	−0.803	0.066
LT Elasticity	959	−0.524	−0.429	0.390	−1.809	0.154

Note: ST, short term; LT, long term.

tries), and energy trade balance (net energy exporters and importers). The paper uses the Human Development Index (UNDP, 2015) to identify developed countries as those having a HDI above the median and it uses World Bank data (World Bank, 2015) for the information concerning the net energy imports/exports of the countries.[4]

– *Data*. The type of data used in each particular study is another important factor that may affect the results. The exercise therefore distinguishes between the studies using cross-sectional data, those employing time series data and the papers using panel data.
– *Type of model*. On the one hand, a large part of the existing empirical research on energy demand has employed dynamic (usually error-correction) models estimated with cointegration techniques on aggregate data (Engle and Granger, 1987). However, the validity of the results obtained with these approaches largely rests on the existence of representative consumers; as they disregard information related to the behavior of individual agents and thus are unable to deal with observable and unobservable heterogeneity. An available alternative when information for individual agents (consumers, companies, etc.) exists is to adjust models that explicitly consider these factors. When using micro data, a first option consists in estimating energy demand using standard econometric techniques. Yet even under these circumstances, it is unlikely that all the decisions of the agents concerning energy demand will be taken into account. For example, the relationship between the

[4] When a given estimation uses data from several countries, these dummies reflect the type of country that represents a majority within the group.

Table 4
Main determinants affecting the estimation of elasticity demand.

Determinants	Number of observations	Average elasticity	
		Short term	Long term
Good			
Energy	376	−0.149	−0.572
Electricity	538	−0.201	−0.513
Natural gas	230	−0.184	−0.568
Car fuels	83	−0.180	−0.372
Gasoline	469	−0.195	−0.526
Diesel	136	−0.157	−0.391
Heating oil	44	−0.188	−0.535
Consumer			
Residential	710	−0.215	−0.617
Industrial	266	−0.168	−0.511
Commercial	61	−0.224	−0.718
Total	839	−0.163	−0.435
Country			
Net energy exporter	481	−0.189	−0.514
Net energy importer	1395	−0.185	−0.527
Developed	1450	−0.186	−0.515
Developing	426	−0.186	−0.548
Data			
Cross-section	188	−0.332	−0.856
Time series	1185	−0.166	−0.445
Panel data	503	−0.205	−0.517
Model			
Aggregate data	1151	−0.159	−0.458
Aggregate data and cointegrated (or ECM)	378	−0.177	−0.449
Demand system	216	−0.266	−0.789
Microeconomic model	86	−0.353	−0.676
Continuous-discrete micro model	45	−0.293	−0.880
Sample period			
Pre-1973	101	−0.224	−0.635
Post-1973	1775	−0.183	−0.518
Pre-1979	354	−0.191	−0.551
Post-1979	1522	−0.185	−0.518
Pre-2008	1849	−0.186	−0.526
Post-2008	27	−0.197	−0.323
Publication			
Peer-review journal	1485	−0.193	−0.567
Other	391	−0.153	−0.382
Estimation method			
Least squares	1176	−0.187	−0.461
Instrumental variables	270	−0.184	−0.558
Other methods	430	−0.181	−0.641

discrete decision to purchase durable goods that consume energy and the decision to consume energy is rarely considered. This may lead to inadequate model specifications, causing a biased estimation of elasticities and thus invalidating the inference relative to public policies and/or price shocks. In this context, one alternative may be to use continuous-discrete sequential models that assume agents first take discrete decisions on the purchase of durable energy-consuming goods and, conditioned by them, subsequently decide how much energy to consume.

On the other hand, most empirical studies in this area have used single-equation econometric models that require separability restrictions. This is a severe disadvantage as it is not possible to estimate cross-price effects between different energy products or consider the effects of non-energy products on the price elasticity of energy goods. Another alternative is to estimate price elasticities using complete systems of demand, such as the translog model (Christensen et al., 1973) or the almost ideal demand system (Deaton and Muellbauer, 1980), AIDS, which allow the correction of various econometric problems that usually cause elasticity estimation biases.

– *Sample period*. It is widely accepted that the economic cycle has a strong influence on energy consumption due to income and (indirect cycle-related) price effects. In the case of economic crises, for example, a depression of energy prices may occur; reduced disposable income may lead agents to reduce consumption through improvements in energy efficiency, adjustments to other types of consumption or changes towards other more inexpensive energy goods. Thus the exercise incorporates a series of dummies indicating whether most of the sample period of each study is before or after the crises of 1973, 1979 and 2008.
– *Type of publication*. The exercise introduces a dummy to distinguish between papers published in peer-review journals and studies published in alternative formats such as working papers series, reports, etc.
– *Estimation method*. The exercise also considers that the procedure used to estimate the model may affect the results. It distinguishes between the papers using least squares methods, from those that employ single equations estimated by ordinary least squares (OLS) to iterate least squares (ILS) and papers using multiple equations, such as seemingly unrelated regression equations (SURE), panel data models estimated by least squares dummy variables (LSDV) and generalized least squares (GLS). It also contemplates papers using single equation or multiple equation models estimated by instrumental variables such as two-stage or three-stage least squares (2SLS or 3SLS) or generalized method of moments (GMM). Finally, the exercise also incorporates papers using alternative estimation approaches such as maximum likelihood methods, Bayesian methods, ridge regression or nonparametric estimation.[5]

4. Results and discussion

4.1. Results

We estimated the model in Section 3 using GLS for both short and long-term elasticities because the elasticity figures provided by the literature, conforming a sample with two dimensions (time and type of study), could lead to heteroskedasticity and correlation of error terms given the different sample sizes in the different studies. Moreover, we attempted to control for unobserved study-specific factors in the estimation of Eq. (1) by using a panel data structure in which the dimensions are the considered energy product and the study. Moreover, we obtained the price elasticities of specific energy goods by estimating individual single equations for each energy product, to explicitly consider potential endogeneity. Table 5 presents the average energy elasticities adjusted using the aforementioned methods, while Table 6 shows the estimated price elasticities for each energy product.[6]

Regarding the results obtained for the specification estimated using fixed effects panel data models, which will subsequently be compared to the outcomes of alternative methodological approaches, the short-term price elasticity of energy demand is −0.21, on average. In this case, the GLS estimation provides slightly higher elasticity values, even though the difference is not statistically significant. In terms of specific energy goods, gasoline shows the highest price elasticity and heating oil displays the lowest price elasticity,[7] although the dispersion of price

[5] A description of most of the above-mentioned estimation methods can be found in Wooldridge (2002). For non-parametric methods and Bayesian procedures seminal references are respectively Härdle and Linton (1994) and Chib et al. (2008).

[6] Tables A1–A4 in Annex I show the complete results of the estimates. Note that the alternatives presented in this section were not the only ones used: they were actually selected by rigorously contrasting their robustness, as further discussed in the paper.

[7] The differences in the price elasticities are related to the use and substitution

Table 5
Average energy elasticities in the empirical literature.

	GLS	Fixed-effects panel
Short term	**−0.221***	**−0.207***
Long term	**−0.584***	**−0.608***

*** Significant at the 1% level.

Table 6
Average energy products elasticities in the empirical literature.

	Short term	Long term
Electricity	**−0.126***	**−0.365***
Natural Gas	**−0.180***	**−0.684***
Gasoline	**−0.293***	**−0.773***
Diesel	**−0.153****	**−0.443***
Heating oil	**−0.017**	**−0.185**

*** Significant at the 1% level.
** significant at the 5% level.
* significant at the 10% level.

elasticities is rather small.

A second relevant matter refers to the factors affecting the reported elasticities. Regarding short-term price elasticities, micro data generates significantly higher elasticities (in absolute values) than do aggregate models. This is, intuitively, an unexpected outcome given that microeconomic models include a wide range of socioeconomic and demographic variables that could induce a reduction on price effects. It is therefore necessary to turn to other factors to obtain a coherent explanation for these results. Indeed, the absence of a representative consumer (and thus, unobserved heterogeneity as well as correlated heterogeneity) could affect the price effect estimates in much the same way. The reported results also show a remarkably higher short-term sensitivity to prices of commercial energy demand as compared to industrial or aggregate energy demands. In aggregate models that adjust industrial energy demand, the most important factor explaining this phenomenon is the business cycle (GDP change). Actually, conditioned on the business cycle, prices have a limited impact on demand. Additionally, the behavioral changes on energy consumption consequent to the 1973 oil crisis led to a lower short-term price elasticity of energy demand. Finally, papers not published in peer-review journals tend to report lower short-term price elasticities (in absolute values).

Regarding long-term elasticities, the average value is −0.61: higher and with a greater dispersion (as expected) than the reported short-term results. Significant differences exist among different goods. Heating oil is the most inelastic product and gasoline is the most elastic one. As expected, GLS estimation results are similar to those obtained using panel data techniques. A number of factors explain long-term results: the crises, type of energy consumed and type of data employed, the modelling strategy of the study and the type of publication (see Table A2). The meta-analysis indicates that long-term price elasticities were lower after the first oil shock (1973), probably due to the significant investments and behavioral changes resulting from the sharp increase in the price of energy goods. Moreover, the second oil crisis (1979) and the recent economic recession (2008) also led to adjustments that generated additional reductions in the long-term price sensitivity of energy demand.

Moreover, long-term price elasticities of commercial demand are significantly higher than those of residential and industrial demands. Long-term price elasticities of energy demand from panel data are significantly smaller (in absolute values, as in the previous comparisons) than those from cross-sections, although they are higher than the ones from time series. Energy demand in developing countries is substantially more price sensitive in the long-term, whereas studies not published in peer-review journals again show lower long-term price elasticities in absolute values. Finally, the use of complete demand systems leads to higher long-term price elasticities than the use of single equations. This may indicate that only some of the models are capable of capturing decisions at both the extensive and intensive margins; and complementary or substitution relationships may exist.

Finally, this meta-analysis indicates differences in the price elasticities of energy demand between developing and developed countries only in the long term. However, an additional estimation including an OECD country dummy indicates that price elasticities of energy demand are significantly higher in developing countries. In this sense, it is possible to infer that income convergence may have important consequences on energy demand (and, indirectly, on environmental matters as well as dependence on foreign energy stocks).[8]

The preceding results show a long-term price elasticity of energy goods that is about three-fold that of short-term elasticity. Indeed, considering the papers that report both short (ST) and long-term (LT) price elasticities, the LT average elasticity slightly triples (3.08) the ST average elasticity. Moreover, all energy products are around that figure: electricity (3.04), natural gas (3.03), gasoline (3.05), diesel (3.20) and heating oil (3.73). This roughly coincides with one of the meta-analyses in the energy demand literature (see Section 2); three other meta-analyses show smaller differences; whereas the two remaining studies find even greater divergences between LT and ST elasticities. The paper reports lower price elasticities for electricity demand (−0.21 vs −0.35 in the short term, and −0.61 vs −0.85 in the long term) with respect to the other existing meta-analysis (Espey and Espey, 2004).[9] Similar reasons may explain the divergence between the results of this paper on the price elasticities of car-fuel demand (−0.15 and −0.29 for respectively diesel and gasoline in the short term, and −0.44 and −0.77 in the long term) and the intervals of the other two meta-analyses (−0.25, −0.76 in the short term; −0.77, −1.16 in the long term). Yet, our results are comparable to those reported by the four meta-analyses specifically focusing on the price elasticity of demand for gasoline.

4.2. Discussion and testing

A major potential determinant of energy demand is technical

(*footnote continued*)
possibilities of the contemplated energy goods. In the case of heating oil, the practical difficulties and costs of substituting heating systems mean that consumers have a limited capacity to react to price increases unless they give up comfort. On the contrary, consumers usually have higher possibilities to react to gasoline price increases by modifying habits and/or means of transportation. Regarding the remaining energy goods, the capacity of reaction by agents to price changes is usually between these two extreme cases and hence the reported price elasticities are within the interval set by heating oil and gasoline. Electricity and natural gas have many uses (heating, cooking, etc.), which increases the capacity of reaction by consumers with respect to heating oil. In any case, electricity is related to uses that are very necessary (lighting, cooking) and it therefore shows a relatively small price elasticity of demand. Although natural gas can substitute electricity in some cases, it is generally not used for lighting and therefore shows a higher price elasticity of demand with respect to electricity. Finally, within car fuels, diesel consumption is usually more related to commercial/industrial uses that show less substitution possibilities and is largely influenced by the economic cycle so that its price elasticity is lower than the reported for gasoline.

[8] For instance, economic development may thus restrict the capacity of countries to reduce energy consumption through higher policy-induced energy prices.

[9] This may be related to the income effect and to the improvements in energy efficiency, as the data from Espey and Espey (2004) covers a much older period (1947–1997 vs. 1990–2016 in our case). A higher disposable income in the period contemplated by this paper means that consumers may afford keeping the level of electricity consumption despite price increases (i.e., a lower price elasticity of demand). Moreover, the significant increases in energy efficiency in the electricity domain since the 1990s led to a reduction in energy intensity, which limits the capacity of agents to adjust their electricity consumption to price increases (again, a lower price elasticity of demand). A combination of both factors could explain the reported reduction of the price elasticity of electricity demand both in the short and long terms with respect to previous evidence.

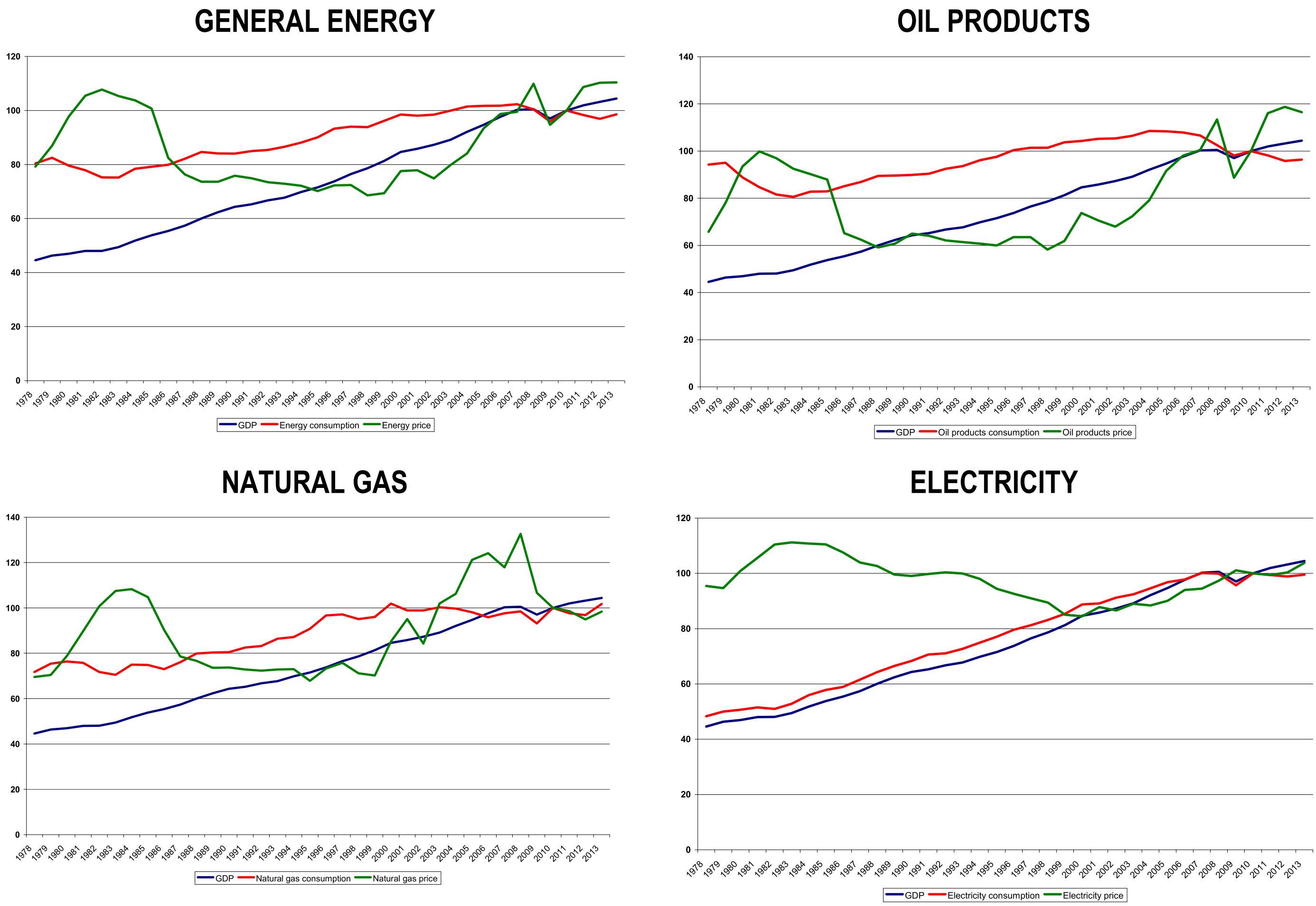

Fig. 2. GDP, energy consumption and real energy price in the OECD, 1978–2013 (2010=100).
Source: IEA (1999, 2015)

progress. Given that the importance of technical progress depends on the time period under observation, an average for each of the periods was calculated to assign the value of the trend. The first year of data is 1945, so this new variable takes value 1 in that year and the subsequent value assigned to the trend follows the average of the calculated sample period. Note that the trend is not significant at any level in any given specification.

Another specification issue that may affect the estimates is the departure from normality in the distribution of the elasticities, as depicted in Fig. 1. We estimate the models using GLS and taking into account the presence of heteroskedasticity and autocorrelation, so this is unlikely to affect the estimation results.

A major aim of this paper is to explain the fit of the demand for energy in terms of price evolution, conditioned upon other determinants of the behavior of agents.[10] In fact, by merely taking a look at any of the components of Fig. 2, we may see several relevant matters to the literature in this field. First, energy consumers adapted to price shocks as soon as the first oil crisis took place at the beginning of the 1970s. Second, the second oil crisis a few years later affected energy demand mainly through oil products and natural gas. However, the evolution of electricity consumption closely followed the evolution of GDP and benefited from decreases in real electricity prices for a long time. Third, even though Fig. 2 does not distinguish between different types of energy consumers (available upon request), the evolution of income is the main determinant of their energy demand, particularly in industrial and commercial sectors; it therefore leaves limited possibilities for corrective pricing signals. Fourth, only the 2008 economic crisis affected aggregate demand (and its components) and this was due to decreases in economic activity rather than to energy price movements. Finally, cross-price effects appear to have the potential to substitute polluting sources in the energy domain. Contrarily, if clean energy sources face price increases, both substitution and the limited capacity of demand reduction through prices will move in an environmentally negative direction. It seems that other alternatives, like information and awareness, may play a relevant role within corrective public policies in this area.

5. Conclusion and policy implications

This paper conducts a meta-analysis of empirical studies estimating the price elasticity of demand of energy. Unlike previous studies, particularly focused on specific energy goods (mainly gasoline), this one considers aggregated energy as well as the demand for the most important energy products: electricity, natural gas, gasoline, diesel and heating oil. Although it focuses on recent empirical evidence, both the number of considered papers and elasticity estimates are much larger than those of previous meta-analyses in the field. A reliable estimation of price elasticities of energy demand is crucial if we are to understand how shocks in energy prices (policy-related or exogenous) may impact

[10] The evolution of elasticities over time is particularly relevant in terms of policy. On the one hand, factors such as technological and fuel flexibilities seem to have a positive impact on price elasticities over time, but other factors such as adaptation to expectations may have the contrary effect. In this sense, Fouquet (2014) considers that price elasticities follow a U-shaped evolution as the economy grows, even though numerous factors such as the increasing consumption of energy services, the access to the market of energy services of the poorer population segments, or the changes in the quality of such services may affect this evolution.

energy consumption at an individual level (firm or household) or growth at an aggregate level, both in the short and long term.

Our results show that, on average, the literature has estimated a price elasticity of energy demand in the short term of −0.21, and −0.61 in the long term. Several short-term elasticities of energy products range between −0.29 and −0.02; whereas long-term elasticities range between −0.77 and −0.19. Apart from the case of gasoline demand, already covered by most existing exercises in the area, the results of this paper depict lower short and long-term energy demand price elasticities than do previous meta-analyses. The main factors that influence the estimates obtained from short-term elasticities are the type of model used for the study, the type of consumer considered, the type of publication and the fact whether the data are previous or subsequent to the 1973 oil crisis. Indeed, the results indicate that studies with micro models, those analyzing the pre-1973 period, the ones published in peer-review journals and those employing commercial data lead to significantly higher price elasticities (in absolute values) than do those using aggregate models and industrial data, respectively. Concerning long-term elasticities, the most important factors affecting the results are the type of data and model used for the study in addition to the type of consumer and country considered, the fact whether the data are previous or subsequent to the different crises and the type of publication. In this case, the meta-analysis shows that price elasticities from panel data approaches are significantly higher (lower) than are those from time series (cross sections). Moreover, price elasticities are substantially higher when using commercial data on energy demand, complete demand models or when the associated studies are published in peer-review journals; and they are significantly lower when using data subsequent to the crises (1973, 1979 and 2008).

We may conclude from the meta-analysis results that agents somewhat react to price changes in energy products; this reaction is greater in the long term than it is in the short term and it is quite similar among different energy products. The average values we obtained classify energy products as price inelastic, so that pricing policies (through taxation or other regulatory tools) can give rise, *ceteris paribus*, to a less than proportional reduction in the demand for these goods both in the short and long term. It is also noteworthy to point out that the crises influenced the energy behavior of the agents by forcing them to reduce their exposure to fluctuations in the price of energy goods. After those crises, given the depletion of abatement possibilities, the long-term sensitivity (and short-term, in 1973) of the agents to changes in the price of energy goods decreased.

Finally, the results of this paper allow us to identify energy goods in which consumption is more vulnerable to price changes, i.e. the goods on which price shocks may have the greatest socio-economic and environmental impact, or where corrective pricing policies are potentially more effective. In this sense, price fluctuations affect gasoline consumption the most both in the short and long term. By contrast, the least price-sensitive energy good is heating oil both in the short and long term.

ANNEX A. Parameter estimates

See Tables A1–A4.

Table A1
Parameter estimates for energy price elasticity. GLS.

Regressor	Short-term	Long term
$\hat{\beta}$	**−0.221***	**−0.584***
Electricity	−0.012	−0.034**
Natural gas	−0.021	−0.093**
Gasoline	−0.028*	−0.110***
Diesel	0.006	0.002
Heating oil	−0.022	−0.126
Net energy exporter	−0.005	−0.009
Developing country	−0.010	−0.064***
Post 1973	0.058**	0.167***
Post 1979	0.012	0.060*
Post 2008	0.001	0.137**
Residential	−0.002	−0.075**
Industrial	0.010	−0.084**
Commercial	−0.068*	−0.321***
Cross-section	−0.031	−0.028
Time series	0.017	0.093***
Cointegration model	−0.029*	−0.012
AIDS model	−0.086**	−0.286***
Micro model	−0.198***	−0.012
Discrete-continuous model	−0.112***	−0.125
No journal	0.031**	0.063
Instrumental variables	−0.004	−0.073*
Other estimation methods	0.017	−0.104***
Joint significance	F (22,894)=6.10 (p-value=0.00)	F (22,935)=36.82 (p-value=0.00)
$\mathbf{R^2}$	0.131	0.464

*** Significant at the 1% level.
** at the 5% level; and.
* at the 10% level.

Table A2
Parameter estimates for energy price elasticity. Fixed-effects panel.

Regressor	Short-term	Long-term
$\hat{\beta}$	**−0.207***	**−0.608***
Net energy exporter	−0.012	−0.039
Developing country	−0.021	−0.048*
Post 1973	0.049*	0.159***
Post 1979	0.015	0.063*
Post 2008	−0.003	0.246**
Residential	−0.017	−0.053
Industrial	0.008	−0.038
Commercial	−0.073**	−0.254***
Cross-section	−0.042	−0.245***
Time series	0.022	0.096***
Cointegration model	−0.027*	−0.025
AIDS model	−0.093***	−0.10854**
Micro model	−0.170***	−0.005
Discrete-continuous model	−0.095***	−0.159
No journal	0.028*	0.078***
Instrumental variables	−0.001	−0.065
Other estimation methods	0.023	−0.044
Joint significance	Wald $\chi^2(17)$=137.63 (p-value=0.00)	Wald $\chi^2(17)$=224.67 (p-value=0.00)
$\mathbf{R^2}$	0.143	0.211

*** Significant at the 1% level.
** at the 5% level; and.
* at the 10% level.

Table A3
Parameter estimates for short-term price elasticities of specific energy goods.

Regressor	Electricity	Natural Gas	Gasoline	Diesel	Heating Oil
$\hat{\beta}$	**−0.126***	**−0.180***	**−0.293*****	**−0.153****	**−0.017**
Net energy exporter	−0.026	0.029	0.012	0.020	−0.320
Developing country	−0.061**	−0.012	−0.019	0.005	0.090
Post 1973	0.035	0.072	0.054*	−0.006	–
Post 1979	−0.045	0.007	0.038	0.023	0.024
Post 2008	0.019	–	−0.004	−0.008	–
Residential	−0.065**	−0.064	0.097***	0.042	−0.110
Industrial	−0.023	−0.069	–	–	−0.005
Commercial	−0.086*	−0.242***	–	–	−0.040
Cross-section	−0.085*	0.082	0.082	0.028	–
Time series	−0.006	−0.023	0.066***	−0.024	0.036
Cointegration model	−0.003	−0.031	−0.000	−0.003	–
AIDS model	−0.119***	−0.044	−0.229***	0.032	–
Micro model	−0.085**	−0.306***	−0.371***	−0.424***	0.023
Discrete-continuous model	−0.054	−0.204*	−0.131*	−0.025	−0.195
No journal	0.080***	−0.001	−0.052	0.010	0.025
Instrumental variables	−0.023	0.031	−0.007	−0.020	−0.027
Other estimation methods	0.052*	0.064*	−0.049	−0.016	−0.085
Joint significance	F(17, 288)=3.73 (p-value=0.00)	F(16, 105)=1.73 (p-value=0.05)	F(15, 256)=6.48 (p-value=0.00)	F(15, 93)=3.43 (p-value=0.00)	F(12, 13)=1.11 (p-value=0.43)
$\mathbf{R^2}$	0.181	0.209	0.275	0.356	0.506

*** Significant at the 1% level.
** at the 5% level; and.
* at the 10% level.

Table A4
Parameter estimates for long-term price elasticities of specific energy goods.

Regressor	Electricity	Natural Gas	Gasoline	Diesel	Heating Oil
$\hat{\beta}$	**−0.365***	**−0.684***	**−0.773*****	**−0.443*****	**−0.185**
Net energy exporter	−0.080	−0.073	0.005	0.014	−0.601
Developing country	−0.105	−0.296*	0.023	0.120**	0.164
Post 1973	0.226	−0.173	0.093	−0.082	–
Post 1979	−0.219**	0.435***	0.088	0.088	–
Post 2008	–	–	0.201	0.097	–
Residential	−0.116	−0.042	0.074	0.055	−0.481
Industrial	−0.145	−0.053	0.551	−0.741***	–
Commercial	−0.299**	−0.292	–	–	–
Cross-section	−0.194	−0.797**	0.063	−0.060	0.119
Time series	0.036	0.137	0.134**	−0.021	–
Cointegration model	−0.073	−0.061	0.126**	0.156**	−0.525
AIDS model	−0.064	0.182	−0.197	−0.166	–
Micro model	−0.086	−0.252	−0.033	–	–
Discrete-continuous model	−0.063	−0.099	0.038	−0.097	–
No journal	0.166***	−0.066	−0.026	0.016	0.054
Instrumental variables	−0.051	0.009	−0.057	0.009	0.300
Other estimation methods	−0.084	0.004	−0.031	−0.076	–
Joint significance	F(16, 215)=2.29 (p-value=0.00)	F(16, 91)=2.20 (p-value=0.01)	F(16, 263)=2.06 (p-value=0.01)	F(15, 94)=2.08 (p-value=0.02)	F(7, 10)=1.19 (p-value=0.39)
$\mathbf{R^2}$	0.146	0.279	0.111	0.249	0.455

*** Significant at the 1% level.
** at the 5% level; and.
* at the 10% level.

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