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Fundación de Estudios de Economía Aplicada

The Costs of Kyoto Adjustments for Spanish Households*

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DOCUMENTO DE TRABAJO 2008-02

Serie Energía y Cambio Climático

CÁTEDRA Fedea – Iberdrola

January 2008

* We have benefited from comments by Martin Browning. Financial support from BBVA Foundation and the Spanish Ministry for Science and Technology and ERDF (Project SEJ2006-12939) is also acknowledged. The authors bear all responsibilities of any error or omission.

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ISSN:1696-7496

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ABSTRACT

In this paper we present a microsimulation model to calculate the effects of a tax levied on Spanish energy-related CO_2 (carbon dioxide) emissions in order to comply with EU (Kyoto-mandated) targets. The model uses the results of our prior estimation of a demand system with Spanish household data from 1973 to 1995, which is especially designed for simultaneous analysis of different energy goods. Our objective is to obtain in-depth information on the behavioural responses by different types of households, which will allow us to determine the welfare effects of tax-induced price changes, their distribution across society and the environmental consequences within the residential sector. The results show a significant response by households, sizeable emission reductions, important tax revenues, moderate welfare changes and distributional effects. The simulated policy can therefore be considered a feasible option for tackling some of the current and severe inefficiencies in Spanish energy and environmental domains.

RESUMEN

En este artículo presentamos un modelo de microsimulación para calcular los efectos de un impuesto sobre las emisiones españolas de CO_2 (dióxido de carbono) de origen energético, con el objetivo de cumplir con los compromisos de la UE dentro del Protocolo de Kioto. El modelo usa los resultados de nuestra estimación previa de un sistema de demanda con datos de consumos familiares de 1973 a 1995, especialmente diseñado para el análisis simultáneo de diferentes productos energéticos. Nuestro objetivo es obtener información profunda sobre las respuestas (con comportamiento) de diferentes tipos de familias, lo que permite deteminar los efectos en términos de bienestar de los cambios de precios ocasionados por el impuesto considerado, su distribución entre agentes y las consecuencias ambientales de su aplicación. Los resultados muestran una respuesta significativa por parte de las familias, una considerable reducción de las emisiones, abundantes ingresos fiscales, y moderados cambios de bienestar y efectos distributivos. La política simulada puede por tanto ser considerada una opción factible para resolver algunas de las ineficiencias actuales y más severas que existen en el ámbito energético-ambiental español.

Key words: Energy demand, carbon tax, distribution, Spain

JEL codes: C33, H23, H31

1. Introduction

Since the 1980s, there has been a sustained and sizeable increase in Spanish energy consumption, growing external dependence and exposure to exogenous price shocks.[1] The increasing Spanish energy/GDP ratio has also resulted in poor environmental performance, especially in greenhouse gases, which are now approximately 50% higher than the 1990 Kyoto baseline (i.e. 35% over the EU bubble allocation to Spain). This is a serious problem for Spain, given its international commitments, the high susceptibility to climate change phenomena and the rocketing oil prices seen during the last few months. Household shares of total energy consumption and associated CO_2 emissions have been growing during the last few decades: in 2005 they were respectively 15% and 25% of Spanish totals, more than doubling the absolute figures for 1995.

In this context, strict, corrective public policies can be expected in the short term and so further insight into the various effects of Spanish energy price changes seems especially necessary. In fact, tax policies are likely to play an increasingly important role in the future, as Spain is well below the EU average in energy tax levels, and they may complement other environmental policy instruments already in place, such as the European market for CO_2 emissions.[2] Indeed, the Spanish government has been announcing during the last few years that it will introduce a green tax reform that will have energy and CO_2 emissions at its core. Moreover, a much-needed improvement in energy efficiency may be fostered by (tax-induced) higher prices.

In this paper we present a microsimulation model, which enables us to analyse the effects of a Spanish carbon tax that is designed to foster compliance with the EU burden-sharing (bubble) allocation of greenhouse gas reductions. Previous attempts to simulate energy price changes in Spain have been infrequent and incomplete, as the underlying demand system did not have a thorough disaggregation of energy goods (e.g. Labandeira and Labeaga, 1999). But even the international literature on the issue is rather limited, as most simulations have been based solely on elasticity estimates, often calculated in a single equation setting (e.g. Micklewright, 1989; Brannlund and Gren, 1999). In contrast, this study yields results with a high degree of precision, thanks to the use of a microsimulation procedure (as in, e.g., Symons, Proops and Gay 1994; Cornwell and Creedy, 1996) and to the fact that the links among energy goods are explicitly and simultaneously taken into account. This in itself constitutes a contribution to the literature.

A comprehensive quantification of the effects of energy price changes on households is very relevant from both positive and normative points of view. A positive approach to household energy price changes, able to reproduce in great detail the behavioural effects of different *ex-ante* or *ex-post* scenarios, is essential for any sound economic and distributional assessment of the issue. In this sense, there is an ongoing trend to concentrate the burden of energy price hikes in households to avoid effects on competitiveness (see Ekins and Speck, 1999). Positive approaches may thus be used to contrast the social acceptability of different policies (Zhang and Baranzini, 2004) with regard to the social unrest caused by steep and sudden price increases.

[1] Oil consumption increased more than 40% in Spain between 1980 and 2005, well above EU averages.
[2] As much as 60% of Spanish emissions are not included in this trading scheme, so efficiency and equity concerns will probably lead to the application of a hybrid tax-permit approach (Labandeira and Rodríguez, 2007).

In general, normative approaches have persuaded policy makers to employ high levies on (some) energy goods due to low price elasticities and large revenue-raising capacities. Besides, increasing environmental problems have brought about active policies to include those negative external costs in energy prices through regulations, taxes or permits. Another reason to restrict energy demand through public intervention on prices is strategic: in order to avoid an excessive dependence on foreign stocks of primary inputs, often located in politically unstable countries. With regard to the normative implications of household evaluations, they are of great relevance, both for reporting on the effectiveness and equity consequences of public policies that affect prices and therefore their reforms, and as a way to design compensatory packages to offset the undesirable effects of price shocks.

The objective of the paper is to obtain, through in-depth and *ex-ante* microsimulation, information on the behavioural responses of different types of households to a 50-Euro tax on CO_2 (carbon dioxide) emissions, to determine its welfare, distributional and environmental effects. This tax rate is designed to encourage emissions reductions from households that, together with other instruments applied on other sectors, could contribute to compliance with the Spanish commitments in this field. The paper concludes that the tax-induced price change would bring about a significant behavioural response by households, with large positive environmental effects, important public receipts, limited welfare losses and moderate distributional effects. Therefore, we deal with key aspects of energy taxation at a level of disaggregation quite infrequent in the literature, which may be very useful for policy design[3]. Indeed, our results show the feasibility of the simulated policies within the Spanish economy and, if considered along with the severe energy and environmental constraints, point to straightforward normative recommendations.

The article is organized in five sections, including this introduction. Section 2 deals with the underlying energy demand model for Spain, including a brief methodological outline, a description of data and the main estimation results. The next section focuses on the microsimulation methods to assess the effects of energy price changes in Spain. Section 4 presents the simulated price change and the results obtained from the model. The final section is, as usual, devoted to highlighting the main conclusions of the paper and outlining some policy implications.

2. Modelling Spanish household energy demand

The first task previous to any specification of the demand model is to undertake a statistical analysis of the data to identify the main facts. Data for estimation of the model comes from a combination of comprehensive microdata surveys on Spanish household expenditure, income and idiosyncracies: (i) two waves of the Family Expenditure Survey (FES) for 1973-74 and 1980-81, and (ii) forty-four waves of the Continuous Family Expenditure Survey (CFES) for the period 1985-1995, both managed by the Spanish National Institute of Statistics (INE).[4] The central aim in combining the three surveys is to solve the main problem in estimating complete demand systems, which is obtaining an adequate identification of price effects.[5]

[3] In fact, the simulated tax rate resembles some actual applications by a number of Northern European countries.
[4] All monetary values (prices, income, expenditure) are deflated by taking 1995 as the base year (the same used for prices by the National Institute of Statistics during that period of time).
[5] This problem does not arise when estimating an aggregated energy demand model or a micro model for a single energy good, but obviously at the cost of information losses on household and energy heterogeneity.

Some remarkable features emerge from analysing Spanish micro databases. All households consume electricity and 70.5% of them also consume liquefied petroleum gases (LPG). The consumption of other energy goods is far less important: natural gas (13.4% of households), central heating (5.84%) and liquid/solid fossil fuels (3.2% and 4.6%, respectively). Interestingly, the size of municipalities directly or indirectly determines the consumption of energy goods for the house according to the availability of local energy suppliers and housing type, thus shaping the geographical distribution of energy consumption. For instance, natural gas is mainly consumed in cities with more than 50,000 inhabitants, whereas the opposite is true for solid and liquid fuels and LPG.

One conclusion of the aforementioned evidence is the need to disaggregate the consumption of different gases (LPG and natural gas) in order to make a sensible distributional analysis. Disaggregation will allow us to analyse the effects that a change in the relative prices of energy goods for the house has on the consumption of gases, in accordance with the characteristics of the household (rural vs. urban, wealthy vs. poor). Furthermore, it is indispensable to introduce as much heterogeneity in consumer demand as possible: (i) introducing several demographic variables common in the literature (e.g. educational level, geographical location [rural, town, cities],[6] ownership of the main residence, whether the head of the household is retired from work, and the number of household members by age [14 or under, older than 14]);[7] (ii) a trend variable to control possible tendencies such as technical progress or efficiency of use in any of the expenditure groups;[8] and (iii) improving the flexibility of the income responses by scaling income (and income squared) by some demographics, in particular geographical location dummies as shifters of the slopes of the share equations.

There is an extensive literature dealing with residential energy demand, mainly concerned with the effects of changes in prices and income.[9] The methodologies used to estimate such effects are diverse, although it is possible to distinguish between two general approaches. Some studies estimate the elasticity of the demand for certain energy goods based on an aggregate model for all households and/or industries (e.g. Considine, 2000; García-Cerruti, 2000; Filippini, 1995); others use microeconomic data to estimate the demand for energy goods at the household level (e.g. Larsen and Nesbakken, 2004; Oladosu, 2003; Halvorsen and Larsen, 2001). Most literature in the second group uses econometric single equation models, useful for analysing residential demand of electricity or petrol consumption but unable to explore the rich interrelations among energy goods and other non-energy commodities.[10]

The simulation model employed in this paper rests on the results of prior estimations of an energy demand system using household microdata from 1973 to 1995 (see full details in

[6] Rural corresponds to those households living in municipalities with fewer than 10,001 inhabitants. Town corresponds to those households living in municipalities with more than 10,000 inhabitants but fewer than 50,001. In order to avoid perfect collinearity, we dropped the dummy corresponding to primary schooling and to households living in cities (municipalities with more than 50,000 inhabitants).

[7] We did not include a variable relating weather conditions and energy demand due to the absence of a proper database, albeit other papers like Halvorsen and Larsen (2001) found this variable to be statistically not different to zero for a similar time span.

[8] This is a reasonable approach as we are only interested in the overall impact of technological change (Popp, 2001)

[9] See the survey by Madlener (1996) for an overview of the main empirical results on this issue.

[10] Some exceptions can be found in Nicol (2003) and Tiezzi (2004), which simultaneously analyse the demand for energy and other non-energy goods.

Labandeira, Labeaga and Rodríguez, 2006). Their model is based on the quadratic extension (QAIDS) proposed by Banks, Blundell and Lewbel (1997) of the Almost Ideal Demand Model (Deaton and Muellbauer, 1980). Thus the model can capture the existence of different elasticities throughout the income distribution and can show whether goods are necessities or luxuries at different points along that distribution. In particular,

$$w_{iht} = \alpha_{ih} + \sum_{j=1}^{I} \gamma_{ij} \ln p_{jt} + \beta_{ih} \ln\left(x_{ht}/a_{ht}\right) + \frac{\lambda_{ih}}{b_{ht}}\left(\ln\left(x_{ht}/a_{ht}\right)\right)^2 + u_{iht} \quad (1)$$

where $\ln a_{ht} = \alpha_0 + \sum_{j=1}^{I} \alpha_{jh} \ln p_{jt} + \frac{1}{2}\sum_{j=1}^{I}\sum_{i=1}^{I} \gamma_{ij} \ln p_{it} \ln p_{jt}$ and $\ln b_{ht} = \sum_{j=1}^{I} \beta_{jh} \ln p_{jt}$

Subscripts *i, j =1, 2, ...I* represent consumer goods considered by the model (electricity, gas, liquefied petroleum gas (LPG), car fuels, public transport, food and non-alcoholic drinks, other non-durable goods), w_{iht} is the participation of good *i* in total expenditure on non-durable goods by household *h* at moment *t*.[11] The price vector faced by households at each moment in time is $\vec{p}_t = \left(p_{1t}, \ldots, p_{It}\right)$, with x_{ht} being total expenditure on the goods modelled for each household. With regard to standard specifications of QAIDS models, the income parameters $\{\beta_i = \beta_i(z_{ht})$ and $\lambda_i = \lambda_i(z_{ht})\}$ depend on some idiosyncratic variables. Besides, we have included quite a lot of heterogeneity in the intercept as far as the data base permits us: $\alpha_{ih} = \alpha_i(z_{ht})$. This allows extra heterogeneity to be accounted for by the model in order to control for the composition of the household, place of residence (urban/rural), etc., which have proven to be very important in the estimation procedure.

We estimate the system in equation (1) by non-linear instrumental variables to take account of measurement errors in total expenditure (which are assumed to be generated by infrequent purchases).[12] We employ the exogeneity of prices and demographic characteristics as an identifying assumption.

Table 1 shows uncompensated own-price elasticities evaluated for the whole sample and for different sub-samples. The most interesting feature we would like to mention here is that the 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. We also found that income elasticities vary when considering different sub-samples, which vindicates the need to introduce observed heterogeneity in the demand models (see Nicol, 2003). Put in other words, estimation with the whole sample (which results in mean value-adjusted regressions) masks the true parameters for population sub-samples that exhibit different behaviours.

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[11] In our data base, there are 51,691 households distributed between 1973-74, 1980-81 and 1985-95.

[12] There are alternatives to estimating the model under different reasons for zeros in some goods. However, it is very difficult to deal with more than 3-4 goods and more than one reason for the zeros, as emphasized by Lee and Pitt (1986).

Table 1. Own-price elasticities by location of the household

Good	whole sample	Rural	Villages	Urban
Electricity	-0.783	-0.447	-0.749	-0.962
Natural/mains gas	-0.046	-13.05	-9.997	-0.439
LPG	-0.249	-0.154	-0.325	-0.630
Car fuels	-0.058	-0.300	-0.272	0.010
Public transport	-0.091	-1.490	-0.777	-0.558
Food and Beverages	-0.190	-0.716	-0.420	-0.286

Source: Labandeira, Labeaga and Rodríguez (2006).
Notes: Uncompensated price elasticities at mean values for each sample. The term village refers to households living in towns between 10,000 and 50,000 inhabitants.

3. Microsimulating changes in energy prices

3.1. Simulation methodology

The objective of this paper is to anticipate, through microsimulation, the response of different consumers to (tax-induced) changes in the prices they pay for energy goods. The parameters for relative prices and income obtained from estimation of the demand system described by equation (1) allow us to calculate the new expenditure shares of goods as a function of prices, total expenditure and the share prediction error, $\hat{w}_{ih} = f\left(\vec{p}, x_h\right) + \varepsilon_{ih}$. The share prediction error is calculated as the difference between the observed participation of goods in household spending and ex-ante predictions by the model (see Baker, McKay and Symons, 1990). It includes something that could be interpreted as an observable fixed effect, that is, the part of each proportion not explained by the relative prices, the actual expenditure or the error term. It therefore incorporates the estimated heterogeneity in demand in the sample of households (place of residence, household composition, tenure regime, etc).

To calculate the new post-reform prices needed to perform any simulation, we assume that the change in tax rates is fully transferred to consumers. Consumer prices, p_i,, are the sum of producer prices, q_i, value added taxes, t_{VAT}, and the equivalent ad valorem tax rate corresponding to excise duties, τ_i, defined as the ratio between excise duties and producer prices, $p_i = (1 + t_{VAT})(1 + \tau_i)q_i$. Then, post-reform expenditure on each good is calculated by multiplying total expenditure by the new shares estimated by the model. Subsequently the new tax revenues are obtained.

Finally, to perform a welfare analysis of tax reforms, we must specify household preferences corresponding to the model equation (1). In particular, the household budget share equations in (1) are derived from the following indirect utility function (Banks, Blundell and Lewbel, 1997),

$$v_{ht}(x_{ht}, \mathbf{p}_{ht}) = \left[\frac{b_{ht}}{\ln(x_{ht}/a_{ht})} + d_{ht} \right]^{-1} \qquad (2)$$

where d_{ht} is defined as

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

By inverting the indirect utility function above, we obtain the equivalent income at pre-reform prices, $\hat{x}_h^0 = f\left(\vec{p}^0, u_h^1\right)$, required to attain the same post-reform utility level at final prices, $u_h^1 = f\left(\vec{p}^1, x_h\right)$. Then, it is possible to estimate the equivalent variation (*EV*) as the difference between the budget constraint and the equivalent income (see King, 1983). Positive equivalent variations measure welfare losses following a rise in consumer prices, as they represent the amount of money that needs to be subtracted from the household in order to attain the post-reform level of utility at initial prices.[13]

Similarly, it is possible to estimate the compensating variation (*CV*) as the difference between the equivalent income to attain the original utility level at post-reform prices, $\hat{x}_h^1 = f\left(\vec{p}^1, u_h^0\right)$ and the budget constraint. In this case, positive compensating variations measure welfare losses following a rise in consumer prices, as they represent the amount of money that needs to be transferred to the household in order to attain the pre-reform level of utility at final prices.[14] Besides, it is possible to calculate the deadweight losses (*DW*) from the tax reform (the welfare losses which cannot be compensated with increased revenues), by subtracting the change in tax revenues from *EV*.

3.2. Data

For simulation purposes, we use 1995 annual data from the CFES, a rotating panel whose collaborating households are observed for a maximum of eight quarters. The simplest approach to estimate individual annual expenditures consists of adding up quarterly expenditure by households that collaborated during the four quarters of 1995. However, the presence of some attrition bias, since there would be too few observations for some groups of households (e.g., residences in rural areas, households with more than 2 children), dissuaded us from using this procedure as a high degree of representativeness is important to estimate total expenditure or tax payments for the whole population.[15] The lack of information to estimate individual annual expenditures of households that collaborate three or fewer quarters could be compensated for by using their average expenditure. Unfortunately, with this procedure we lose some information about the seasonal pattern of household spending, which is crucial for estimating annual expenditure on energy goods. Furthermore, the seasonal bias is enlarged by the presence of infrequency problems (see Labandeira, Labeaga and Rodríguez, 2006).

Therefore, the aim of the methodology used for constructing annual data for individual households with CFES data must be twofold. First, it should be able to keep the representativeness of households as high as possible. Second, it should maintain the seasonal behaviour of household expenditures throughout the year. Subject to these two restrictions, we selected those households that collaborate in at least one quarter of 1995 and also in four consecutive quarters. As a result, there are 2,900 households in the database used for simulations, representing about 92% of households in CFES for 1995. The database for

[13] That is the maximum amount of money that the household would be willing to pay in order to avoid the price change.
[14] That is the minimum amount of money that the household will demand as compensation.
[15] Population values are calculated by multiplying data from each household by a representative grossing up factor provided for each household by the INE.

simulation purposes includes, for example, households that collaborate the four quarters of 1995 and households that collaborate the last three quarters of 1994 plus the first quarter of 1995.[16] For the latter, we estimate the unknown expenditures in 1995, $\hat{e}_{iht}^{1995}$, with the expenditures in 1994, e_{iht}^{1994}, scaled by the corresponding quarterly price indexes, I_{iht}^{94-95}, provided by INE where the subscript *t* denotes the quarter.

4. The effects of carbon taxes on Spanish households

4.1. The simulated reform

As previously mentioned, in this article we simulate the effects of the introduction of a tax on Spanish CO_2 emissions equal to 50 Euros per ton of CO_2, similar to the one applied in certain countries such as Sweden and Norway.[17] This is a relatively high tax rate if we compare it with those in other European countries, like The Netherlands and Finland, or with prices for carbon emissions in the EU emissions trading scheme (EUETS). However, it is justified by the considerable deviation of Spanish CO_2 emissions from the EU burden sharing agreement which requests a strong corrective intervention such as this to foster compliance (for more on this see Labandeira and Rodríguez, 2007). In addition, the estimations of the social cost produced by the emissions of this greenhouse gas situate the rate in a plausible interval.[18]

To perform simulations with the household demand model, we need to know the effects that the tax under consideration will have on the prices paid by consumers. In order to calculate them, we have used an input-output model which allows us to compute the changes in the prices of all the goods consumed by the households following the simulated tax (Symons, Proops and Gay, 1994; Labandeira and Labeaga, 1999). This is because, given the strong dependence of all sectors on the energy sector, any analysis that examines the direct effects on the prices of energy goods would necessarily be incomplete.

The input-output model used makes it possible to compute the carbon content of each of the goods and services produced in the economy. We can thus calculate the direct CO_2 emissions (through the consumption of fossil fuels) as well as the indirect emissions (consumption of other goods and services) by households. The data regarding the intensity of the CO_2 emissions in each of the sectors has been taken from Labandeira and Labeaga (2002), who use 1992 as the year of reference. Unfortunately, we do not have reliable disaggregated data for more recent years in Spain, although the changes in sector intensities of CO_2 between 1992 and 1995 are probably of little significance owing to the absence of structural changes in such a short span of time.

The price changes brought about by the environmental tax are calculated by combining the data of the input-output table for the Spanish economy in the year 1995 with the sectoral intensities of CO_2 for 1992. To do this, we deflate the tax rate to 1992 prices and obtain the price changes as percentage increments, calculated as an adjusted average of the weight of each sector in the input-output table of 1995 on each group of goods in the household demand model.

[16] The database is completed with households that collaborate the last two quarters of 1994 plus two quarters of 1995 and households that collaborate the last quarter of 1994 plus three quarters of 1995.
[17] See, e.g., Swedish Tax Authority (2003).
[18] See the survey on the issue by Pearce (2003).

4.2. Results

In this section we address some of the economic, distributional and environmental effects of the simulated (hypothetical) tax rate. First, we look at the degree of behavioural response to the change in relative prices by households, and then proceed to describe the revenue effects and their distribution across goods and households. Finally, we explore the welfare effects of the simulated reform in terms of welfare measures, efficiency losses and pollution correction. Even though all simulations are performed with microdata, the results are aggregated for the population.

Table 2 shows the effects of the simulated tax on the prices of each of the goods. The environmental tax causes a significant increase in the retail price of electricity and of the different fossil gases, also bringing about sizeable but lesser increments in the price of public transport services and car fuels. This is to be expected given the reduced taxation of energy goods for the household in relation to fuels, which are already the object of a notable excise duty with clear revenue-raising purposes.

Table 2. Percent changes in prices, expenditure, demand and tax revenue by group of goods

	Prices	**Expenditure**	**Demand**	**Tax Revenue**
Electricity	23.66	14.0	–7.8	151.0
Natural/mains gas	15.85	1.8	–12.1	89.0
LPG	17.18	22.9	4.8	281.0
Car fuels	6.39	2.5	–3.6	4.9
Public transport	8.51	4.2	–4.0	120.3
Food and Beverages	2.35	–1.3	–3.5	36.1
Other non-durables	0.96	–0.4	–1.4	5.5
Total				*12.8*

Source: Own calculations.

Table 2 also depicts the changes in the expenditure by all households, as well as the changes in the demand for different groups of goods. The latter are estimated upon the basis of price changes and the monetary expenditure made by households. The rise in the cost of electricity leads to its partial substitution by LPG due to the generalised use of both types of energy for cooking and house heating. There is a notable reduction in the demand for natural gas, used mainly for heating purposes by households located in urban areas. Only reductions in the expenditure on food and other goods are observed, despite the relatively small increase in the prices of these items. The relative rigidity of the demand for energy goods for the household and for transport services, along with the increase in their prices, requires adjustments to be made in the expenditure on food and other goods.

Finally, the last column in Table 2 shows the percentage changes in the tax revenues obtained from the goods included in the demand system. In the pre-reform situation, most tax revenues are collected from three groups: other non-durables, car fuel and food-beverages. In this sense, the high relative weight of vehicle fuel within indirect taxation (despite a relatively low share on household expenditure) has to do mainly with the high excise duties and demand rigidity. Regarding post-reform, the simulated tax increase clearly generates a significant amount of receipts, while its distribution among the various goods is rather uneven. The greatest revenue change comes from the consumption of LPG, which responds not only to the increase in taxation, exceptionally low in the pre-reform situation, but also to an increase in its consumption due to the substitution effects. There is also a sharp increase in the revenue obtained from electricity, where the greatest price increases occur, and public transport services. Revenues from food and non-alcoholic beverages grow more than one third, a result which could not be anticipated and which is due to the significant increase, in relative terms, of the taxes levied on these goods. Car fuels and other goods experience the smallest revenue increases in relative terms, although in the case of car fuels, there is a significant rise in absolute public receipts.

A relevant matter is how the burden of those tax revenues is distributed over income groups, which can be observed in Table 3. The increase in tax payment caused by the introduction of the environmental tax is noteworthy, and ranges from an average of about 19% for households in the first decile to around 10% for those belonging to the last decile. These values correspond to indirect consumption taxes once durable goods have been excluded from calculations (e.g., housing, car). This suggests that an environmental tax such as the one simulated has a regressive effect on income distribution in Spain. The finding is obviously related to the fact that most energy goods are considered necessities (see Labandeira, Labeaga and Rodríguez, 2006) and also to the interaction effects that they have on other goods such as food (e.g., energy for cooking). Also, the relatively smaller increase in the price of fuels diminishes the potential progressive effects that could be expected from this phenomenon[19].

The results described above are coherent with those obtained by other empirical studies (Metcalf, 1999; Cornwell and Creedy, 1996; Symons Proops and Gay, 1994). However, they contradict the usual argument that a tax on CO_2 emissions would have a neutral effect in Mediterranean countries (e.g. Barker and Kolher, 1998; Labandeira and Labeaga, 1999; Tiezzi, 2004). In particular, Labandeira and Labeaga (1999) stated that the distributive effects of a Spanish tax on CO_2 emissions tended toward proportionality (for a lower tax rate). Their result can be explained by the smaller increases in the prices of energy goods and other goods, which could have masked the real distributive changes.

In Table 3 we also show the distributive effects when we classify the households according to other variables of interest (work status, number of children under the age of 14, place of residence). The effects depicted by the table are now of little significance, the maximum difference being 1.5 percentage points. Households with a retired head and households living in rural areas are the most negatively affected. There are several factors that can explain this result: (i) both groups of households have lower than average income levels and therefore the energy goods have a greater weight in their total expenditure; (ii) retired persons tend to be more sedentary, which increases their consumption of energy goods for the house; (iii) at the same time, households living in rural areas depend to a greater extent on private transport and therefore consume more fuels. In sum, the income level of households is the main determinant of the distributive effects of energy price changes, above other considerations such as the place of residence or household composition.

[19] See Speck (1999) for a discussion on this subject.

Table 3. Distributional effects. Average tax payments and percent increases over pre-reform tax payments

	By Decile			By Idiosyncratics	
	Euros	**%**		**Euros**	**%**
Decile 1	106.7	19.1	**Retired**	223.9	13.9
Decile 2	151.1	16.5	**No Children**	260.5	12.9
Decile 3	183.3	15.5	**2 Children**	295.2	12.8
Decile 4	213.8	14.2	**>2 Children**	322.2	13.2
Decile 5	242.4	13.6	**Rural**	246.2	13.4
Decile 6	272.7	13.5	**City**	295.4	12.4
Decile 7	303.8	12.8	***Average***	*277*	*12.8*
Decile 8	339.3	12.3			
Decile 9	396.9	11.8			
Decile 10	540.7	10.7			

Source: Own calculations.

The micro model also makes it possible to calculate the effects of the environmental tax on the welfare of households. Table 4 shows the absolute and relative (with respect to total expenditure) welfare losses measured as equivalent and compensating variations. The welfare effects of the simulated carbon tax are certainly significant since the losses are substantial in absolute terms for each type of household. Variable distributional effects are not detected in such measurements, however, representing approximately the same proportion of expenditure for each grouping of households. This table also informs on the efficiency (deadweight) losses caused by the introduction of the simulated tax. It is evident, as anticipated by public economics textbooks, that the efficiency loss in relative terms rises progressively with level of income, i.e., the simulated tax more intensely distorts the decisions of wealthier households. Obviously, this is because households with less income are more dependent on the expenditure on necessities and they have fewer possibilities of substitution and/or adaptation when faced with price hikes. In the most extreme case, households belonging to the tenth decile, there is an excess burden of more than two thirds of the extra tax revenue.

With regard to the environmental effects produced by the simulated reform, we have considered both the direct CO_2 emissions by the households in their consumption of fossil fuels as well as the indirect emissions associated with consuming other goods and services (in our model, electricity, food and beverages, public transport and other non-durable goods).[20] The outcome is an important reduction in direct emissions from combustion of natural gas (-12.1%) and car fuels (-3.6%), followed by drops in indirect emissions from consumption of public transport services (-4%), food and beverages (-3.5%) and other non-durable goods (-1.4%). As expected, the greatest impact on emissions (-16.7%) has come up as a consequence of a decreased demand of electricity by the households (-7.8%). The carbon tax will have a heterogeneous impact on the diverse generation technologies coexisting in that sector, the greatest on coal generation plants, the technology with the greatest carbon emission ratios

[20] For the latter we have taken the emissions by each productive sector in 1995, provided by INE.

(Linares, Santos, Ventosa and Lapiedra, 2006).[21] This reduction represents 13% of the total emissions produced by the households in 1995, which vindicates our specific consideration of the carbon tax impact on electricity generators.

Table 4. Welfare and efficiency effects measures (Euros and percent changes)

	EV		CV		DW	
	Euros	**%**	**Euros**	**%**	**Euros**	**%**
Decile 1	133	2.70	138	2.80	26	25
Decile 2	202	2.70	208	2.79	51	34
Decile 3	253	2.70	261	2.79	70	38
Decile 4	304	2.70	313	2.78	90	42
Decile 5	354	2.70	364	2.78	112	46
Decile 6	405	2.70	417	2.78	132	49
Decile 7	461	2.69	474	2.76	157	52
Decile 8	532	2.69	546	2.77	193	57
Decile 9	644	2.69	662	2.76	247	62
Decile 10	937	2.67	964	2.75	396	73
Retired	334	2.68	344	2,77	110	49
No Children	399	2.68	410	2.76	138	53
2 Children	454	2.70	467	2.77	159	54
>2 Children	496	2.71	511	2.79	174	54
Rural	361	2.69	371	2.77	115	47
City	468	2.69	482	2.77	173	58

Source: Own calculations.

Notes: EV as Equivalent Variations; CV as Compensating Variations; DW as Deadweight losses; rev_{ih}^0 and rev_{ih}^1 as pre-reform and post-reform tax revenues, respectively. Percent changes are calculated over total expenditure (for EV and CV) and tax revenue (DW) on non-durable goods.

Definitions: $EV_h = x_h - \widehat{x}_h^0$; $CV_h = \widehat{x}_h^1 - x_h$; $DW_h = EV_h - \sum_{i=1}^{I}(rev_{ih}^1 - rev_{ih}^0)$.

There is also notable substitution between electricity and LPG, so that a tiny part of the fall in the CO_2 emissions generated by the consumption of electricity is compensated for by an increase in the consumption of LPG (4.8%), one of the fossil fuels with the smallest carbon emission ratios and similar to natural gas. To summarize, the household CO_2 emissions fall

[21] The share of coal plants in the 1995 Spanish electricity market was equal to 41% (Miner, Spanish Ministry of Energy and Industry, 1996). Therefore, we can assume the same weight of coal power plants in the total electricity consumed by the households. As a consequence, their supply of this kind of electricity to the households, and related emissions, must decrease a 19% to accommodate the lower demand (-7.8%). Then, the -19% reduction in coal generation can be converted into a -16.7% reduction in emissions by taking into account that CO_2 emissions generated by coal power plants represented 88% of total emissions produced by this sector in 1995.

approximately 17% (with respect to the total emissions produced by the households in 1995) if we consider both the direct and the indirect emissions of the residential sector.

Finally, significant reductions are produced in the emissions of nitrogen oxides (NO_x), approximately –10%, and sulphur dioxide (SO_2), approximately –16%. Those emissions are responsible for acid rain and adverse health effects, mainly caused by the consumption of fuels for transport and indirectly through the consumption of electricity and some non-energy goods. Therefore, changes in energy prices contribute significantly to the reduction of different environmental problems, providing ancillary benefits and yet another reason for the introduction of the simulated corrective policy.

5. Conclusions

In this article we have presented a microsimulation model to calculate the effects of hypothetical *ex-ante* price changes in the Spanish energy domain. Our main aim was to obtain in-depth information on the behavioural responses by different types of households, which would allow us to determine the welfare effects of such price changes, their distribution across society and the environmental consequences within the residential sector. The model uses the results of our prior estimation of a demand system with Spanish household data from 1973 to 1995, specially designed for a simultaneous analysis of different energy goods and summarized in this paper.

Our contribution to the empirical literature is threefold. We have greatly improved previous attempts to simulate the effects of carbon taxes in Spain, enlarging the relatively scarce international literature on the issue. Besides, unlike in most applications, we have provided precise results on several effects associated with energy price hikes (efficiency, distribution, welfare, environment), as we used a microsimulation procedure that focused on the energy domain and took into account the links among different energy goods. Finally, we have dealt with key aspects of energy taxation at a level of disaggregation quite infrequent in the literature, which may be very useful for future policy design or reform.

Indeed, we believe that the context surrounding this piece of research shows the practical relevance of the article. The significance of the economic and distributional effects related to energy price changes (such as those seen in the last few months) is clearly unquestionable, from both positive and normative points of view. Just as important are the growing environmental concerns and stark inefficiencies that have marked the Spanish energy domain in recent years, matters that demand a detailed economic approach to the issue.

The paper simulates the effects of an energy tax that resembles a 50-Euro tax on carbon dioxide emissions. In the first place, this tax rate intends to approximate the externality arising from such emissions, being close to those actually applied by some European countries. Secondly, it can be justified by the uncontrolled path of Spanish emissions and energy consumption. Indeed, the context surrounding this piece of research shows the practical relevance of the article. The significance of the effects related to energy price changes (such as those seen in the last months) is clearly unquestionable, from both positive and normative points of view, and demand a detailed economic approach to the issue.

The results of the simulation point to a significant behavioural response by households (as we adjust demand in the long run), sizeable emission reductions and tax revenues. The changes in expenditures on different goods are varied and cannot be explained exclusively by the effect of the simulated tax on prices. Other relevant variables are the heterogeneity of households and the possibilities of substituting certain energy goods for others. Tax receipts from a tax on CO2 emissions are sizeable, as expected for goods with relatively rigid demand and important tax rate increases. We have also seen how the distribution of the tax burden among the population tends toward a slight regressivity, which is an important contribution of the paper in view of previous results for the Mediterranean countries. The effects of the reform on the welfare of households also appear to be significant in absolute terms. Unlike welfare losses, the loss of efficiency in relative terms grows progressively with the level of income; i.e., the environmental tax more intensely distorts the decisions made by households with higher incomes. Finally, we have shown how the environmental impact of this tax reform is noteworthy, and it does not only affect carbon dioxide emissions but also produces secondary environmental benefits.

With regard to policy recommendations, we conclude that the simulated policy seems to be a feasible option for tackling some of the current and severe inefficiencies in Spanish energy and environmental fields. In particular, carbon taxes may play an important role in controlling the emissions by the sectors excluded from the EUETS (as stated in the National Allocation Plans), like transport and direct emissions from households. Additionally, this result can be relevant not only for Spain but also for other European countries with a negative profile in their progress towards achieving their Kyoto targets (e.g., Italy, Ireland, or Portugal). In this sense, carbon taxes could be introduced in a green tax reform fashion to further increase their efficiency enhancing properties (see Labandeira, Labeaga and Rodriguez, 2004).

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