The E®ects of a Sulphur Tax Levied on the Spanish Electricity Industry

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Abstract

This paper deals with the design and e®ects of a hypothetical environmental tax on the Spanish electricity generating industry in 1994. The tax intends to reduce the sizable Spanish SO_2 emissions and responds to both internal and external (EU) pressures to control acidi¯cation. It applies a uniform tax rate, representing the damage from Spanish sulphur emissions, on a product tax base (fossil fuel use). Under an assumed full tax shifting to residential electricity prices we simulate the economic, environmental and distributional impacts of the tax, with the use of Spanish micro data on household consumption.

Key words: Acid Rain; Environmental Taxation; Environmental Valuation; Demand Systems; Spain.

JEL classi¯cation: C33; H23; H31; Q28; Q41

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1 Introduction

Acid deposition has been long recognized as a key European transboundary environmental problem. With a focus on Spain and an empirical approach, this paper studies the negative consequences of SO_2 emissions, a chief cause of acidi¯cation, and the usefulness of sulphur taxes. Special attention is also given to the distributional e®ects arising from the taxation of electricity-related sulphur emissions.

The structure of the paper is as follows. Section 2.1 shows some basic information on Spanish SO_2 emissions and the requirements to control them. We then examine sulphur tax design and implementation in section 2.2. With this background, section 2.3 yields the short-term e®ects of the hypothetical Spanish sulphur tax on electricity prices. Section 3.1 discusses the theoretical and empirical requirements to implement a micro-simulation of an indirect tax reform. Finally, section 3.2 deals with the actual micro-simulation of the changes in electricity prices, presenting some results for Spain.

2 Spanish SO_2 Emissions and the Use of Sulphur Taxation

2.1 Main Emitters and the Need for Control

The considerable use of fossil fuels in electricity generation de¯nes Spain as the ¯fth major European emitter of sulphur dioxide. Indeed, table 1 shows that the electricity industry alone causes as much as two thirds of Spanish SO_2 emissions.

The substantial damage associated to acid rain phenomena is itself a strong reason to control sulphur discharges, and a clear explanation of the concerted international e®ort to control SO_2 emissions. In fact, European regulations to tackle acidi¯cation have been in°uenced by the so-called sulphur Protocols, which establish maximum emission limits for the participating countries[1]. The ¯rst sulphur Protocol (Helsinki, 1985), not signed by Spain, called for all parties to reduce their SO_2 emissions by 30% between

[1] The basic structure for international cooperation to cope with acidic deposition in Europe is the UN ECE Convention of Long-Range Transboundary Air Pollution (see section 2.4.1), adopted in Geneva in 1979 and in force since 1983. The Convention has been extended by ¯ve speci¯c Protocols, two of them dealing with SO_2 emissions.

1980 and 1993. Per contra, the second sulphur Protocol (Oslo, 1994) used an e®ect-oriented approach by basing the SO_2 emission ceilings on the susceptibility of natural ecosystems to sulphur depositions (critical loads).

Table 1 Spanish SO_2 Emissions in 1994

	tonnes	per cent
Energy-related:	1,919,468	95.49
Electricity(¤)	1,237,000	61.54
Industries	482,758	24.02
Transport	123,104	6.12
Households	48,510	2.41
Industrial Processes	58,715	2.92
Waste	31,955	1.59
Total	2,010,138	100.00

Source: Spanish Ministry of the Environment and (¤)OFICO (1995)

Yet, a review of the existing Spanish (and EU-mandated) environmental legislation shows a conspicuous laxity with Spanish SO_2 emissions[2]. Even the second sulphur Protocol has been quite permisive with Spain, only setting a minor reduction commitment. Actually, this may re°ect the comparatively limited e®ects of the acidic depositions of Spanish origin, both inside and outside Spain[3].

There are, however, growing demands for a reduction of Spanish sulphur emissions. On the one hand, the sizable SO_2 emissions from Northern Spain are rather damaging due to the climatic and soil characteristics of that region (see ¯gure A1.1). On the other hand and most importantly, the European Commission has recently produced a EU strategy to combat acidi¯cation (ESCA, COM(97) 88¯nal) which is considerably tough on Spanish

[2]Legislation on this issue comprises Decree 833/1975 (with the maximum levels of industrial SO_2 emissions) and Royal Decrees 1613/1985 and 646/1991 that respectively gave formal e®ect to Directives 80/779/EEC (on SO_2 inmission levels) and 88/609/EEC (on emissions from large combustion plants). The fundamental RD 646/1991 not only re°ects the EU's preferential treatment to Spain in terms of emission standards, but it also perpetuates the exemptions granted by D 833/1975 on grounds of industrial and energy needs.

[3]First, acidi¯cation problems tend to be insigni¯cant in the South of Spain because base cations counteract any acidic deposition. Second, meteorological and geographical conditions imply that Spanish SO_2 abatement does not contribute much to the attainment of critical loads abroad, especially when compared to other European territories (see Labandeira-Villot, 1996b). Hence, we can a±rm that Spain faces other more pressing environmental problems.

SO_2 emissions[4].

The objective of ESCA is to reduce the area of sensitive ecosystems with excessive acidic depositions (i.e. above critical loads) in 1990 by at least 50% for the year 2010. This is an `interim target' towards the achievement of zero ecological damage from acidi¯cation, as concluded by the EU's 5th Environmental Action Programme. Such interim target would lead to important SO_2 abatement by EU members, to be determined in an ad hoc Directive by the end of 1997. Table 2 presents the expected Spanish SO_2 emission ceiling to comply with ESCA, together with the o±cial Spanish ¯gures (ESEMA, Economic and Environmental Strategy) and the maximum technically viable abatement.

Table 2 Spanish SO_2 Emissions and Abatement Costs in 2010

Scenario	kt of SO_2	% Change[a]	Pesetas/year[b]
ESEMA[c]	1,452	-35.0	n.a
ESCA Interim Target	618	-72.3	61,600,000,000
Max. Feasible Reduction	137	-93.9	199,360,000,000

[a] relative to 1990; [b] cost-e®ective calculation; [c] ¯gures for 2000
Source: Amann et al. (1996) and MINER (1995a)

2.2 The Sulphur Tax: Design and Implementation

Table 2 has reported the extensive (minimum) costs associated to Spanish SO_2 abatement. As a consequence, market-based instruments are to be obviously preferred to conventional environmental regulations. In particular, a sulphur tax on the electricity industry can be a cost-e®ective method to reduce Spanish SO_2 emissions.

There are some reasons to circumscribe the application of the Spanish sulphur tax to the electricity generating industry. On the one hand, the comparative magnitude of electricity-related SO_2 emissions recommends a speci¯c treatment. On the other hand, such a partial sulphur tax is more feasible from an administrative perspective and its short-term price e®ects can be easily appraised.

Although a direct taxation of electricity-related SO_2 emissions is not implausible in practice, our empirical exercise implements a product sulphur tax. The sulphur tax base is the amount of fossil fuels used in electricity generation, re°ecting the good nexus between actual SO_2 emissions and the

[4]Even without considering ESCA, the new Integrated Pollution Prevention Control Directive (96/61/EC) is very severe on SO_2 emissions. Moreover, a stringent Directive on emissions from large combustion plants is being negotiated.

sulphur content of fuels. Given the minor sulphur content of natural gas, only fuel-oil, (black and brown) lignites and (Spanish and imported) hard coals are subject to sulphur taxation. By introducing a variable rebate for desulphurization[5], the linked product tax becomes a suitable proxy of a genuine tax on SO_2 emissions.

Concerning the sulphur tax rate setting, there are a number of possibilities. To begin with, the sulphur tax rate may either represent SO_2 damage or the required incentive to achieve a deposition or emission target. Moreover, the regulator may either introduce uniform or spatially-di®erentiated tax rates across the country. In this exercise, however, we have only considered the use of a uniform tax that re°ects the external costs from sulphur emissions.

Whereas the choice of spatially-unaware taxation with non-uniformly mixed pollutants can be defended on administrative grounds, the use of SO_2 emission damages needs further comments. Intuitively, there is a strong case against it because the primary reason for the sulphur tax was the existence of strict limits on Spanish SO_2 emissions. Nevertheless, the practical di±culties to calculate the precise rate that promotes compliance with a distant target has advised the damage assessment. In this sense, the adopted tax rate is not discretionary and encourages a cost-e®ective move towards tougher environmental objectives.

Assessing the damage costs of Spanish SO_2 emissions is far from simple too, as we broadly relate in appendix 1. First of all, there is a total lack of background valuation studies for Spain so we must either produce our own estimates -a formidable task- or extrapolate the results obtained in other countries. But even the international literature on sulphur damage valuation is quite limited and questionable. In fact, imprecise `top-down' analyses have been profusely followed and several damage categories have not been even estimated.

In consequence, we restricted our valuation to four damage categories (human infrastructure, forests, crops and human health-mortality), combining Spanish and carefully extrapolated international estimates. In all cases we produced spatially-unaware ¯gures[6] to avoid incongruities with the adopted (uniform) tax rate. As a result, the total damage (UN ECE region) caused by Spanish sulphur emissions was estimated to be 41 pesetas per kg of SO_2,

[5] Desulphurization may be achieved through conventional physical cleaning or end-of-pipe technologies, with approximate removal e±ciencies of respectively 20% and 90%. However, only the former were somewhat present in the Spanish electricity industry during 1994.

[6] This only applies to the location of SO_2 sources within Spain, since our estimates re°ect the (standard) geographical dispersion of Spanish emissions across Europe.

which is equivalent to the set of product tax rates reported by table 3. In light of this new evidence, previous estimates by Labandeira-Villot (1996b) seem now excessive due to his straight extrapolation of UK damage costs. Still, the shortcomings of the valuation process recommend a cautious interpretation of the new damage figure and implemented tax rate.

With the assignment of revenues to the general budget, the hypothetical Spanish sulphur tax largely resembles its successful Swedish counterpart. In this sense, even if a comparatively low Spanish rate will not lead to an immediate revenue debacle, as in Sweden (see appendix 1 and Labandeira-Villot, 1996a), the likely instability of sulphur receipts diminishes the fiscal relevance of the simulated tax.

Table 3 Hypothetical Sulphur Tax Rates. Spain, 1994

Product	Tax Rate (Ptas/t)	Average Price Increase (%)
Black Lignite	3,895	54.0[a]
Brown Lignite	1,640	52.4
Spanish Coal	820	6.9[a]
Imported Coal	533	4.1
Fuel-Oil	1,025	4.8

Note: Assuming the usual sulphur contents in Spain; [a] with mining subsidies
Source: Table A1.1 and Ministerio de Medio Ambiente (1996)

2.3 Internalizing the External Costs of Emissions in Electricity Prices

Although the Spanish electricity system has obviously changed over time, its current structure largely responds to the strong constraints faced during the seventies and early eighties. The oil world crises, the nuclear moratorium and the protection granted to domestic fossil fuels have thus defined, among other factors, a somewhat inefficient electricity industry. This is clearly observed in the extensive use of low-quality Spanish fuels and obsolete technologies, origin of substantial internal and external costs.

As a matter of fact, the proposed sulphur tax could tackle some of the previous structural failures. In this exercise, however, our objective is not to appraise the reaction of the Spanish electricity industry to the hypothetical tax, but to study the demand side effects. This has to do with the institutional setting of the electricity sector in 1994, the year of the simulation, which would presumably minimize any immediate structural alteration.

Indeed, a significant short-term reduction of SO_2 emissions by electricity suppliers is unlikely. First of all, the introduction of desulphurizing facilities takes time and considerable resources. Moreover, capacity constraints prevent any meaningful short-term reallocation of electricity production with this purpose[7]. Finally, whereas the use of a cleaner fuel mix in power stations could improve matters straightaway, this is somewhat precluded by the strong (price and quota) protection to Spanish coal and lignite[8]. As a consequence, most short-term reductions of electricity-related SO_2 emissions are to be expected from demand response to higher electricity prices.

However, the hypothetical tax will eventually encourage a less polluting electricity industry. In the medium and long terms the tax will concentrate its effects on fossil fuel generators, given the nuclear moratorium and the difficulties for new hydro developments. Thus, the sulphur tax will induce fuel substitution and desulphurization in modern coal power plants, also favouring the irruption of natural gas fired stations to replace obsolete capacities.

The easiness to shift the sulphur tax to consumption also explains the lack of immediate reaction by electricity producers. In fact, under the `Legal and Stable Framework' (Marco Legal y Estable, RD 1538/1987), the government sets the annual electricity rates that accomplish the equalization of the total costs of service[9] with the revenues obtained from electricity sales. Since the sulphur tax burden can be interpreted as an extra cost to production, the calculation of the electricity price increase is straightforward.

Figure 1 presents some basic data on Spanish electricity production and fossil fuel consumption during 1994 (from MINER, 1995). With this information and the sulphur tax rates of table 3, household electricity prices would rise by 7.5% (see OFICO, 1995b) assuming a full shifting of the sulphur tax burden to residential consumption.

There are of course several shortcomings in the preceding calculation. First, a selective price increase for households is certainly disputable because residential consumption only represents a portion of total electricity demand. Nevertheless, transferring the sulphur burden to industrial consumption would affect the precarious competitive standing of Spanish industries, already facing comparatively high electricity prices. Second, indirect electricity demands by final consumers are not contemplated[10]. Third, we

[7] Spanish electricity production follows a joint cost-minimization of the generating units (merit-order procedure) that is centrally performed by Red Eléctrica de España, a government controlled society.

[8] Some electricity suppliers may still react to the sulphur tax, as Padrón-Fumero (1997) has recently showed with a linear programming model that replicates the short-run dispatch by Spanish electricity generators.

[9] These costs (generally standardized) include fixed costs of generation, costs of operation and maintenance, costs of fuels, costs of distribution, etc.

[10] In another paper we have used input-output methods to assess the indirect consumers' demand for CO_2 emissions (see Labandeira and Labeaga, 1997). However, given the less

are using ex post information on Spanish electricity generation with prediction purposes, which may be misleading as electricity supply and demand are closely related. Finally, the adopted price setting procedure will not exist once the ongoing liberalization of the Spanish electricity industry is completed.

Figure 1: The Spanish Electricity System in 1994

3 The Effects of Sulphur Taxes from Micro Data

In this section we explore the short-term effects of the hypothetical Spanish sulphur tax on households' demand, tax payments and government receipts. To do so we simulate with micro data from Spanish family surveys, appraising the consequences of the prior tax-induced rise in the price of electricity. Before simulation, however, it is imperative to estimate a demand system in order to obtain some needed parameters.

Some prudence is necessary when interpreting the effects of our `non-discretionary' sulphur tax. In fact, the simulated electricity price change is not a precise indicator of the externality caused by residential electricity consumption. Still, the electricity price increase was obtained by a simple and realistic procedure.

significance of indirect electricity requirements, we have not followed that approach here.

3.1 Theoretical Framework and Econometric Implementation

3.1.1 A Demand Model

Our study focuses on the demand for non-durable universally consumed commodities, that is, we exclude durable goods such as vehicles or domestic appliances. This is due to the use of micro data, as current expenditure can only proxy consumption if the good is non-durable. In this sense, the implicitly imposed intratemporal weak separability restrictions on marginal rates of substitution are ameliorated by the use of conditioning variables related to labour status as regressors (Browning and Meghir, 1991).

We employ a two stage budgeting process, where savings, labour supply and durable good tenure are determined in a first stage and the remaining expenditure is subsequently split between a range of non-durable categories: food and non-alcoholic drinks, alcoholic beverages, clothing and footwear, electricity expenses, gas expenses, petrol for private transport, public transport and a residual category of other non-durable goods. In this context, for consistent system estimation we must be sure that zero expenditures are only generated by infrequency of purchase. Therefore, we drop the observations in which a household provides all zeros in any commodity group of the system. We believe that infrequency of purchase occurs when households indicate at least one positive expenditure in every commodity group.

Given that we need the parameter estimates with simulation purposes, we should expect from our demand system the ability to obtain a realistic picture of the substitution, own price and income effects. Thus we opt for the quadratic extension (QAIDS) to the Almost Ideal Model of Deaton and Muellbauer (1980), as proposed by Banks et al. (1997). In this model, the budget share equations for good i can be expressed as

$$w_i = \alpha_i + \sum_{j=1} \gamma_{ij} \ln p_j + \beta_i \ln \frac{x}{a(p)} + \frac{\lambda_i}{b(p)} \left(\ln \frac{x}{a(p)} \right)^2 \qquad (1)$$

with

$$\ln a(p) = \alpha_0 + \sum_{i=1} \alpha_i \ln p_i + \frac{1}{2} \sum_{i=1} \sum_{j=1} \gamma_{ij} \ln p_i \ln p_j \qquad (2)$$

and

$$b(p) = \prod_{i=1} p_i^{\beta_i} \qquad (3)$$

where x and p are respectively total expenditure and prices. The model embodies the theoretical restrictions of adding up, homogeneity, symmetry (which can be imposed and tested as restrictions on the parameter vectors) and negativity (which cannot be imposed but can be tested by looking at the sign of the Slutsky matrix). For additional details on this demand system and the restrictions see Banks et al. (1997).

Such a functional form is appropriate for the purposes of our study. First of all, the preferences from which the QAIDS is derived do not embody additive separability and permit °exible price responses. Secondly, a quadratic term in the logarithm of real expenditure that yields a `rank three' demand system allows elasticities to depend on the level of expenditure, showing if the commodities are luxuries or necessities at di®erent expenditure levels. Hence we use a functional form that precludes the imposition of implausible price responses on data and permits a good degree of °exibility in income responses. Our results actually support the inclusion of the quadratic term in total real expenditure, as observed in appendix 3. In addition, if the theoretical restrictions are satis¯ed, the QAIDS can be integrated back to a cost function, a crucial requirement when studying the welfare impact of tax reforms (Banks et al., 1997).

3.1.2 Econometric Implementation and Empirical Results

Micro data present the problem of households recording zero expenditures. It is well known that when the dependent variable is censored an alternative to ordinary least squares (OLS) must be used. For the categories included, the sample selection and data analysis suggest that infrequency of purchase is the cause of censoring. Table 4 reports the percentage of positive expenditure in the estimating sample, where the problem of zeros does not seem to be severe except in the case of public transport.

Nevertheless, in those circumstances OLS yield biased estimators due to the existence of correlation between the error term and the total expenditure regressor. This can be solved by instrumenting total expenditure by total income which, in principle, should not display correlation with the error term as this variable is not a®ected by the decision to purchase (Keen, 1986). However, this procedure may actually fail due to the presence of non-linear terms in total expenditure. The solutions to overcome that problem include the proposals by Meghir and Robin (1992) or Hausman et al. (1995). Here we opt for instrumenting total expenditure with its lag which, in the absence of autocorrelation in the residuals, should be a suitable instrument. Thus, following Hausman et al. terminology, we use the repeated measurement estimator.

In addition to total expenditure, the empirical counterpart of equation (1) contains squared total expenditure, prices and a set of constant shifters as defined in appendix 2 (number of children in several age ranges, number of adults, dummies for age of household head and partner and dummies for education, occupation and geographical location). The model is estimated by a non-linear instrumental variables method (and minimum distance to impose the restrictions on the whole system) with total expenditure in t-1 as instrument for current total system expenditure.

Concerning the imposition of the theoretical restrictions, to avoid the singularity of the variance-covariance matrix of errors as any equation is a linear combination of the others (additivity), the last equation (other non-durable goods) is left out in the estimation and its parameters are retrieved with the additivity restriction[11]. Besides, the homogeneity restriction is imposed by entering all prices relative to that of the excluded good, and it is tested by means of a Chi-square test against the unrestricted system. In particular, we impose homogeneity in only one equation at a time in each of seven consecutive runs, so that a test statistic for each equation is available even if estimation is system-wide. We also provide a whole system homogeneity test. Symmetry, a whole system restriction, is imposed during estimation and jointly checked with homogeneity by means of a Chi-square test.

Table 4 Percentage of Positive Expenditures

Commodity Group	%
Food and Non-alcoholic Drinks	99.7
Alcohol	69.5
Clothing and Footwear	92.6
Electricity	98.4
Natural and Manufactured Gas	92.3
Fuel for Private Transport	71.0
Public Transport	41.0
Other Non-durables	100

Table A3.1 (appendix 3) presents the estimation results for the homogeneity restricted model and table A3.2 contains the symmetry restricted model. We find that homogeneity is not rejected in any equation, with the joint test of homogeneity also sustaining this hypothesis. Per contra, symmetry is strongly rejected at standard significance levels (see table A3.3) and, although this precludes the integrability of the demand functions for welfare evaluations, we will impose the theoretical restrictions at the simulation stage. The lack of significance of some price parameters results from the multicollinearity that can be detected in the price series during the time

[11] This is because adding-up requires $\sum_i \alpha_i = 1$, $\sum_i \beta_i = 0$, $\sum_i \gamma_{ij} = 0$ and $\sum_i \lambda_i = 0$. Moreover, homogeneity is satisfied if and only if $\sum_j \gamma_{ij} = 0$.

span of our sample. In any case, fifty per cent of the price parameters are significantly different from zero, at least at ten per cent significance levels.

Regarding the shape of the Engel curves, we have tested for the existence of higher order terms in the log of expenditure and found evidence for the presence of a significant quadratic term in the share equations for food and non-alcoholic drinks, electricity and gas. Moreover, the t-ratio on this variable for clothing-footwear is on the borderline of significance, which confirms the adequacy of the QAIDS model both for estimation and simulation. In addition, an exercise using total income as instrument for total expenditure does not provide good results, thus confirming the possible inconsistencies of the parameter estimates when using this variable in a context of non-linear Engel curves and non-linear errors in variables (Hausman et al., 1995).

The effects of real expenditure and prices on each household are given by their respective elasticities, which are presented in the bottom row of table A3.2 and calculated at sample means using the expressions detailed in Banks et al. (1997). In general, the pattern of expenditure elasticities falls in the expected classification, with food, alcoholic drinks, electricity and gas as necessities and clothing-footwear, petrol and public transport as luxuries (with some doubts for the last two groups). The sign of the price elasticities is also the expected except for clothing-footwear, probably affected by the mentioned errors in variables. The high value of the own price elasticity for electricity is probably reflecting not only the demand for this commodity but also the associated demand for electricity appliances, not explicitly considered. Although we do not report the cross-price elasticities in appendix 3, electricity and gas are substitutes.

The effects of demographics are also plausible for most parameter estimates. Children positively contribute to expenditure in food, clothing, electricity and gas, while the effect of young children on petrol consumption is negative and important[12]. The ages of the household head and partner and their squared terms are determinants of consumption, showing non-linear profiles of demand. Moreover, older than 65 household members have positive effects on electricity expenditure and negative effects on petrol consumption and public transport use. Finally, the geographical location of the household has significant and different effects in all shares: while rural families spend more on food, alcoholic drinks, clothing-footwear and petrol, urban households devote a large share to electricity, gas and public transport.

[12] This is probably because young children are often carried to school by their parents. Older children show positive effects on expenditure in public transport.

3.2 Simulation Methodology and Results

3.2.1 Simulation Methodology

In this exercise we consider an indirect tax reform as the tax-induced change in the relative prices of the commodities that compose the system, focusing on the short-run effects on revenues and households' welfare. We are aware that revenue changes will be normally fed back to consumers through subsidies and/or changes in the supply of public goods. Yet the revenues from the recent Spanish tax increases have not been handed back to consumers in a straightforward manner so, despite the reasons to model our reform as revenue neutral, we do not follow this option here.

Another important issue is the treatment of expenditure in commodities that are left out of the demand system (durable goods). In this case we assume that households continue consuming the same quantities as before the reform, at least in the short run. In fact, given that there are only changes in the relative prices of the commodities of the estimated model, the total expenditure devoted to those commodities and to the extra-system categories must remain constant before and after the reform.

As the system expenditure groups are composed of goods bearing different tax rates, we calculate the pre- and post-reform price indices as the sum of the prices of all individual goods weighted by their contribution to the composite category. The pre-reform price for good i is

$$p_i^0 = \left(1 + t_i^0\right)\left(q_i + e_i^0\right) \tag{4}$$

where t_i^0; q_i and e_i^0 respectively denote the initial value added tax (VAT), the net-of-tax producer price and the excise rates. Therefore, the post reform price is given by

$$p_i^1 = \left(1 + t_i^1\right)\left(e_i^1 - e_i^0 + \frac{p_i^0}{1 + t_i^0}\right) \tag{5}$$

Although the price changes also apply to goods bearing excise duties, the reform does not affect these duties, i.e. e_i^0 equals e_i^1.

The first step for revenue simulation consists in calculating the new predicted budget shares by using the parameter estimates and the new prices. When doing this, we must take into account that the model does not predict shares in a perfect manner. Since we are interested in the price and real expenditure effects, it is desirable to separate those components from the overall expenditure in each commodity. We add the share prediction error to the predicted shares as in Baker et al. (1990), that is, the part of each share not explained by prices and real expenditure or, equivalently, the component of the share explained by household characteristics, other non-price and non-real expenditure variables and the residual, which may contain household fixed effects.

Once the new shares have been computed, we can calculate the tax changes and the revenue forecasts. In particular, the aggregate tax revenues are obtained from expression

$$\sum_{h=1}^{H} g_h \sum_{i=1}^{N} \left(\frac{t_i^1}{1 + t_i^1} + \frac{e_i^1}{p_i^1} \right) E_{hi}^1 \qquad (6)$$

where g_h is the sample weight of each household and E_{hi}^1 is the estimated post-reform level of expenditure on good i by household h.

3.2.2 Simulation Results and Policy Implications

We now explicitly study the consequences of an electricity price increase brought about by our hypothetical Spanish sulphur tax. Indeed, section 2.3 showed that the proposed sulphur tax would induce a 7.5% rise in electricity prices for residential consumers. This central estimate is complemented by a sensitivity analysis with bounds in 5 and 10 per cent price increases, leading to the consideration of three alternative reforms.

Before describing the micro-simulation outcome, we present some partial equilibrium results on the environmental effects from the sulphur tax. Our estimations largely rely on the own price elasticity of electricity demand and should be taken with caution for several reasons. On the one hand, the figures only refer to short-term reductions of electricity-related SO_2 emissions induced by the response of residential consumers to higher electricity rates. On the other hand, we have assumed a linear reduction in fossil fuel generators to equilibrate demand and supply[13]. With these limitations in mind, there would be a 7.3% expected reduction in SO_2 emissions (around 90,000 tonnes). Taking into account that the implemented sulphur tax rate reflects the estimated SO_2 damage with Spanish origin (see appendix 1), the benefits from abatement would amount 3,687 million pesetas, approximately one tenth of total sulphur revenues.

Focusing on the actual simulation, table 5 yields a first insight into the alteration of consumption patterns, with the expenditure share change in each commodity of the system. Therefore, all effects are contemplated after our demand system estimation. A major result emerging from this table is the

[13] We understand that nuclear and hydro capacities are not likely to be affected because of the cost-minimizing allocation procedure and the circumscribed application of the sulphur tax to fuel-oil and coal-fired power plants.

large substitution existing between electricity and gas in Spanish households. It is also clear that electricity price rises lead to an increase in the expenditure shares of alcohol, gas and public transport, with a simultaneous reduction of the remaining shares.

Table 5 Tax-induced Changes in Expenditure Shares (in %)

Commodity	Lower[a]	Upper[b]	Medium[c]
Food and Non-alcoholic Drinks	-0.043	-0.054	-0.048
Alcohol	1.620	2.947	2.277
Clothing and Footwear	-0.398	-0.815	-0.609
Electricity	-1.182	-2.140	-1.629
Natural and Manufactured Gas	15.61	23.36	17.68
Fuel for Private Transport	-0.156	-0.310	-0.230
Public Transport	0.766	1.440	1.100

[a] 5-point increase in VAT; [b] 10-point increase; [c] 7.5-point increase.

Table 6 yields the tax payment increases for the three reforms by deciles of expenditure and by demographic breakdown. The column headed `Electric.' shows the increased payments in the electricity group, whereas the `Gas' column contains the same measure for natural and manufactured gas. We observe how the increase in tax payments relative to total expenditure is larger the poorer is the household. In fact, the range of variation in such relative payments indicates a certain degree of regresivity: households in the ¯rst decile increase their tax payments in around 0.14% of their total expenditure, as compared to the 0.08% increase for the richest households.

Table 6, here (t6.doc)

Focusing on the central reform, around 5.05% of total VAT payments by an average household originate in the electricity group, showing a 44.3% increase with respect to the pre-reform situation. Still, this increase is lower than the estimated without behavioural response by consumers (a 50% rise in payments).

The negative distributional e®ects of the reforms are also evident in table 7, which provide aggregate information on tax revenues. Our simulation predicts a moderate increase in the overall indirect tax receipts, nearing a two per cent rise in the central scenario (around 42,000 million pesetas[14]).

[14] Higher electricity prices lead to approximately 38,000 million pesetas. The remaining revenues are simply obtained from changes in the consumption of other non-durables.

As the extra revenue contributions mostly stem from groups classi¯ed as necessities (except food), the reform can be de¯ned as regressive.

Table 7, here (t7.doc)

The in°uence of modelling behaviour in the aggregate calculations is also remarkable and again sustains our simulation procedure. The expected revenue with no behavioural reaction is some 20% larger than the ¯nal ¯gure, which obviously has important consequences. On the one hand, the absolute and relative signi¯cance of such a revenue loss would be meaningful for any policy maker. On the other hand, given the close relationship between electricity supply and demand, the sizable behavioural response of electricity consumers have unambiguous e®ects on the determination of the electricity price change (see section 2.3).

4 Conclusions

In this paper we have dealt with the design and e®ects of a hypothetical sulphur tax implemented on the Spanish electricity industry in 1994. This research was justi¯ed by the signi¯cant Spanish contribution to acid rain phenomena and by the toughening European regulations on this matter.

As a ¯rst step, we de¯ned the environmental instrument as a product tax on fossil fuel use with a uniform tax rate re°ecting the environmental damage of Spanish SO_2 emissions. Assuming a full shift to residential consumption, quite plausible in the 1994 Spanish context, we calculated the ex-ante electricity price rise.As a second step, we estimated an 8-commodity demand system for the Spanish economy with micro data from Spanish family surveys, which allowed for micro-simulation of the ex-post e®ects from higher electricity prices.

The exercise has indicated the remarkable in°uence of the hypothetical sulphur tax on electricity demand, thus showing a positive environmental performance. However, the distributional e®ects of the environmental tax are rather regressive because electricity is a necessity.

APPENDIX 1: CALCULATING THE DAMAGES FROM SPANISH SO_2 EMISSIONS

As a major cause of acidi¯cation, European SO_2 emissions are generating signi¯cant external costs. Therefore, we have decided to determine the hypothetical tax rate from the estimated SO_2 damage with Spanish origin. This appendix deals with the complex valuation of Spanish sulphur emissions.

It must be noted that the lack of previous research on this issue has demanded a heterogeneous approach, where Spanish estimates coexist with ¯gures extrapolated from other countries. There is also a wide methodological diversity, with the application of both `top-down' and `bottom-up' analyses[1]. In all cases, the money estimates were obtained through the production function (dose-response) technique, using market or near-market values to valuate physical impacts.

A careful extrapolation of foreign estimates has been indispensable, as the calculation of Spanish values for all damage categories was well beyond the possibilities of this paper. Nevertheless, some negative e®ects from sulphur emissions have not been reported due to the absence of reliable international estimates. Our assessment has only covered the most relevant damages, as currently perceived. They include impacts on forests (commercial use), crops, human infrastructures, and human health (mortality-related). In consequence, we have simply considered a portion of the external costs from the fossil fuel cycles (see Pearce et al., 1992).

The forest damage estimate was directly obtained from previous research for the year 1992 (Labandeira-Villot, 1995). The model employed a linear damage function relating sulphur depositions above critical loads to loss of forest growth in the UN ECE region (measured at wood prices). Therefore, we had to use a European inventory of exploitable forests, the Spanish SO_2 blame matrix, wood prices, and data on sulphur depositions and critical loads. Although the reported ¯gure represents the damage caused by a `marginal' power plant, it is not a true bottom-up measure because Spain was implicitly treated as a single geographical unit.

If the impact on forests was expressly calculated for Spanish sulphur emissions, the remaining damage estimates have a derived nature. In general, the latter have been partially adjusted to introduce some Spanish basic features.

[1] Top down estimates are obtained from aggregated data on emissions and impacts, representing average unit costs of emissions. On the contrary, bottom up methods estimate the marginal damages from site-speci¯c emissions (see European Commission, 1995a).

However, the well-known di±culties to transfer contextual environmental values advise a cautious interpretation.

Damage to human infrastructures, excluding heritage, was extrapolated from the estimated e®ects of UK SO_2 emissions (ECOTEC, 1992), although considering the Spanish di®erences in population densities (from EUROSTAT, 1997) and emission-depositon ratios (from Barrett et al., 1995). Unfortunately, the lack of data on Spanish building composition did not allow for further adjustments of the original top-down estimate.

The e®ects on human health were also extrapolated from the mortality damage of UK sulphur emissions, as reported by Pearce (1994) with a top-down approach. Pearce's ¯gure was modi¯ed to account for Spanish population density, emission-deposition ratios, and value of statistical life (from Albert and Malo, 1994).

Crop damage from sulphur emissions was directly transferred from the ExternE study (European Commission, 1995b), given the consistency of its bottom-up estimates for several locations in Germany and the UK. Therefore, it is the only extrapolated ¯gure without adjustment. Sadly, we could not obtain other estimates from this ambitious project, still in its early phases.

Table A1.1 presents the ¯nal results for the year 1994, in pesetas per kilogram of emitted SO_2. Notice that approximately half the damage stemming from Spanish sources actually occurs outside Spain.

Table A1.1 Damage from Spanish SO_2 Sources (Ptas/kg), 1994

Categories (currency in source)	Spain	UN ECE Area
Human Infrastructures (1992 sterling)	9.3	23.5
Forests (1992 pesetas)	7.5	12.0
Crops (1990 ECU)	3.2	4.0
Human Health (1991 sterling)	1.0	1.5
Total	21.0	41.0

Note: We have followed IMF (1995) for translation to 1994 pesetas
Source: Own calculations as showed above

Yet the use of the previous estimates as an input for environmental tax policies may be questionable, at least from a theoretical point of view. Leaving the valuation problems aside, the average nature of most assessed damages is against theory, unless an implausibly constant MEC function is assumed.

However, accurate bottom-up (marginal) estimates can hardly guide a feasible taxation of acid rain precursors. In this sense, our damage appraisal provides a basis for a sub-optimal but non-discretionary tax rate setting.

Moreover, the estimates rightly reflect the relatively low damages produced by Spanish sulphur emissions[2].

2 This is clear after a review of other international damage appraisals (e.g. Pearce, 1994; +110%) and of existing sulphur tax rates in highly sensitive areas (+555% in Sweden; Lövgren, 1994).

APPENDIX 2: DATA

The data used to estimate the demand system derives from the `Encuesta Continua de Presupuestos Familiares', covering the period 1985-1994. This survey is organized by the Spanish Institute of Statistics (see INE, 1985) and constitutes a rotating panel with households contributing a maximum of eight quarters (12.5 per cent of rotating rate).

We start with the total number of observations from the households that collaborate during the entire time span (N=6100, T=8). As we only use the balanced panel there is a possibility of attrition bias, which can be tested by using the unbalanced panel. After dropping possible non-infrequent purchases, the final sample contains 29,648 households, i.e. 60.75 per cent of the original sample. This sample selection process could induce selection bias, although when the model is estimated from the initial sample there are not important differences in most groups. For welfare and revenue simulation we use the households that correspond to the second quarter of 1994 in the sample, the latest available. Every household has a grossing-up factor which indicates the number of households theoretically represented in the whole country. We also conduct simulations using a random sample covering the period 1985-1994, after correcting expenditures on all commodities and total expenditure with the price indices.

We next enumerate the variables appearing in the specification of the shares, whose descriptive statistics are reported in table A2.1. As constant shifters: number of adults, number of children in the age ranges 0-6, 7-14 and 14-23 and two dummies indicating whether the household head and partner are older than 65. Moreover, all specifications include quarterly dummies that are important determinants of some demands, as in electricity and gas. The slope is composed by the natural logarithm of real expenditure and its square and by the natural logarithm of prices relative to the price of the excluded category ($\ln p_i$, $i=1,\ldots,7$). Prices are calculated using information from the INE on indices for retail prices, subgroups and weights. Prices are allowed to change quarterly, constituting averages of the published monthly indices. The Stone index used in equation (1) is computed with the observed shares for each household in the sample.

Table A2.1, here (ta21.doc)

APPENDIX 3: RESULTS FROM THE ESTIMATION OF THE DEMAND SYSTEM

Table A3.1, here (ta31.doc)

Table A3.2, here (ta32.doc)

Table A3.3 Tests for Homogeneity and Symmetry

Test and Equation	Value
Homogeneity (Â^2 (1))[1]	
Food and Non-alcoholic Drinks	0.08
Alcohol	0.37
Clothing and Footwear	2.55
Electricity	2.38
Natural and Manufactured Gas	0.17
Fuel for Private Transport	2.30
Public Transport	0.02
Homogeneity (Â^2 (7))[2]	7.17
Homogeneity and Symmetry (Â^2 (28))[3]	108.04

Notes:

1. Individual homogeneity test.
2. Joint homogeneity test.
3. Joint test for homogeneity and symmetry.

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