Fiscal Studies (1999) vol. 20, no. 3, pp. 305–320

Combining Input–Output Analysis and Micro-Simulation to Assess the Effects of Carbon Taxation on Spanish Households

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Abstract

This paper explores the effects of a tax levied on Spanish energy-related CO_2 emissions. After justifying the relevance of carbon taxation in the Spanish context, we consider the introduction of a product (fossil-fuel) tax with a rate obtained through the 'actual damage cost' method. Our empirical analysis proceeds in two stages. First, we employ an input–output demand model to calculate the price changes after the introduction of carbon taxation. In a second stage, simulation with Spanish household micro-data for 1994 yields the environmental and economic effects of a Spanish carbon tax. We find a limited short-run reaction to the carbon tax, which hampers its environmental success. The carbon tax burden is, however, significant, with a proportional distribution across households.

JEL classification: C33, C67, H31, Q28.

I. INTRODUCTION

The environmental and economic importance of climate change phenomena is well established, as pointed out by growing scientific evidence and consensus. Such climatic alterations are provoked by the increasing atmospheric

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The authors acknowledge Alberto Gago, José M. González-Páramo, Stephen Smith, an editor and an anonymous referee for their helpful comments on earlier versions. Labeaga is also grateful to DGES project PB95-0980. The usual disclaimer applies.

concentrations of greenhouse gases, with anthropogenic CO_2 production as the main contributor. Accordingly, there is now a manifest need to control man-made CO_2 emissions in an effective and efficient manner, with carbon taxes constituting a favoured alternative for economists.

In the context of growing and sizeable Spanish CO_2 emissions, this paper addresses the design of a hypothetical carbon tax levied on energy-related emissions and estimates its effects on Spanish final consumption. Apart from the theoretical advantages associated with environmental taxation, there are various reasons to carry out this exercise. First of all, given the inefficiency of the Spanish energy domain at the moment, there is an irrefutable need for a reliable and cost-effective (market-based) climate change strategy in Spain. Moreover, there are also grounds to expect a pre-eminent role for carbon taxes within the emerging green tax reform model in the developed world (Álvarez, Gago and Labandeira, 1998).

Following carbon tax design (tax-rate and tax-base setting), our empirical analysis of the hypothetical tax proceeds in two stages. We first employ an input–output demand model to calculate the price effects of the Spanish carbon tax. With this information and the results from the estimation of a demand system for the Spanish economy, micro-simulation yields consumers' reaction to the carbon tax and thus the environmental (in terms of behavioural responses), distributional (in terms of tax payments and welfare measures) and revenue outcomes.

Although a similar combination of input–output analysis and micro-simulation of demand responses has already been used to assess the economic and distributional effects of carbon taxation in a number of countries (for example: Symons, Proops and Gay (1994) for the UK; Hamilton and Cameron (1994) for Canada; Cornwell and Creedy (1996) for Australia), our exercise delivers several contributions. To begin with, it is the first comprehensive assessment of a Spanish carbon tax and allows for a wider international comparison of results. Besides, unlike the preceding literature and also for the first time in Spain, it uses the quadratic extension of the Almost Ideal Demand Model of Deaton and Muellbauer (1980) for simulation, thus providing a more accurate representation of the behavioural responses to the carbon tax. Finally, our hypothetical carbon tax rate is exogenous and rightly reflects the damage associated with Spanish CO_2 emissions, which contrasts with the (endogenous) high rates needed to achieve the major and immediate CO_2 reductions contemplated in previous applications.

Regarding the main findings of this exercise, it is noteworthy that the proposed Spanish carbon tax would raise considerable tax revenue. This is due to the generalised dependence of developed economies upon CO_2 emissions and to the difficulties in modifying behaviours in the short run. As expected, the carbon tax has limited environmental effectiveness. However, against intuition, the hefty tax burden is not regressively distributed across households.

The structure of the article is as follows. Section II first justifies the use of carbon taxation in Spain, as a preamble to the proposed design and implementation of a carbon tax. Section III deals with the input–output framework to assess the impact of the hypothetical carbon tax upon the prices of consumer goods. Section IV contains the microeconometric simulation to analyse the effects of the environmental tax on total CO_2 emissions, government revenues and the distribution of tax burdens across households. Finally, the main conclusions are presented in Section V.

II. SPANISH CO_2 EMISSIONS AND THE USE OF CARBON TAXATION

1. The Need for Control

Despite the fact that Spain is not a major CO_2 emitter and is currently subject to rather lax international commitments,[1] there are powerful reasons to think that environmental taxation may play a significant role in future Spanish climate change policies. First of all, one can observe increasing internal pressures to control the emission of greenhouse gases. In fact, Spain is extremely susceptible to desert advance and water scarcity, and both are likely to worsen with climate change phenomena.

The external pressures to control Spanish greenhouse gas emissions are also significant and mounting, as noticed in the latest Conferences of the Parties of the UNFCCC. The large rise of Spanish CO_2 emissions in recent years, directly linked to strong economic growth and to an inefficient energy system, makes unjustifiable the preferential treatment enjoyed by Spain so far. Indeed, at the moment of writing, Spain has almost consumed the (conceivable) Kyoto permitted increase in greenhouse gas emissions for 2010.[2]

Table 1 shows the main sources of Spanish CO_2 emissions in 1994 (the year of our tax simulation). It is remarkable the importance of energy-related emissions, which obviously make CO_2 emissions quite dependent on the economic cycle and on the structural efficiency of the energy system. Actually, Spanish energy-related CO_2 emissions saw a 25 per cent increase between 1984 and 1994.

If the current need for a credible Spanish climate change policy is indisputable, there are also arguments that favour the use of carbon taxation in

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[1]Spain signed and ratified the United Nations Framework Convention on Climate Change (UNFCCC). As an Annex I party of the Convention, Spain should return to 1990 levels of anthropogenic greenhouse gas emissions by 2000 (Rio target). Moreover, as an Annex B party of the 1997 Kyoto Protocol developing the Convention, Spanish greenhouse gas emissions in 2010 should be below 1990 levels. However, in both cases, Spain was granted a surprising exemption through the EU's overall targets which allowed Spanish emissions to grow substantially. This was justified on the grounds of the large energy requirements considered to be needed to overcome the relative 'underdevelopment' of the Spanish economy (see Labandeira (1997)).

[2]It is expected that Spanish greenhouse gas emissions will be allowed to increase by about 15 per cent between 1990 and 2010 (see Mas-García (1998)).

TABLE 1

Spanish CO_2 Emissions, 1994

	1,000 tonnes	*Per cent*
Energy-related:	227,197	85.9
Electricity	76,082	28.8
Transport	59,722	22.6
Industry	50,896	19.2
Households	17,262	6.52
Agriculture	17,554	6.63
Industrial processes	16,370	6.19
Waste	2,657	1.00
Total	*264,641*	*100*

Source: Spanish Ministry of the Environment.

this context. On the one hand, environmental taxes constitute an extremely efficient decentralised (market) mechanism for implementing environmental policies. On the other hand, the practical feasibility of carbon taxes and their substantial revenues have defined a so-called green tax reform model in which distortionary conventional taxes are partly substituted by new environmental taxes (see Álvarez, Gago and Labandeira (1998)).

2. Carbon Tax Design and Implementation

As indicated above, carbon taxes not only constitute key tools for climate change policies but are also powerful fiscal instruments. In this section, we build a practicable carbon tax from various theoretical results.[3]

First, we must refer to the jurisdictional allocation of the carbon tax. Optimal carbon taxes should be allocated to a world-wide authority because they are a response to a global environmental problem. However, the implausibility of that institutional arrangement recommends the assignment of the hypothetical tax on Spanish CO_2 emissions to the Spanish central government.

Concerning tax-rate setting, there are a number of options. The Pigouvian alternative would introduce a rate equal to the marginal damage of CO_2 emissions at the optimum.[4] As an alternative, the cost-effective carbon tax rate would be the shadow price from cost minimisation with an exogenous CO_2 concentration standard (see Baumol and Oates (1988)). The latter, known as the carbon budget approach, requires less information than the former as damage from greenhouse gases does not need to be modelled and valued. Yet in both

[3]For a comprehensive discussion of real-world environmental taxes, see Smith (1992).
[4]Therefore the carbon tax rate would be the shadow price in an intertemporal cost–benefit model. See Smith (1992) for a fuller explanation.

cases complete international co-ordination of carbon taxation would be necessary, as the tax rates are calculated to keep future emissions on an optimal global path towards the maximum net benefits or the exogenous environmental standard.

Previous approaches based on shadow price approximations contrast with the simpler 'actual damage cost' approach, where the carbon tax rate is set to equal the marginal damage from CO_2 discharges at the existing level of world emissions. As climate change is a dynamic process, the method must take into account the trajectory of future CO_2 emissions for damage calculation. If future emissions change due to policy action, the method becomes more complex as a new trajectory has to be assessed.

Therefore this approach is especially appealing when the carbon tax causes a small-scale CO_2 reduction unable to alter the original (and known) trajectory. Indeed, the actual damage approach is ideal for determining a unilateral Spanish carbon tax rate because Spain is a small economy that causes slightly less than 1 per cent of the world's CO_2 emissions.

We have decided to use the CO_2 actual damage estimate obtained by Fankhauser (1994) to determine our hypothetical carbon tax rate. Fankhauser employed a stochastic greenhouse damage model in which all parameters were defined as random because of the scientific controversies on climate change processes. Fankhauser's central damage estimate for the period 1991–2000 (in 1990 US dollars) is 20.3 per tonne of carbon, with a wide 90 per cent confidence interval: 6.2 as lower bound and 45.2 as upper bound.

Focusing on the central damage estimate, it is significantly higher than those reported by the shadow price literature, which is not only explained by the methodological differences but also by Fankhauser's use of expected values instead of the usual best guesses, as the distribution of global warming damage is skewed to the right (see Labandeira and Labeaga (1998a)). Moreover, if we compare the central damage estimate to the original 'ecotax' proposal by the European Commission for 1994 without taking the energy segment into account (see Pearson and Smith (1991)), the figures are surprisingly close. The central damage estimate is, however, lower than some implemented carbon tax rates, such as the Swedish tax on industries (60 per cent higher) and on households (550 per cent higher) — Lövgren (1994).

Besides, our hypothetical carbon tax rate is much lower than those obtained with a carbon budget approach for the UK and Australia (Symons, Proops and Gay, 1994; Cornwell and Creedy, 1996). Although the preceding studies also combined input–output analysis and simulation with micro-data, the carbon tax rates were endogenously determined to meet the Toronto target: a 20 per cent reduction in CO_2 emissions between 1988 and 2005. Such a stringent and immediate CO_2 target, which should be exclusively fulfilled through final demand responses (see Section III), led to extremely high carbon taxes in those exercises.[5]

Regarding the carbon tax base, it is quite easy to choose a non-contentious and simple one. Given the major significance of CO_2 emissions from fossil-fuel combustion (see Table 1), it seems reasonable to tax energy-related emissions alone. Whereas this clearly leads to higher administrative feasibility, the presence of a large number of polluters renders difficult the direct taxation of emissions. However, the existence of good linkage between fossil-fuel consumption and CO_2 emissions sustains the use of product taxation to overcome the previous problem. The product tax rates can be directly calculated by combining the adopted carbon tax rate and the available carbon contents of fossil fuels.

Given the expected stability of carbon tax revenues to be controlled by the Spanish tax administration, they could be employed either for general fiscal purposes or to compensate some negative distributional effects brought about by the externality correction.

III. CALCULATING THE PRICE CHANGES CAUSED BY CARBON TAXATION THROUGH INPUT–OUTPUT METHODOLOGY

In this paper, we deal exclusively with the impacts of carbon taxation on consumer prices. To do so, we employ input–output methodology to assess the price effects of carbon taxes, which is justified on multiple grounds. On the one hand, the generalised dependence of contemporary societies upon CO_2 emissions means that it is not possible to approximate the influences of carbon taxes by focusing on a single sector. On the other hand, the comparative significance of ‘indirect’ emissions from final consumption also requires the use of a comprehensive approach.[6]

The use of input–output methods to appraise the incidence of energy taxes is widely accepted, as they are able to disentangle the complex industrial relationships within any developed economy. In particular, input–output analysis has been used recently to estimate the price effects of carbon taxation in Australia (Cornwell and Creedy, 1996), Britain and Germany (Proops, Faber and Wagenhals, 1993). The preceding studies employed an input–output demand model to calculate the CO_2 intensities for each industrial branch — i.e. the carbon contents of their products — which allows for a straightforward

[5]The (minimum) hypothetical British carbon tax rate needed to achieve the Toronto target would amount to 1990 US$411 per tonne of carbon. The simulated Australian carbon tax rate amounts to 1990 US$306 per tonne of carbon.

[6]Consumers ‘directly’ cause CO_2 emissions through fossil-fuel combustion. In addition, consumers are responsible for some ‘indirect’ CO_2 emissions that were generated to satisfy their demands.

computation of the price changes after carbon taxation. Our exercise for the Spanish economy basically follows the same procedure.

Input–output analyses are therefore well suited to assessing the effects of a carbon tax levied on fossil fuels (coal, lignite, natural and manufactured gas and liquid fuels in this exercise) on the relative prices of outputs. Yet a key assumption of this process is the full shifting of carbon taxation to consumption, a very strong and unlikely premiss that does not allow for general equilibrium effects such as changes in factor prices and pre-tax prices of goods. Moreover, it is assumed that no substitution takes place in production following the introduction of the carbon tax, which is obviously related to the incidence presumption. Therefore the results should only be taken as a short-term approximation to the impacts of taxes on inputs.

The underlying input–output demand model is rather simple, depicting the relationship between CO_2 emissions and fossil-fuel use by industries and final consumers. Still, we found some difficulties with its practical implementation, given the absence of reliable and updated data on disaggregated Spanish energy consumption. Therefore we had to produce our own set of energy data from various and fragmentary sources, which fortunately seems largely consistent with reality.[7]

Our sole concern with the actual emissions from Spanish soil determined the use of domestic magnitudes to calculate the CO_2 intensities and price effects (except in the case of imported fossil fuels, as their use in Spain leads to Spanish CO_2 emissions). This means that we considered a domestic carbon tax with effects on the price of domestically produced goods but not of imports.[8] This procedure is also linked to the World Trade Organisation (WTO) legal objections to measures designed to protect internal and external markets against non-taxed foreign products.

As required for the micro-simulation, the price rises refer to 1994, albeit they were calculated from the 1992 CO_2 intensities. This is explained by the unavailability of disaggregated energy and conventional input–output data for the Spanish economy after 1992. In any case, given the short-term structural stability, we expect few variations between the 1992 and 1994 CO_2 intensities. A full description of this input–output application to Spain can be found in Labandeira and Labeaga (1998a).

Table 2 reports the price increases for the eight-commodity grouping of the demand system used by the micro-simulation. They stem from the range of carbon tax rates obtained by Fankhauser (1994) for the period 1991–2000, after reconciling the 57-sector input–output classification with the eight new groups

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[7]Indeed, the total and disaggregated emission estimates from our input–output model are very similar to the figures provided by the official Spanish environmental inventories (see Labandeira and Labeaga (1998a)).

[8]To differentiate between domestic goods and imports, we used a Leontief inverse, accounting only for domestic intermediate demands and imported fossil fuels.

TABLE 2

Price Changes from Carbon Taxes, Spain, 1994

Per cent

Category	*Central estimate*	*Lower bound*	*Upper bound*
Food and non-alcoholic drinks	0.3490	0.1065	0.7758
Alcohol	0.3033	0.0925	0.6742
Clothing and footwear	0.2275	0.0694	0.5057
Electricity	3.8456	1.1734	8.5483
Natural and manufactured gas	3.2066	0.9784	7.1279
Fuel for private transport	2.7991	0.8541	6.2221
Public transport	1.1990	0.3658	2.6650
Other non-durables	0.1550	0.0473	0.3445

through the PROCOME-CNAE translation (see INE (1993)). For the cases where several 57-sector classifications related to one of the new commodity groups, the new price increase was taken as the weighted average of the related sector price increases, with the weights being the proportional contribution to the new group's final demand.

IV. THE EFFECTS OF THE HYPOTHETICAL CARBON TAX FROM MICRO-DATA

This section describes the micro-simulation procedure we employed to assess the effects of the proposed environmental tax. The main results of this micro-simulation are also presented here, with an explicit calculation of the impact of carbon taxation on aggregate government receipts, CO_2 emissions, monetarised environmental benefits and the distribution of burdens across households.

The micro-simulation procedure uses a demand system that is estimated from the Continuous Spanish Family Expenditure Survey (ECPF) for 1985–94 and a sample of 29,648 households. In order to obtain a realistic picture of the substitution, own-price and income effects, we opted for the quadratic extension (QAIDS) to the Almost Ideal Demand System of Deaton and Muellbauer (1980) as proposed by Banks, Blundell and Lewbel (1997). Full details on this demand system estimation can be obtained from Labandeira and Labeaga (1998b).

We consider an indirect tax reform as the tax-induced change in the relative prices of the commodities that compose the demand system, focusing on the short-run effects from the price changes. 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

(1) $$p_i^0 = (1 + t_i^0)(q_i + e_i^0)$$

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. Although the price changes also apply to goods bearing excise duties, the reform does not affect these duties. Therefore the post-reform price is

(2) $$p_i^1 = (1 + t_i^1)\left(\frac{p_i^0}{1 + t_i^0}\right)$$

where t_i^1 is the post-reform VAT.

The first step for revenue simulation consists of calculating the new predicted budget shares by using the parameters obtained in the estimation and the new after-tax 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 on each commodity. We add the share prediction error to the predicted shares as in Baker, McKay and Symons (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 effects of fixed unobserved characteristics specific to households.

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 the expression

(3) $$\sum_{h=1}^{H} g_h \sum_{i=1}^{N} \left(\frac{t_i^1}{1 + t_i^1} + \frac{e_i^0}{p_i^1} \right) E_{hi}^1$$

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*.

We also provide some measures of the welfare effects from the simulated tax reforms. Despite its various conceptual drawbacks (see Banks, Blundell and Lewbel (1996)), the change in household welfare is quantified through the equivalent gain, a money-metric impact of price changes. An equivalent gain (loss) is actually the amount of money that needs to be subtracted from (given to) the household in order to attain the pre-reform level of utility at final prices. We follow the method of King (1983) in computing this measure, although adapting it to the QAIDS. In this sense, we evaluate the equivalent loss (gain) as

$$(4) \qquad EL^h = c(u_0, \mathbf{p}^0) - c(u_0, \mathbf{p}^1)$$

where u_0 is pre-reform utility, $\mathbf{p}^0$ pre-reform prices, $\mathbf{p}^1$ post-reform prices, $c(u_0, \mathbf{p}^0)$ the observed pre-reform expenditure and $c(u_0, \mathbf{p}^1)$ the equivalent income — the expenditure level at pre-reform prices that is equivalent in utility terms to household expenditure at final prices.

1. Overall Impacts: The Dividends from Carbon Taxation

For welfare and revenue simulation, we have used the 3,000 households that correspond to the second quarter of 1994 in the sample, the latest available from the ECPF. Tables 3 and 4 describe the overall impacts of the simulated reform, which is not revenue-neutral.[9] The first table presents government receipts, as calculated from equation 3, with a prediction of a 6.74 per cent increase in VAT revenues relative to the pre-reform situation. The groups contributing most to such a revenue expansion are those with the highest price rises: electricity, gas, fuel for private transport and public transport. This would lead to a sizeable revenue boost, with some extra 160,000 million pesetas (approximately 1,000 million euros). Those revenues represent 1.5 per cent of total Spanish receipts in 1994 and could be used in a double dividend fashion, i.e. to reduce other distortionary tax burdens.

TABLE 3

Overall Impacts of the Tax Reform: VAT Revenues

Category	*Pre-reform (million 1994 pesetas)*	*Post-reform (million 1994 pesetas)*	*Percentage increase in revenue (%)*
Food and non-alcoholic drinks	342,753.4	362,006.5	5.62
Alcohol	72,438.4	75,422.1	4.12
Clothing and footwear	376,000.5	380,338.1	1.15
Electricity	81,326.4	101,596.7	24.9
Natural and manufactured gas	8,180.6	11,162.2	36.4
Fuel for private transport	464,379.5	553,010.7	19.1
Public transport	39,949.0	48,630.7	21.7
Other non-durables	943,071.6	952,770.3	1.03
Total	*2,327,919.5*	*2,484,937.4*	*6.74*

[9]There are strong reasons to model the reforms as revenue-neutral, since the changes in receipts will normally be fed back to consumers through subsidies and/or changes in the supply of public goods. However, the short-term nature of the exercise explains the use of such ‘absolute’ measures of distributional tax incidence.

TABLE 4

Environmental Effects of the Tax Reform

Category	*Demand*[a] *(%)*	*Emissions*[b] *(tonnes)*	*Benefits*[c] *(thous. 1994 pesetas)*
Food and non-alcoholic drinks	–0.78	–206,000	172,792
Alcohol	1.75	3,520	–2,953
Clothing and footwear	–0.58	–45,750	38,376
Electricity	–4.25	–1,215,399	1,019,476
Natural and manufactured gas	8.92	213,130	–178,774
Fuel for private transport	–2.37	–2,873,969	2,410,686
Public transport	–15.7	–2,671,602	2,240,939
Other non-durables	–0.16	–21,378	17,932
Total	*n.a*	*–6,817,448*	*5,718,474*

[a]Percentage change in total demand following the introduction of the carbon tax.
[b]Imputed reduction in CO_2 emissions from demand changes.
[c]Environmental benefits from CO_2 abatement following the introduction of the carbon tax.

Table 4 shows the expected relative demand changes by commodity group after carbon taxation, already implicit in Table 3. Especially noticeable is the substantial increase in the demand for natural and manufactured gas, which is due to the strong substitution of electricity by natural gas, as indicated by the cross-price elasticities (see Labandeira and Labeaga (1998b)).

With the preceding information and the CO_2 intensities, we are able to calculate the tax-induced modification in CO_2 emissions. The appraisal of environmental benefits is straightforward: we apply the carbon tax rate to abatement. Note the relatively low CO_2 abatement achieved by the carbon tax (6,817 kt, only 3 per cent of energy-related emissions), with environmental benefits merely representing 3.5 per cent of total carbon tax receipts. This obviously reflects the huge dependence of contemporary economies on fossil-fuel consumption and is not surprising as the carbon tax affects all sectors in the economy.

2. Some Distributional Effects

In looking at distributional effects, we begin by presenting in Table 5 the percentage increase in tax payments (relative to the pre-reform situation) by decile of expenditure and using subsamples corresponding to some socio-economic variables. It is noticeable that there are not significant differences in the relative tax-payment increase by demographic breakdown. In this sense, we sustain the conclusions of other empirical exercises on this issue, corroborating the proportionality of tax payments from a broad Spanish carbon tax (see Smith (1995)).

TABLE 5

Quarterly Change in Tax Payments by Demographic Variable and by Decile

	Percentage change
All households	6.48
Age < 65	6.48
Age ≥ 65	6.51
No children	6.54
1 child	6.64
≥ 2 children	6.37
Decile 1	5.55
Decile 2	6.15
Decile 3	6.26
Decile 4	6.70
Decile 5	6.38
Decile 6	6.75
Decile 7	6.99
Decile 8	6.64
Decile 9	6.73
Decile 10	6.68

TABLE 6

Quarterly Equivalent Loss by Demographic Variable and by Decile

	Equivalent loss (1994 pesetas)	*Equivalent loss as a percentage of pre-reform total expenditure*
All households	15,924.7	2.91
Age < 65	16,065.8	2.83
Age ≥ 65	15,125.5	3.35
No children	13,685.4	2.97
1 child	15,791.3	2.92
≥ 2 children	17,405.5	2.86
Decile 1	5,168.8	2.70
Decile 2	7,613.8	2.76
Decile 3	9,423.7	2.81
Decile 4	11,045.7	2.85
Decile 5	12,428.3	2.81
Decile 6	14,657.1	2.93
Decile 7	17,028.6	3.00
Decile 8	19,429.3	2.95
Decile 9	24,637.6	3.11
Decile 10	37,834.3	3.14

At this stage, we must note that all the distributional measures of our exercise refer not to household income but to household expenditure. This is because short-run income may be an unreliable indicator of well-being, as is clear from the life-cycle and permanent-income theories of consumption. Indeed, household income may easily vary from year to year, whereas consumption is thought to be set on the basis of long-run income (Poterba, 1989).

Table 6 reports the welfare effects of the carbon tax for the same groups as in Table 5. The first column contains our money-metric measure of utility change, while the second column represents the relative size of the equivalent loss (with respect to pre-reform total expenditure). All figures are equivalent losses because every reform leads to price increases in all the expenditure groups of the demand system.

TABLE 7

Effects of Alternative Damage Estimates

Total revenues after reform

	Lower damage estimate		Upper damage estimate	
	Million 1994 pesetas	*Percentage increase in revenue*	*Million 1994 pesetas*	*Percentage increase in revenue*
Food and non-alcoholic drinks	347,409.1	1.36	387,730.0	13.1
Alcohol	73,946.3	2.08	79,143.3	9.26
Clothing and footwear	377,432.1	0.38	385,490.8	2.52
Electricity	87,499.2	7.59	126,190.0	55.2
Natural and manufactured gas	9,030.1	10.4	15,399.1	88.2
Fuel for private transport	491,335.4	5.80	662,255.9	42.6
Public transport	42,618.9	6.68	59,425.2	48.8
Other non-durables	948,769.6	0.60	959,801.5	1.77
Total	*2,377,489.1*	*2.13*	*2,675,435.9*	*14.9*

Distributional effects

	Percentage change in quarterly tax payments	
	Lower damage estimate	*Upper damage estimate*
All households	1.98	14.47
Age < 65	1.97	14.48
Age ≥ 65	2.08	14.38
No children	2.07	14.48
≥ 2 children	1.89	14.31
Decile 1	1.63	12.51
Decile 10	2.18	14.65

There are several issues that emerge from the figures in Table 6. First, the equivalent losses are comparatively substantial in all groups, which means that price increases are significant and affect Spanish households in a non-negligible way. Second, the variation of equivalent losses across total expenditure deciles is inconclusive on the regressivity or progressivity of the reform, although the reform has a greater effect on households with older heads.[10]

3. Sensitivity Analysis

In this section, we present the results of two new tax reforms, using the lower- and upper-bound damage estimates of Fankhauser (1994) as tax rates and their incidence on prices (see Table 2). This information is also useful as a sort of sensitivity analysis of the effects of the hypothetical carbon tax rates and it allows for an easier comparison with other implemented or proposed carbon tax rates.

Table 7 shows the revenue and distributional effects of the alternative carbon tax rates and can be easily compared with the results presented in Tables 3 and 5 for the central tax reform. In general, we can observe that the main trends pointed out across the paper are still valid: lower or higher carbon taxes do not modify the pattern of distributional incidence, and tax receipts are mainly determined by the tax rate, i.e. the demand for carbon emissions seems to be rather rigid.

V. CONCLUSIONS

This article has explored the economic effects of a hypothetical tax levied on Spanish energy-related CO_2 emissions. The paper responds to the large rise in Spanish CO_2 emissions in recent years and, therefore, to the mounting need to control Spanish greenhouse gas emissions in an efficient manner. Our proposed tax design includes jurisdictional allocation to the Spanish central government, the use of linked product (carbon) taxation and the adoption of an 'actual damage' tax rate.

The empirical analysis has proceeded in stages. First, we employed an input–output demand model to calculate the CO_2 intensities for each industrial branch, which allowed for a direct computation of the price changes following the introduction of carbon taxation. We then estimated a demand system for the Spanish economy, as this was necessary for micro-simulation. Finally, we simulated the environmental and economic effects of the new tax-induced prices.

Given the size and stability of carbon tax revenues, we were particularly interested in appraising the distributional impacts of the hypothetical carbon tax

[10]In Labandeira and Labeaga (1998a), we simulate a revenue-neutral tax reform by returning the carbon tax receipts as a constant lump-sum subsidy to households. In this particular case, the tax reform shows a largely progressive profile.

as its environmental effects were likely to be modest in the short run. In this sense, the use of *ad hoc* welfare measures did not sustain the presumed regressivity of carbon taxation in Spain.

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