RECYCLING CARBON TAX REVENUES IN SPAIN. ENVIRONMENTAL AND ECONOMIC ASSESSMENT OF SELECTED GREEN REFORMS

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Abstract

The design of the key elements of a public budget-neutral environmental fiscal reform could have very different implications in terms of its environmental and macroeconomic impact. Our proposals rely on a carbon tax on fossil fuels covering all economic sectors. It would be a powerful and efficient instrument for reducing emissions, as it gives economic agents an incentive to find ways to save energy and switch to greener energy sources while generating significant tax revenues whose judicious use may have positive macroeconomic effects. In addition, a carbon tax is easy to administer since it can be integrated into existing fuel excise duties. We build a novel model to assess the environmental and economic impact of a set of environmental fiscal reforms in Spain which are defined by different levels of the carbon tax, the possibility of a border carbon adjustment and alternative uses of the tax revenues generated. In this framework, we incorporate technological innovation, which will allow firms to produce with non-polluting inputs and, specifically, the electricity sector, to increase the role of renewables in its generation mix. The results indicate that carbon tax designs with border carbon adjustment tend to be more effective in lowering emissions in Spain. They also suggest that an appropriately designed environmental fiscal reform may even boost economic activity in the medium term if the revenues are used to reduce other, more distorting taxes.

Keywords: carbon tax, environmental policy, modelling, green tax reform.

JEL classification: C6, H2, Q5.

Resumen

Los diferentes elementos del diseño de una reforma fiscal verde, neutra presupuestariamente, pueden generar efectos medioambientales y económicos muy dispares. Nuestras propuestas de reforma fiscal para España pivotan en torno a un impuesto sobre el carbono que abarca todos los sectores económicos. Este sería un instrumento efectivo y eficiente para reducir las emisiones de gases de efecto invernadero, ya que brinda a los agentes los incentivos para ahorrar energía y para utilizar fuentes más ecológicas. Además, generaría sustanciales ingresos fiscales, cuyo uso podría compensar potenciales efectos macroeconómicos adversos. Este impuesto sería fácil de gestionar, al integrarse en los impuestos especiales sobre los hidrocarburos. En este trabajo construimos un modelo para evaluar el impacto medioambiental y económico de una serie de reformas fiscales caracterizadas por diferentes niveles del impuesto sobre el CO_2, la posibilidad de un ajuste en frontera por las emisiones de carbono y los usos alternativos de los ingresos fiscales generados. Este enfoque considera, asimismo, que la innovación tecnológica permite a las empresas producir con factores de producción no contaminantes, y, en concreto, al sector eléctrico, impulsar la generación eléctrica con energías renovables. Los resultados indican que las reformas fiscales que consideran el ajuste del carbono en frontera son más efectivas para reducir las emisiones en España. También sugieren que una reforma fiscal ambiental adecuadamente diseñada puede impulsar incluso la actividad económica a medio plazo si los ingresos se utilizan para reducir otros impuestos más distorsionadores.

Palabras clave: impuesto sobre el carbono, política medioambiental, modelización, reforma fiscal verde.

Códigos JEL: C6, H2, Q5.

1. Introduction

In the absence of major actions to curb the accumulation of carbon dioxide (CO_2) and other greenhouse gases (GHGs) in the atmosphere, global warming will continue, with risks of extreme weather events, higher sea levels and destruction of the natural world.[1] In simple economic terms, this process could be seen as the result of a market failure derived from producing costs not incorporating the social cost of GHG emissions. As private costs of production do not reflect those social costs, this has led to larger emissions over decades or centuries than would be socially optimal. There are several alternatives to internalising the externality derived from GHGs. One is so-called Pigouvian taxes. A tax on GHG emissions could be an effective theoretical alternative for agents to reduce their emissions. Alternatively, given the direct link between emissions of the most relevant of the GHGs, namely CO_2, and the consumption of fossil fuels, a charge on the carbon content[2] of fossil fuels, often called carbon tax, could achieve the same purpose.

Carbon tax rationale is fairly simple. Since a carbon tax increases the prices of fossil fuels, electricity and consumer goods and services produced using these inputs intensively will be more expensive in relative terms than other, less carbon-intensive products. This change in relative prices will promote a shift to cleaner technologies, for instance, to lower-carbon fuels in power generation, conserving energy use and switching to cleaner vehicles. Another important advantage of carbon taxes is that they could raise significant revenue, of approximately 1% of GDP for G20 countries at around USD 35 per ton tax (IMF 2019b, Parry 2019). Smart use of this revenue could help offset the harmful macroeconomic effects –in terms of income, employment and investment– of higher fuel prices and exert positive macroeconomic effects without leaving anybody behind, but only if it is appropriately designed. In addition, a carbon tax can improve the health of citizens in terms of exposure to local air pollution caused by fossil fuel combustion. Finally, the carbon tax would be easy to administer if integrated into the existing tax code.

Obviously, the design of the reform is key to its success. In this regard, these are some of the desired features of a carbon tax proposal. First, a good design requires that the carbon tax level reflects the social cost of emissions, which is highly uncertain, and covers all economic sectors.[3] Second, in the absence of international coordination, the unilateral introduction of a carbon tax also has side effects; it may lead to carbon leakage, a flight of polluting companies to other countries where such a tax does not exist. Combating climate change is a global challenge, and such leakages would make these country/region-specific initiatives highly inefficient. One way to reduce this drawback is through a border carbon adjustment, i.e. charging imports with an equivalent tax and exempting exports from it. Third, the final macroeconomic impact depends on alternative uses of the funds collected, i.e. how they are recycled, whether to reduce other distorting taxes (social contributions or personal income tax, among others), to lower public debt, to promote renewable sources of energy, to improve efficiency in the use of energy, to provide

[1] Among advanced economies, Spain is especially vulnerable to climate change since it will become warmer, drier and more prone to extreme weather events with potential impacts on health, the environment and the economy (Ciscar 2020 and IMF 2017). Regarding past extreme weather events, Spain was already the 29th most affected country between 2000 and 2019, according to the Global Climate Risk Index (Eckstein et al. 2021).

[2] The greenhouse gases behind global warming are composed of CO_2 (81% of emissions), methane (10%), nitrous oxide (7%) and fluorinated gases (3%). Attention has focused on CO_2 as it is the cause of most emissions and can be measured in industry with a high level of precision.

[3] We assume that pre-existing taxes in Spain are not designed to curb GHG emissions, in particular the excise duties on fossil fuels. In fact, the structure of these duties are not associated with their carbon content (see Agencia Tributaria (2015), "Impuesto sobre hidrocarburos" and Figure A-1 in Appendix A).

direct payments to those households more relatively affected by these environmental taxes or a combination of all of these. In any case, from a dynamic perspective, part of the increase in revenues is temporary since the higher carbon prices will lead to innovation towards cleaner sources of energy which, in turn, would entail and lead to positive effects of the use of these funds.

In this paper, we propose several environmental tax reforms based on a carbon tax on the CO_2 content of fossil fuels, which covers all economic sectors and whose revenues can be 'recycled'. Hence, our proposal is not just a tax increase but, on the contrary, a full, fiscal, green reform promoting a cleaner economy that improves the health and the revenues of citizens.

The carbon tax is integrated as a surcharge on existing fuel excise duties on those inputs that are a source of carbon emissions. The tax base will be the carbon content of each fossil fuel. The increase in fossil fuel prices will be incorporated along the production linkages via intermediate consumption into the prices that firms and, ultimately, consumers face. Thus, it will give economic agents incentives to find ways to conserve energy and switch to greener energy sources, constituting a powerful and efficient instrument for reducing emissions.

To assess the environmental and economic impact of introducing this carbon tax in Spain in the medium term, we define a set of 'fiscal reforms' that cover (i) different levels of the carbon tax instrumented in those inputs (fossil fuels) that are a source of carbon emissions, (ii) the possibility of a border carbon adjustment, and (iii) different uses of the tax revenues generated (to lower public debt, reduce social contributions, transfer them to households, or to subsidise the energy bill).

The modular model developed to assess the environmental and economic impact consists of two modules that interact with each other and that combine sectoral information with a general equilibrium approach with real and financial frictions. The first module, sectoral in nature, is made up of a static partial equilibrium model for the Spanish economy that combines information from the input-output tables, sectoral CO_2 emissions, a demand system for households and a demand system for intermediate energy inputs. This model allows results in terms of CO_2 emissions disaggregated at sectoral level to be obtained. The main drawbacks are that it is not possible to simulate a complete tax reform since it does not allow interactions among economic agents. Therefore, the implications derived from the use of the additional fiscal revenues obtained cannot be assessed, and there are no-dynamic considerations. The second module, favouring a general equilibrium approach, allows a parametric tax reform to be simulated, sacrificing the granularity of the results. This module, with aggregate variables, consists of a semi-structural model where accounting identities are combined with behavioral equations estimated for the representative agents (households, firms, public sector, external sector, etc.). This module allows for analysis of the effect on the main macroeconomic variables of the different designs of the carbon tax and of the different uses of the revenues generated. In any case, it should be taken into account that our model does not allow us to fully incorporate the costs associated with the reallocation of resources across sectors and firms which the carbon tax will induce. These costs could be greater the lower the capacity of the economy to reallocate resources across sectors and firms. Therefore, labour market institutions are crucial to facilitate labour reallocation, as are the financial system to identify opportunities in the green economy and insolvency proceedings to prevent losses of value in the ailing firms that were not able to adapt to a low-carbon economy.

The rest of the paper is organised as follows. In Section 2, we summarise the literature on the role of fiscal policy in mitigating climate change. In Section 3, we discuss the alternatives to a carbon tax fiscal reform. In Section 4, we describe the features of different scenarios considered to assess the environmental and economic impact of each reform. Section 5 explains how the model is built and its main properties. In Section 6, we present the results and, finally, Section 7 draws the main policy implications.

2. Literature review

Fiscal policy plays a natural role in mitigating climate change. As already suggested, from a theoretical perspective, at least two market failures in mitigating climate change could be addressed with fiscal instruments: the externalities related to CO_2 emissions and to knowledge spillovers from research and development (R&D) that may prevent their full social benefit from being harnessed. To address these market failures, the use of fiscal policy tools is an optimal policy response: Pigouvian taxes on emissions at source (and equivalent subsidies for capture and storage of GHGs) and subsidies on R&D (Pigou 1932, Stern 2006).

Policymakers can use fiscal tools, along with regulatory policies, to encourage economic agents to reduce CO_2 emissions. Although a broad set of price and quantity-based policy measures are available to combat climate change, only a fraction of the instruments are in the fiscal toolkit. Price-based interventions aim at internalizing the externality through price signals. They are associated with higher prices for carbon emissions, providing economic agents with an incentive to conserve energy and switch to greener sources. Fiscal price policies include carbon taxes[4] or cap-and-trade schemes[5], feebates[6], subsidies for mitigation action, low-carbon investment subsidies, interest rate subsidies and tax breaks. In addition, public guarantees can help secure higher private-sector participation in projects to mitigate climate change. Conversely, quantity-based interventions have a goal of effectiveness rather than efficiency. On the fiscal front, quantity-based tools include outright public investment, concessional loans from development banks and public investment funds.[7] In many cases, some of the quantity-based interventions are outside the scope of fiscal policy, such as restrictions on energy consumption and emissions using laws, regulations, standards and enforcement. It should be noted that price-based intervention could become ineffective when supply turns inelastic and, hence, quantity-based interventions are the available option.

In most cases, carbon pricing appears to be the most powerful and efficient way of reducing emissions since it gives economic agents an incentive to find ways to conserve energy and switch to greener sources, and it could also generate significant fiscal revenues [Krogstrup and Oman, (2019) and IMF (2019a, 2019b, 2020)]. Carbon taxes are widely seen to be critical to any successful mitigation strategy since they allow the above-mentioned externalities to be internalised (Akerlof et al. 2019; Farid et al. 2016; Parry, de Mooij, and Keen 2012; Parry, Morris, and Williams 2015). Thus, carbon prices should incorporate all the environmental costs of emissions associated with climate change. In terms of internalising other externalities, some authors argue that they should also consider local air pollution, traffic congestion, road damage

[4] A carbon tax is a tax on the supply of fuel in proportion to their carbon content.

[5] In cap and trade schemes, firms hold allowances of their emissions, and the government sets a cap on total allowances or emissions; market trading of allowances establishes the emissions price.

[6] Feebates impose a sliding scale of fees on products or activities with above-average emissions and subsidize (rebates) on a sliding scale for products or activities with below-average emissions. The structure of fees and rebates would usually be set to make the system self-financing.

[7] Despite cap and trade schemes are sometimes classified as quantity-based tool, we considered as price-based intervention since they encourage the reduction of emissions through price signals and it is not a mere quantitative scheme setting a limit to emissions.

and accidents (IMF 2019a), and co-benefits in terms of innovation and productivity growth, among others (Aghion et al. 2009). One important limitation of carbon pricing is that the costs of carbon emissions are still highly uncertain. IMF (2019a) shows several features of an appropriate carbon pricing design: a wide-ranging coverage of emissions; an alignment of carbon prices with mitigation objectives; a predictable steady increase over time of carbon prices (to help mobilise low-carbon technology investment); and an efficient use of the additional fiscal funds generated.

Other fiscal measures such as cap and trade schemes, feebates, low-carbon investment subsidies or outright public investment do not discourage activities that use energy and thus are less efficient in reducing emissions. The first three measures also rely on prices but they are less effective and efficient since they cover a narrower set of activities than a carbon tax. However, subsidies need to be financed through fiscal revenues or public debt which could be infeasible to implement if they are used on a large scale, given public sector budget constraints, and they could also have other macroeconomic implications if they increase the distortions. Moreover, if subsidies are not properly targeted and sized, they could induce the wrong incentives for private agents. Cap and trade schemes have been mostly limited to power generators and large industry, given the feasibility of accurately measuring their emissions, among other reasons. Compared with comprehensive carbon pricing, current cap and trade schemes limit the CO_2 reduction benefits by 20-50% across countries (Parry, 2019). Moreover, a feebate, for instance, consisting of an extra fee on vehicles with lower-than-average fuel efficiency and a rebate on more efficient vehicles, would lead consumers to purchase more efficient vehicles, but it would not reduce distance driven, perhaps even the contrary. Thus, to deliver an emission cut, these measures might need to be used aggressively and could entail greater economic costs than those incurred through carbon pricing, which allows agents to identify and exploit all available avenues to reduce emissions (IMF 2019b).

Carbon taxes are also effective in promoting innovation. Carbon taxes push firms to move toward the best-practice frontier and, when firms face higher fuel prices, will tend to be more innovative in clean technologies with path dependence in the type of innovation (Aghion et al. 2015). In addition, carbon taxes could improve energy efficiency, since countries with persistently low carbon prices are characterised by very low energy efficiency (Grubb et al. 2018). Nonetheless, carbon taxes may not always be effective, when there are few low-carbon technological alternatives or in the absence of long-term credibility (Fay et al. 2015).

Carbon taxes might also incorporate border carbon adjustments to reduce emissions leakage, but may have limited effectiveness and raise practical issues (Keen and Kotsogiannis 2014). In the absence of international coordination, carbon taxation also has side effects; it may lead to carbon leakage, a flight of polluting companies to other countries where such tax does not exist. One way to reduce this drawback is through a border carbon adjustment, i.e. to levy charges on imports and remit charges on exports to ensure a level playing field given carbon prices levied elsewhere. However, measuring embodied carbon in traded goods can be contentious. Border carbon adjustments risk retaliation, as there is a possibility of them being used for protectionist purposes, and they could be subject to challenge under the WTO. In this connection, IMF (2019b) advocates for an international carbon price floor that could muster consensus among key countries on greater mitigation ambition.

The macroeconomic implications of the carbon tax scheme depend on the use of the funds collected and, if used wisely, may increase economic efficiency (Goulder 1995). The implied increase in energy prices not only has the potential to suppress labour demand in energy-intensive sectors but also to reduce households' purchasing power. At the same time, carbon taxes increase government revenues. The additional budget funds arising from carbon taxes could be substantial. For instance, IMF (2019b) estimated that a carbon price set at USD 35 per ton would generate revenues amounting to around 1% of GDP in G20 economies. Nonetheless, part of this increase in revenues is temporary, since the carbon tax will push innovation towards cleaner energy technologies and, consequently, the consumption of polluting inputs will diminish.

These funds could be used to reduce more distortionary taxes (e.g. taxes on labour or capital income) that affect the economy by discouraging investment and labour force participation or, more generally, to fund public investments or to reduce fiscal deficits (Goulder 1995). Revenues can be also used to promote R&D into clean technologies, to provide direct payments to those households more relatively affected by these environmental taxes, to increase the social acceptability of the carbon tax or a combination of all of these. The foregoing highlights the relevance of climate mitigation policies that consider both revenue and spending components. Thus, the recycling of this additional revenue could generate a "double-dividend", creating benefits on the environmental and economic fronts.

Public promotion of R&D into clean technologies with these funds could also increase economic efficiency. As already mentioned, government support is needed to address the knowledge spillovers from R&D that may prevent their full social benefit from being harnessed. In addition, technology barriers are particularly acute in the clean energy sector as energy technologies often require networks and have long lifetimes, high upfront costs and face uncertain returns. The support is required at the basic research, at the applied R&D and at the deployment stages. Among the incentives that may be needed are tax rebates, subsidies and loan guarantees, but they should be designed with care (e.g. to avoid forcing through new technologies irrespective of their future costs) (IMF 2019b, IMF 2020).

Recycling the revenues into government spending and investment policies could also be effective in climate change mitigation. Green public procurement can help foster low-carbon innovation, generate economies of scale and increase the demand for lower-carbon industrial products (IEA 2017). Public infrastructure investments are particularly relevant since they can lock in the type of energy mix used for a long time (e.g. in public transport and urban infrastructures) and, hence, limit carbon emissions.

While the revenues from carbon pricing should be used to provide the highest social value (Pigato, ed., 2019, Guillaume et al. 2011), political economy considerations appear to be pivotal for gaining public acceptance of carbon pricing (Guillaume et al. 2011, Heine and Black 2019, Klenert et al. 2018). In this sense, lump sum payments to households or subsidies to improve the energy efficiency of houses are measures which tend to increase public approval.

Taking these considerations into account, IMF (2020) proposes a comprehensive strategy to mitigate climate change that consists fundamentally of increasing carbon prices globally, which would both raise energy efficiency and the share of low-carbon sources in energy supply, and in promoting green investment. That would help to lower the economic costs of higher carbon prices. As regards instruments, it proposes using simultaneously (i) carbon taxes or carbon-emission trading programmes to price the emissions externality; (ii) direct public investment in low-carbon technologies and infrastructure and subsidies and price guarantees to make low-carbon energy sources more abundant and cheaper, and R&D subsidies to spur innovation; and (iii) compensatory transfers to households. The simulations show that this strategy is associated with few economic costs in terms of the growth that this policy mix will generate in the coming decades. Governments can protect those most affected by mitigation by providing targeted cash transfers financed by carbon revenues.

In terms of evidence from Spain, there is growing empirical literature on the effects of environmental tax reforms. It generally finds that that these reforms are helpful to reduce GHG emissions without generating any large negative macroeconomic impact. Most of these papers have analysed the "double dividend" hypothesis in which increases in revenues associated with environmental policies are used to reduce social security contributions (Labandeira et al. 2004, André et al. 2005, Sancho 2010, De Miguel et al. 2015), and indirect and capital taxes (Freire-González and Ho 2019), among other alternatives, such as to promote renewable energies (Labandeira et al. 2019). They generally found that macroeconomic impact tends to be positive if revenues are recycled towards a reduction of social security contributions. Regarding modelling, in the Spanish case, some of the previous papers rely on static computable general equilibrium (CGE) models. Freire-González and Ho (2019) introduce intertemporal considerations by developing a dynamic CGE model and found, as a novelty, that the positive effects on the economy of the revenue recycled are achieved only for small CO_2 taxes and in the initial years of implementation. On their part, García-Muros et al. (2017) combine Input-Output and micro-simulation models to analyse the distributional implications of a revenue-neutral tax reform.

This paper assesses several environmental fiscal reforms based on a carbon tax on fossil fuels that covers all economic sectors, which is easy to administer since it can be integrated into existing fuel excise duties. It also explicitly considers the effects of the introduction of a border carbon adjustment and alternative uses of the tax revenues generated (reducing the public deficit or social security contributions, lump sum payments to households or subsidising the electricity bill). To assess the environmental and economic impact of the proposed green tax reforms in Spain, this paper builds a novel model that combines the sectoral information, in a somewhat similar vein to the CGE approach, with the advantages of multi-country semi-structural models based on the Neo-Keynesian framework, which allows us to have much greater detail of the behaviour of economic agents and their interactions. The model developed is not fully integrated and should be operated sequentially. This allows us to simulate with greater flexibility how carbon tax revenues are recycled accounting for nominal and real frictions. Moreover, it is possible to analyse the economic impact of the transition to a low-carbon economy considering international spillovers derived from the tax, analysing the alternatives with border carbon adjustment. However, it should be taken into account that climate change is a non-linear phenomenon and that its mitigation implies a structural change in the economy. Given the rather linear nature of our model and the absence of reallocation costs, our exercise has been designed only to assess the mid-term implications of the carbon tax on the environmental and economic fronts.

3. Carbon tax design

Bearing in mind the literature on carbon prices, in this section we analyse some of the elements that a carbon tax in Spain should consider.

- Tax base. One possibility is to establish a CO_2-added tax scheme that charges the carbon content incorporated into each production stage. The tax would be collected at each firm and household and the tax base would be the CO_2 emitted by that particular enterprise and household. This option is optimal for reducing emissions both from the point of view of consumers (who will see the relative prices of the most polluting goods and services rise) and firms (who will choose cleaner inputs and technologies). This approach would also allow the mitigating actions the firms could introduce into the productive process, such as CO_2 capture mechanisms, to be taken into account. However, the management of the tax would have unaffordable costs, since it would require reliable emission measurement systems which, in the case of most activities, would currently be infeasible to implement. For example, in the case of transportation it would be necessary to measure the effective use of the vehicles and the conditions of that use. Unsurprisingly, international examples of environmental taxes whose tax base is the emissions of polluting gases are always confined to very specific sectors, such as the European Emissions Trading System (EU ETS), which covers the GHG emissions of the energy sector and large industries.

Given the stable relationship between fossil fuel inputs consumption and the generation of CO_2,[8] the alternative chosen in this study is to impose a surcharge on the existing unit taxes on these inputs that generate CO_2 and create new excise duties for those energy inputs that currently do not have any.[9, 10] In this way, although taxes do not charge the taxable event (externality), the incentives are maintained for consumers to demand products with a lower carbon footprint and for firms to choose cleaner inputs and technologies, assuming that the main aim of previous excise duties on those products was not the mitigation of emissions.[11] This tax could be collected at the beginning of the production process (mines, refineries, or natural gas wholesale distribution points), so it would be easy to administer since in many cases will not require additional administrative procedures and will be integrated into existing fuel excises. One drawback of this proposal is that it does not allow for the inclusion of carbon capture mechanisms in the productive process. Establishing a reimbursement system in these cases would complicate tax management, but it would be feasible to incorporate it.

- Coexistence with EU ETS. The setting of the carbon tax must consider the coexistence with other public policies aimed at reducing emissions, such as the EU ETS which price around 40% of total emissions in Spain in 2015 (see Figure 1). EU ETS cover power and heat generation, energy-intensive big industry sectors (refineries, metals, chemicals, …) and part of the commercial aviation sector. The system covers these sectors and gases, focusing on emissions that can be measured, reported and verified with a high level of accuracy. Coordination between the two initiatives could be resolved if all sectors were subject to the tax but, to avoid double taxation, the sectors covered by the EU ETS are reimbursed for the rights acquired in the market, which is what we propose in this paper.

  Extending the EU ETS to diffuse sectors covering all economic activities could be equivalent to the previous carbon tax proposal under certain conditions that are not currently in place. Then, emissions and revenues of the EU ETS are in principle the same as under an equivalent

[8] The amount of CO_2 generated when a fuel is burned per unit of energy is a chemical property, a function of the carbon content of the fuel. The amount of emissions produced when a fuel is burned is mainly determined by the carbon (C) and hydrogen (H) content of the fuel. Water and other elements, such as sulphur and non-combustible elements in some fuels, increase their CO_2-to-energy contents.

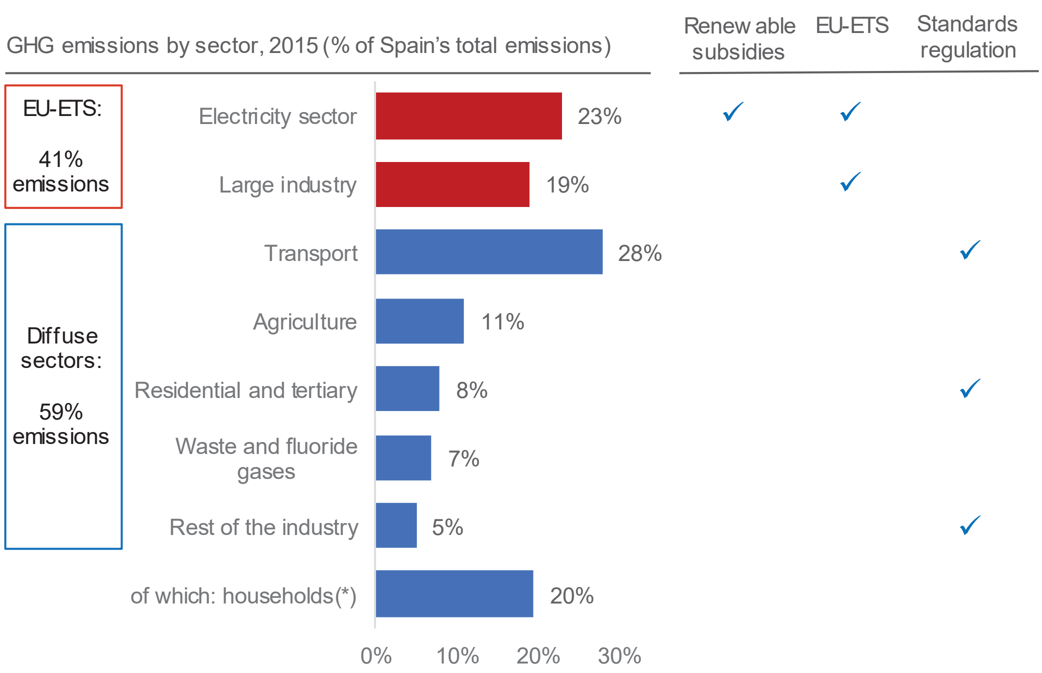
[9] According to the US Energy Information Administration, CO_2 emissions from fossil fuel combustion (burning) for energy were equal to about 93% of US CO_2 emissions in 2018.

[10] As it can be deduced from the previous footnote, a part of the CO_2 emissions does not come from the use of energy inputs but from other chemical reactions resulting from the production of certain products. Although these products and emissions are not incorporated in our carbon tax proposal, their respective level of excise taxes could be calculated in a similar vein, considering the individual carbon content associated to its production (excluding the part derived from burning fossil fuels) and the objective carbon price.

[11] For example, excise duties collected on gasoline and diesel consumption in Spain are very similar to the maintenance costs of the public transport infrastructures.

carbon tax. To achieve that, it is necessary not only that EU ETS comprehensively cover all emissions through reliable emission measurement systems, but also that governments charge for all the initial emissions allowances (for example, by issuing them through an auction). However, in practical terms, the accurate emission measurement systems for many activities are infeasible to implement with existing technologies. For instance, with current measurement systems, it is unconceivable that households could be part of the EU ETS while their consumption of fossil fuels accounts for approximately 20% of GHG emissions. In addition, in contrast with predictable carbon prices from a carbon tax, carbon prices resulting from cap and trade schemes tend to be volatile and, hence, more difficult to predict, which could ultimately affect economic agents' decisions. On the other hand, under the carbon tax proposed, GHG emissions that does not come from the use of energy inputs will not be charged. If properly measured, the EU ETS could consider these emissions and, thus, will be superior internalizing the externality.

Figure 1. Spain: GHG emissions by sector and policies aimed at reducing emissions



Source: Authors' calculations based on Sistema Español de Inventario de Emisiones and INE.
(*) Based on INE's Sectoral Accounts of GHG emissions to the atmosphere.

- Carbon leakage. In addition, in the absence of international coordination, a CO_2 tax induces carbon leakage in which third economies can benefit from reducing emissions in others. For activities subject to international competition, the introduction of a CO_2 tax results in a loss of competitiveness of the national industry, and activity (and emissions) move to other regions. Moreover, since the EU-ETS scheme is designed to achieve a cap on emissions at the European level, if a country reduces its emissions, it does not affect overall emissions of this sector at the European level, but simply moves emissions from this country to another one (the so-called waterbed effect). Lastly, the carbon tax, if applied in a sufficiently large number of economies, will result in the demand for fossil fuels reducing oil producer prices which, in turn, encourages their consumption in the economies where there is no such tax. One way to mitigate carbon leakage is through a border carbon adjustment, i.e. imposing surcharges on imports and exempting exports from the tax, as we will evaluate in this paper.

However, measuring carbon embedded in trade is controversial: there is scope for protectionist use; it could be subject to challenge under the WTO rules; and it risks retaliation. Notice that, to be effective, it would be necessary to impose a different surcharge for every country and product depending on their emissions, and this is not the normal practice in WTO.

4. The environmental fiscal proposals

Given the previous considerations, we define a set of proposals to assess the environmental and economic impact of introducing a carbon tax in Spain (see Table 1). The fiscal reforms cover: (i) different levels of the carbon tax instrumented in those inputs that are a source of carbon emissions (fossil fuels); (ii) the possibility of a border carbon adjustment; and (iii) different uses/recycling of the tax revenues generated (lower public deficit/debt, reduction in social contributions, lump sum transfers to households, or subsidisation of the electricity bill).

Table 1. Summary of the environmental fiscal proposals

Scenario	Carbon tax level (€ per CO_2 ton)	Sectoral coverage	Border carbon adjustment	Tax revenue use/recycling
1	30€ (and 15€)	Domestic production: Diffuse sectors + EU ETS (exports are taxed but imports are exempted)	NO	Public deficit/debt reduction
2				Social security contributions reduction
3				Transfer to households
4				Electricity bill subsidy
5	30€ (and 15€)	Domestic demand: Diffuse sectors + EU ETS + Imports (exports exempted)	YES	Public deficit/debt reduction
6				Social security contributions reduction
7				Transfer to households
8				Electricity bill subsidy

At the level of the carbon tax, the best choice could be to align it with the social cost associated with CO_2 emissions, which will induce agents to generate through their consumption or production the optimal amount of emissions at each pointe in time. There is great uncertainty over the magnitude of the social costs, but the median of current estimates in peer-review studies is around USD 31 per CO_2 ton (Wang et at, 2019). In the simulations, in fact, we considered two levels of the carbon tax, namely 30 and 15 euros per ton, aligned with the above-mentioned social cost and the pricing of CO_2 emissions in the EU ETS in recent years. In any case, given the quasi-linear nature of the model the results are easily interpolable to consider higher pricing of CO_2. However, considering that climate change is clearly a non-linear phenomenon and given the rather linear nature of the model, the exercise is designed only to assess mid-term implications of these policies.

Another feature of the design is the border carbon adjustment. We considered alternative scenarios in which all domestic production were charged and, alternatively, in which each product export was exempted from the carbon tax and imports were charged according to their carbon content. The carbon incorporated into imports is calculated from the corresponding national production of the same product. The latter is a drawback of our approach since we are not considering the fact that production technologies could differ across importers and we could be penalising less polluting producers. There is a clear scope for expanding this analysis. Moreover, imports are assumed to be priced at the border free of carbon taxes, which will avoid any double carbon taxation.

The use of the funds collected by the carbon tax is one of the key features of this analysis. We considered four scenarios in which the tax were used either: (i) to lower the public deficit or debt; (ii) to reduce other distortionary taxes, such as social security contributions; (iii) to transfer a lump sum to households; or (iv) to subsidise the electricity bill as a means of promoting cleaner electricity generation. In this respect, in the latter three uses, we are assuming that balance of the public budget remains unaltered, but if the tax is successful in curbing emissions, it should be taken into account that a decline in environmental tax revenues will gradually occur. This will mean that the initial calibration of the social contributions reduction, the lump sum payments to households or the electricity subsidy will diminish over time and, hence, so will their potential positive economic impact.

5. The model

We adopt a modular approach to the problem. In particular, we develop a model that combines sectoral information with a general equilibrium approach to assess the environmental and economic impact of introducing the above-defined designs of a carbon tax in Spain. It comprises two modules that interact with each other and that combine sectoral information with the general equilibrium approach. Figure 2 below summarises the main features of the model.

The first module, which is sectoral in nature, is made up of a static partial equilibrium model for the Spanish economy that combines information from the input-output tables, sectoral CO_2 emissions, a demand system for households, a demand system for intermediate energy inputs and a Phillips curve. This model allows us to obtain results in terms of CO_2 emissions disaggregated into 64 sectors. The module works as follows. Firstly, the surcharges on existing taxes on energy products that are a source of CO_2 are estimated according to their individual carbon content and the objective carbon price. Given that all economic agents will bear the tax on energy inputs, to avoid double taxation for those firms subject to EU ETS, a part of the tax collection is reimbursed to these firms in compensation for the cost of emission rights bought. There is also the possibility of introducing a border carbon adjustment, in which case a reimbursement process is also considered for exporters. Secondly, the input-output tables allow us to calculate the implicit tax burden borne by each product, which depends on the CO_2 content incorporated into its production and, consequently, the increase in its price. Using a demand system of the Spanish economy, we estimate the reduction in demand for each product associated with the change in relative prices (substitution effect) and with the general price level (income effect), which will translate into lower CO_2 emissions. Thirdly, we estimate how the carbon tax changes the relative prices of polluting and clean energy inputs, and by using the elasticities estimated in the literature we assess the change in the relative input demand for clean and polluting inputs. One drawback of this module is that it is not possible to simulate a complete tax reform since it does not allow for behavioral interactions between all economic agents.

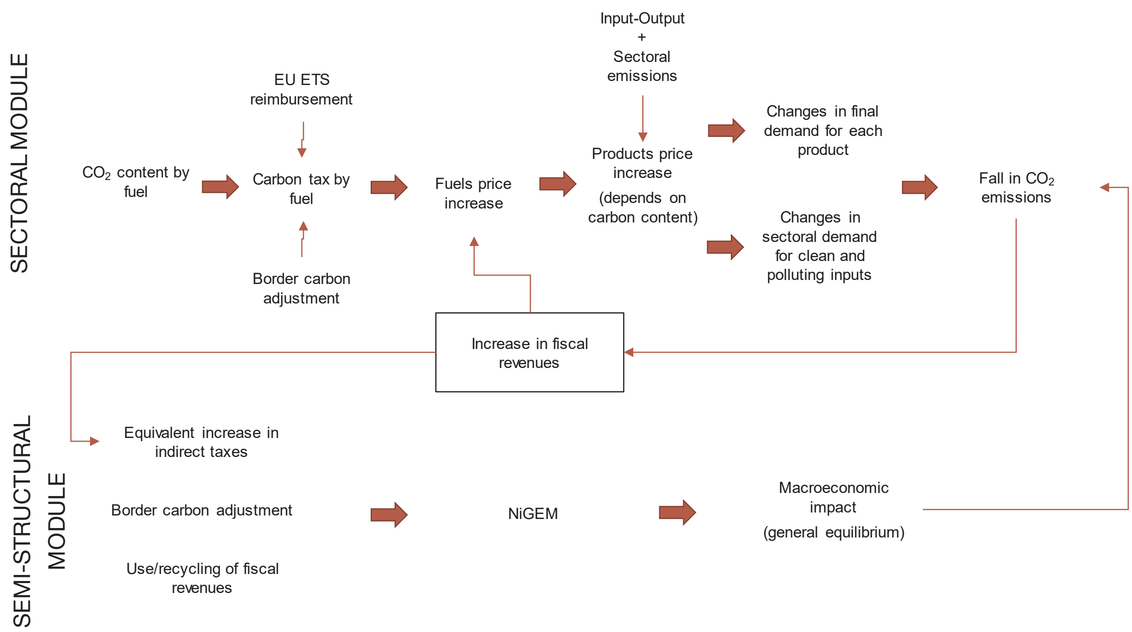
The second module, favouring a general equilibrium approach, allows us to simulate a parametric tax reform, sacrificing the granularity of the results of the first one. This module, with aggregate variables, consists of a semi-structural model[12] where accounting identities are combined with behavioral equations estimated for the representative agents (households, firms, public sector, external sector, ...). The model incorporates demand, supply and financial markets. It is based around a 'New-Keynesian' framework, with the long-run properties of equations imposed

[12] Based on the NiGEM model, developed by the National Institute of Economic and Social Research.

consistent with theory, but with dynamic adjustment estimated using historical data. Economic agents are presumed to be forward-looking, but with liquidity constraints, myopic behaviour and nominal rigidities in other sectors slowing the process of adjustment to shocks. The model is flexible enough to introduce alternative economic policies and changes into the behaviour of the agents. This module allows us to analyse the effect on the main macroeconomic variables of the different designs of the carbon tax, and of the different uses of the revenues generated. Although this module incorporates explicitly short-term dynamics, thus allowing us to analyse the transition from one steady-state to another resulting from the environmental reform, it does so from an aggregate perspective. Therefore, it considers that the structure of the economy does not change at sectoral level and does not take into account all the costs associated with the reallocation of resources. These could be sizable depending on the flexibility of the economic system to reallocate resources across sectors and firms and adapting workers' skills. More flexible labour markets (e.g. with lower firing costs, more effective active labour policies, etc.) would help to reallocate the labour force to greener activities. At the same time, if the financial system incorporates the climate change risks into their risk analysis and their pricing policy, financial resources will flow more quickly to the most sustainable activities. A further example is the regulation of insolvency proceedings, which should be accelerated in order to minimise the loss of value of ailing companies.

The link between the two modules is structured in the following way. First, the fiscal revenues associated with each level of the carbon tax considered is translated into an equivalent increase in the indirect tax rate on consumption. Second, in those reforms with border carbon adjustment, an additional shock is introduced into import prices and, in the simulations without border carbon adjustment, an equivalent shock is added to export prices. Third, in the scenarios in which the use of funds is to reduce social security contributions or, alternatively, to provide lump sum payments to households, we calculate their equivalence to the increase in tax revenues due to carbon tax. Finally, in the subsidy to electricity bill scenarios, the matching reduction in the electricity rate increases the disposable income of households and reduces the unit costs of firms. Further details on the derivation of both modules can be seen in Appendix B.

Figure 2. Diagram of the model



5.1. Sectoral Module

As already mentioned, we have chosen to impose surcharges on the taxes of consumption of fossil fuels instead of creating a specific tax on emissions to reduce administrative costs, given the stable relation between these energy inputs consumption and CO_2 emissions.

The surcharge of the unit tax to be applied to each fuel depends on the level of the carbon tax and the relative level of pollution generated by each energy input. To avoid double taxation, a part of the tax collection is reimbursed to those sectors subject to the EU ETS in compensation for the cost of emission rights bought.[13] This module also allows for the possibility of introducing a border carbon adjustment in which imports are taxed equivalently to local production and exporters are reimbursed for the carbon tax paid.

The key elements of the 64-sector module could be summarised as follows.

5.1.1.Surcharge on fuel excises and change in the prices of the products

First, we design the carbon tax as a surcharge on unit fuel taxes.[14] To establish this surcharge in a way that encourages the transition to a less polluting economy given an objective price of CO_2 emissions, it is necessary to determine how these taxes are passed downstream through the production chain and the relative pollutant intensity of each input. Thus, the surcharges on existing taxes on energy products that are a source of CO_2 are estimated according to their individual carbon content (see Table 2 and Table A-1 in the Appendix) and the objective carbon price.[15] Table 3 shows the initial surcharges on unit taxes for each of the fossil fuels.[16]

Table 2. CO_2 emissions in Spain. Conversion factors and decomposition by product, 2015

	Consumption	CO_2 emissions coefficient	CO_2 emissions
LPGs	3607	1.64	5921
Gasoline	6283	2.35	14757
Kerosene	6821	2.58	17573
Automotive diesel	25962	2.68	69687
Other diesel	9564	2.68	25672
Lubricants	484	2.83	1370
Asphalt	1151	3.16	3635
Petroleum coke	3416	3.88	13264
Natural gas	1072	53.07	56898
Coal	27	2336.4	62666
Total			271447

Note: Consumption of petroleum derivatives is expressed in thousands of kilolitres, natural gas in billions of BTU and coal in thousands of tons. CO_2 emissions are expressed in thousands of tons.
Sources: EIA, Cores, MITECO and authors' calculations.

[13] As we said before, it is disputable as to whether the current level of excise duties on some fossil fuels can be considered as a partial internalisation of the CO_2 emissions.

[14] We also consider asphalts and lubricants which strictly are not fossil fuels.

[15] CO_2 emissions per physical unit of polluting input have been obtained from the information provided by the US Energy Information Administration. Although they are calculated for the US, combined with data on the demand for energy products provided by Cores and the Ministry for the Ecological Transition, Spain's CO_2 emissions can be replicated with an error margin of less than 3%.

[16] Specifically, once the CO_2 emissions of each fuel type are taken into account, the highest surcharge corresponds to coal and the lowest to natural gas. The surcharge for petroleum products is similar, reaching the highest level in petroleum coke and the lowest in diesel. The case of diesel illustrates the possibility of broadening the base of environmental taxes to include emissions of other greenhouse gases such as nitrogen oxides, given that the emissions of this derivative are much higher than others such as gasoline.

Table 3. Initial change in prices (excluding VAT), %, 2015, 30 € per CO_2 ton

	With border carbon adjustment	Without border carbon adjustment
LPGs	8.9	8.4
Gasoline	10.1	9.5
Kerosene	21.5	20.3
Automotive diesel	11.2	10.6
Other diesel	12.7	12.0
Lubricants	7.3	6.9
Asphalt	31.6	29.9
Petroleum coke	187.2	177.1
Natural gas	19.0	18.0
Coal	106.0	100.3

Source: Authors' calculations.

From the input-output tables and the sectoral emissions, we calculate the CO_2 content embedded in each product (Table 4). An estimate of the CO_2 emissions that each product embeds during the production process is the basis of the carbon tax and determines the changes in the relative costs and prices of each product. The Spanish National Statistics Institute (INE) only provides the direct emissions generated by each sector. However, through the demand for intermediate goods and services, the production of each sector is an input for the production of other sectors, so part of the emissions generated by that sector is embedded in the final production of the rest of the sectors. Consequently, it is necessary to consider the structure of the economy's domestic intermediate consumption in order to correctly assign CO_2 emissions to final products. This is estimated by using the 2010 Input-Output Tables of the Spanish economy updated to 2015.

Table 4. CO_2 emissions in Spain (thousand tons), 2015

		Agriculture	Manufacturing	Energy*	Construction	Market services	Non-market services
By sector	Total	12262	59444	158468	416	44218	4468
	By unit**	0.238	0.114	1.105	0.003	0.048	0.018
By product	Total	6422	67701	100525	27882	63938	12806
	By unit**	0.125	0.13	0.701	0.196	0.07	0.051

* Incorporates households' CO_2 emissions; ** Per unit of final production measured in euro millions
Sources: INE and authors' calculations.

Table 4 shows the CO_2 emissions of the sectors and their allocation to the final products manufactured by those sectors, both in absolute terms and relative to total production. As can be seen, the emissions by branches of economic activity are very heterogeneous, with the energy sector having the highest emissions per unit of production (in value), and construction the lowest. These results are altered to some extent when calculating the emissions embedded in the production of the final products of these sectors, considering the intermediate consumption of other sectors. In particular, given that energy and agriculture (the latter to a lesser extent) are producers, above all, of intermediate goods, their emissions are incorporated into the production of the other sectors and, hence, are reassigned to those products. The largest upward correction in emissions is observed in the construction sector, as it uses many inputs from other sectors that are emissions-intensive; in fact, this reallocation reveals that its products are the second most polluting per unit of production. The new ranking is completed with products from manufacturing, agriculture, market services and non-market services. The case of market services is very interesting since it includes highly polluting sectors such as transport, but they also produce mainly intermediate consumption for other sectors, which is why they are incorporated into the final production of the latter.

5.1.2. Changes in final demand

The effect on final demand is calculated as follows.

First, using the input-output tables, the implicit tax burden borne by each product is calculated, which depends on the CO_2 content embedded in its production[17] and, consequently, the increase in its price.[18]

Second, using a demand system of the Spanish economy (Bover et al. 2017), we estimate the reduction in demand for each product associated with the change in relative prices (substitution effect) and with the general price level (income effect), which will be translated into lower CO_2 emissions.

Finally, from the macroeconomic perspective the increase in taxes reduces aggregate demand and, thus, an aggregate Phillips curve for the Spanish economy (Álvarez and Urtasun, 2013) allows us to estimate the change in overall price level associated with fall in demand because of the carbon tax, which reduces the income effect.

5.1.3. Changes in demand for polluting inputs

The input-output framework considers a fixed proportions production function in which the factors of production are used in fixed (technologically predetermined) proportions and, hence, there is no substitution among factors.

To deal with this shortcoming, we estimate the effect on the demand for energy inputs using the sectoral elasticities of substitution among inputs derived from the constant elasticity substitution production function. In particular, we use the elasticities for clean and polluting inputs estimated by Papageorgiouy et al. (2017).

As a first step, we estimate how the carbon tax changes the relative prices of polluting and clean energy inputs according to their carbon content. Using the above mentioned elasticities, we can approximate the change in the relative demand for clean and non-polluting inputs for all sectors, differentiating electricity production from the rest of the sectors. Given that the increase in the demand for clean energy by the non-electric sectors also implies an increase in the demand for and production of electricity (which is supposed to be a clean input), it is also necessary to consider the capacity of the electricity sector for replacing polluting inputs with clean ones, i.e. to generate cleaner electricity, as will be explained in Section 6.1.

5.2. Semi-structural module

The second module, favouring a general equilibrium approach, allows us to simulate a parametric tax reform, sacrificing the granularity of the results. This module allows us to analyse the effect

[17] Through intermediate consumption, the production of each branch of activity is an input for the production of other branches, so part of its emissions are 'embedded' in the final production of the other branches, making it necessary to take into account the structure of domestic intermediate consumption to make a correct allocation of CO_2 emissions to products. To do this, we use the 2010 Input-Output Tables of the Spanish economy updated to 2015 due to the availability of data.

[18] This exercise has been carried out assuming that neither compensation of employees nor gross operating surplus maintain their participation in aggregate income. If they did, the increase in the general price level would be greater and the income effect more pronounced, which would further reduce agents' real income and, thus, emissions would be further reduced.

on the main macroeconomic variables of the different designs of the carbon tax and of the different uses of the revenues generated by the tax. The procedure to simulate the fiscal reform is as follows.

Firstly, with the fiscal revenues associated with each level of the carbon tax considered (and deducting the expenses in emission rights and exports when relevant), we calculate the equivalent increase in the indirect tax rate on consumption, which is the shock introduced into the model.

Secondly, in the simulations without border carbon adjustment, an equivalent shock is introduced into export prices, to consider the downstream effects caused by the carbon tax and the deterioration of competitiveness. Conversely, in the scenarios with border carbon adjustment, the shock is introduced into import prices and exports are exempted from the carbon tax.

Thirdly, in the scenarios in which the use of funds is to reduce social security contributions, we calculate the equivalent reduction to the increase in tax revenues due to carbon tax. Conversely, when revenues are transferred as a lump sum to households, we increase households' gross disposable income towards a public transfers shock of the size of carbon tax revenues.
Finally, in the subsidisation of electricity bills scenarios, the reduction in electricity costs increases households' disposable income and reduces the costs per unit of firms' production.

6. Results

6.1. Environmental effect

In our framework, CO_2 emissions are reduced after the introduction of the tax because the rise in carbon prices led households to demand products with less carbon content and firms to produce with less polluting inputs. Considering both channels and for a carbon tax of EUR 30 per CO_2 ton[19], the reduction in emissions will range between 11-16% per year depending on the scenario considered (see Table 5).[20] This is between 32-46% of the Spanish GHG emission goal for 2030.[21] We will explain these results looking at detail at both households' and firms' demand channels.

Table 5. Change in CO_2 emissions, 2015 (%). 30€ per CO_2 ton

	With border carbon adjustment				Without border carbon adjustment			
	Public deficit/debt reduction	Social security contributions reduction	Transfer to households	Electricity bill subsidy	Public deficit/debt reduction	Social security contributions reduction	Transfer to households	Electricity bill subsidy
Households	-3.2	-2.9	-3.1	-2.0	-2.4	-2.0	-2.3	-1.1
Firms	-9.8	-9.8	-9.8	-13.5	-9.2	-9.2	-9.2	-12.9
Total	-13.0	-12.7	-12.9	-15.5	-11.6	-11.2	-11.5	-14.0

Source: Authors' calculations.

The first channel from which CO_2 emissions will be reduced is through households' demand. They will react to the changes in prices of final goods and derived from their carbon content and

[19] The model presented is rather linear and the results for a EUR 15 per CO_2 ton carbon price target has roughly half of the impact. We show only the 30-euro target given that it is closer to the (uncertain) social cost of carbon.

[20] These estimates are slightly lower than those of Fereire-González and Ho (2018), who found a 21% CO_2 emissions reduction for a EUR 30 per CO_2 ton.

[21] Spain's National Energy and Climate Plan (NECP) sets a target of 23% GHG emission cuts by 2030, compared with 1990 levels. As part of the European Green Deal, the European Commission proposed to raise the 2030 greenhouse gas emission reduction target, including emissions and removals, to at least 55% compared to 1990.

the carbon price target. The reduction in demand for each product is associated with both the change in the relative prices of the different products (substitution effect) and the general price level (income effect). In addition, alternative uses of tax revenues alter the aggregate demand and the overall price level of the economy, leading to different income effects (see Table 6).

The reduction in emissions is in the range of 1-3% through households' demand depending on the scenario considered (see Table 6). The results show that those carbon tax designs with border carbon adjustment are more effective for lowering emissions. This is simply because they also tax imports. In fact, just from the household demand perspective, carbon leakage reduces by between 25% to 45% the emissions cut in Spain depending on the scenario. If the revenues are not 'recycled', i.e. they are used to reduce the public deficit or debt, the fall in emissions is more acute since they are associated with lower levels of economic activity (see section 6.2). If carbon tax revenues are set to subsidise the electricity bill, contrary to the aggregate results, it results in a lower emissions cut. This is a consequence of the lower capacity of households, compared to firms, to replace polluting energy inputs with cleaner ones, and the increase in the demand for energy induced by the subsidy.

Table 6. Final demand effect. Change in CO_2 emissions, 2015 (%). 30€ per CO_2 ton

	With border carbon adjustment				Without border carbon adjustment			
	Public deficit/debt reduction	Social security contributions reduction	Transfer to households	Electricity bill subsidy	Public deficit/debt reduction	Social security contributions reduction	Transfer to households	Electricity bill subsidy
Sustitution effect	-1.9	-1.9	-1.9	-1.2	-1.4	-1.4	-1.4	-0.6
Income effect	-1.2	-1.0	-1.1	-0.8	-0.9	-0.6	-0.8	-0.5
Total	-3.2	-2.9	-3.1	-2.0	-2.4	-2.0	-2.3	-1.1

Source: Authors' calculations.

Looking at the sectoral dimension, the biggest reduction in emissions is seen in large industry, followed by the household sector, the energy sector and extractive industries, and transport. The reduction depends on the carbon content of their inputs – and, hence, on their price increase – and on the elasticity of demand each product faces. Table A-2 in the appendix provides further details on these results.

The second channel from which CO_2 emissions will be reduced is through changes in firms' demand for polluting inputs. The surcharges on fossil fuel unit taxes modify the relative prices of polluting and clean energy inputs. Using the long-term elasticities of substitution between polluting and clean inputs estimated by Papageorgiouy et al. (2017), we approximate the change in the relative demand for both types of inputs. They estimated this elasticity for the electricity industry and the rest of the sectors, a feature that we benefit from.

We take into account the fact that the increase in demand for 'clean energy' inputs by non-electricity sectors also implies an increase in demand for and production of electricity. Thus, it is key to consider the capacity of the electricity sector to replace polluting inputs with clean ones, i.e. to make electricity generation cleaner.

The fall in polluting inputs demand from non-electricity sectors leads to a reduction of around 3-6% of CO_2 for a EUR 30 per carbon ton price target (see Table 7) depending on the scenario. The largest reduction in emissions is observed when the carbon tax revenues subsidise the electricity bill, since the change in relative prices of polluting to clean inputs is higher and producing electricity is less polluting than using fossil fuels as an input. This substitution effect is much higher than the increase in energy demand generated by the subsidy on electricity.

Moreover, the electricity sector accounts for the bulk of the reduction in CO_2 emissions and it is larger when the electricity bill is subsidised, as it introduces a larger incentive in that sector to switch to a less polluting generation mix. Using the elasticities for the electricity sector provided in the above-mentioned paper, the fall in emissions will be around 7% if the electricity bill is not subsidised. In the scenarios in which revenues are recycled to reduce the electricity bill, the reduction of emissions by the electricity sector is even larger, at around 0.7 percentage points, despite the increase in production of electricity derived from the demand of non-electricity sectors.

Table 7. Substitution of polluting inputs. Change in CO_2 emissions, 2015 (%). 30€ per CO_2 ton

	With border carbon adjustment		Without border carbon adjustment	
	Public deficit/debt reduction Social security contributions reduction Transfer to households	Electricity bill subsidy	Public deficit/debt reduction Social security contributions reduction Transfer to households	Electricity bill subsidy
Non-electricity sectors	-2.8%	-5.8%	-2.7%	-5.7%
Electricity sector	-7.0%	-7.7%	-6.5%	-7.2%
Total	-9.8%	-13.5%	-9.2%	-12.9%

Source: Authors' calculations.

Summing up both considerations, we can draw some conclusions. First, the reduction in polluting input demand by firms is a more powerful channel to reduce emissions than households' demand for final goods. Second, we observe that those carbon tax designs with border carbon adjustment are more effective for lowering emissions in Spain since they also tax imports. In fact, just from a household demand perspective, carbon leakage reduces the emissions cut derived from the carbon tax by between 25% to 45%. Third, when revenues are set to subsidise the electricity bill, it gives a larger incentive to the non-electricity sectors for electrification and for the electricity sector to produce with a less polluting mix and, consequently, to reduce the emissions per unit of energy generated. However, from a final demand perspective, the subsidy to the electricity bill encourages household demand for energy produced with a mix of polluting and clean inputs, which offset the reduction of emissions derived from the changes in final goods consumption, resulting in the lowest emissions cut. Adding both effects, the first one prevails, and the emissions cut is the largest given the incentive to introduce cleaner technologies in electricity generation.

6.2. Macroeconomic effect

As already explained, those carbon tax designs with border carbon adjustment are more effective for lowering emissions in Spain because of the macroeconomic implications of taxing imports and exempting exports. In the simulations with border carbon adjustment, the introduction of the environmental tax translates immediately into an increase in inflation for households, which would reduce their consumption, resulting in a drop in GDP (always with respect to the baseline scenario). The fall in GDP is cushioned since, when introducing a surcharge on imports, a replacement of goods produced abroad with domestic production takes place. If there is no border adjustment, the outcome is worse: the reduction of emissions is lower and the GDP fall larger. Since imports are not environmentally taxed, the global reduction in carbon emissions induced by Spanish domestic demand is lower. The negative impact on GDP is more acute because net foreign demand does not act as a counterweight to the reduction in the income of private agents.

In fact, exports fall due to the loss of competitiveness and there is no substitution of national production for imports, just the opposite since import relative prices fall. However, the inflationary effect is lower since imports are not taxed and GDP falls more. A feasible alternative to the border carbon adjustment scheme could be to introduce some degree of carbon tax coordination at a supranational level, since carbon leakage and loss of competitiveness will be limited without the need to introduce tax refund/surcharge systems, potentially subject to challenge under WTO rules, as measuring embodied carbon in traded goods can be contentious.

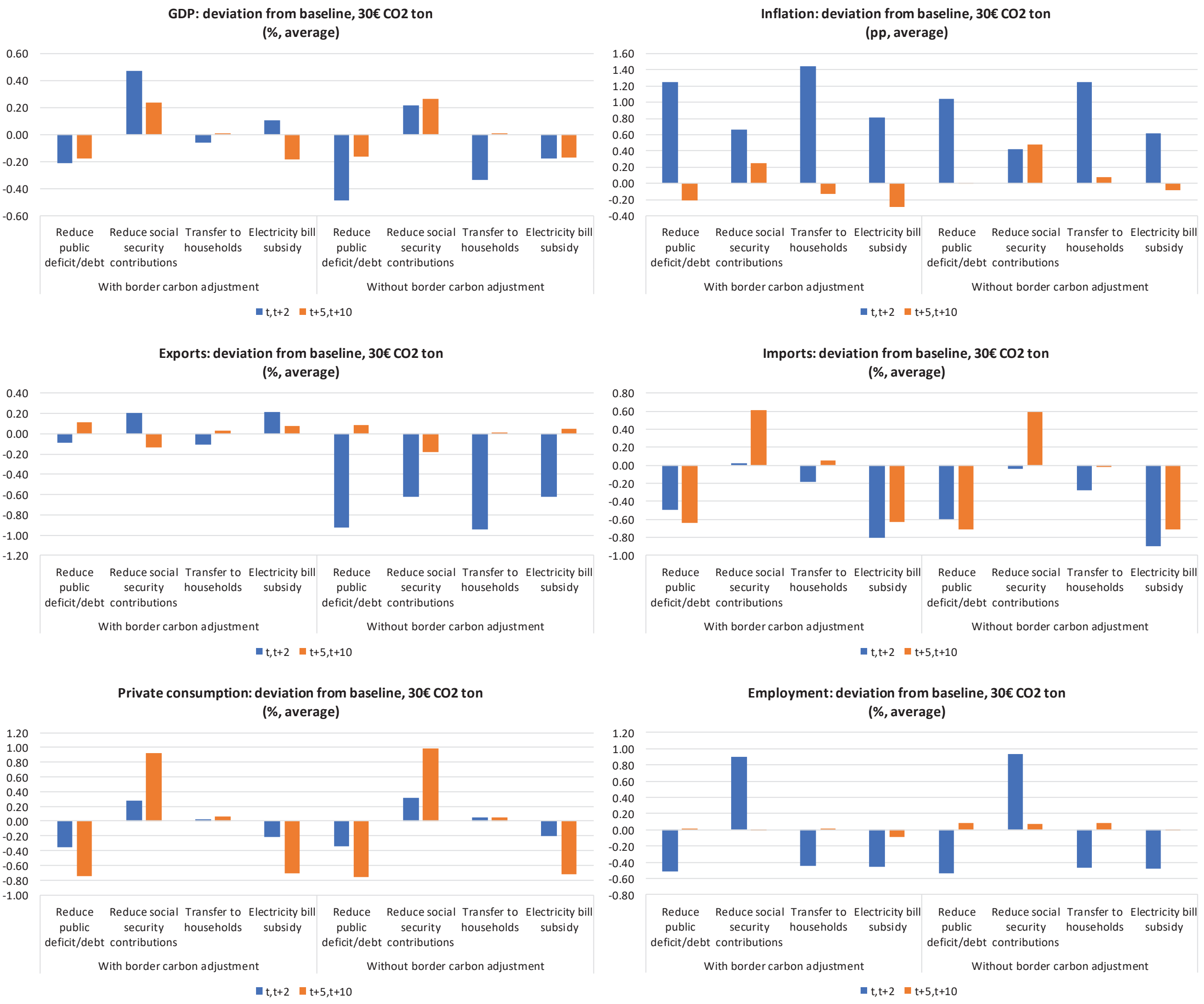
The results also point out that if the carbon tax revenues are used to reduce more distortionary taxes, it is possible to boost economic activity in the medium term. When the funds are used to reduce social contributions not only do labour costs decline but employment also increases, raising household income, which begins to consume more, and boosting production. Obviously, this increase in activity will cushion the initial reduction in emissions, but the net effect continues to be effective from an environmental perspective. However, note that this new activity will probably arise in cleaner sectors and requires a reallocation of resources across sectors and, depending on the flexibility of the economy, it could take some time. Besides, although replacing a highly distorting tax with one that is much less so produces overall efficiency gains for the economy, part of this increase in GDP is not permanent. Part of the increase in the revenues raised by the carbon tax will be temporary given that the tax will encourage the development of cleaner sources of energy.[22]

Recycling carbon tax revenues into lump sum payments to households almost offsets the initial negative impact on economic activity, while it is a fairly powerful proposal to reduce GHG emissions. However, compared with reducing social security contributions, the positive macroeconomic impact is lower since part of the increase in households' disposable income is saved, it does not reduce effective labour costs and the derived private consumption increase leads to higher inflation, which worsens competitiveness. Instead of giving lump sum payments to all households, the revenues could be distributed among those with lower incomes, who also are more hit by the carbon tax (Álvarez, 2019). In this case, the positive impact on GDP and employment would be greater as these groups show a higher marginal propensity to consume and, likewise, the inflationary effect would be larger. However, our model only considers a representative household and, thus, distributional aspects are outside its scope.

Lastly, the scenarios that use the funds to subsidise the electricity bill lead to a reduction in electricity costs, encouraging agents to consume energy which in the long term is compensated for by the efficiency gains in the production of electricity with clean inputs. The tax increase has an immediate effect on the price of energy inputs, which is transferred to consumer prices, and company costs are partly offset by the lower electricity bill. The increase in inflation leads households to reduce consumption and, in the case of firms, brings about labour cost increases, since the higher wage demands of workers are not compensated by the reduction in social contributions as in previous simulations. Consequently, the GDP performance is less favourable than when fiscal revenues are used to reduce social contributions.

[22] The experience with the car registration tax in Spain is very illustrative in this respect. Since 2008, motor vehicle registration tax rates have been aligned to the CO_2 emissions of each car instead of its power, and revenues have continuously diminished as the vehicles sold have been environmentally cleaner.

Figure 3. Macroeconomic effect



Source: Authors' calculations.

7. Conclusions

The conclusions that can be drawn from this study suggest how a reform of the tax system could be designed to reduce CO_2 emissions, containing potential adverse effects on macroeconomic performance.

First, a carbon tax that covers all economic sectors would be a powerful instrument to reduce emissions, as it gives households and firms an incentive to find ways to conserve energy and switch to less polluting energy sources. However, with a carbon tax of EUR 30 per ton, the maximum reduction in emissions is less than half of the Spanish current emission goal for 2030. Therefore, either carbon prices are further increased or they must be accompanied by other policy measures. Although carbon pricing is the most cost-efficient way to achieve successful mitigation, it could be combined with innovation policy that helps remove obstacles to developing new low-carbon technologies.

Second, to preserve the competitiveness of the economy and to achieve a larger emissions reduction, it is necessary either: (i) to introduce a border carbon adjustment scheme, which would involve introducing environmental tariffs on imports potentially subject to challenge and to dispute under WTO rules, since measuring embodied carbon in traded goods can be contentious; or (ii) to coordinate the introduction of the carbon tax at a supranational level: the coordination at EU level appears to be an effective solution, since carbon leakage and loss of competitiveness are reduced without the need to introduce tax refund/surcharge systems. Our analysis for Spain reveals that, just from the household demand perspective, carbon leakage reduces CO_2 emissions derived from the carbon tax proposals by between 25% to 45%.

Third, the use of the revenues is crucial to minimise the potential adverse economic and social impact of the carbon tax. If funds raised are used to reduce other distorting taxes, the outcome could be positive in the medium term, once the reallocation of resources across sectors has taken place. Specifically, given the recurring problem of unemployment in Spain, the reduction of social contributions seems to be an advisable option. Using tax funds to reduce the electricity bill results in lower emissions, given that all non-electricity sectors are encouraged to use electricity and the electricity sector is, in turn, encouraged to switch the electricity generation mix towards clean technologies; but it also results in lower GDP than the previous option, as labour costs do not diminish.

In addition, it is worth noting that carbon taxes tend to be regressive, increasing inequality. In this respect, the funds collected could be used to mitigate this effect (Álvarez, 2019). In this paper, we have considered recycling carbon tax revenues into lump sum payments to households. This proposal is able to offset the negative impact on economic activity of the carbon tax, retaining most of its strength to curb emissions. More targeted alternatives focusing on distributional aspects are outside the scope of our model but are sensible in economic and political economy terms. For instance, revenues could be recycled through payments to the individuals for which the energy bill represents a higher share in their income, conditional upon improving, for example, the climate-related adaptation of their houses or the use of cleaner means of transportation. Probably, the latter measures will not reduce emissions much, but they will increase the social and political acceptability options of the carbon tax.

Lastly, there are costs to reallocating resources across sectors and firms induced by the carbon tax that our model does not take fully into account and, thus, the macroeconomic performance indicators should be understood as an upper bound. These costs will be larger the lower the flexibility of the economy. In that respect, labour market institutions are crucial to facilitate labour reallocation, the financial system to identify opportunities in the green economy and insolvency proceedings to avoid losses of value in troubled firms that were not able to adapt.

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Appendix A. Tables and charts

Table A-1. Carbon dioxide emissions coefficients by fuel

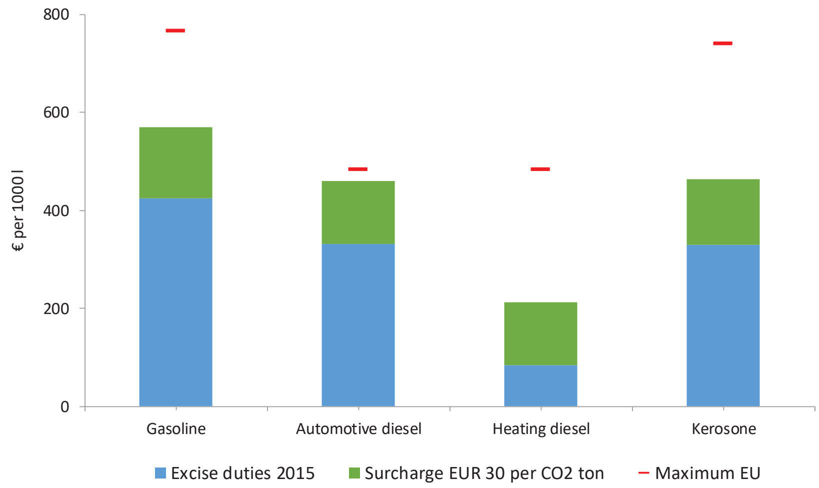
Carbon Dioxide (CO_2) Factors:	Pounds CO_2 Per Unit of Volume or Mass		Kilograms CO_2 Per Unit of Volume or Mass		Pounds CO_2 Per Million Btu	Kilograms CO_2 Per Million Btu
For homes and businesses						
Propane	12.70	gallon	5.76	gallon	139.05	63.07
Butane	14.80	gallon	6.71	gallon	143.20	64.95
Butane/Propane Mix	13.70	gallon	6.21	gallon	141.12	64.01
Home Heating and Diesel Fuel (Distillate)	22.40	gallon	10.16	gallon	161.30	73.16
Kerosene	21.50	gallon	9.75	gallon	159.40	72.30
Coal (All types)	4,631.50	short ton	2,100.82	short ton	210.20	95.35
Natural Gas	117.10	thousand cubic feet	53.12	thousand cubic feet	117.00	53.07
Gasoline	19.60	gallon	8.89	gallon	157.20	71.30
Residual Heating Fuel (Businesses only)	26.00	gallon	11.79	gallon	173.70	78.79
Other transportation fuels						
Jet Fuel	21.10	gallon	9.57	gallon	156.30	70.90
Aviation Gas	18.40	gallon	8.35	gallon	152.60	69.20
Industrial fuels and others not listed above						
Flared natural gas	120.70	thousand cubic feet	54.75	thousand cubic feet	120.60	54.70
Petroleum coke	32.40	gallon	14.70	gallon	225.10	102.10
Other petroleum & miscellaneous	22.09	gallon	10.02	gallon	160.10	72.62
Nonfuel uses						
Asphalt and Road Oil	26.34	gallon	11.95	gallon	166.70	75.61
Lubricants	23.62	gallon	10.72	gallon	163.60	74.21
Petrochemical Feedstocks	24.74	gallon	11.22	gallon	156.60	71.03
Special Naphthas (solvents)	20.05	gallon	9.10	gallon	160.50	72.80
Waxes	21.11	gallon	9.57	gallon	160.10	72.62
Coals by type						
Anthracite	5,685.00	short ton	2,578.68	short ton	228.60	103.70
Bituminous	4,931.30	short ton	2,236.80	short ton	205.70	93.30
Subbituminous	3,715.90	short ton	1,685.51	short ton	214.30	97.20
Lignite	2,791.60	short ton	1,266.25	short ton	215.40	97.70
Coke	6,239.68	short ton	2,830.27	short ton	251.60	114.12
Other fuels						
Geothermal (average all generation)	NA		NA		16.99	7.71
Municiple Solid Waste	5,771.00	short ton	2,617.68	short ton	91.90	41.69
Tire-derived fuel	6,160.00	short ton	2,794.13	short ton	189.54	85.97
Waste oil	924.0	barrel	419.12	barrel	210.00	95.25

Source: U.S. Energy Information Administration estimates.

Note: To convert to carbon equivalents multiply by 12/44.

Coefficients may vary slightly with estimation method and across time.

Figure A-1. Excise duties and carbon tax



Sources: Agencia Tributaria and authors' calculations.

Table A-2. Final demand channel. CO_2 emissions reduction (thousands tons)

	With border carbon adjustment				Without border carbon adjustment			
	Public deficit/debt reduction	Social security contributions reduction	Transfer to households	Electricity bill subsidy	Public deficit/debt reduction	Social security contributions reduction	Transfer to households	Electricity bill subsidy
Households	-1144	-1035	-1112	-749	-951	-778	-902	-466
Agriculture and food	-447	-393	-431	-296	-303	-217	-279	-135
Large industry	-3870	-3691	-3817	-2501	-2770	-2489	-2691	-1269
Energy and extractive industries	-819	-741	-796	-536	-681	-557	-646	-334
Rest of manufacturing	-374	-349	-367	-239	-286	-247	-275	-129
Construction	-298	-269	-289	-195	-248	-203	-235	-121
Transport	-798	-753	-784	-580	-539	-468	-519	-301
Other market services	-674	-605	-654	-409	-517	-408	-487	-203
Non-market services	-377	-337	-365	-220	-318	-254	-300	-122
Total	-8802	-8172	-8615	-5723	-6613	-5621	-6334	-3080

Source: Authors' calculations.

Table A-3. Main macroeconomic variables

			With border carbon adjustment				Without border carbon adjustment			
			Reduce public deficit/debt	Reduce social security contributions	Transfer to households	Electricity bill subsidy	Reduce public deficit/debt	Reduce social security contributions	Transfer to households	Electricity bill subsidy
GDP	(1)	t,t+2	-0.21	0.47	-0.06	0.11	-0.49	0.22	-0.33	-0.17
		t+5,t+10	-0.17	0.24	0.00	-0.18	-0.16	0.27	0.01	-0.17
Private Consumption	(1)	t,t+2	-0.35	0.27	0.03	-0.21	-0.34	0.32	0.05	-0.20
		t+5,t+10	-0.75	0.92	0.07	-0.71	-0.76	0.99	0.05	-0.73
Private Investment	(1)	t,t+2	-0.58	1.15	-0.36	-0.29	-0.79	1.02	-0.57	-0.49
		t+5,t+10	0.01	-0.27	-0.10	-0.06	0.04	-0.26	-0.08	-0.03
Exports	(1)	t,t+2	-0.09	0.21	-0.11	0.22	-0.93	-0.62	-0.95	-0.62
		t+5,t+10	0.12	-0.14	0.03	0.08	0.08	-0.18	0.00	0.04
Imports	(1)	t,t+2	-0.50	0.03	-0.19	-0.80	-0.60	-0.05	-0.28	-0.90
		t+5,t+10	-0.64	0.61	0.05	-0.63	-0.71	0.59	-0.02	-0.71
Current account (% GDP)	(2)	t,t+2	0.36	-0.18	-0.08	1.01	0.20	-0.36	-0.25	0.86
		t+5,t+10	0.94	-1.34	-0.28	0.93	1.04	-1.34	-0.18	1.04
Employment	(1)	t,t+2	-0.52	0.90	-0.44	-0.46	-0.54	0.94	-0.46	-0.48
		t+5,t+10	0.01	0.00	0.00	-0.09	0.09	0.08	0.08	-0.01
Unemployment rate (%)	(2)	t,t+2	1.76	-3.07	1.51	1.55	1.85	-3.20	1.59	1.65
		t+5,t+10	-0.03	0.00	-0.01	0.30	-0.31	-0.27	-0.29	0.02
Inflation (%)	(2)	t,t+2	1.25	0.66	1.44	0.82	1.04	0.42	1.24	0.62
		t+5,t+10	-0.21	0.25	-0.13	-0.29	0.01	0.48	0.07	-0.08

1) Percentage deviation from baseline
2) Deviation from baseline

Source: Authors' calculations.

Appendix B. The model

B.1 Sectoral module

Given the CO_2 emissions per unit of consumption of each fuel, c_f, and an objective carbon price per CO_2 emissions CO_2^O, we determine the increase in excise taxes of each fossil fuel per unit of consumption, $\Delta t_f = c_f \times CO_2^O$. As already mentioned, c_f is determined by the CO_2 emissions per physical unit of polluting input, which have been obtained from the information provided by the US Energy Information Administration (Table A-1).

Given the diagonal matrix of sectoral emissions of CO_2, B, we are able to calculate the emissions embedded in the final demand of each product from the Input-Output tables of the Spanish economy. If the matrix X is the 64-sector production matrix, Y the final demand vector, A is the technical coefficient matrix and I is the identity matrix, it is assumed that the amount of emissions associated with each product is proportional to the amount of production:

$$X = (I - A)^{-1}Y$$

$$M = BX = B(I - A)^{-1}Y$$

M, which corresponds to the emissions embedded in final demand, captures the total direct and indirect pollutant emissions by the 64 domestic industries/products implied in satisfying a certain amount of final demand Y.

Matrix A contains the multipliers for the inter-industry inputs required to supply one unit of industry output. A certain total economic output x is required to satisfy a given level of final demand y. The Leontief inverse $(I - A)^{-1}$ contains the multipliers for the direct and indirect inter-industry inputs required to provide 1 unit of output to final demand. In the scenarios without carbon adjustment, we use domestic technical coefficient matrix, which only considered domestic linkages, instead of the overall technical coefficient matrix.

In addition, since the tax is set to those polluting inputs that generate CO_2 emissions, the increase in the value of the production is limited to three of the 64 sectors in the input-output tables that produce polluting inputs, namely, extractive industries; coke and refined petroleum; and electricity, gas, steam and air conditioning. The increase in prices ΔP_S^P in each sector is calculated using the production of each contaminating input (f) in total production of each sector X_s.

$$\Delta P_S^P = \frac{\sum \Delta t_f \times f}{X_s}$$

The overall increase in prices of each product $\Delta P_s{}^{Overall}$ derived from incorporating the increase in the price of inputs can be expressed, given the technical coefficient matrices, as

$$\Delta P_s{}^{Overall} = (I - A)^{-1}\Delta P_S^P$$

Household demand system

We use the demand system for the Spanish economy estimated by Bover et al. (2017). They use the Quadratic Almost Ideal Demand System. The demand system consists of a set of 13 non-durable goods demand equations, which are estimated jointly, and a durable good. To estimate the demand system, we match the expenditure on the 64 products/industries of the sectoral model in 14 groups of expenditures.

Thus, given the increase in prices of each product, we know the increase in demand associated with the changes in its own price and the prices of other products (cross-substitution effect) and related to change in the overall price level (income effect) using the elasticities reported in tables B-1 and B-2.

Table B-1. Observed and predicated shares, income and own-price elasticities

	Observed shares	Predicted shares	Income elasticity	Uncompensated own-price elasticity
1. Food and beverages	0.2775	0.2766	0.715***	-0.109
2. Alcoholic drinks	0.0106	0.0114	1.010***	-0.993***
3. Tobacco	0.0219	0.0221	0.846***	-0.833***
4. Clothing and footwear	0.0739	0.0759	1.385***	-1.011***
5. Domestic utilities	0.1370	0.1362	0.538***	-0.525***
6. Household non-durables	0.0402	0.0433	1.548***	-1.969***
7. Health	0.0382	0.0354	1.901***	-0.524***
8. Vehicle fuels	0.0635	0.0652	0.973***	-0.159***
9. Transport	0.0522	0.0520	0.955***	-1.090***
10. Communications	0.0511	0.0479	0.592***	-0.189***
11. Leisure and culture	0.0476	0.0478	1.421***	-2.253***
12. Hotels and restaurants	0.1254	0.1234	1.404***	-0.974***
13. Other non-durables	0.0607	0.0638	1.224***	-0.572*

* p<0.05, **p<0.01, ***p<0.001

Source: Bover et al. (2017)

TABLE B-2. Cross-price elasticities

	1. Food and beverages	2. Alcoholics drinks	3. Tobacco	4. Clothing and footwear	5. Domestic utilities	6. Household non-durables	7. Health	8. Vehicle fuels	9. Transport	10. Communications	11. Leisure and culture	12. Hotels and restaurants	13. Other non-durables
1. Food and beverages	-0.109	0.02	-0.009	0.181***	0.216***	-0.079	-0.179***	-0.224***	-0.142**	0.091**	0.170***	-0.379***	-0.272**
2. Alcoholic drinks	0.487	-0.993***	0.104	0.256***	0.715***	-1.959***	-0.281*	-0.806***	0.711***	0.422**	1.852***	-0.874*	-0.645
3. Tobacco	-0.14	0.046	-0.833***	-0.364***	-0.106	0.456	0.556***	-0.027	0.188	0.427***	0.117	-0.61	-0.556
4. Clothing and footwear	0.449*	0.029	-0.120*	-1.011***	-0.404***	0.076	0.042	-0.158**	0.007	-0.053	0.16	-0.462*	0.061
5. Domestic utilities	0.576***	0.067	-0.014	-0.210***	-0.525***	0.118	-0.577***	0.046	0.062	-0.019	0.056	-0.377***	0.258*
6. Household non-durables	-0.784*	-0.489	0.246**	0.135*	0.216	-1.969***	0.944***	-0.176*	-0.058	0.307*	-1.013***	1.468***	-0.375
7. Health	-1.998***	-0.102	0.405***	0.068	-2.356***	1.255***	-0.524***	1.320***	0.253	-1.200***	0.026	-0.252	1.203*
8. Vehicle fuels	-0.925***	-0.109	-0.012	-0.136***	0.021	-0.073	0.569***	-0.159***	-0.032	-0.145*	-0.232*	0.272	-0.011
9. Transport	-0.854***	0.141	0.084	0.046	0.092	-0.022	0.180**	-0.045	-1.090***	0.210**	0.480***	-0.191	0.016
10. Communications	0.522***	0.085	0.197***	-0.015	-0.047	0.277*	-0.651***	-0.176***	0.222**	-0.189***	0.046	-0.334**	-0.530***
11. Leisure and culture	0.746***	0.366	0.041	0.249***	0.025	-0.816***	0.03	-0.375***	0.461***	0.004	-2.253***	1.196***	-1.095***
12. Hotels and restaurants	-1.069***	-0.076	-0.131**	-0.302***	-0.458***	0.496***	-0.047	0.132**	-0.103	-0.187**	0.494***	-0.974***	0.823***
13. Other non-durables	-1.594***	-0.125	-0.257***	0.105**	0.486***	-0.277	0.713***	-0.034	0.002	-0.563***	-1.036***	1.929***	-0.572*

* p<0.05, **p<0.01, ***p<0.001

Source: Bover et al. (2017)

Sectoral substitution

The first step is to calculate how the carbon tax changes the relative prices of polluting and clean energy inputs according to their carbon content. Given the increase in the price of each polluting input and its respective consumption, we can calculate the average increase in the polluting inputs prices $\Delta P^{Polluting} = \sum \Delta t_f \times w_f$, where w_f is the consumption share of the fuel *f*. For the non-electricity sectors, the clean input is the electricity, which, in turn, is partly produced by polluting inputs by the electricity sector.

Papageorgiouy et al. (2017) estimates the sectoral elasticities of substitution (σ) among polluting and clean inputs derived from constant elasticity substitution production function. This work provides different estimates for two sectors: the electricity sector (σ^E) and the non-energy industries (σ^{NE}). As a matter of prudence, we consider the lower bound of their estimates which would lead to a lower demand for clean inputs and, hence, a lower reduction of emissions.

Using the above-mentioned elasticities, we can approximate the change in the relative demand for clean and non-polluting inputs for all sectors, differentiating between electricity production and the rest of the sectors.

For simplicity's sake and starting in the non-electricity sectors (NE), the change in emissions is the sum of the reduction of the input demand for polluting inputs plus the emissions generated by the electricity sector to supply the new demand for electricity (with the current generation mix).

$$\Delta Emissions^{NE} = -\sigma^{NE}(\alpha^{NE} - \beta^{NE})\Delta P^{Polluting}$$

where α^{NE} is a parameter that captures the demand for polluting inputs by non-electricity sectors and β^{NE} is associated with the relevance of these sectors in the demand for electricity and the (current) emissions per unit of energy in the electricity sector. In the scenarios in which the electricity bill is subsidised, the reduction in the price of electricity in P is also taken into account, since it is a relative price.

We continue considering the capacity of the electricity sector (E) to replace polluting inputs with clean ones. To that end, we also take into account the new demand for electricity derived from the switch towards clean inputs (electricity) for the rest of the sectors, bearing in mind the capacity for the replacement of of polluting inputs by the electricity sector (σ^{E}).

$$\Delta Emissions^{E} = -\sigma^{E}\alpha^{E}(1 - k\beta^{NE})\Delta P^{Polluting}$$

where α^{E} is a parameter that captures the demand for polluting inputs by the electricity sector and k is associated with the increase in demand for electricity by non-electricity sectors, which is now produced replacing polluting inputs with (genuinely) clean ones.

B.2 Semi-structural module

B.2.1 Derivation of the model

The semi-structural module is built on the NiGEM macroeconomic model.[23] This section relies on Hantzsche et al. (2018), who formalise the main features of the NIGEM model. These are summarised and streamlined below.

NIGEM is formed of individual country models for the more than 60 economies that are linked through trade in goods and services and international capital markets. All country models have generally the same New Keynesian structure in that agents are mostly assumed to have rational expectations, and there are nominal rigidities that determine the dynamic adjustment. Short-term dynamics are usually expressed in error correction form from the long-term relationships. Country models incorporate a supply side that determines the evolution of the economy in the medium and long term. They also include domestic demand, export and import volumes, prices, current accounts and net assets. International linkages stem from trade volumes, the influence of trade prices on domestic prices, exchange rates and the financial asset holdings and their income flows.

[23] NiGEM model has been developed by the National Institute of Economic and Social Research. Model background documentation is available at https://nimodel.niesr.ac.uk/.

Since the same theoretical structure is generally adopted, the variation in the properties of country models reflects differences emerging from the estimation of the parameters.

Agents

Households

Life-cycle considerations are behind household consumption, which is a function of current and expected future real disposable income and wealth from housing and financial assets (all net of taxes).

$$lnC_t = \alpha^C + \beta^C ln(RHW_t) + (1-\beta^C)\ln(RTW_t + RNW_t)$$

where C is real consumption, RHW is real human wealth, RTW is real tangible wealth (mainly housing), and RNW is real net financial wealth. Human wealth is a function of expectations of future real disposable income (RDI) discounted by a function of the real interest rate and it is the forward-looking component of the above equation.

Firms

Firms are described by a CES production function with constant returns-to-scale and labour-augmenting technical progress. Labour and capital demands are the result of the profit maximisation objective. In the long run, the labour/output ratio depends on real wages and technical progress and the capital/output ratio is a function of the real user cost of capital.

$$lnL = \alpha^L + lnY - (1-\sigma)\lambda_t - \sigma ln\left(\frac{w}{p}\right)$$

$$lnK = \alpha^K + lnY - \sigma ln\left(\frac{c}{p}\right)$$

where $\alpha^L$and $\alpha^K$are constants, $\frac{w}{p}$ is the real wage, $\frac{c}{p}$ is the real user cost of capital and σ is the elasticity of substitution between capital and labour. The user cost of capital is determined by the real long-term interest rate and a risk premium. Labour and capital demands ultimately determine unit total costs (UTC), feeding consumer prices.

Government

The government faces the traditional budget constraint. The budget deficit is represented as

$$BUD = CED \times (GI + GC) + TRAN + GIP - TAX - CTAX - ITAX - TSOC$$

Public spending includes government investment (GI), consumption (GC), transfers (TRAN) to households (mainly to the unemployed and pensioners) and interest payments (GIP), a function of the size of public debt and the prevailing interest rate. The revenues are formed by corporate (CTAX) and personal (TAX) direct taxes, indirect taxes (ITAX) on spending and social security contributions (TSOC).

Fiscal deficit flows add to the public debt stock, which affects interest payments and private sector wealth. Budget rules are incorporated into the model to guarantee long-term solvency.

Central banks

Central banks set the short-term nominal interest rate according to a monetary policy rule. Alternative rules can be defined choosing different weights for inflation, output gap, price level and nominal output

Prices, trade and equilibrium

Prices of goods and services

Producer prices depend on unit total costs, the cost of inputs. Market structure is a sort of monopolistic competition and, thus, firms establish a mark-up over the marginal cost of production.

Consumer prices (CED) are a function of unit total cost and import prices (*PM*):

$$lnCED = \beta^{CED} ln(UTC) + (1 - \beta^{CED}) \ln PM$$

where β^{CED} reflects how sensitive consumer prices are to international prices which, in turn, are related to the degree of openness of the economy.

Wages

Real wages are set in a bargaining process between firms and workers, although they are required to be aligned with labour productivity in the long term. The bargaining power of workers is a negative function of unemployment. Implicitly, the model incorporates a Phillips curve-type relation between real wage growth and unemployment.

International trade

In the model, international trade is always in equilibrium (global exports equal global imports). Trade is driven by demand factors, i.e. by imports. Import volumes are a function of final expenditure and import price competitiveness (the ratio of import to domestic consumer prices). In the long run, export volumes are governed by external demand and export price competitiveness. Export prices (PX) are determined by both own domestic prices and competitors' domestic prices.

Financial markets

In the model, international financial markets clear such that global liabilities equal global assets.

The current account balance is the sum of the trade, net foreign income and transfers balances, the latter being proportional to nominal GDP in foreign currency terms. Net foreign income is determined as the difference between income from credits and payments from debits.

Short-term interest rates are set by the monetary policy rule, which reacts endogenously to the economic conditions. Long-term interest rates result from a 10-year forward convolution of short-term rates plus a term premium, which may capture risks associated with uncertainty about monetary policy, bond liquidity or sovereign default.

The bilateral exchange rate is determined by an uncovered interest parity condition, reacting to changes in the expected path of interest rates.

Equity prices are set by the discounted future profits relative to capital stock of the private sector and an equity risk premium over the returns on interest-bearing debt.

Long-term interest rates, exchange rates and equity prices adjust in a forward-looking manner, allowing for (small) deviations from a standard no-arbitrage condition.

B.2.2 Calibration of the shocks

Firstly, with the fiscal revenues associated with each level of the carbon tax considered (and deducting the expenses in emission rights), the equivalent increase in the indirect tax rate (ITAXR) is calculated, which is the shock introduced into the model.

$$\Delta ITAXR: \Delta REVENUES = \sum_{\forall f} \Delta t_f \times d_f - \mathrm{ETS}$$

where d_f is the demand for each fuel, Δt_f is the surcharge on excise taxes of each fuel and ETS is the expenses in emission rights paid by the firms subject to double taxation.

Secondly, in the simulations without border carbon adjustment, an equivalent shock to the increase in the indirect tax rate is introduced into export prices (PX), to consider the downstream effects caused by the carbon tax and the deterioration of competitiveness

$$\frac{\Delta PX}{PX} = \Delta ITAXR, \Delta PM = 0$$

Conversely, in the scenarios with border carbon adjustment, the shock is introduced into import prices (PM) and exports are exempted from the carbon tax

$$(\frac{\Delta PM}{PM} = \Delta ITAXR, \Delta PX = 0)$$

Thirdly, in the scenarios in which the use of funds is to reduce social security contributions (TSOC), we calculate the equivalent reduction to the increase in tax revenues due to carbon tax.

$$(\Delta TSOC = -\Delta REVENUES)$$

Conversely, when revenues are transferred as a lump sum to households, we increase households' gross disposable income towards a public transfers shock of the size of carbon tax revenues.

$$(\Delta TRAN = -\Delta REVENUES)$$

Finally, in the subsidy to electricity bills scenarios, the reduction in electricity costs is calibrated to increase household gross disposable income (RDI) and to reduce firms' unit total costs (UTC).

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