Green Policies and Transition Risk Propagation in Production Networks

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This paper introduces a general equilibrium sectoral model including two types of energy sectors (green and brown) to study the short-run impact of different emission taxes schemes in production networks. The model is calibrated to the Spanish economy at the industry level using the input-output matrix and captures the effective cost of emissions associated to the use of energy in each industry. We show that for an increase in the price of emission allowances similar to that observed in recent years (from approximately €25 per tonne of CO2 in 2019 to almost €100 per tonne in 2022) the model predicts a cumulative decline in Spanish GDP after three years of 0.37%. The loss in value added is very heterogeneous among industries, depending on the exposure to the ETS and to their network ETS exposure, with values ranging from losses of 4% in the most affected industries to no impact in others.

JEL classification: Q48, H30
Keywords: Climate Change, Green Policies, Production Networks, Input-Output Matrix

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1 Introduction

Climate change is one of the biggest challenges of this century. An overwhelming amount of research points at an increasing concentration in the atmosphere of greenhouse gases (GHG), which is causing severe environmental, economic and health damages\(^1\). Throughout the world, countries have started taking action against climate change, with specific policies to reduce greenhouse emissions. While the benefits of these policies are likely to be seen in the long term, the costs of these policies are much more short term. This is what is known as transition risks of climate change policies, that is, the risks associated with the tax and regulatory measures implemented to try to prevent climate change. Cross-sector differences in greenhouse gas emission volume and intensity, and the inter-linkages among different industries, suggest that the green transition poses a highly uneven challenge for different sectors. It is of utmost importance for policymakers to understand which sectors are going to be the most affected by these transition risks in the short run, to be able to implement effective policies to mitigate the negative impact on firms and workers of these industries, and even on financial stability.\(^2\)

To answer this relevant question, we present a static general equilibrium model with rich sectoral networks based on Baqee and Farhi (2019), which we extend to include two energy sectors. Concretely, we model 51 non-energy industries and two energy industries (fuel and electricity) accounting for all cross-sectoral relationships. We introduce in the model what we call a ‘green tax’, which is a tax that aims to capture in a reduced form the effective cost paid by the final user for the greenhouse emissions. It is comprised by the different components of greenhouse emission that affect the final cost of goods produced: a) technological, capturing the amount of emissions per unit of energy consumed; b) regulatory, capturing the ratio of surrendered emission

\(^1\)See for instance the United Nations Climate Change Annual Report that quantifies carbon emissions at records high in the recent years and an increase of the global temperature by 1.1ºC above the pre-industrial level. Similar findings are reported in the OECD Annual Climate Change Action Monitor.

\(^2\)One of the relevant policy needs for this is banking stress-tests. Under the most pessimistic scenarios, some financial institutions may find themselves in difficulty if they are poorly diversified in newly-relevant dimensions, e.g. if they are highly exposed to sectors that can be expected to display more negative effects in response to shocks related to climate change. Financial institutions include not only banks, but also other financial intermediaries, such as insurance companies and investment funds, which are closely linked to banks in Spain. In principle, the scenarios generated by this model may be used to analyze the effects of the shock on all of them.
rights to total emissions; and c) *pricing*, or the price of surrendered emission rights, in euros per equivalent tonne of $CO_2$. We calibrate the model to the Spanish economy, using industry $CO_2$ atmospheric emission accounts published by the INE (National Statistics Institute), the EU Emissions Trading System (ETS) dashboard published by the European Environment Agency (EEA), and the input-output tables from INE.

We perform several policy experiments and counterfactual scenarios within this model derived from different types of implementation and increases in the green taxation, paying particular attention to sectoral asymmetries arising from the intensity with which different types of energy are used in each industry, the interdependencies summarized in the input-output tables, and the general equilibrium effects in terms of relative price changes and sectoral reallocation. These simulations aim to capture the short-term effects of transition risks of different policies used to reduce GHG emissions.

The first exercise simulates an increase in the price of emission allowances similar to that observed in recent years (from approximately €25 per tonne of CO2 in 2019 to almost €100 per tonne in early February 2022). After this policy, the model predicts a decline of GDP of -0.37%. This policy reduces activity in non-energy sectors, such as building materials and other non-metal mineral products, aviation, paper and chemical products. The impact is not necessarily higher in those generating larger emissions (the *technological* component of the green tax), but those that were covered by the Emission Trading System - ETS - (the *regulatory* component of the green tax). This is the case, for example, of printing and recorded media, that buys a lot of inputs from paper manufacturers, and of repair and installation of machinery and equipment, that sells a lot of their products and services to various chemical and metal manufacturing sectors. On the other hand, sectors such as agriculture and fishing, that have relatively high emissions intensity, are not particularly affected by this shock, since their regulatory ETS coverage is low.

The second scenario simulates an expansion of the coverage of the ETS system to all sectors. Compared to the previous policy, it represents a smaller shock in terms of GDP.

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3The study of long-term physical risks, which are those directly associated with the process of climate change, is out of the scope of this paper. These include, inter alia, rising temperatures, ice melt and sea level rises, a higher frequency and intensity of adverse atmospheric phenomena, progressive degradation of environmental variables such as air and water quality, deforestation and biodiversity loss. Various European and international bodies have published evidence on the long-term physical impact of climate change. See OECD (2015), G20 (2016), Giuzio et al. (2019) and Commission (2020).
(-0.12%), but it generates a bigger fall in emissions (-14.5%). The non-energy sectors most affected by this policy are those with higher emission intensity that were not previously covered by ETS (agriculture, fishing, transport, sewerage and waste); and the sectors indirectly hit through their commercial relations with other highly-affected sectors (such as warehousing and support for transportation, repair and installation of machinery and equipment, water collection and supply).

In a third exercise, we simulate the implementation of the two previous policies at the same time: an increase in the price plus expansion of the coverage of the ETS system. We find that indirect and propagation effects are large, since the total effect is much bigger than the sum of both individual simulations: the fall in GDP ascends to -0.9%, but the cost of reducing emissions by a given amount is higher than in the second exercise. In a final exercise, we perform this same policy exercise (increase in the price plus expansion of the coverage), with the difference that the increase in tax revenues collected is used to reduce labor taxes, rather than given lump-sum to the household, as it was the case in all previous exercises. In this case, the effect on GDP is positive, as it increases 2.7%. However, although there is a reduction in the use of fuel and electricity from the baseline, this reduction is smaller than when the policy was financed lump-sum. Even though the impact of the policy is positive in most sectors, there are some that suffer a strong negative effect, which comprise mainly transport industries and agriculture.

The traditional approach to climate change in the literature is based on integrated assessment models (IAMs and DICE, in their dynamic version) that study how economic growth impacts climate conditions and what is the cost-benefit of policies that mitigate emissions seeking to reduce global warming in the long-run. The most notorious example is the neoclassical climate-change growth model of Nordhaus (2007) and Nordhaus (2017) that internalizes climate change damages, measured as greenhouse emissions, in the social welfare function when deciding the growth path that leads to an optimal level of climate change mitigation. However IAMs models are often a too simplified representation of the economy (compared with standard macroeconomic models), lacking in transmission channels, such as commodity price changes during the transition, which reduce the level of detail in the macroeconomic impact of climate change.

policy.

More recently, the dynamic stochastical approach to general equilibrium (DSGE) model, now a fundamental tool in the quantitative analysis of the macroeconomy, has also been adapted to analyse environmental policies and simulate the effects of climate change. Environmental DSGE (E-DSGE) incorporate emissions in firms production function and internalize its cost, featuring environmental externalities, as in the models of Heutel (2012) and Golosov et al. (2014). Alternatively, other models of this kind introduce environmental externalities either in agents’ utility (see Angelopoulos et al., 2013) or affecting indirectly their utility (see Chang et al., 2009). E-DSGE are also useful for the analysis of cross-border emissions and climate cooperation as in the multi-country model of Ernst et al. (2022), that shows how countries taxing emissions benefit from others cooperating, while there is no incentive for non-cooperating countries to join them.

In parallel, the development of Computable General Equilibrium (CGE) models, that introduce a detailed representation of the economy allows for tractable simulations of climate change policies at a more granular level than DSGE models, see for instance Branger and Quirion (2014) and Matsumoto and Fujimori (2019). Some institutions, such as the Bank of Canada, have incorporated this type of models for climate policy analysis. Other representations of the economy, based on macroeconometric relationships, are also popular for the analysis of climate policies. This is the case for the De Nederlandsche Bank (DNB) or the Banque de France that use the NiGEM model for policy scenarios. Unlike IAM and the DSGE models abovementioned, the model presented in this paper, CATS\(^5\), works on a relatively short time horizon and calibrated at the industry level to the Spanish economy. It is primarily used to generate transition-risk scenarios related to green taxation that assess the different productive sectors’ degree of exposure in the event of an increase in the price of emission allowances or an extension of EU-ETS coverage, hence abstracting from environmental externalities and long-run implications.

The remainder of the paper is organized as follows. Section 2 discusses the main characteristics of the model and Section 3 details the calibration. Section 4 presents the results of the transition risk simulations and Section 5 concludes.

\(^5\)This paper was previously circulated under the title "Carbon tax sectoral model" which was published as Banco de España Documento Ocasional N.º 2218. We maintain the short-name of CATS for its simplicity.
2 Model

The model is based on Baqee and Farhi (2019), extended to include two energy sectors that have to pay a green tax for the emissions they generate. It is a static general equilibrium model with rich sectoral networks. The economy is closed, with the exception of basic energy inputs, which are imported. The structure of the model is summarized on Figure 1.

There is a representative household, that consumes and supplies her labor elastically, with constant relative risk aversion utility. Her labour is perfectly mobile across sectors. The model includes $N_e$ energy producers, $N_s$ non-energy producers, $N_s$ non-energy intermediate product retailers, $N_s$ energy intermediate product retailers, one energy consumption retailer, one non-energy consumption retailer, and one final consumption retailer.

Each one of the $N_s$ non-energy production sectors use a production function with three inputs: it first combines homogeneous labor and a sector-specific bundle of intermediate non-energy inputs using a Cobb-Douglas technology, and then this is nested into a CES that combines it with a sector-specific bundle of energy inputs.

There are $N_e$ energy production sectors. They use a naïve production function where imported basic energy goods are the only input, and output equals input, with no value added.\textsuperscript{6}

There are $N_s$ non-energy intermediate input retailers; each of them buys goods from all non-energy producers, combines them with Cobb-Douglas technology, and sells the resulting bundle to a specific non-energy production sector. And there are $N_s$ energy intermediate input retailers, again one for each non-energy sector; they combine the energy goods coming from the $N_e$ energy production sectors, using a CES aggregator to create unique energy good bundles to be sold to the non-energy sectors.

There is another set of aggregators in the consumption side of the economy. One energy consumption retailer buys from the $N_e$ energy producers and bundles those goods using a CES aggregator. One non-energy consumption retailer buys inputs from the $N_s$ non-energy production sectors, and combines them using another CES to produce a

\textsuperscript{6}Using a more complicated production function here, with other inputs such as elastic labor supply or non-energy goods is not necessarily an improvement, because even with realistic parametrization it could bring unrealistic results such as the following: a strong green tax that reduces the amount of energy used in the economy would free up those other inputs to be used by non-energy sectors, generating a positive supply channel that reduces the negative effects for the rest of the economy.
single non-energy consumption good. Finally, there is a consumption retailer that buys the energy consumption bundle and the non-energy production bundle, and combines them through a new CES aggregator to produce the final good that households buy for consumption.

In practice, we use $N_s = 51$ non-energy sectors and $N_e = 2$ energy sectors. The two energy sectors represent electricity and fuel. Inside the model they only differ in terms of the amount of emissions that each unit of output requires, and what share of them are subject to the green tax. The way this simplified specification relates to real-world structures is not straightforward. In the case of fuels, their production does not generate a large amount of emissions, but their use does; it is the agents who use the fuels that have to acquire the associated emission allowances if subject to the ETS system, while the fuel producer receives a price that does not include the amount corresponding to such rights. Electricity, in contrast, generates emissions when it is produced\(^7\), but not necessarily when it is used; thus, electricity users do not need to acquire emission allowances, but simply pay a price to electricity producers, who are responsible for obtaining the necessary emission allowances to be able to produce that

\(^7\)A future version of the model could separate the electricity sector into renewables and non-renewables. The biggest challenge in this is the calibration, since input-output tables don’t have that level of disaggregation. In the meantime, in the current version electricity generation generates emissions at the average rate observed in each economy, which is a good description of the current situation but doesn’t allow for substitution channels within the electricity sector as a response to higher green taxes; in time horizons of one to three years, for which the model is mostly used, such substitution would be expected to be very limited.
electricity. In the model, though, both sectors function in the same way: energy users pay a gross price that includes the electricity or fuel itself along with the emission allowances required to produce or consume it, and energy producers receive a net price from which the cost of these emission allowances has already been deducted. The fitting of the model to the data resolves this divergence between the real-world and model structures: the fuel price in the real world corresponds to its net price in the model, while the electricity price in the real world corresponds to its gross price in the model.

An additional issue related to this is that the structure in the model is a green tax, whereas the ETS system is not. Under certain assumptions, they could be equivalent, e.g. if emission rights are sold by the government in carefully-calibrated auctions so that it effectively sets the price instead of the quantity. More broadly, the structure in the model would correctly represent the current ETS system up to first order, but there is a second-order channel that would be missing: the endogenous fall in the price of ETS allowances when a shock makes agents in the model want to use less energy and reduce their greenhouse gas emissions. This could cause a second-order upwards bias in the simulations of the model (i.e. real-world effects could be slightly smaller than what the model predicts). A priory, this bias should be small. Further versions of the model may address this issue.

In the standard specification of the model, the revenue that the green tax generates for the public sector is given back to households in the form of lump sum transfers. Even though it is not out of line with the early stages of the ETS system, this is a relatively pessimistic assumption: it could also be used for reducing other distortionary taxes. For example, if it is used to reduce a proportional tax on labor income, it would induce a positive supply shock and can generate a positive aggregate effect on GDP and employment, as shown at the end of the section that presents the simulations. Even though these optimistic alternatives can still generate a negative impact on specific sectors, we only consider the lump sum option when generating scenarios for climate change stress tests, where there is an explicit aim of generating a sizable but plausible fall in economic activity in the simulations.\(^8\)

Next, we summarize the decision problem of the different agents in this economy.

\(^8\)This is in line with the model for climate change transition at the IMF as discussed in the chapter on “Near-Term Macroeconomic Impact of Decarbonization Policies” from the IMF latest (October 2022) World Economic Outlook.
here, and Appendix A contains the full problem solved by each agent. For simplicity of exposition, we omit the time subscripts of the variables.

2.1 Household

The household chooses consumption of the final aggregate product, $C$, and the amount of labor to provide, $L$, to maximize its utility over time subject to a budget constrain.

$$\max_{C_t, L_t} \sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-\sigma}}{1-\sigma} - \gamma \frac{L_t^{1+\vartheta}}{1+\vartheta}$$

s.t. $PC = (1 - \tau_l)WL + T,$

2.2 Non-energy production sector

The production of the non-energy sector is determined by a CES function that uses energy, $E_s$, labor, $L_s$ and non-energy intermediate input, $H_s$, that is sold to the non-energy consumption retailer, and the $N_s$ non-energy intermediate-input retailers, $Z_s = C_s + \sum_{x=1}^{s} H_{x,s}$. The production function is the following:

$$Z_s = \left[ \omega_{E,s}^\frac{1}{\varrho_E} E_s^\frac{\varrho_E-1}{\varrho_E} + (1 - \omega_{E,s})^\frac{1}{\varrho_E} \left[ L_s^\alpha H_s^{1-\alpha_s} \right]^\frac{\varrho_E-1}{\varrho_E} \right]^\frac{\varrho_E}{\varrho_E-1}$$

2.3 Energy production sector

There are $N_e$ energy production sectors. In each of these sectors, denoted by the subscript $e$, production of energy is determined by the imported energy input from abroad, $M_e$

$$Z_e = M_e. \quad (1)$$

The energy good $Z_e$ is sold to the consumption good consumption retailer, $C_e$, and to each of the energy intermediate-input retailer, $E_{e,s} (N_s)$:
\[ Z_e = C_e + \sum_{s=1}^{N_s} E_{e,s} \] (2)

2.4 Non-energy intermediate-input retailers
For each non-energy sector \((N_s)\), there is a retailer that purchases the goods \(H_{x,s}\) from each of the non-energy producers \((N_s)\), and aggregates them into \(N_s\) non-energy intermediate-input bundle, \(H_s\), using a Cobb-Douglas function with constant returns to scale:

\[ H_s = \prod_{x=1}^{N_s} H_{x,s}^{\omega_{H,x,s}}, \quad \sum_{x=1}^{N_s} \omega_{H,x,s} = 1, \]

where \(H_{x,s}\) is the intermediate input produced from sector \(x\) and then used by sector \(s\) \((N_sxN_s)\).

2.5 Energy intermediate input retailers
For each of the \(N_s\) non-energy sectors there is a retailer that purchases the energy intermediate goods \(e_e\) from the \(N_e\) energy sectors and aggregates them into an energy intermediate-input bundle for each non-energy sector, \(E_s\), using a CES function as follows:

\[ E_{s,t} = \left[ \sum_{e=1}^{N_e} \omega_{e,s}^{\frac{1}{\nu_{H,E}}} e_e^{\frac{\nu_{H,E}-1}{\nu_{H,E}}}, \quad \sum_{e=1}^{N_e} \omega_{e,s} = 1 \right]^{\frac{\nu_{H,E}}{\nu_{H,E}-1}}, \quad \sum_{e=1}^{N_e} \omega_{e,s} = 1 \]

where \(\nu_{H,E}\) is the elasticity of substitution across different energy intermediate goods.

2.6 Non-energy consumption retailer
The non-energy retailer purchases the goods \(C_s\) from the 51 non-energy produces and aggregates them into an unique non-energy consumption bundle, \(C_{NE}\), using the following CES function:
\[ C_{NE} = \left[ \sum_{s=1}^{N_s} \left( \frac{1}{\omega_{C,s}} C_s^{\frac{1}{\omega_{C,s}}} \right)^{\frac{1}{\omega_{C,s}}} \right]^{\frac{1}{\sum_{s=1}^{N_s} \omega_{C,s}}} = 1, \]  

(3)

where \( \psi_{C,s} \) is the elasticity of substitution across different non-energy final consumption goods. From the maximization problem, we obtain

\[ P_s = \left( \frac{\omega_{C,s} C_{NE}}{C_s} \right)^{\frac{1}{\psi_{C,s}}} P_{NE}. \]  

(4)

2.7 Energy consumption retailer

There is a retailer who purchases the energy consumption goods, \( C_e \), from the two kinds of energy producers (coke and refined petroleum and electriciy and gas) and aggregates them into an energy consumption bundle, \( C_E \), using the following CES function:

\[ C_{E,t} = \left[ \sum_{e=1}^{N_e} \left( \frac{1}{\omega_{C,E}} C_e^{\frac{1}{\omega_{C,E}}} \right)^{\frac{1}{\omega_{C,E}}} \right]^{\frac{1}{\sum_{e=1}^{N_e} \omega_{C,E}}} = 1, \]

where \( \psi_{C,E} \) is the elasticity of substitution across different energy consumption goods (i.e., energy consumption of different types are substitute goods, so that green tax can lead to a rise of “greener” energy sectors). From the profit maximization problem, and using the fact that there are \( N_e = 2 \) energy sectors in our calibration of the model, we obtain the relative prices between their products (see Appendix A.3 for details):

\[ \frac{P_{E1}}{P_{E2}} = \left( \frac{\omega_{C,E1}}{\omega_{C,E2}} \right)^{\frac{1}{\psi_{C,E}}} \left( \frac{C_{E1}}{C_{E2}} \right)^{\frac{1}{\psi_{C,E}}} C_E, \]  

(5)

and the price of the final consumption good becomes:

\[ P_{E,t} = \left[ \sum_{e=1}^{N_e} \omega_{C,E} P_{e,t}^{\frac{1}{\psi_{C,E}}} \right]. \]  

(6)

2.8 Consumption retailer

The consumption retailer purchases the consumption energy good, \( C_E \), from the energy consumption retailer and the non-energy consumption good, \( C_{NE} \), from the non-energy consumption retailer and aggregate them into the final consumption good sold to the
household under a CES production function:

\[ C = \left[ \frac{1}{\omega_C} \left( \frac{\omega_C}{1 - \omega_C} C_E \right)^{\frac{1}{\nu_C}} + (1 - \omega_C) \left( \frac{\omega_C}{1 - \omega_C} C_{NE} \right)^{\frac{1}{\nu_C}} \right]^{\frac{1}{\nu_C}} , \]

where \( \nu_C \) is the elasticity of substitution between energy and non-energy consumption. From the profit maximization problem, we obtain the relative prices between energy and non-energy consumption goods (see Appendix A.2 for details on the derivations):

\[ \frac{P_E}{P_{NE}} = \left( \frac{\omega_C}{1 - \omega_C} \right)^{\frac{1}{\nu_C}} \left( \frac{C_E}{C_{NE}} \right)^{\frac{1}{\nu_C}} C , \]  
(7)

and the price of the final consumption good becomes:

\[ P = \left[ \omega_c P_E^{\frac{1}{\nu_C}} + (1 - \omega_c) P_{NE}^{\frac{1}{\nu_C}} \right] . \]  
(8)

2.9 Closing the model

**Taxes:** government collects all the revenue from the green tax, and pays it back to the household either in as lump-sum transfers\(^9\),

\[ T = \sum_{s=1}^{N_e} \tau_e P_e Z_e . \]  
(9)

Or, in an alternative specification, through a reduction in labor taxes,

\[ -\tauWL = \sum_{s=1}^{N_e} \tau_e P_e Z_e . \]  
(10)

**Labor Market:** The demand for labor equals the supply of labor,

\[ L = \sum_{s=1}^{N_s} L_s . \]  
(11)

\(^9\)This is in line with other analysis such as the IMFNear-Term Macroeconomic Impact of Decarbonization Policies
Summary of agents and solution of the model: with $N_s = 51$ and $N_e = 2$, there are a total of 159 agents interacting in this economy: 1 representative household, 51 non-energy producers (who use employment, a basket of different energy intermediate products and a basket of different non-energy intermediate products), 2 energy producers (who use imported basic energy products), 51 energy intermediate product retailers (each of which combines 2 energy products, fuels and electricity), 51 non-energy intermediate product retailers (each of which combines 51 non-energy products), 1 energy consumption aggregator (who combines two products, fuels and electricity), 1 non-energy consumption aggregator (who combines 51 non-energy products), and 1 consumption aggregator (who combines two products, an energy bundle and a non-energy bundle). Computing the model equilibrium requires finding the 159 prices and the almost 3,000 quantities that simultaneously satisfy the optimality conditions of all these agents and the economy's aggregate constraints.

3 Calibration

One of the main features of the model is its detailed sectoral breakdown: given the fact that the risks associated with climate change have a very marked asymmetric component in this respect, it is essential for the model to be capable of capturing both the characteristics of each sector in terms of the use of energy, and also the interrelations between sectors. Table 1 sets out the sectoral breakdown currently used by the model, which corresponds to 2-digit NACE classification: 51 non-energy sectors and 2 energy production sectors (“fuels” and “electricity”).

The model is calibrated with observed data for Spain in 2015\textsuperscript{10}. Figure 3 shows how the model precisely replicates the share of each sector in final consumption\textsuperscript{11} and replicates reasonably well (but not exactly, owing to the simplifications involved in the stylized form of the aggregator and production functions) the share of each non-energy sector in total energy used as input in production of other goods and services.

\footnote{\textsuperscript{10}2015 is the most recent year for which a suitable input-output table is available both for the Spanish economy and for the euro area, which allows for a homogeneous alternative calibration that can highlight the effect of differences in the structure of the economy.}

\footnote{\textsuperscript{11}Since the model is of a closed economy without capital, the concept of “household consumption” in the model is actually matched to the sectoral data for the sum of consumption plus gross fixed capital formation plus exports.}
<table>
<thead>
<tr>
<th>#</th>
<th>Sector</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Crop and animal production</td>
<td>27</td>
<td>Other wholesale trade</td>
</tr>
<tr>
<td>2</td>
<td>Forestry and logging</td>
<td>28</td>
<td>Other retail trade</td>
</tr>
<tr>
<td>3</td>
<td>Fishing and aquaculture</td>
<td>29</td>
<td>Land transport</td>
</tr>
<tr>
<td>4</td>
<td>Mining and quarrying</td>
<td>30</td>
<td>Water transport</td>
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<tr>
<td>5</td>
<td>Manufacture of food, beverages and tobacco products</td>
<td>31</td>
<td>Air transport</td>
</tr>
<tr>
<td>6</td>
<td>Manufacture of textiles, wearing apparel, leather</td>
<td>32</td>
<td>Warehousing &amp; support activities for transportation</td>
</tr>
<tr>
<td>7</td>
<td>Manufacture of wood and wood products, except furniture</td>
<td>33</td>
<td>Postal and courier activities</td>
</tr>
<tr>
<td>8</td>
<td>Manufacture of paper and paper products</td>
<td>34</td>
<td>Accommodation and food service activities</td>
</tr>
<tr>
<td>9</td>
<td>Printing and reproduction</td>
<td>35</td>
<td>Publishing activities</td>
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<tr>
<td>10</td>
<td>Manufacture of chemicals and chemical products</td>
<td>36</td>
<td>Motion picture, video, television, music and radio</td>
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<tr>
<td>11</td>
<td>Manufacture of pharmaceutical products</td>
<td>37</td>
<td>Telecommunications</td>
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<tr>
<td>12</td>
<td>Manufacture of rubber and plastic products</td>
<td>38</td>
<td>Computer programming and information services</td>
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<tr>
<td>13</td>
<td>Manufacture of other non-metallic mineral products</td>
<td>39</td>
<td>Financial services, except insurance and pensions</td>
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<tr>
<td>14</td>
<td>Manufacture of basic metals</td>
<td>40</td>
<td>Insurance and pension funding</td>
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<td>15</td>
<td>Manufacture of fabric, metal products, exc. mach. &amp; equip.</td>
<td>41</td>
<td>Auxiliary activities to financial services</td>
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<td>16</td>
<td>Manufacture of computer, electronic and optical products</td>
<td>42</td>
<td>Real estate activities</td>
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<td>17</td>
<td>Manufacture of electrical equipment</td>
<td>43</td>
<td>Legal and accounting activities</td>
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<td>Manufacture of machinery and equipment</td>
<td>44</td>
<td>Architectural and engineering activities</td>
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<td>Manufacture of motor vehicles</td>
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<td>Advertising</td>
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<td>Manufacture of other transport equipment</td>
<td>46</td>
<td>Other professional services</td>
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<td>21</td>
<td>Manufacture of furniture; other manufacturing</td>
<td>47</td>
<td>Administrative services</td>
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<td>22</td>
<td>Repair and installation of machinery and equipment</td>
<td>48</td>
<td>Public administration and social security</td>
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<tr>
<td>23</td>
<td>Water collection, treatment and supply</td>
<td>49</td>
<td>Education</td>
</tr>
<tr>
<td>24</td>
<td>Sewerage &amp; waste collection, treatment &amp; disp. activities</td>
<td>50</td>
<td>Health</td>
</tr>
<tr>
<td>25</td>
<td>Construction</td>
<td>51</td>
<td>Other service activities</td>
</tr>
<tr>
<td>26</td>
<td>Wholesale and retail trade and repair of motor vehicles</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Energy sectors

<table>
<thead>
<tr>
<th>#</th>
<th>Sector</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>52</td>
<td>Manufacture of coke and refined petroleum products</td>
<td>53</td>
<td>Electricity, gas, steam and air conditioning supply</td>
</tr>
</tbody>
</table>

Table 1

{Sectors in the model}
and the relative size of the various industries in terms of value-added and production. Furthermore (not shown in the figure), the model also matches the full set of trade relationships for the Spanish economy summarized in the input-output table.

Apart from this economic data published by INE (the Spanish National Statistics Institute), the calibration of the model also uses a lot of information relating to the use of energy, the taxation of emissions of greenhouse gases, etc. The main sources for this information are the industry CO₂ atmospheric emission accounts published by the INE (National Statistics Institute), and the EU Emissions Trading System (ETS) dashboard published by the European Environment Agency (EEA), which, apart from including their own information, also summarizes data coming from the European Union Transaction Log (EUTL), the European Energy Exchange (EEX) and the Intercontinental Exchange (ICE).

That information is used for calibrating the structure of the green tax included in the model. For electricity, the tax rate is obtained from the relationship between the value of the emission allowances surrendered by the electricity production sector and the sectors’ aggregate revenues net of these rights; it is therefore assumed that all non-energy sectors pay the same homogeneous green tax when they use electricity. In the case of fuels, the green tax rate is sector-specific: it is estimated using the relationship between the value of the emission allowances surrendered by each non-energy sector, and the sector’s expenditure in fuels as intermediate inputs, net of the allowances it uses. This implies that that green tax structure in the model is the multiplication of three components:

- A technological component that captures the amount of emissions per unit of energy consumed.
- A regulatory component that captures the ratio of surrendered emission rights to total emissions.
- A pricing component that is just the price of surrendered emission rights, in euros per equivalent tonne of CO₂.

Figure 3 shows the regulatory component of each sector. As can be seen, as of 2022, only the firms from a few selected sectors have to surrender ETS rights when they emit greenhouse gases, meaning that most regulatory coefficients are zero, and only a few sectors have high regulatory coefficients, mainly a few industrial sectors with big factories generating big amounts of emissions, and airlines.

In model, electricity is a homogeneous good, meaning that the technological and
Figure 2
Model calibration: fitting of the sectoral data.
regulatory components related to electricity are identical across sectors. This is not the case for fuels, where each sector has a different technological and regulatory component. The pricing component is common to all agents and energy types. All of these components are calibrated using observed data for 2019.

The most difficult parameters to calibrate in this model are the ones that do not relate to the static structure of the economy, but to the speed and degree of adjustment in response to shocks or policy changes. This is the case of the numerous parameters in aggregator and production functions that control the degree of substitution between different goods. These parameters are calibrated at values bigger than zero but usually smaller than one, indicating that some — albeit limited — substitution between goods is to be expected in response to a shock. Their value must depend on the simulation horizon: under the current calibration, that assumes a common elasticity of substitution for all sectors, a rise in the price of emission allowances would not be expected to lead to significant substitution between fuels and electricity in any given sector (e.g. in the road transport sector) within a 3-year period, but a strong substitution could be expected if the relevant time horizon is 10 or 20 years.

Different approaches have been used to select the value for each of these elasticity-of-substitution parameters. In the case of non-energy inputs used in the production of non-energy goods, since the functional form used for the aggregator is a Cobb-Douglas, substitution is one-to-one, meaning that the quantities react proportionately to the relative-price changes, so that the nominal weight of the different sectors in the basket of intermediate products acquired by each non-energy producer remains constant. This
is imposed in order to simplify the biggest block in the model, and make computation simpler; this assumption could be revised in the future in order to reduce the degree of substitution in this part of the model.

For the elasticity of substitution between non-energy goods in consumption \( (v_{C,s}) \), a slightly lower value of 0.9 is selected, following the literature: this is the value used by Atalay (2017), Baqaee and Farhi (2019), and Allen et al. (2020).

The elasticities of substitution involving energy are calibrated through an empirical exercise. This includes the elasticity of substitution between energy and non-energy inputs in production \( (v_E) \), between different energy inputs in production \( (v_{H,E}) \), between energy and non-energy goods in consumption \( (v_C) \), and between different energy goods in consumption \( (v_{C,E}) \); given the limitations of the exercise, these four parameters are assumed to share a single value. This data-matching exercise ended up selecting values that are lower than what is often used in the literature; this is somehow to-be-expected, as this model is being used for shorter time horizons than is common among its peers, and substitution is more difficult in the short term. With all other elasticities fixed at the values detailed above\(^\text{12}\), the model is used to simulate a 32.5% fall in the price of oil in euros. This corresponds to the observed fall between 2014 and 2016 (which was 46.3%), adjusted by a factor of 0.7 to compensate for the fact that oil makes 100% of the input of the fuel sector in the model, but only 70% in the real world. We simulate the shock with the model using different values for the elasticities of substitution involving energy, and the results for each parameter value are compared with the observed data in terms of the cumulative change in nominal production of the energy sectors between 2014 and 2017\(^\text{13}\). A value of 0.25 for all the elasticities of substitution involving energy

\(^\text{12}\)This empirical methodology could not be used for the non-energy elasticity of substitution, as the signal-to-noise ratio in the response to an oil price shock is too low in these sectors: a 46% fall in oil prices can be expected to be the biggest shock for the fuels and electricity sectors over a period of three years, but may be just another factor affecting the telecommunications or advertising sector.

\(^\text{13}\)It is therefore a two-years-shock, evaluated at a three-years-horizon; longer time frames can’t be used regarding this episode because the oil price grew back in the following years. Since the model can’t pin down prices, the observed growth of the GDP deflator is added to the simulation results before comparing with the data for nominal production. Using sector-specific value added deflators, or comparing value added instead of production, or real variables instead of nominal variables, didn’t seem adequate, as these more complex measures, which involve more granular data or indirectly-constructed data, are very volatile in the National Accounts data: nominal energy production fell approximately 21-22% in both energy sectors between 2014 and 2017, which seems reasonable; but, at the same time, nominal value added grew almost 300% in the fuels sector and fell slightly in the electricity sector; real value added grew 640% in the fuels sector, and just 3.8% in the electricity sector. It wouldn’t be a good idea to make the model replicate these extremely noisy dynamics, so the more moderate measure
Table 2
Simulation exercise used for calibrating the elasticity of substitution parameters involving energy

<table>
<thead>
<tr>
<th>Elasticity:</th>
<th>Fuels sector</th>
<th>Electricity sector</th>
<th>distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>-28.3</td>
<td>-8.1</td>
<td>9.91</td>
</tr>
<tr>
<td>0.15</td>
<td>-26.8</td>
<td>-7.6</td>
<td>9.57</td>
</tr>
<tr>
<td>0.20</td>
<td>-25.3</td>
<td>-7.1</td>
<td>9.32</td>
</tr>
<tr>
<td><strong>0.25</strong></td>
<td><strong>-23.9</strong></td>
<td><strong>-6.7</strong></td>
<td><strong>9.21</strong></td>
</tr>
<tr>
<td>0.30</td>
<td>-28.2</td>
<td>-8.1</td>
<td>9.89</td>
</tr>
<tr>
<td>0.35</td>
<td>-21.1</td>
<td>-5.7</td>
<td>9.33</td>
</tr>
<tr>
<td>0.40</td>
<td>-19.5</td>
<td>-5.3</td>
<td>9.60</td>
</tr>
<tr>
<td>0.45</td>
<td>-18.0</td>
<td>-4.8</td>
<td>9.98</td>
</tr>
<tr>
<td>0.50</td>
<td>-16.4</td>
<td>-4.3</td>
<td>10.48</td>
</tr>
<tr>
<td>0.55</td>
<td>-14.8</td>
<td>-3.8</td>
<td>11.09</td>
</tr>
<tr>
<td>0.60</td>
<td>-13.3</td>
<td>-3.3</td>
<td>11.77</td>
</tr>
<tr>
<td>0.65</td>
<td>-11.6</td>
<td>-2.8</td>
<td>12.59</td>
</tr>
<tr>
<td>0.70</td>
<td>-10.0</td>
<td>-2.3</td>
<td>13.44</td>
</tr>
</tbody>
</table>

is the one that most closely matches the evolution observed in the data, in the sense that it minimizes the unweighted distance from the simulated responses of nominal production of the two energy sectors to the observed ones, and that is the value we select for simulations with a time horizon of approximately three years (see Table 3). Bigger values for these parameters (which are common in the literature) would imply a much bigger substitution in real terms, and a fall in nominal terms that would be much smaller than what was observed in Spain in this episode; this was to be expected, because these higher values used in the literature usually refer to longer time horizons than just three years.

The rest of the parameters in the model take standard values from the literature. This is the case of the relative risk aversion (with a value of one) and the Frisch elasticity of labor (also one).
4 Simulation exercises

4.1 A increase in the price of greenhouse gas emissions

The main use of the model is to evaluate the effects on the Spanish economy of changes in the EU Emissions Trading System (EU ETS), which is the scheme that the green tax in the model tries to replicate, as detailed in the calibration section. Table 3 and Figure 4 show the results of a simulation in which the price of emission allowances changes from 25 euros per ton of CO2 (which was approximately the average price in 2020) to 100 euros in 2023 (it has already been hovering above 80 for most of 2022). In the simulation, the average rate of the green tax (the total ETS costs paid by firms, including for electricity generation, divided by the total net cost of their energy intermediate inputs) goes from 3.6% to 14.2%\textsuperscript{14}.

As emissions become more expensive, firms reduce their energy intensity, with a 9.7% fall in emissions, a 0.37% fall of GDP, and a reduction of employment of 0.58%. The increase in the cost of emissions affects both energy sectors, but the resulting reduction in the use of fuels is slightly larger than for electricity. Figure 5 shows the heterogeneous sectoral effects of this policy: it plots the relationship between the impact on sectoral real value added and both initial greenhouse emission taxes paid per unit of output, and initial greenhouse gas emissions per unit of output (measured as the potential ETS that the sector would have to pay if all of its emissions were taxed at the initial rate, as a percentage over total production costs). In this simulation, the non-energy sectors that suffer the biggest fall in real value added are not necessarily those generating the most emissions, but those that were covered by the ETS system in the initial situation. The model also identifies some sectors that suffer a big impact even if they are not directly affected by the shock; this is the case, for example, of printing and recorded media, that buys a lot of inputs from paper manufacturers, and of repair and installation of machinery and equipment, that sells a lot of their products and services to various chemical and metal manufacturing sectors. On the other hand, sectors such as agriculture and fishing, that have relatively high emissions intensity, are not particularly affected by this shock, since their regulatory ETS coverage is low.

\textsuperscript{14}The focus on relatively big shocks is in line with the purpose of the model of serving as a tool to generate climate change stress test scenarios that help Banco de España evaluate the exposure of the financial system to transition risks in time horizons of approximately three years.
Figure 5
Simulation of an increase in the price of CO$_2$ emissions, from 25 to 100 euros per tonne

% change in sectoral value added

1 - Agriculture and farming
2 - Forestry and logging
3 - Fishing
4 - Mining and quarrying
5 - Food products, beverages and tobacco
6 - Textiles, clothes and leather products
7 - Products of wood and cork, except furniture
8 - Paper and paper products
9 - Printing and recorded media
10 - Chemical products
11 - Pharmaceutical products
12 - Rubber and plastic products
13 - Other non-metallic mineral products
14 - Basic metals
15 - Metal products, except machinery and equipment
16 - Computer, electronic and optical products
17 - Electrical equipment
18 - Machinery and equipment
19 - Motor vehicles
20 - Other transport equipment
21 - Furniture and other manufacturing
22 - Repair and installation of machinery and equipment
23 - Water collection and supply
24 - Sewerage and waste
25 - Construction
26 - Trade and repair of motor vehicles
27 - Wholesale trade, except of motor vehicles
28 - Retail trade, except of motor vehicles
29 - Land transport
30 - Water transport
31 - Air transport
32 - Warehousing and support for transportation
33 - Postal services
34 - Accommodation and food service
35 - Publishing activities
36 - Motion picture and television, music and radio
37 - Telecommunications
38 - Computer programming and information services
39 - Financial services, except insurance and pensions
40 - Insurance and pensions, except social security
41 - Activities auxiliary to financial services
42 - Real estate
43 - Legal and accounting activities, and consultancy
44 - Architectural and engineering activities
45 - Advertising
46 - Other professional activities
47 - Administrative activities
48 - Public administration and social security
49 - Education
50 - Healthcare
51 - Other services
E1 - Coke and refined petroleum
E2 - Electricity and gas
4.2 An expansion of the coverage of the ETS system to all sectors

A second way of increasing the green tax in the model is to extend the coverage of the ETS system, so that all emissions by all sectors are taxed. As of 2022, only the firms from a few select sectors have to surrender ETS rights when they emit greenhouse gases. In the section about the calibration of the model this was reflected as a low or zero regulatory coefficient for most sectors, and a non-zero one for some, mainly a few industrial sectors with big factories generating big amounts of emissions, and airlines. The simulation in this section keeps the price of greenhouse gas emissions at 25 euros per ton of CO2, but increases coverage so that all emissions from all sectors are taxed at this price (all regulatory coefficients are set to one). The results of this simulation are summarized by Table 4 and Figures 6 and 7.

Compared with the previous simulation (the increase in price), this one represents a smaller shock if we look at metrics such as the effect on GDP (-0.12%), but it generates a bigger fall in emissions (-14.5%), because its impact is focused on some sectors with relatively high emissions that are currently exempt from the green tax, and therefore only responded indirectly to the shock in the previous subsection. One important channel through which this simulation achieves bigger reductions in emissions with lower cost in terms of GDP or employment, is electrification: whereas the increase in the price of emissions generated a relatively similar reduction in the use of fuels and
Table 4
Simulation of an expansion of the coverage of the ETS system, to fully cover all emissions from all firms, of all sectors

<table>
<thead>
<tr>
<th>% change</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Real GDP</td>
<td>-0.12</td>
</tr>
<tr>
<td>Real consumption</td>
<td>-0.24</td>
</tr>
<tr>
<td>Employment</td>
<td>-0.19</td>
</tr>
<tr>
<td>Use of fuels</td>
<td>-4.4</td>
</tr>
<tr>
<td>Use of electricity</td>
<td>-0.5</td>
</tr>
<tr>
<td>Emissions</td>
<td>-14.5</td>
</tr>
</tbody>
</table>

electricity, this expansion of the coverage of the ETS system affects the cost of using fuels to a bigger extent, and induces a substitution towards electricity. The rate at which this is feasible is controlled by the elasticities of substitution that were discussed in the section about the calibration of the model, and most notably $v_{H,E}$, which controls the rate at which one energy input is substituted for another when their relative prices change.

In terms of the non-energy sectors most affected by this shock, they tend to be those with higher emission intensity (agriculture, fishing, transport, sewerage and waste), minus the ones that are already highly covered by the ETS system (chemicals, basic metals and non-metallic products, that display a sizable effect but not as much as their emissions intensity would suggest), plus some that are indirectly hit through their commercial relations with other highly-affected sectors (warehousing and support for transportation, repair and installation of machinery and equipment, water collection and supply, etc).

4.3 Increase in the price of greenhouse gas emissions plus expansion of the coverage

When both shocks are implemented at the same time, the total effect is much bigger than the sum of both individual simulations presented above: it is equivalent to first increasing the price, and then, at this higher price, expanding the coverage. Table 5 and Figures 6 and 9 summarize the results from this simulation.
Figure 6
Simulation of an expansion of the coverage of the ETS system, to fully cover all emissions from all firms, of all sectors
Figure 7
Simulation of an expansion of the coverage of the ETS system, to fully cover all emissions from all firms, of all sectors

Table 5
Simulation of an increase in the price of CO₂ emissions, to 100 €/ton, plus an expansion of the coverage, to all firms in all sectors

<table>
<thead>
<tr>
<th>% change</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Real GDP</td>
<td>-0.90</td>
</tr>
<tr>
<td>Real consumption</td>
<td>-1.52</td>
</tr>
<tr>
<td>Employment</td>
<td>-1.27</td>
</tr>
<tr>
<td>Use of fuels</td>
<td>-15.9</td>
</tr>
<tr>
<td>Use of electricity</td>
<td>-4.8</td>
</tr>
<tr>
<td>Emissions</td>
<td>-31.1</td>
</tr>
</tbody>
</table>
Figure 8
Simulation of an increase in the price of CO₂ emissions, to 100 €/ton, plus an expansion of the coverage, to all firms in all sectors.

% change in sectoral value added

1 - Agriculture and farming
2 - Forestry and logging
3 - Fishing
4 - Mining and quarrying
5 - Food products, beverages and tobacco
6 - Textiles, clothes and leather products
7 - Products of wood and cork, except furniture
8 - Paper and paper products
9 - Printing and recorded media
10 - Chemical products
11 - Pharmaceutical products
12 - Rubber and plastic products
13 - Other non-metallic mineral products
14 - Basic metals
15 - Metal products, except machinery and equipment
16 - Computer, electronic and optical products
17 - Electrical equipment
18 - Machinery and equipment
19 - Motor vehicles
20 - Other transport equipment
21 - Furniture and other manufacturing
22 - Repair and installation of machinery and equipment
23 - Water collection and supply
24 - Sewerage and waste
25 - Construction
26 - Trade and repair of motor vehicles
27 - Wholesale trade, except of motor vehicles
28 - Retail trade, except of motor vehicles
29 - Land transport
30 - Water transport
31 - Air transport
32 - Warehousing and support for transportation
33 - Postal services
34 - Accommodation and food service
35 - Publishing activities
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39 - Financial services, except insurance and pensions
40 - Insurance and pensions, except social security
41 - Activities auxiliary to financial services
42 - Real estate
43 - Legal and accounting activities, and consultancy
44 - Architectural and engineering activities
45 - Advertising
46 - Other professional activities
47 - Administrative activities
48 - Public administration and social security
49 - Education
50 - Healthcare
51 - Other services
E1 - Coke and refined petroleum
E2 - Electricity and gas
In terms of the GDP cost of reducing emissions by a given amount, this simulation falls in an intermediate point between the previous two, with 0.03 pp of GDP lost for every percentage point of emissions reduction, against 0.04 pp for the price increase and 0.01 pp for the expansion of coverage. The electrification channel is still present, with a reduction in electricity use that is 3.3 times smaller than the reduction in the use of fuels. In terms of the impact across non-energy sectors, those that have high emissions intensity show an almost-linear relationship, as they are now all directly affected by the shock (both the ones covered and not covered currently by the ETS system), whereas for those with low emissions intensity the size of the effect is determined by their network of commercial relations with other sectors, as defined by the input-output tables that the model captures.

4.4 Increase in the price of greenhouse gas emissions plus expansion of the coverage, with compensation through lower labor taxes

All the simulations presented above are based on the standard configuration of the model, in which revenue from the green tax is used to reduce the lump-sum taxes paid by households. Using lump-sum taxes to redistribute the green tax gains is not efficient, and it can be thought of as the worst-case scenario of the transition risks. In this section, we relax this assumption, and allow the government to redistribute the new revenues of
the green tax via a decrease in labor taxes, which can generate an endogenous positive response in labor supply and reduce the negative impact of the policy, or even bring a net positive aggregate result.\textsuperscript{15,16}

\textsuperscript{15}For example, see Beiser-McGrath and Bernauer (2019) and Douenne (2020).

\textsuperscript{16}The size of this effect is controlled mainly by the Frisch elasticity of labor. As explained in the section about the calibration of the model, this parameter is taken from the literature and has a value of one. Sensitivity analysis has been carried out, with results as expected: when households expand their labor supply to a greater extent in response to the reduction in labor taxes, effects become more positive. Even if the size may change, the positive sign of the effects remains for a wide range of reasonable values of this parameter.
Figure 10
Simulation of an increase in the price of $CO_2$ emissions, to 100 €/ton, plus an expansion of the coverage, to all firms in all sectors, with the revenue from those measures used to finance a reduction in labor taxes.
As seen in Table 6, in aggregate terms the effect on output is now strongly positive. This in turn affects energy use and greenhouse gas emissions: the reduction achieved is smaller than in the case with revenue recycling through lump-sum taxes. But because there’s no negative output cost in this case, the fact that the simulation still shows a strong reduction in emissions showcases that, if revenue from a green tax is used in ways that reduce inefficiencies and improve productivity or incentives, it can become a revenue-neutral measure that incentives growth while reducing greenhouse gas emissions.

Still, figures 10 and 11, where the sectoral effects of this simulation are presented, show that, while the effect can be positive on aggregate and for most sectors, there can still be some sectors with a strongly negative effect. In this case, as the positive effect of increased output supply has a broad positive effect on all the economy, the ones showing negative effects are the same ones that showed a strongly negative effect in the simulation where green tax revenues were financing a lump-sum transfer.

5 Conclusions

Both climate change and the policies implemented to counter it may have negative effects on the economy, which would be transmitted to financial institutions through their exposure to the firms and sectors most affected. We present a model for the
Spanish economy, designed as a tool for generating macromonic scenarios that can be used as an initial ingredient in climate-change stress test exercises. The model closely approximates the productive structure of the Spanish economy and allows reasonably realistic simulations to be formulated.

The model is primarily used to generate medium-term climate stress scenarios, as we focus on capturing transition risks associated with regulatory measures, to assess the different productive sectors’ degree of exposure in the event of an increase in the price of emission allowances or an extension of EU-ETS coverage. We show that in the event of an increase in the price of emission allowances similar to that observed in recent years (from approximately €25 per tonne of CO2 in 2019 to almost €100 per tonne in early February 2022), the model predicts a cumulative decline after three years of 0.37% in Spanish GDP. The losses in value added among industries are very heterogeneous, ranging from losses of 4% to virtually no losses. This stresses how the transitional risks for banks depend on their exposure to the most affected sectors, being a latent threat to financial stability.

Further ahead, the model could be expanded into an open economy model, with imports and exports (including the export of the home produced basic energy good), and to include capital in the production function, enhancing the realism with which the model fits the data and allowing effects on assets used by firms as loan collateral to be incorporated into the simulations. The electricity-generation sector could be divided into renewables and non-renewables, with asymmetric investment allowing a gradual increase in the weight of renewables. There is a lot of work still to be done in terms of enhancing the modelling of climate change issues for the Spanish economy, and the current version of CATS is but a first attempt at Banco de España, to be followed by other, bigger, projects.
References


6 Appendix

Appendix

A Further details on the model

The model described in the paper is formed using the first order conditions as detailed in the appendix from households, retailers, the energy and non-energy sectors.

A.1 Household

The household chooses consumption of the final aggregate product, $C$, and the amount of labor to provide, $L$, to maximize its utility over time subject to a budget constrain.

$$\max_{C_t, E_t} \sum_{t=0}^{\infty} \beta^t \frac{C_1^{1-\sigma} - \sigma}{1-\sigma} - \frac{Y_1^{1+\theta}}{1+\theta}$$

s.t. $PC = WL + T$,

The first order condition associated to the choice of consumption implies the following shadow price $\lambda = 1/PC^\sigma$.

A.2 Consumption retailers

The consumption retailer purchases the consumption energy good, $C_E$, from the energy consumption retailer and the non-energy consumption good, $C_{NE}$, from the non-energy consumption retailer and aggregate them into the final consumption good sold to the household under a CES production function:

$$C = \left[ \omega_C^{1/ \nu_C} C_E^{\nu_C-1} + (1 - \omega_C)^{\nu_C^{-1}} C_{NE}^{\nu_C^{-1}} \right]^{\nu_C^{-1}}$$

where $\nu_C < 1$ is the elasticity of substitution between energy and non-energy consumption (in this case, there is a strong complementarity between energy and non-energy consumption in the production function of the consumption retailer, meaning that the ability of households final good, $C_t$, to move away from energy consumption is limited.)
The demand for the energy and non-energy consumption goods is determined by the profit maximization:

$$\max_{C_E, C_{NE}} P_t C_t - P_E C_E - P_{NE} C_{NE}$$

s.t. $C_t = \left[ \frac{1}{\omega_c} C_E^{-\frac{1}{\nu_C}} (1 - \omega_c) \frac{1}{\nu_C} C_{NE}^{-\frac{1}{\nu_C}} \right]^{\frac{\nu_C}{\nu_C - 1}}$.

The respective first order conditions for $C_E$ and $C_{NE}$ are the following:

$$F_{OC_E} : P \left[ \frac{1}{\nu_C} C_E^{-\frac{1}{\nu_C}} + (1 - \omega_c) \frac{1}{\nu_C} C_{NE}^{-\frac{1}{\nu_C}} \right]^{\frac{1}{\nu_C - 1}} \omega_c^{\frac{1}{\nu_C}} C_E = P_E,$$

$$F_{OC_{NE}} : P \left[ \frac{1}{\nu_C} C_E^{-\frac{1}{\nu_C}} + (1 - \omega_c) \frac{1}{\nu_C} C_{NE}^{-\frac{1}{\nu_C}} \right]^{\frac{1}{\nu_C - 1}} (1 - \omega_c) \frac{1}{\nu_C} C_{NE}^{1-\frac{1}{\nu_C}} = P_{NE},$$

If we evaluate this expression to the power of $\nu_C$, it becomes:

$$P_{\nu_C} C_{\nu_C} C_{\nu_C}^{-1} = P_E^{\nu_C},$$

$$C_E = \omega_c \left( \frac{P}{P_E} \right)^{\nu_C} C$$

(12)

$$F_{OC_{NE}} : P \left[ \frac{1}{\nu_C} C_E^{-\frac{1}{\nu_C}} + (1 - \omega_c) \frac{1}{\nu_C} C_{NE}^{-\frac{1}{\nu_C}} \right]^{\frac{1}{\nu_C - 1}} (1 - \omega_c) \frac{1}{\nu_C} C_{NE}^{1-\frac{1}{\nu_C}} = P_{NE},$$

$$C_{NE} = (1 - \omega_c) \left( \frac{P}{P_{NE}} \right)^{\frac{1}{\nu_C}} C$$

(13)

Using these two equations we can obtain the relative prices between energy and non-energy consumption goods:

$$\frac{P_E}{P_{NE}} = \left( \frac{\omega_c}{1 - \omega_c} \right)^{\frac{1}{\nu_C}} \left( \frac{C_E}{C_{NE}} \right)^{\frac{1}{\nu_C}}$$

(14)

and the price of the final consumption good becomes:

$$P = \left[ \omega_c P_E^{\frac{1}{\nu_C}} + (1 - \omega_c) P_{NE}^{\frac{1}{\nu_C}} \right]$$

(15)

Additionally we can define:
A.3 Energy consumption retailers

This retailer purchases the energy consumption goods, \(C_e\), from the energy producers. In this model, there are two energy sectors, \(N_e = 2\) (coke and refined petroleum, and electricity and gas), so we already express the following formulas taking this into account. The retailer aggregates the energy consumption goods into an energy consumption bundle, \(C_E\), using the following CES function:

\[
C_E = \left[ \frac{1}{\omega_{C,e}} C_{e1}^{\frac{1}{\nu_{C,E} - 1}} + (1 - \omega_{C,e}) C_{e2}^{\frac{1}{\nu_{C,E} - 1}} \right]^{\frac{\nu_{C,E}}{\nu_{C,E} - 1}},
\]

where \(\nu_{C,E} > 1\) is the elasticity of substitution across different energy consumption goods (i.e., energy consumption of different types are substitute goods, so that carbon tax can lead to a rise of “greener” energy sectors).

The demand for the different energy types is determined from the following profit maximization:

\[
\max_{C_{e1}, C_{e2}} P_E C_E - P_{e1} C_{e1} - P_{e2} C_{e2}
\]

s.t. \(C_E = \left[ \frac{1}{\omega_{C,e}} C_{e1}^{\frac{1}{\nu_{C,E} - 1}} + (1 - \omega_{C,e}) C_{e2}^{\frac{1}{\nu_{C,E} - 1}} \right]^{\frac{\nu_{C,E}}{\nu_{C,E} - 1}},
\]

The respective first order conditions for \(C_{e1}\) and \(C_{e2}\) are the following:

\[
F_{oc_{C_{e1}}} : P_E \left[ \frac{1}{\omega_{C,e}} C_{e1}^{\frac{\nu_{C,E} - 1}{\nu_{C,E}}} + (1 - \omega_{C,e}) C_{e2}^{\frac{\nu_{C,E} - 1}{\nu_{C,E}}} \right]^{\frac{1}{\nu_{C,E} - 1}} \frac{1}{\omega_{C,e}} C_{e1}^{\frac{1}{\nu_{C,E} - 1}} = P_{e1},
\]

\[
F_{oc_{C_{e2}}} : P_E \left[ \frac{1}{\omega_{C,e}} C_{e1}^{\frac{\nu_{C,E} - 1}{\nu_{C,E}}} + (1 - \omega_{C,e}) C_{e2}^{\frac{\nu_{C,E} - 1}{\nu_{C,E}}} \right]^{\frac{1}{\nu_{C,E} - 1}} \frac{1}{\omega_{C,e}} C_{e2}^{\frac{1}{\nu_{C,E} - 1}} = P_{e2},
\]

Following a similar argument as before, we obtain:
\begin{equation}
C_{e1} = \omega_{C,E} \left( \frac{P_E}{P_{e1}} \right)^{\nu_{C,E}} C_E
\end{equation}

\begin{equation}
C_{e2} = (1 - \omega_{C,E}) \left( \frac{P_E}{P_{e2}} \right)^{\nu_{C,E}} C_E
\end{equation}

Using these two equations we can obtain the relative prices between the two energy sectors:

\begin{equation}
\frac{P_{e1}}{P_{e2}} = \left( \frac{\omega_{C,E}}{1 - \omega_{C,E}} \right)^{\frac{1}{\nu_{C,E}}} \left( \frac{C_{e1}}{C_{e2}} \right)^{\frac{1}{\nu_{C,E}}} C_E
\end{equation}

and the price of the final consumption good becomes:

\begin{equation}
P_E = \left[ \omega_{C,E}P_{e1}^{\frac{1}{\nu_{C,E}}} + (1 - \omega_{C,E})P_{e2}^{\frac{1}{\nu_{C,E}}} \right]
\end{equation}

A.4 Non-energy consumption retailers

The non-energy retailer purchases the goods \( C_s \) from the 51 non-energy producer and aggregates them into a non-energy consumption bundle, \( C_{NE} \), using the following CES function:

\begin{equation}
C_{NE} = \left[ \sum_{s=1}^{N_s} \omega_{C,s}^{\frac{\nu_{C,s}}{\nu_{C,s} - 1}} C_s^{\frac{\nu_{C,s} - 1}{\nu_{C,s}}} \right]^{\frac{1}{\nu_{C,s} - 1}} \sum_{s=1}^{N_s} \omega_{C,s} = 1,
\end{equation}

where \( \nu_{C,s} > 1 \) is the elasticity of substitution across different non-energy consumption goods.

The demand for the different non-energy consumption goods is determined from the following profit maximization:

\begin{equation}
\max_{C_s} P_{NE} C_{NE} - \sum_{s=1}^{N_s} P_s C_s
\end{equation}

\begin{equation}
s.t. \quad C_{NE} = \left[ \sum_{s=1}^{N_s} \omega_{C,s}^{\frac{\nu_{C,s}}{\nu_{C,s} - 1}} C_s^{\frac{\nu_{C,s} - 1}{\nu_{C,s}}} \right]^{\frac{1}{\nu_{C,s} - 1}},
\end{equation}

The respective first order conditions for the \( s \) goods is the following:
\[ FocC_s : P_{NE} \left( \sum_{s=1}^{N_s} \omega_{C,s}^{v_{C,s}} C_s^{v_{C,s}-1} \right)^{\frac{v_{C,s}-1}{v_{C,s}}} \left( \sum_{s=1}^{N_s} \omega_{C,s}^{v_{C,s}} C_s^{v_{C,s}-1} \right) = P_s, \]

Operating as in the previous CES functions, we reach the following condition (expressed in terms of prices):

\[ P_s = \left( \frac{\omega_{C,s}}{C_s} \right)^{\frac{1}{v_{C,s}}} P_{NE} \quad (22) \]

### A.5 Energy intermediate-input retailers

For each of the \( N_s \) non-energy sectors there is a retailer that purchases the energy intermediate goods \( e_e \) from the \( N_e \) energy sectors and aggregates them into an energy intermediate-input bundle for each non-energy sector, \( E_s \), using a CES function as follows:

\[ E_s = \left[ \frac{1}{\omega_{H,E}^{v_{H,E}}} e_s^{v_{H,E}-1} + (1 - \omega_{e,s}) \frac{1}{v_{H,E}} e_s^{v_{H,E}-1} \right]^{v_{H,E}} \]

where \( v_{H,E} > 1 \) is the elasticity of substitution across different energy intermediate goods.

The demand for the different energy types is determined from the following profit maximization:

\[ \max_{e_{1,s}, e_{2,s}} \sum_{s=1}^{N_s} P_{E,s} E_s - P_{e1} \sum_{s=1}^{N_s} e_{1,s} - P_{e2} \sum_{s=1}^{N_s} e_{2,s} \]

s.t. \( E_s = \left[ \frac{1}{\omega_{H,E}^{v_{H,E}}} e_{1,s}^{v_{H,E}-1} + (1 - \omega_{e,s}) \frac{1}{v_{H,E}} e_{2,s}^{v_{H,E}-1} \right]^{v_{H,E}} \),

The respective first order conditions for \( E_{e1,s} \) and \( E_{e2,s} \) are the following:

\[ FocE_{e1,s} : P_{E,s} \left[ \frac{1}{\omega_{H,E}^{v_{H,E}}} e_{1,s}^{v_{H,E}-1} + (1 - \omega_{e,s}) \frac{1}{v_{H,E}} e_{2,s}^{v_{H,E}-1} \right]^{v_{H,E}-1} \left( \frac{1}{\omega_{H,E}^{v_{H,E}}} e_{1,s}^{v_{H,E}-1} + (1 - \omega_{e,s}) \frac{1}{v_{H,E}} e_{2,s}^{v_{H,E}-1} \right) = P_{e1} \]

That operating becomes:
\[ e_{e1,s} = \omega_{H,E} \left( \frac{P_{E,s}}{P_{e1}} \right)^{v_{H,E}} E_s \]  

and in the case of \( e_{e2,s} \):

\[ e_{e2,s} = (1 - \omega_{H,E}) \left( \frac{P_{E,s}}{P_{e2}} \right)^{v_{H,E}} E_s \]

Using these two equations we can obtain the relative prices between the two energy sectors:

\[ \frac{P_{e1}}{P_{e2}} = \left( \frac{\omega_{H,E}}{1 - \omega_{H,E}} \right)^{v_{H,E}} \left( \frac{e_{e1,s}}{e_{e2,s}} \right)^{v_{H,E}} E_s \]

and the price of the energy intermediate-input good becomes:

\[ P_{E,s} = \left[ \omega_{H,E} \frac{1}{P_{e1}} + (1 - \omega_{H,E}) \frac{1}{P_{e2}} \right] \]

### A.6 Non-energy intermediate-input retailers

For each non-energy sector \((N_s)\), there is a retailer that purchases the goods \( H_{x,s} \) from each of the non-energy producers \((N_s)\), and aggregates them into \( N_s \) non-energy intermediate-input bundle, \( H_s \), using a Cobb-Douglas function with constant returns to scale:

\[ H_s = \prod_{x=1}^{N_s} H_{x,s}^{\omega_{H,x,s}}, \quad \sum_{x=1}^{N_s} \omega_{H,x,s} = 1, \]

where \( H_{x,s} \) is the intermediate input produced from sector \( x \) and then used by sector \( s \) \((N_s x N_s)\).

The demand from sector \( x \) for the different non-energy intermediate inputs \( s \) is determinated from the following profit maximization:

\[ \max_{H_s} P_{H_s} H_s - \sum_{s=1}^{N_s} P_{H,x,s} H_{x,s} \]

\[ \text{s.t. } H_s = \prod_{x=1}^{N_s} H_{x,s}^{\omega_{H,x,s}} \]

The first order conditions for the intermediate producer \( x \) is:
\[ \omega_{H,x,s} P_{H,s} H_{x,s}^{\omega_{H,x,s} - 1} = P_{H,x,s} \]

Multiplying both sides by \( H_{x,s} \), we get:

\[ H_{x,s} = \frac{P_{H,x,s} H_{s}}{\omega_{H,x,s} P_{H,s}} \quad (27) \]

and the price of the the 51 intermediate-input bundle, \( H_s \), can be defined as:

\[ P_{H,s} = \prod_{x=1}^{N_s} \left( \frac{P_{H,x,s}}{\omega_{H,x,s}} \right)^{\omega_{H,x,s}} \quad (28) \]

### A.7 Energy production sectors

There are \( N_e \) energy production sectors. In each of these sectors, denoted by the subscript \( e \), production of energy is determined by the imported energy input from abroad,

\[ Z_e = M_e. \quad (29) \]

The energy good \( Z_e \) is sold to the energy consumption retailer, \( C_e \), and to each of the energy intermediate-input retailer, \( E_{e,s} \) \( (N_s) \):

\[ Z_e = C_e + \sum_{s=1}^{N_s} E_{e,s} \quad (30) \]

The maximization problem of the energy sector determines the labor demand to produce energy:

\[ \max_{L_e} (1 - \tau_e) P_e M_e - P_{M,e} M_e \]

s.t. \( Z_e = M_e \),

where the taxes are a function of the emissions \( \tau_e = \frac{P_{CO_2,CO_2,e}}{P_e Z_e} \).

The profit maximization yields to the following condition:

\[ P_M = (1 - \tau_e) P_e \quad (31) \]

We assume that the price of the imported good, \( P_{M,e} \), is the same as that of the final good in the home economy.
A.8 Non-energy production sectors

The production of the non-energy sector is determined from a CES function that uses energy, $E_s$, labor, $L_s$ and non-energy intermediate input, $H_s$, that is sold to the non-energy consumption retailer, and the $N_s$ non-energy intermediate-input retailers, $Z_s = C_s + \sum_{x=1}^{s} H_{x,s}$. The production function is the following:

$$Z_s = \left[ \frac{1}{\omega_{E,s} E_s^v} + (1 - \omega_{E,s}) \frac{1}{\nu_E} \left[ L_s^\alpha H_s^{1-\alpha} \right] \frac{1}{\nu_E} \right]^\frac{1}{\nu_E-1}$$

The maximization problem of the non-energy sector determines the demand for the different inputs:

$$\max_{E_s, L_s, H_s} P_s Z_s - P_{E,s} E_s - W L_s - P_{H,s} H_s$$

s.t. $Z_s = \left[ \frac{1}{\omega_{E,s} E_s^v} + (1 - \omega_{E,s}) \frac{1}{\nu_E} \left[ L_s^\alpha H_s^{1-\alpha} \right] \frac{1}{\nu_E} \right]^\frac{1}{\nu_E-1}$

The respective first order conditions for $E_s$ becomes:

$$Foc_{E_s} : P_s \left[ \frac{1}{\omega_{E,s} E_s^v} + (1 - \omega_{E,s}) \frac{1}{\nu_E} \left[ L_s^\alpha H_s^{1-\alpha} \right] \frac{1}{\nu_E} \right]^{-1} \left[ \frac{1}{\omega_{E,s} E_s^v} \right] = P_{E,s}$$

That operating becomes:

$$E_s = \omega_E \left( \frac{P_s}{P_{E,s}} \right)^\frac{1}{\nu_E} Z_s \tag{32}$$

In the case of labor and the intermediate input, we split the problem into the following:

$$\max P_{va} V_a - W L_s - P_{H,s} H_s$$

s.t. $V_{a,s} = L_s^\alpha H_s^{1-\alpha}$

whose optimal conditions are:
\[ L_s = \left[ \frac{P_{H,s}}{(1 - \alpha)P_{va}} \right]^{1/\alpha} \]

so that

\[ P_{va} = \frac{w^\alpha P_{H,s}^{1-\alpha}}{\alpha(1 - \alpha)^{1-\alpha}} \quad (33) \]

\[ V_{as} = \frac{WL}{\alpha P_{va}} \quad (34) \]

and since the optimal condition for \( E_{e,s} \) is equivalent for the “good” \( V_{a} \), we have:

\[ V_{as} = (1 - \omega_E) \left( \frac{P_s}{P_{va}} \right)^{\nu_E} Z_s \quad (35) \]

Then

\[ H_s = \frac{(1 - \alpha)P_{va}}{P_{H,s}} \quad (36) \]

### A.9 Closing the model

**Labor Market**

\[ L = \sum_{s=1}^{N_s} L_s \]

**Taxes**

\[ T = \sum_{s=1}^{N_e} \tau_e P_e Z_e \]

### A.10 List of variables

The model contains \( N_s = 51 \) sectors and \( N_e = 2 \) energy sectors (electricity, gas, steam and air conditioning supply, and manufacture of coke and refined petroleum products). There is one final good \( C \) that is formed using the consumption energy good, \( C_E \), from the energy consumption retailer and the non-energy consumption good, \( C_{NE} \), the respective prices are \( P, P_E, P_{NE} \). The consumption energy good is produced using the two kinds of intermediate inputs from energy producers (coke and refined petroleum and electricity and gas), \( C_{e1}, C_{e2} \) and their prices are \( P_{e1}, P_{e2} \), while the non-energy consumption good uses the inputs, \( C_s \), from the 51 non-energy producers with the respective
51 \( P_s \) prices.

The intermediate inputs produced from the energy producers come from the energy producer that use the imported energy input \( M_{e1} \) and \( M_{e2} \) respectively with prices \( P_{M,e1} \) and \( P_{M,e2} \). This input is also used for the production of the energy used in each of the 51 non-energy producers \( E_s \), with prices \( P_{E,s} \). This producer (the non-energy) also uses 51 inputs of labor \( L_s \) and 51 inputs of non-energy intermediate input, \( H_s \) in the production of the input to the non-energy consumption retailer (\( C_s \) to produce \( C_{NE} \)) and in the input for the non-energy intermediate retailer 51x51 \( H_{x,s} \). The prices of his inputs are \( W \) (same wage for all kinds of labor) and 51x \( P_{H,s} \). With respect to these two inputs used in the non-energy production sector, the labor comes from the final consumer, and the non-energy intermediate input comes from the non-energy intermediate retailer, that uses input produced from sector \( x \) and then used by sector \( s \) (\( N_xN_s \), 51x51), \( H_{x,s} \) with their respective (51x51) \( P_{x,s} \) prices.

Therefore the model contains 1 final good \( C \), 1 energy good \( C_E \), 1 non-energy \( C_{NE} \), 2 intermediate inputs from the energy producers \( C_{e1}, C_{e2} \), 51 non-energy inputs from the non-energy producers \( C_s \), 51x51 inputs for the intermediate non-energy retailer \( H_{x,s} \), 2 imported energy input \( M_{e1} \) and \( M_{e2} \). It also has, 51 energy inputs used in the non-energy producers \( E_s \), 51 kind of labors input \( L_s \) and 51 non-energy intermediate input, \( H_s \) in the non-energy producer and 51x51 inputs \( H_{x,s} \) in the non-energy intermediate retailer. All of these with the respective prices: \( 1xP, 1xP_{E}, 1xP_{NE}, 1xP_{e1}, 1xP_{e2}, 51x51P_{H_{x,s}}, 1xP_{M,e1}, 1xP_{M,e2}, 51xP_{E,s}, 51xP_{H,s} \).

**A.11 Exercise strategy**

Given the parameters and shares are calibrated from the data (see the Calibration section) the algorithm for finding the steady-state of the model is as follows:

a) Initial guess for the variables in the model: \( c_s, n_s, n_e, p_s \), and \( P \), the price that closes the labor market.

b) Equations 1 to 21 in the model are solved (see list of equations above) with the following order:

1. Fix wages to one as the numenary.

2. Define energy prices \( P_{e1}, P_{e2} \) as function of wages and taxes (for energy type and coverage, \( \tau_{e1}, \tau_{e1c} \) and \( \tau_{e2}, \tau_{e2c} \) respectively) and likewise for the non-energy
producers $P_{E,s}$ (that includes either $\tau_{e1}$ or $\tau_{e2}$ and two specific taxes). These equations come from 31.

3. Adjust the shares of $C_{e1}, C_{e2}$ to obtain $\tilde{\omega}_{C,E}$ and normalize them to obtain $\omega_{C,E}$. Note that from the data we get a share that doesn’t correspond directly to the normalised share in the models and needs some computations.

4. Obtain the price of the energy aggregated good $P_E$ from 20.

5. Obtain the price of the non-energy aggregated good $P_{NE}$ from 15.

6. Adjust the shares of $C_s$ to obtain $\omega_{tilde}$ and then find the shares compatible with the data using equation 22.

7. Obtain the consumption of the aggregate non-energy good $C_{NE}$, using equation 21.

8. Obtain the consumption of the aggregate energy good $C_E$, using equation 14.

9. Find the price of non-energy consumption good $P_s$, from equation 22.

10. Define the production in each energy sector $Z_{e1}, Z_{e2}$, from equation 29.

11. Obtain the consumption of each energy good $C_{e1}, C_{e2}$ from equations 17 and 18.

12. Find the prices of the non-energy intermediate input ($51xP_{Hs}$) from equation 28.

13. Define the price of the value added good, $P_{va}$ in the non-energy producers as in equation 33.

14. Define the value added, $V_{as}$, of the non-energy producers as in equation 34.

15. Obtain the production of the non-energy intermediate input, $H_s$ from equation 36.

16. Then one can obtain the non-energy intermediate inputs of each sector by each non-energy sector, $H_{x,s}$ as in equation 27.

17. Adjust the shares of energy use in energy consumption retailer, $\tilde{\omega}_{e,s}$ ($51x2$). This is defined by an additional equation and the normalised to obtain $\omega_{e,s}$. 

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18. Define the price of the energy inputs used by the non-energy sector, $P_{E,s}$, as in equation 26.

19. Adjust the shares of non-energy consumption retailer, $\omega_{C,s}$ (51). This is defined by an additional equation.

20. Obtain the total output of each non-energy sector, $Z_s$, from equation 35.

21. The energy inputs of each non-energy sector, $E_s$, are determined by equation 32.

22. The energy inputs of each kind for each non-energy sector $E_{e,s}$, come from equations 23 and 24.

23. Additional equations are included to compute the labor supply, the tax revenue and labor tax.

24. Derive the new implied values of the guessed variables, $c_s$, $n_s$, $n_e$, $p_s$, from the market clearing conditions:

(a) $C_s = Z_s - \sum_{x=1}^{s} H_{x,s}$, from the resource constraint of the energy production sector

(b) $n_s$ from the production function of the non-energy producer

(c) $n_e$ from the production function of the energy producer

(d) $p_s$ from equation 22

25. Compute the residuals to be minimised.