Title:

OPTIMAL TAXES ON FOSSIL FUELS, CARBON TAXES AND ENVIRONMENTAL TARGETS: A GENERAL EQUILIBRIUM ANALYSIS FOR THE SPANISH ECONOMY

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Abstract

Spain targets a 40% reduction in carbon emissions compared to 1990 levels, as it is specified in the 2030 European Union Energy Strategy. This implies a decrease in CO2 emissions by 55% in 2030 from current levels. In this policy context, we identify the optimal tax-mix for oil, natural gas and coal in order to achieve this specific carbon emissions target. This analysis is conducted in a general equilibrium model for a small open economy in a competitive framework. We highlight the optimal tax mix is a second best since it is not the solution provided by a central planner. We find that, for any environmental target the tax on coal should be very high because it is, at the same time, the fossil fuel with the highest level of emissions and the lowest productivity. We also find that, despite the relative high level of emissions, the tax on oil should be the lowest due to its high productivity. To achieve the target for 2030, Spain must increase the taxes on oil from 130% to 182%, the taxes on natural gas from 50% to 255%, and the taxes on coal from 100% to 747%. Finally, we estimate the carbon tax needed to reduce carbon emissions to reduce emission by 55%. The carbon tax is 218 €/tCO2, leading to a welfare loss almost identical to the optimal tax mix. This study suggests that a carbon tax is the right policy tool if the environmental policy is sufficiently ambitious.

Keywords: CO2 emissions, environmental policy, fossil fuels, optimal tax mix, carbon tax.

JEL Classification: C61, C63, F41, H21, H23, Q43

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1. Introduction

There is wide international consensus on the need to limit global warming to no more than 2°C. Proof of this consensus is that 195 countries adopted a binding deal on global climate change in December 2015, known as the Paris Agreement. This agreement reveals an increasing global pragmatism in terms of reducing greenhouse emissions as soon as possible. Each country must define a national target on carbon emissions, the ‘nationally determined contributions’ and must report transparently and regularly on its polies and level of emissions. Although, the 2°C target could be merely aspirational, given that it is only binding to the extent to which each of the nations decide to commit. The Paris Agreement has a decentralized approach, since each country can determine its individual carbon targets and chooses the tools to curb emissions. In this context, this study suggests that a carbon tax could be an adequate environmental tool to curb emissions in developed economies.

The Special Report on Global Warming of 1.5 °C by the Intergovernmental Panel for Climate Change1 emphasizes that the reduction in emissions needed to limit global warming to no more than 2°C is very large in almost all the scenarios considered. The 2°C scenario defined by the International Energy Agency (2016) considers a reduction of “CO\textsubscript{2} emissions (including emissions from fuel combustion and process and feedstock emissions in industry) by almost 60 percent by 2050 (as compared to 2013).” In the same vein, in its 2030 Energy Strategy, the European Union sets a 40 percent reduction in carbon emissions as compared to 1990 levels2. As a member of the European Union, Spain must achieve this level of reduction in 2030. Figure 1 shows annual carbon emissions from combusted fossil fuels in Spain in 1965-2018 and the target. Spain must reduce current emissions around 50-60% to reach the goal.

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1 https://www.ipcc.ch/
2 https://ec.europa.eu/clima/policies/strategies/2030_en
The final impact of a specific policy on emissions will ultimately depend on the structure of the economy, household preferences, technological conditions, international energy prices and, the flexibility available to switch among different fuels. Aldy and Stavins (2012), for example, studied the advantages and disadvantages of different environmental policy tools such as carbon taxes, cap-and-trade, emission reduction credits, clean energy standards and fossil fuel subsidy reductions. In addition, in this study, policymakers could choose to adapt or to live with the consequences of climate change. Precisely, the Paris Agreement suggests that some combination of mitigation and adaptation policies provides the most cost-effective policy response at the national level, given each country’s differing social-economic circumstances, state of development and resource endowments.

This paper explores which is the best tax mix to achieve a given target of carbon emissions in Spain. Our study uses a general equilibrium model for the Spanish economy in which the chosen structural parameters are the ones estimated by Blazquez et al. (2017). The government, to achieve its environmental target, taxes the consumption of oil, coal and natural gas independently, focusing on the long-run impacts. We identify the optimal mix of taxes on fossil fuels under a competitive equilibrium solution to curb emissions and achieve a specific carbon
emissions reduction target. Therefore, the optimal mix is a second-best solution. We compare the optimal tax-mix to standard carbon tax. For the sake of completeness, we also find the first best or social planner solution and compare this “first best” to the “second best” or the optimal tax-mix in a competitive environment.

The rest of the paper is organized as follows. Section 2 explores the most relevant literature for this study. Section 3 describes and solves the model. Section 4 presents and discusses the results. Finally, section 5 concludes and presents policy implications.

2. Literature review

This study explores the interaction among taxes on fossil fuels, social welfare and carbon emissions in the long run. We developed a model that allows the government to tax fossil fuels independently in a general equilibrium framework. Our analysis is based in the model by Blazquez et al. (2017). They explore the relationship between international prices of these three primary fossil fuels and carbon emissions in the short term by a Dynamic Stochastic General Equilibrium (DSGE) model. They find that international prices affect carbon emissions directly through their impact on the fossil fuel mix and indirectly through their impact on economic growth. Pereira and Pereira (2014) also explore the impacts of international prices of fossil fuels in Portugal, but via a dynamic general equilibrium model with endogenous growth. They find that fossil fuel prices have a clear impact on economic activity, tax revenues and, ultimately, carbon emissions. Using also a DSGE model, Golosov et al. (2014) analyze the optimal environmental taxation in the long run. They find that the optimal carbon tax is, in general terms, higher than the well-known estimates by Nordhaus and Boyer (2000). Golosov et al. (2014) also states that coal is the main threat to climate change due to its abundant reserves. Finally, Tumen et al. (2016) develop a DSGE model with a representative fossil fuel input to assess the macroeconomic short-term impacts of taxes on fossil fuels. They find that environmental taxes have a negative impact on GDP and inflation in the short term.
Using a computable general equilibrium model (CGE), Barker et al. (2007) explore the short-term impacts of environmental taxation on carbon leakage in six European countries, find that carbon leakage is relatively small. Kumbaroğlu (2003), using the same methodology for a small emerging open economy, suggests that, to accelerate economic growth in the short term in Turkey, the government should use taxes to incentivize coal consumption and disincentive oil and natural gas. Solaymani (2017) explores the impact of taxes on fossil fuels on carbon emissions in a small open economy using a CGE. This study states that carbon taxes are more efficient than energy taxes to reduce CO₂ emissions in Malaysia. For the USA economy, Parry and Williams (1999) compare a set of eight policy instruments under different scenarios and they find that quotas tend to generate higher welfare losses than taxes and emission permits.

Other studies focus on the impact of environmental taxes on the economy and on emissions.

Franks et al. (2015) suggest that fiscal objectives can be as relevant as environmental targets. They find that carbon taxes in fossil fuel importing countries may capture part of the rents of fossil fuel producers. Fraser and Waschik (2013), also using a CGE, find that environmental taxes on different types of energy resources, including fossil fuels, lead to a double dividend in the case of Australia. Ferran (2010), using a similar methodology for Spain, states that elasticities of substitution among inputs play a critical role in achieving a double dividend.

Nordhaus (2007) analyses the advantage of price-type approaches such as carbon taxes and taxes on fossil fuels, over quantity-oriented control instruments. He concludes that price-type approaches have some relevant advantages to reduce greenhouse emissions. Hassler et al (2016) state also that a carbon tax is preferred over a quantity-based system. Finally, Marron and Toder (2014) point out that implementing carbon taxes, at a global level, poses significant challenges and the potential benefits of a carbon tax will depend on the practical implementation of this tax.

This paper focuses on the optimal tax-mix on fossil fuels to curb carbon emissions under the solution of a competitive equilibrium; our analysis is therefore second-best from this point of
view. Previous studies focused on the optimal tax on a specific fossil fuel, but, to best of our knowledge, there is a gap regarding optimal taxes on oil, natural gas and coal simultaneously. In addition, we estimate the carbon tax in Spanish needed to achieve the carbon target in 2030.

3. The model

We adapted the neoclassical growth model for Spain proposed by Blazquez et al. (2017) to include the government. Thus, we model a decentralized small open economy with a representative household, competitive firms, government and external sector. These interact actively by trading final goods, foreign bonds and three primary energy inputs3: oil, natural gas and coal. The government taxes fossil fuels and transfers the revenues to the representative household by means of a lump sum transfer. Finally, the government runs a balanced fiscal budget.

It is important to stress that Spanish CO$_2$ emissions do not impact on household’s welfare or on economic activity through global warming. Given the size of the Spanish carbon emissions (0.9% of global emissions), this is a reasonable assumption. In this model, the level of carbon emissions is not relevant for the household or the firm. They only pay attention to economic variables such as private consumption, investment or profits. As it is the case in the European Union, the government sets a target of carbon emissions according to exogenous environmental criteria.

In this model, revenues from fossil fuels taxes are directly transferred to households via a lump-sum transfer. In this context, it is possible to imagine that higher taxes imply, at the same time,

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3 From a methodological point of view, a limitation of our study is that a renewables technology is not taken into consideration. Renewables make possible to keep the consumption of energy constant while reducing the use of fossil fuels. In other words, it would be possible to curb the consumption of fossil fuels through the deployment of renewable sources. However, from a technical point of view, renewable sources can replace fossil fuels only up to a certain point. In the electricity sector it is possible to shift partially from using coal or natural gas as a fuel to renewable sources. But, given the limitations of current renewable technologies, fossil fuel fired generation plant will remain critical. Perhaps in the future, technological development such as cost-effective large-scale batteries will provide a solution to the problem of intermittency. These developments could make the case for taxes on fossil fuels or carbon emissions less important. In any cases, fossil fuels represent 82.3% of the primary energy during the sample considered.
higher transfers to the household and, as such, there is no negative impact on welfare or output. However, this is not the case. This negative relationship between carbon reduction and welfare happens because taxes distort the allocation of resources, thus having a negative impact on macroeconomic activity.

3.1 The representative household

There is a representative household that maximizes the utility defined over the sequences of consumption \((c_t)\) and labor \((N_t)\) subject to the budget constraint:

\[
\max_{\{c_t, N_t, k_{t+1}, d_{t+1}\}} \left\{ \sum_{t=0}^{\infty} \rho^t \frac{1}{1-\sigma} \left[ (c_t - \Psi N_t)^{1-\sigma} - 1 \right] \right\}
\]

subject to:

\[
c_t + K_{t+1} - (1 - \delta)K_t + (1 + r^*)D_t = w_tN_t + r_tK_t + D_{t+1} + T_t \quad (1)
\]

\[
r_t = r^* + \Lambda(D_t)
\]

\[
D_0, K_0 \text{ are given}
\]

where \(K\) is capital, \(r^*\) is the exogenous international interest rate, \(w\) is the real wage, \(D\) is the level of foreign debt and \(T\) are public transfers. The parameter \(\rho\) is the intertemporal subjective discount rate, \(\sigma\) is the risk aversion parameter, \(\Lambda(D_t)\) is the Spanish risk premium that depends on the level of foreign debt, and \(1/(\nu - 1)\) is the intertemporal elasticity of substitution for the labor supply. Finally, we impose that \(\Psi > 1, \nu > 1, 0 < \rho < 1, \sigma > 0\). Imposing \(r_t = r^* + \Lambda(D_t)\), we follow the strategy of Schmitt-Grohé and Uribe (2003) to close the economy.

The representative household chooses the paths \(\{c_t, N_t, D_{t+1}, K_{t+1}\}\) that maximizes the utility, taking prices \(\{w_t, r_t, r^*_t\}\) and state variables \(\{K_t, D_t\}\) as given. The following expressions are the optimality conditions:

\[
\nu \Psi N_t^{\nu-1} = w_t \quad (2)
\]

\[
(C_t - \Psi N_t^{\nu})^{-\sigma} = \rho \left[ (C_{t+1} - \Psi N_{t+1}^{\nu})^{-\sigma} \cdot (\beta \theta_{t+1} K_{t+1}^{\beta-1} N_{t+1}^{\alpha-\beta} E_{t+1}^{1-\sigma-\beta} + 1 - \delta) \right] \quad (3)
\]

\[
(C_t - \Psi N_t^{\nu})^{-\sigma} = \rho \left[ ((C_{t+1} - \Psi N_{t+1}^{\nu})^{-\sigma}) \cdot (1 + r^*_t + \varphi \text{ | } e^{\beta \theta_{t+1} - \sigma e \omega_{t+1}} - 1) \right] \quad (4)
\]
3.2. **The competitive firms**

We assume that there are three competitive and representative firms that produce i) intermediate energy (composite energy) using as inputs coal and natural gas, ii) final energy (another type of composite energy) using as inputs oil and intermediate energy, and iii) final goods or final output using labor, capital and final energy.

3.2.1. **The intermediate energy firm**

A representative and competitive firm produces an *intermediate energy* \( (E^*_t) \) using natural gas and coal. This composite energy is produced using a Constant Elasticity of Substitution (CES) technology with constant returns to scale. The firm in this sector solves the following maximization problem:\(^4\)

\[
\max_{(E_{gt}^*, E_{ct}^*)} \Pi^*_E = P^*_{E^*_t} E^*_t - P^*_{gt} (1 + \tau_g) E_{gt} - P^*_{ct} (1 + \tau_c) E_{ct}
\]

subject to

\[
E^*_t = \left( b E_{gt}^{\delta_E} + (1 - b) E_{ct}^{\delta_E} \right)^{1/\delta_E}
\]

where \( E_{gt} \) and \( E_{ct} \) are natural gas and coal, \( b \) is the participation of natural gas on \( E^*_t \) and \( \frac{1}{1 - \delta_E} \) is the interfuel elasticity of substitution between coal and natural gas. \( P^*_{E^*_t} \) is the price of *intermediate energy* and \( P^*_{gt} \) and \( P^*_{ct} \) are the international market prices of natural gas and coal. Finally, \( \tau_g \) and \( \tau_c \) are the tax rates on natural gas and coal. It is important to highlight that \( P^*_{gt} \) and \( P^*_{ct} \) are exogenous, given that Spain is a small open economy, and it is a net importer of these energy inputs.

The first order conditions of the *intermediate energy* sector are:

\[
E^*_{ct} = \left[ (1 - b) \left( \frac{P^*_{E^*_t}}{P^*_{E^*_t} (1 + \tau_c)} \right)^{1/\delta_E} \right] E^*_t
\]

---

\(^4\) Spain imports all the crude oil and natural gas that consumes, since its indigenous production is negligible. This paper assumes, for the sake of simplicity, that all the fossil fuels are imported at international prices. Even though there is some domestic production of coal, this is a reasonable assumption since currently coal represents only 3% of the fossil fuel expenditure.
\[ E_{gt} = \left[ b \left( \frac{P_{E_t^*}}{P_{E_{gt}} (1 + \tau_g)} \right) \right]^{1 - \delta_E} E_t^* \]  

(6)

3.2.2. The final energy firm

There is another representative and competitive firm that produces final energy \( (E_t) \), using oil and intermediate energy, \( E_{o_t} \) and \( E_t^* \). This firm solves the following problem:

\[
\max_{(E_t^*, E_{o_t})} \Pi_E = P_{E_t} E_t - P_{o_t} (1 + \tau_o) E_{o_t} - P_{E_t}^* E_t^* \\
\text{subject to} \quad E_t = \left( a E_{o_t}^\gamma + (1 - a) E_t^* \right)^{1/\gamma_E}
\]

where \( E_{o_t} \) and \( E_t^* \) are oil and intermediate energy, \( a \) is the participation of oil on \( E_t \) and \( \frac{1}{1 - \gamma_E} \) is the interfuel elasticity of substitution between oil and intermediate energy. \( P_{E_t} \) is the price of the final energy and \( P_{o_t} \) is the international price of oil and \( P_{E_t}^* \) is the price of intermediate energy. Finally, \( \tau_o \) is the tax rate on oil.

The first order conditions of the final energy sector are:

\[
E_{o_t} = a \left( \frac{P_{E_t}}{P_{E_{o_t}} (1 + \tau_o)} \right)^{1 - \gamma_E} E_t \\
E_t^* = a \left( \frac{P_{E_t}}{P_{E_{t}^*}} \right)^{1 - \gamma_E} E_t
\]

(7)

(8)

3.2.3. The final goods firm

Finally, there is a representative and competitive firm that produces the final output according to a Cobb-Douglas production function, combining capital, labor and final energy as inputs. The firm solves the following problem:

\[
\max_{(N_t, K_t, E_t)} P_t Y_t - w_t N_t - r_t K_t - P_{E_t} E_t \\
\text{subject to} \quad Y_t = \theta N_t^\alpha K_t^\beta E_t^{1 - \alpha - \beta}
\]
where $Y_t$ is the final good, $N_t$ represent labor, $K_t$ is the stock of capital, $E_t$ is the final energy and $\theta$ is the total factor productivity. The first order conditions of final good sector are:

$$w_t = \alpha \theta N_t^{\alpha-1} K_t^\beta E_t^{1-\alpha-\beta}$$  \hspace{1cm} (9)

$$r_t = \beta \theta N_t^\alpha K_t^{\beta-1} E_t^{1-\alpha-\beta}$$  \hspace{1cm} (10)

$$P_{E_t} = (1 - \alpha - \beta) \theta N_t^\alpha K_t^\beta E_t^{-\alpha-\beta}$$  \hspace{1cm} (11)

### 3.3. The Government

The government taxes fossil fuels $\{\tau_o, \tau_g, \tau_c\}$ and the revenues from those taxes are directly transferred to the household as a lump-sum transfer. The budget constraint of the government is balanced period by period. Therefore, the public budget constraint is as follows:

$$G_t = T_t = P_{o_t} \tau_o E_{o_t} + P_{g_t} \tau_g E_{g_t} + P_{c_t} \tau_c E_{c_t}$$  \hspace{1cm} (12)

### 3.4. Decentralized Competitive Equilibrium

**Definition:** A competitive equilibrium for this economy is a set of allocations $\{C_t, N_t, D_{t+1}, K_{t+1}, E_t, E_t^*, E_{o_t}, E_{g_t}, E_{c_t}, T_t\}$ and a price system $\{P_{E_t}, P_{E_t^*}, P_{g_t}, P_{o_t}, P_{c_t}\}$ such that given the price system and a tax mix $\{\tau_o, \tau_g, \tau_c\}$: i) $\{C_t, N_t, D_{t+1}, K_{t+1}\}$ maximizes the household utility subject to budget constraint; ii) $\{E_{g_t}, E_{c_t}\}$ satisfies the intermediate energy firms’ profit maximization conditions; iii) $\{E_t^*, E_{o_t}\}$ satisfies the final energy firms’ profit maximization conditions; iv) $\{N_t, K_t, E_t\}$ satisfies the final good firms’ profit maximization conditions; and v) all markets clear, that is, the allocations satisfy the resources constraint:

$$c_t + K_{t+1} - (1 - \delta)K_t + (1 + r_t)d_t - d_{t+1} + P_{o_t}E_{o,t} + P_{g_t}E_{g,t} + P_{c_t}E_{c,t}\]

$$= f \left( N_t, K_t, E_t \left( E_{o,t}, E_{g,t} \right) \right)$$

### 3.5. The steady state

The steady state is a vector $\{C_{ss}, N_{ss}, D_{ss}, K_{ss}, E_{ss}, E_{ss}^*, E_{o,ss}, E_{g,ss}, E_{c,ss}, P_{E_{ss}}, P_{E_{ss}^*}, T_{ss}\}$ that is constant over time, which satisfies the optimality conditions of all the agents. We impose a

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5 Appendix 1 has a detailed resolution of the steady state.
constant percentage of net exports to determine the steady-state solution of this decentralized economy. That is, \( \mu f \left( N_{ss}, K_{ss}, E_{ss} \left( E_{o,ss}, E_{g,ss} \right) \right) = r_{ss} d_{ss} + P_{o,ss} E_{o,ss} + P_{g,ss} E_{g,ss} + P_{c,ss} E_{c,ss} \). This steady state characterizes the long run properties of the economy. We must highlight that the steady state allocations in competitive equilibrium are a function of the tax-mix \( \{\tau_o, \tau_g, \tau_c\} \).

3.6. The Second-Best policy or the government problem: what is the optimal tax-mix to achieve the environmental target?

In this competitive framework, the government has an environmental target in terms of carbon emissions or CO\(_2\) emissions. We define \( Em_t \) as the level of CO\(_2\) emissions and \( \overline{Em} \) as the carbon target. The level of emissions is given by the following expression:

\[
Em_t = \xi_o E_o + \xi_g E_g + \xi_c E_c \tag{13}
\]

where \( \{\xi_o, \xi_g, \xi_c\} \) are the level of CO\(_2\) emissions per calorific unit from oil, natural gas and coal.

In other to achieve the target in terms of CO\(_2\) emissions in a decentralized and competitive economy, the government solves the following problem, assessed at the steady-state. That is, the government has to choose the combination of tax rates on fossil fuels that maximizes household welfare in steady state while achieving, at the same time, a specific level of carbon emissions, \( \overline{Em} \) (this target on carbon emission is set exogenously, in the Spanish case by a supranational entity as the European Union):

\[
\max_{(\tau_o, \tau_g, \tau_c)} \sum_{t=0}^{\infty} \beta^t \left[ C_{ss}^{(CE)} (\tau_o, \tau_g, \tau_c) - \Psi \left( N_{ss}^{(CE)} (\tau_o, \tau_g, \tau_c) \right) \right]^{1-\sigma} \tag{14}
\]

subject to \( \overline{Em} = \xi_o E_{o,ss}^{(CE)} (\tau_o, \tau_g, \tau_c) + \xi_g E_{g,ss}^{(CE)} (\tau_o, \tau_g, \tau_c) + \xi_c E_{c,ss}^{(CE)} (\tau_o, \tau_g, \tau_c) \)

where \( CE \equiv \text{Competitive Equilibrium.} \)
This optimal tax-mix \( \{ \tau_o, \tau_g, \tau_c \} \) in a decentralized and competitive economy must satisfy the following first order conditions6:

\[
\bar{m} = \xi_o E_{0,ss}^{(CE)} (\tau_o, \tau_g, \tau_c) + \xi_g E_{g,ss}^{(CE)} (\tau_o, \tau_g, \tau_c) + \xi_c E_{c,ss}^{(CE)} (\tau_o, \tau_g, \tau_c)
\]

\[
\frac{\partial C_{ss}^{(CE)}}{\partial \tau_c} - \Psi_v \left( N_{ss}^{(CE)} \right)^{v-1} \frac{\partial N_{ss}^{(CE)}}{\partial \tau_c} = \xi_c \frac{\partial E_{c,ss}^{(CE)}}{\partial \tau_c} + \xi_g \frac{\partial E_{g,ss}^{(CE)}}{\partial \tau_c} + \xi_o \frac{\partial E_{o,ss}^{(CE)}}{\partial \tau_c}
\]

\[
\frac{\partial C_{ss}^{(CE)}}{\partial \tau_g} - \Psi_v \left( N_{ss}^{(CE)} \right)^{v-1} \frac{\partial N_{ss}^{(CE)}}{\partial \tau_g} = \xi_c \frac{\partial E_{c,ss}^{(CE)}}{\partial \tau_g} + \xi_g \frac{\partial E_{g,ss}^{(CE)}}{\partial \tau_g} + \xi_o \frac{\partial E_{o,ss}^{(CE)}}{\partial \tau_g}
\]

\[
\frac{\partial C_{ss}^{(CE)}}{\partial \tau_o} - \Psi_v \left( N_{ss}^{(CE)} \right)^{v-1} \frac{\partial N_{ss}^{(CE)}}{\partial \tau_o} = \xi_c \frac{\partial E_{c,ss}^{(CE)}}{\partial \tau_o} + \xi_g \frac{\partial E_{g,ss}^{(CE)}}{\partial \tau_o} + \xi_o \frac{\partial E_{o,ss}^{(CE)}}{\partial \tau_o}
\]

4. Empirical results and discussion

4.1 Discussion of the results from a theoretical perspective

This section analyses the optimal taxes on oil, natural gas and coal to reduce carbon emissions in Spain which is a small, decentralized and competitive economy. Then, the section compares the outcome of these taxes with those from a standard carbon tax. We define the optimal tax-mix as the combination of tax rates on fossil fuels that minimizes the negative impact on household welfare while achieving, at the same time, a specific target of CO\(_2\) emissions. As it is standard, we define welfare loss in terms of the increase in private consumption required to keep welfare constant in the steady state7. This implies that we focus on the long-term impacts of different

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6 The taxes that solve this problem are compatible with the optimality conditions of the central planner described in Appendix 2.

7 Our analysis ignores the potential impacts of energy policies on the demand for fossil fuels and their prices because we analyze a small economy and the impact on global demand of fossil fuels is negligible. In addition, we pay no attention to the depletion of fossil fuels reservoirs in the long run and the potential impact on international prices of fossil fuels. This is due to growing consensus on the fact that fossil fuel consumption will peak in the next decades given the current environmental policies and energy efficiency progress. On the other hand, new technologies in exploration and production constantly raise estimates for proven reserves of fossil fuels. According to the BP Statistical Review of World Energy 2016, proven reserves of oil increased from 683 billion barrels in 1980 to 1,698 billion in 2015. Over the same period, proven reserves of natural gas tripled. In the case of coal, current reserves
taxes rather than the short-term transitionary effects. Appendix 3 summarizes the parameters used in this analysis.

We initially find the steady state for the Spanish economy assuming no taxes and then obtain the initial level of carbon emissions. Subsequently, we define an environmental objective. That is, we set a new level of carbon emissions as a percentage \( \omega \) of the initial level \( (\bar{E}_{m} = \omega E_{m}^{(E.C.)}_{SS}) \) with \( 0 \leq \omega < 1 \). To achieve the environmental target \( (\bar{E}_{m}) \) the government sets the optimal tax-mix \( \{\tau_{o}^{*}, \tau_{g}^{*}, \tau_{c}^{*}\} \) which are a function of \( \omega \). We want to make clear that this optimal tax mix is a second best.

As usual in this type of models, the optimal tax-mix is obtained numerically. Although there is no analytical solution, we find that the optimal tax-mix satisfies the following two conditions represented in Eq. (18):

\[
\frac{P_{o}(1 + \tau_{o}^{*})}{P_{c}(1 + \tau_{c}^{*})} = \frac{\xi_{o}}{\xi_{c}} \quad \text{and} \quad \frac{P_{g}(1 + \tau_{g}^{*})}{P_{c}(1 + \tau_{c}^{*})} = \frac{\xi_{g}}{\xi_{c}}
\]  

(18)

The economic interpretation of this equation is that the ratio of marginal productivity between two fuels equals the ratio of domestic prices and, in addition, the ratio of marginal productivity also equals the ratio of marginal levels of emissions. Additionally, Eq. (18) implies that first, the higher the level of \( \text{CO}_2 \) emissions the larger the tax rate and, second, the higher the level of international prices the lower the tax rate. This is because international prices mirror marginal productivities of fuels. This implies that more expensive fossil fuels are also more productive and, therefore, they should have lower taxes.

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represent more than 100 years of consumption. However, other studies such as Hoel and Kverndokk (1996) and Strand (2010) point out that fossil fuels are exhaustible resources and, therefore, energy policy must take this into account together with environmental concerns.

8 This paper finds the optimal tax mix, keeping the conditions of the competitive equilibrium. This approach is different from the first best provided by a central planner, who internalizes all externalities.

9 Notice that these two expressions are equivalent to those of the equations (38) and (39) in Appendix 2.
Given the level of emissions \( \{ \xi_o = 3.06, \xi_g = 2.35, \xi_c = 4.06 \} \)\(^{10}\) and the long-term international prices \( \{ P_{oSS} = 0.34, P_{gSS} = 0.21, P_{cSS} = 0.17 \} \), the optimal tax-mix satisfies that \( \tau_o^* < \tau_g^* < \tau_c^* \).

This means that the tax rate on coal should be the highest because it is, at the same time, the fossil fuel with the highest level of emissions and the lowest prices and productivity. However, an interesting result of the study is that even despite natural gas being the cleanest fossil fuel, the tax rate on oil should always be the lowest due to its high productivity. It is important to highlight that this is a general conclusion for any economy since the international relative prices and the relative level of emissions of fossil fuel are almost identical for all the economies. Figure 2 shows the optimal tax-mix for a reduction of emissions up to 80\% (0 \leq \omega < 0.8).

**Figure 2**

According to Figure 2, subsidizing oil and natural gas can be part of an optimal strategy to reduce CO\(_2\) emissions. This is a counterintuitive result and only relevant from a pure academic perspective given the current environmental target of the Spanish economy. For reductions below 11\% (\( \omega < 0.11 \)), the optimal strategy is to tax coal heavily and subsidize oil and, to a lesser extent, natural gas. As the CO\(_2\) target becomes more ambitious, the scope to subsidize oil and natural gas disappears. For a CO\(_2\) target above 11\% and below 34\% (0.11 < \omega < 0.34), the

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\(^{10}\) This level of emissions are derived from BP Statistical Review of World Energy 2018.
optimal strategy is to subsidize oil and tax natural gas and coal. The economic intuition behind this result is that governments can take advantage of the gap in emissions and the gap in marginal productivity among fossil fuels. Taxing coal heavily reduces carbon emissions and provides revenues that can be used to promote the consumption of more productive and less polluting fossil fuels, i.e., oil and natural gas. The idea is not new. For example, Van der Ploeg and Withagen (2012) suggest that policymakers should disincentivize consumption of coal in favor of oil.

An interesting finding of our analysis is that the optimal tax-mix \( \{ \tau^*_o, \tau^*_g, \tau^*_c \} \) keeps the fossil fuel energy-mix constant for any given rate of emissions, as it shown in Figure 3. In other words, given the economic structure of the Spanish economy\(^{11}\), an optimal energy mix is present regardless of the environmental target of emissions. This energy mix is constant, and the shares are 50.2% for oil, 30.9% for natural gas and 18.9% for coal. We highlight that the optimal energy mix is identical to that of a central planner\(^{12}\). This implies that the “second best energy mix”, resulting from the optimal tax-mix \( \{ \tau^*_o, \tau^*_g, \tau^*_c \} \), is identical to the “first best energy mix”.

\(^{11}\) See Appendix 3 for the calibration and estimation parameters of the model.
\(^{12}\) Appendix 2 shows the central planner’s solution. It is easy to see that Equations (36) and (37) in Appendix 3 lead to Equation 18 in a competitive environment.
Now, we compare the optimal tax-mix with the carbon tax, $\tau^{\text{CO}_2}$. Eq. (18) shows that the relative domestic price (after taxes) of fossil fuels equals the relative ratio of carbon emissions. It is straightforward to verify that the ratio of domestic prices with the carbon tax does not satisfy Eq. (18) as it is shown in Eq. (19):

$$\frac{P_o + \tau^{\text{CO}_2} \xi_o}{P_c + \tau^{\text{CO}_2} \xi_c} \neq \frac{\xi_o}{\xi_c} \quad \text{and} \quad \frac{P_g + \tau^{\text{CO}_2} \xi_g}{P_c + \tau^{\text{CO}_2} \xi_c} \neq \frac{\xi_g}{\xi_c} \quad (19)$$

Only if $\frac{P_o}{P_c} = \frac{\xi_o}{\xi_c}$ and $\frac{P_g}{P_c} = \frac{\xi_g}{\xi_c}$ then Eq. (19) and Eq. (18) are identical, implying that the optimal tax mix in a competitive economy is the carbon tax. It is straightforward to derive that Eq. (19) converges to equation Eq. (18) when the environmental target is very ambitious and all the required tax rates $\left\{\tau^{\text{CO}_2}, \tau_o^*, \tau_g^*, \tau_c^*\right\}$ are high.

It is important to note that the international price of fossil fuels provide information to economic agents in two different ways. They give information on the ‘economic value’ of one unit of caloric energy, but they also provide information on the ‘economic value’ of one unit of carbon.
emissions depending on the fuel. The negative externality of one ton of carbon is identical regardless the source of emission, but the economic value depends on the type of fuel. In a competitive economy, the carbon tax leads to an energy mix that is not constant. Figure 3 shows that as the environmental target becomes more ambitious (lower $\bar{Em}$ or higher $\omega$) the share of coal in the energy mix declines, and the share of natural gas and oil increases.

Only when the environmental target is very ambitious, the carbon tax converges to the optimal tax-mix. An insight for policymakers would be that carbon taxes should only be implemented to achieve large reductions in CO$_2$ emissions.

Figure 4 shows that the welfare losses from the carbon tax are larger than those from the optimal tax-mix. As mentioned previously, both policies tend to converge as the environmental target becomes more ambitious. In addition, Figure 4 also gives the idea that the abatement cost of CO$_2$, in terms of welfare losses, is not linear and it increases as the target becomes more ambitious.

**Figure 4**

```
Finally, and as a complementary theoretical result, we compare the tax revenues from the optimal taxes and those from carbon tax. We find that, for any environmental target, the carbon tax leads to a higher level of tax revenues. This could create a dilemma for policymakers given that
```
revenues from taxation could also be a policy objective. Logically, as the environmental target becomes more ambitious, tax revenues for both tax strategies tend to converge.

4.2 An estimation of the optimal tax mix and the carbon tax for Spain

The European Union target for carbon emissions in 2030 implies a reduction of around 55% from the level of emissions of 2018 (from 0.29 to 0.13 GtCO₂). The level of emissions in 2018 is consistent with the existing tax structure. As it is standard in European countries, taxes on fossil fuels are different among fuels and, in the case of Spain, even among different provinces. For this reason, it is not straightforward to assess the tax rate on coal, natural gas, and oil. There is a VAT of 21% for energy, a special tax on electricity generation of 5.1%, a special tax on hydrocarbons between 150 and 551 euros per 1,000 liters of gasoline and gasoil (it is different among regions, economic sectors, and fuels), and the carbon price given by the EU Emission Trading System, a market price that changes on daily basis. All this taxes and fees impact the final price of fossil fuels to consumers. With this information and assuming a carbon tax of 20 euros per ton13, we can roughly estimate a total tax on oil of around 130%14, a total tax on natural gas of 60% and, a total tax of coal of 100%.

This tax mix on fossil fuels reduces the level of carbon emissions around 54% compared to an economy with no taxes. However, the EU target for 2030 implies a decrease in emissions of 55% compared to the 2018 levels. In other words, the EU target implies a reduction in emissions of around 80% compared to a hypothetical economy with no taxes on fossil fuels. The taxes needed to achieve this additional reduction in carbon emissions are those presented in Table 1. These taxes replace the cascade of different existing taxes. The main idea from this exercise is that there is the need for a substantial increase in fossil fuel taxes to achieve the carbon target in

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13 The carbon price in Europe moved between 8 and 25 euros/tCO₂ in 2018.
14 We assume that around 60% of a barrel of oil is gasoline and gasoil once the barrel is refined. The special tax is 432 euros/1,000 litre of gasoline 98, 401 euros/1,000 litre of gasoline 95, 307 euros/1,000 litre of gasoil A, 79/ 1,000 litre gasoil B and C, and 14 euros/ton of fuel oil.
the long run. When we compare the actual tax mix with the optimal one, the misalignment is evident in the case of coal and, to a lesser extent, in the case of natural gas and oil.

<table>
<thead>
<tr>
<th>Table 1: Optimal taxes on fossil fuels to achieve the EU carbon target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tax rate on oil</td>
</tr>
<tr>
<td>182%</td>
</tr>
<tr>
<td>Tax rate on natural gas</td>
</tr>
<tr>
<td>255%</td>
</tr>
<tr>
<td>Tax rate on coal (%)</td>
</tr>
<tr>
<td>747%</td>
</tr>
</tbody>
</table>

How different is this tax structure from a carbon tax? A carbon tax has some advantages over the current tax structure on fossil fuels in European countries. First, a carbon tax directly penalizes the negative externality, according to the Polluter Pays Principle. This makes carbon taxes attractive from a political point of view. And second, due to its simplicity, a carbon tax is easy to administer, and it reduces the need for information. For this reason, it is relevant to compare how large is the welfare associated with the carbon tax compared to an optimal tax-mix.

Table 2 compares the optimal tax mix and the carbon tax (and the implicit tax rate on each fossil), showing that the taxes are relatively similar. To achieve the carbon target in 2030, Spain needs a carbon tax of 218 euros per ton of CO₂. This carbon tax is high, but it is consistent with the EU objective and it is similar to other studies. For example, an exercise by top energy modelers organized at Stanford University in 2014 found that a 50% reduction in US emissions by 2050 would require a carbon tax between $100 and $300 (Metcalf, 2019). A takeaway for policymakers from this analysis would be that given the actual carbon target for the Spanish economy, a carbon tax is a quasi-optimal tool.
Table 2: Optimal tax mix and carbon tax

<table>
<thead>
<tr>
<th></th>
<th>Optimal tax</th>
<th>Carbon tax</th>
<th>Tax rate implied by the carbon tax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tax rate on oil</td>
<td>182%</td>
<td>218 €/tCO₂</td>
<td>206%</td>
</tr>
<tr>
<td>Tax rate on natural gas</td>
<td>255%</td>
<td>218 €/tCO₂</td>
<td>259%</td>
</tr>
<tr>
<td>Tax rate on coal (%)</td>
<td>747%</td>
<td>218 €/tCO₂</td>
<td>618%</td>
</tr>
</tbody>
</table>

From a theoretical point of view there is small difference between the welfare losses in the optimal tax mix and the carbon tax. The parameter $\omega$ that describes the carbon target as percentage of the initial level is $\omega = 0.793$ in this simulation, this is a reduction of around 80%. Therefore, the optimal tax mix and the carbon tax almost converge. The welfare loss difference under optimal tax mix and under the carbon tax is only 0.1%. From practical perspective both tax structure lead to the same results in terms of welfare losses, as it shown in Figure 4.

**Conclusions and policy implications**

The Paris Agreement, signed in December 2015, shows wide international consensus on the need to limit global warming to no more than 2°C and it is considered a relevant landmark in climate policy. In this context, the European climate and energy framework for 2030 includes, as a key target, a 40% cut in greenhouse gas emissions from 1990 levels. In the case of Spain, this target represents a 55% reduction from 2018 emissions. This study, based on Spanish economic data, assesses the optimal taxes on fossil fuels to curb carbon emissions. To conduct this analysis, we use a general equilibrium model for a small open economy in a competitive framework. The best policy in this scenario is, then, a second-best policy, since it is not the central planner solution.

This study finds that, first, for optimal efficiency in terms of reducing CO₂ emissions, any tax on coal must be substantial, since this is the fossil fuel with the highest carbon emissions and lowest level of energy productivity. This result was expected. Second, again for optimal efficiency, our analysis shows that the tax on oil should be lower than the tax on natural gas, and lower still than
that on coal. This is because the marginal economic productivity of oil is the highest of the three fossil fuels, though natural gas has the lowest level of carbon emissions. Third, the analysis shows that taxes on oil, coal, and natural gas in Spain should be significantly increased to achieve the 2030-environmental target in terms of carbon emissions. We estimate that taxes on oil must increase from 130% to 182%, taxes on natural gas must increase from 50% to 255%, and finally, taxes on coal from 100% to 747%. These increases lead to a reduction in carbon emissions from energy by 55%, consistent with the EU target.

Carbon tax is emerging as the best policy response to curb greenhouse gas emissions around the world (see for example the Economists’ Statement of Carbon Taxes published in the Wall Street Journal in January 17, 2019, and endorsed by US economist\(^\text{15}\) and EU economists\(^\text{16}\)). For this reason, we estimate the carbon tax needed to reduce carbon emissions by 55%. We find that carbon tax needed is 218 €/tCO\(_2\). The welfare loss associated with this tax is almost identical to the optimal tax mix. We show that a carbon tax is an optimal policy if the environmental policy is sufficiently ambitious. This study suggests that, for Spain, carbon taxes are an appropriate policy instrument to achieve the carbon target for year 2030 for three reasons: its simplicity, it penalizes the negative externality, and it is -almost- identical to the optimal taxes on oil, natural gas, and coal.

**Acknowledgements**

We are grateful to Lester C. Hunt, Doug Cooke, and David Hobbs for their comments and suggestions that have helped to considerably improve the paper. Martín-Moreno thanks Spanish Ministry of Economy and Competitiveness and FEDER and the Xunta de Galicia for financial support through grants RTI2018-093365-B-100 and “Programa de Consolidación e Estructuración de Unidades de Investigación Competitivas do Sistema Universitario de Galicia

\(^{15}\) [https://www.clcouncil.org/economists-statement/](https://www.clcouncil.org/economists-statement/)

\(^{16}\) [http://www.eaere.org/statement/](http://www.eaere.org/statement/)
REFERENCES


Appendix 1. Solving the steady state

The solution of the steady state can be carried out as follows:

Step 1: The following system of equations characterizes the steady state for these variables \( \{C_{ss}, N_{ss}, D_{ss}, K_{ss}, E_{ss}, E_{a,ss}, E_{g,ss}, E_{c,ss}, P_{E,ss}, P_{E,ss}, T_{ss}\} \). The trade balance relative to aggregate output is exogenous \( (NX/Y = \mu) \):

\[
\begin{align*}
\nu\Psi N_{ss}^{\nu-1} &= \alpha \theta N_{ss}^{\alpha-1} K_{ss}^{\beta} E_{ss}^{1-\alpha-\beta} \\
\rho \left[ \beta \theta K_{ss}^{\beta-1} E_{ss}^{1-\alpha-\beta} + 1 - \delta \right] &= 1 \\
\frac{NX_{ss}}{Y_{ss}} &= \mu \\
NX_{ss} &= r^* D_{ss} - P_0 E_{o,ss} - P_c E_{c,ss} - P_g E_{g,ss} \\
c_{ss} + \delta K_{ss} + G_{ss} + NX_{ss} - P_0 E_{o,ss} - P_c E_{c,ss} - P_g E_{g,ss} &= \theta N_{ss}^{\alpha} K_{ss}^{\beta} E_{ss}^{1-\alpha-\beta} - P_E E_{ss} \\
E_{o,ss} &= \left[ a \left( \frac{P_E}{P_0 (1 + \tau_0)} \right) \right]^{1-\gamma_E} E_{ss} \\
E_{c,ss} &= \left[ (1 - b) \left( \frac{P_E^{*}}{P_c (1 + \tau_c)} \right) \right]^{1-\delta_E} E_{ss}^{*} \\
E_{g,ss} &= \left[ b \left( \frac{P_E^{*}}{P_g (1 + \tau_g)} \right) \right]^{1-\delta_E} E_{ss}^{*} \\
E_{ss} &= \left( a E_{o,ss}^{\gamma_E} + (1 - a) E_{c,ss}^{\gamma_E} \right)^{1/E_{ss}} \\
E_{ss}^{*} &= \left( b E_{g,ss}^{\delta_E} + (1 - b) E_{c,ss}^{\delta_E} \right)^{1/E_{ss}^{*}} \\
P_{E,ss} &= (1 - a) \left( \frac{E_{ss}}{E_{ss}^{*}} \right)^{1-\gamma_E} P_{E,ss} \\
P_{E,ss} &= (1 - \alpha - \beta) \theta N_{ss}^{\alpha} K_{ss}^{\beta} P_{E,ss}^{* - \alpha - \beta} \\
T_{ss} &= P_0 \tau_0 E_{o,ss} + P_c \tau_c E_{c,ss} + P_g \tau_g E_{g,ss}
\end{align*}
\]

Step 2: i) From Eq. (19)- Eq. (28) we obtain \( (E_{ss}/Y_{ss}), (E_{g,ss}/Y_{ss}), (E_{c,ss}/Y_{ss}), (E_{ss}^{*}/Y_{ss}) \) and \( (E_{o,ss}/Y_{ss}) \). ii) Then, \( P_{E,ss}, P_{E,ss}^{*} \) is obtained from Eq. (29)-Eq. (30). iii) From Eq. (20) we obtain \( (K_{ss}/Y_{ss}) \). iv) From the production function we obtain \( (N_{ss}/Y_{ss}) \). v) From Eq. (16) and taking \( N_{ss} = 0.31 \), we obtain \( \Psi \). vi) From Eq. (22) we obtain \( (D_{ss}/Y_{ss}) \) and from Eq. (23) \( (C_{ss}/Y_{ss}) \) is obtained. vii) Finally, we obtain then \( \{C_{ss}, N_{ss}, K_{ss}, D_{ss}, E_{o,ss}, E_{g,ss}, E_{c,ss}, E_{ss}, E_{ss}^{*}, T_{ss}\} \) and, given \( \Psi \), from Eq. (20) we obtain \( \rho \).

Step 3: From the first order conditions of the problem faced by the firm that produces the final good, it is possible to find \( \{w, r\} \).
Appendix 2. The first best or the solution of a central planner.

We assume that there is a central planner that, is not restricted by the international prices of fossil fuels. To this end, we impose net exports are a given percentage of the final output. That is:

\[
\mu f \left( N_t, K_t, E_t \left( E_{o,t}, E^{*}_{o,t}, E^{*}_{g,t}, E^{*}_{c,t} \right) \right) = (1 + r_t)d_t - d_{t+1} + P_{o,t}E_{o,t} + P_{g,t}E_{g,t} + P_{c,t}E_{c,t} \quad .
\]

The central planner will maximize welfare while achieving the carbon target. The solution to this problem is the first best.

\[
\max_{\{c_t, n_t, k_{t+1}, E_{o,t}, E_{g,t}, E_{c,t}\}} \sum_{t=0}^{\infty} \rho^t \frac{1}{1 - \sigma} \left[ (c_t - \Psi N_t^\gamma)^{1-\sigma} - 1 \right]
\]

subject to:

\[
\begin{align*}
\{ & c_t + K_{t+1} - (1 - \delta)K_t + \mu y_t \quad \text{net exports} \quad = f \left( N_t, K_t, E_t \left( E_{o,t}, E^{*}_{o,t}, E^{*}_{g,t}, E^{*}_{c,t} \right) \right) \\
\bar{E}m &= \xi_o E_{o,t} + \xi_g E_{g,t} + \xi_c E_{c,t}
\end{align*}
\]

The first order conditions of this problem respect the fossil fuel consumption are:

\[
E_{o,t}: \lambda_{1,t} (1 - \mu) \frac{\partial f}{\partial E_t} \frac{\partial E_t}{\partial E_{o,t}} = \lambda_{2,t} \xi_o
\]

\[
E_{g,t}: \lambda_{1,t} (1 - \mu) \frac{\partial f}{\partial E_t} \frac{\partial E_t}{\partial E_{g,t}} = \lambda_{2,t} \xi_g
\]

\[
E_{c,t}: \lambda_{1,t} (1 - \mu) \frac{\partial f}{\partial E_t} \frac{\partial E_t}{\partial E_{c,t}} = \lambda_{2,t} \xi_c
\]

From these expressions, we can obtain:

\[
\frac{\partial E_t}{\partial E_{o,t}} \frac{\partial E_t}{\partial E_{c,t}} = \frac{\xi_c}{\xi_o}
\]

(36)

\[
\frac{\partial E_t}{\partial E_{g,t}} \frac{\partial E_t}{\partial E_{c,t}} = \frac{\xi_c}{\xi_g}
\]

(37)
Substituting Eq. (5)- Eq. (8) in Eq. (36)- Eq. (37) we obtain:

\[
\tau_o = \frac{\xi_o}{\xi_c} \frac{p_{ct}}{p_{ct}} (1 + \tau_c) - 1
\]  

(38)

\[
\tau_g = \frac{\xi_o}{\xi_c} \frac{p_{ct}}{p_{ct}} (1 + \tau_c) - 1
\]  

(39)

These taxes are the optimal taxes given by Eq. (18). In other words, the second-best tax-mix in a competitive environment satisfies conditions Eq. (36) and Eq. (37) of the problem of the central planner.
Appendix 3. Calibration and parameters of the model.

Table 3: Parameters used for the numerical resolution of the model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$</td>
<td>Discount factor</td>
<td>0.96</td>
</tr>
<tr>
<td>$\delta$</td>
<td>Depreciation rate</td>
<td>0.05</td>
</tr>
<tr>
<td>$N$</td>
<td>Fraction of hours worked</td>
<td>0.31</td>
</tr>
<tr>
<td>$r^*$</td>
<td>International interest rate</td>
<td>0.04</td>
</tr>
<tr>
<td>$\mu$</td>
<td>Ratio trade balance over GDP</td>
<td>-0.05</td>
</tr>
<tr>
<td>$\nu$</td>
<td>Parameter related to labor elasticity</td>
<td>1.56</td>
</tr>
<tr>
<td>$\Psi$</td>
<td>Parameter related to disutility of labor</td>
<td>1.60</td>
</tr>
<tr>
<td>$\delta_E$</td>
<td>Parameter related to elasticity of substitution of coal and natural gas</td>
<td>-0.86</td>
</tr>
<tr>
<td>$b$</td>
<td>Parameter related to share of natural gas in the production $E^*$</td>
<td>0.59</td>
</tr>
<tr>
<td>$\gamma_E$</td>
<td>Parameter related to elasticity of substitution of oil and $E^*$</td>
<td>-1.34</td>
</tr>
<tr>
<td>$a$</td>
<td>Parameter related to share of oil in the production $E$</td>
<td>0.72</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Share of labor in GDP</td>
<td>0.61</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Share of capital in GDP</td>
<td>0.34</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Parameter related to productivity</td>
<td>1.16</td>
</tr>
<tr>
<td>$P_o$</td>
<td>Price of oil in the long term</td>
<td>0.34</td>
</tr>
<tr>
<td>$P_g$</td>
<td>Price of natural gas in the long term</td>
<td>0.21</td>
</tr>
<tr>
<td>$P_c$</td>
<td>Price of coal in the long term</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Source: Blazquez et al. (2017)