What is it going to take to achieve 2020 Emission Targets?
Marginal abatement cost curves and the budgetary impact of CO_2 taxation in Portugal (*)

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Abstract

The objective of this paper is to study CO_2 taxation in its dual role as a climate and fiscal policy instrument. It develops marginal abatement cost curves for CO_2 emissions using a dynamic general equilibrium model of the Portuguese economy which highlights the mechanisms of endogenous growth and includes a detailed modeling of the public sector. It also considers complementary cost curves corresponding to the impact of CO_2 taxes on GDP and on the public budget. Simulation results show that a tax of 17.00 Euros per tCO_2 has the capacity to limit emissions to 62.6 Mt CO_2 in 2020, consistent with the existing climate policy target for Portugal. In turn, changes in tax revenues, together with reductions in public spending, lead to a 2.7% decline in public debt. These desirable outcomes come at the cost of a 0.7% reduction in GDP. In general, stricter emission targets imply greater equilibrium CO_2 tax levels and larger GDP losses, although these are accompanied by greater reductions in public debt. Finally, the paper highlights the importance of public spending behavior for projecting the impact of CO_2 taxes on public revenues and the public account and designing policies to promote fiscal consolidation.

Keywords: Marginal Abatement Costs, Economic Effects, Budgetary Effects, Carbon Taxation, Dynamic General Equilibrium, Portugal.
JEL Classification: Q41, Q43, Q54, Q58, C68, D58, H20, H50, H60.

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1. Introduction

Marginal abatement cost curves are a standard tool for evaluating environmental policies [see, for example, Ellerman and Decaux (1998), Klepper and Peterson (2006), Bovenberg et al. (2008), Metcalf and Weisbach (2008), Böhringer et al. (2009), and Morris et al. (2012)]. The objective of this paper is to construct marginal abatement cost curves for CO_2 emissions associated with carbon (CO_2) taxes in a framework that explicitly incorporates the interactions among endogenous economic growth, public sector behavior and accounts, and the energy system. This framework allows us to examine the role of CO_2 taxes in reducing emissions and contributing to fiscal consolidation efforts.

The impact of climate policy on economic performance has been a central part of the climate change debate [see, for example, Babiker et al. (2009), Congressional Budget Office (2003, 2009, 2010), Dissou (2005), Ekins et al. (2011), Meng et al. (2013), Morris et al. (2008), Nordhaus (1993a, 1993b, 1993c), Rivers, (2010), and Stern (2007)]. More importantly, from the standpoint of this paper, we have witnessed a growing concern over mounting public debt in recent years and the need to promote fiscal sustainability. In this context, CO_2 taxes and auctioned emissions permits have emerged as potentially important fiscal policy instruments for increasing public revenues [see, for example, Metcalf and Weisbach (2008), Galston and MacGuineas (2010), Metcalf (2010) and Nordhaus (2010)].

The interactions between climate policy, economic growth and the public sector account are fundamental since they correlate to some of the most important policy constraints faced by energy-importing economies in their pursuit of sound climate policies: the need to enact policies that promote long-term growth and budgetary consolidation. These policy constraints are particularly relevant for the less developed energy-importing economies in the European Union

(EU). As EU structural transfers have shifted towards new members, countries such as Ireland, Greece, and Portugal have been forced to rely on domestic public policies to promote real convergence. This poses a challenge since growing public spending, pro-cyclical policies, and more recently, falling tax revenues have contributed to rapidly increasing levels of public debt and a sharp need for budgetary consolidation.

In this context, the focus of this paper is on the budgetary implications of CO_2 taxes and everything included in this paper is filtered through this lens. Generally, analyses of the public debt implications of climate policies focus on using CO_2 tax revenue to finance the purchase of financial assets, paying down debt [see, for example, Shackelton et al. (1996), Farmer and Steininger (1999) and Conferey et al. (2008)]. In this paper, we examine the economic and budgetary impact of CO_2 taxation, with revenues directed to the general public account, in an endogenous growth framework with optimal public sector adjustments to both public consumption and investment activities.

We develop marginal abatement cost curves for CO_2 taxes in a small, open, energy-importing economy, Portugal, using a dynamic general equilibrium model with endogenous growth and a detailed modeling of public sector activities. In addition to the traditional marginal abatement cost curve, describing the relationship between the CO_2 tax level and the reduction in emissions, we present a pair of complementary marginal abatement cost curves which highlight the impact CO_2 taxation on economic performance and public debt.

Our model incorporates fully dynamic optimization behavior, endogenous growth, and a detailed modeling of the public sector activities, both tax revenues and public consumption and investment spending. The model is calibrated to replicate the stylized facts of the Portuguese economy over the last decade. Previous versions of this model have been used to evaluate the impact of tax policy [see Pereira and Rodrigues (2002, 2004)], social security reform [see Pereira and Rodrigues (2007) and environmental fiscal reform [see Pereira and Pereira (2013)].

This model brings together two important strands of the taxation literature [see the above applications of this model for a detailed list of the references]. On one hand, it follows in the footsteps of computable general equilibrium modeling. It shares with this literature the ability to consider the tax system in great detail. This is important given the evidence that the costs and effectiveness of climate policies are influenced by existing tax distortions [see Goulder (1995), Goulder et al (1999) and Goulder and Parry (2008)]. On the other hand, it incorporates many of the insights of the endogenous growth literature. In particular, it recognizes that public policies have the potential to affect the fundamentals of long term growth and not just for generating temporary level effects [see Xepapadeas (2005)].

While the economic impact of financing reductions in public debt with CO_2 tax revenue has been explored in a general equilibrium framework [see, for example, Barker et al. (1993), Koeppl et al. (1996), Farmer and Steininger (1999), and Conefrey et al. (2008)], the key distinguishing feature of our methodological approach is our focus on endogenous growth – in contrast to endogenous technical change – and the associated treatment of public sector behavior [see Conrad (1999) and Bergman (2005) for literature surveys]. Productivity enhancing investments in public and human capital, which have been largely overlooked in applied climate policy [Carraro et al. (2009)], are, in addition to private investment, the drivers of endogenous growth. Furthermore, the analysis of the interaction between fiscal policies, public capital, economic growth, and environmental performance has garnished little attention and then only in a theoretical framework [Bovenberg and de Mooij (1997), Greiner (2005), Fullerton and Kim (2008), Glomm et al. (2008) and Gupta and Barman (2009)].

The remainder of this paper is organized as follows. Section 2 provides a description of the model and a discussion of implementation issues. Section 3 presents the marginal abatement cost curves for CO_2 emissions in Portugal. Section 4 analyzes the equilibrium tax levels for, and the economic and budgetary impacts of compliance with, existing, and potentially more stringent, emissions targets. Section 5 provides a deeper look at the mechanisms behind the economic and budgetary impacts of CO_2 taxes. Finally, Section 6 provides a summary and policy implications.

2. The Dynamic General Equilibrium Model

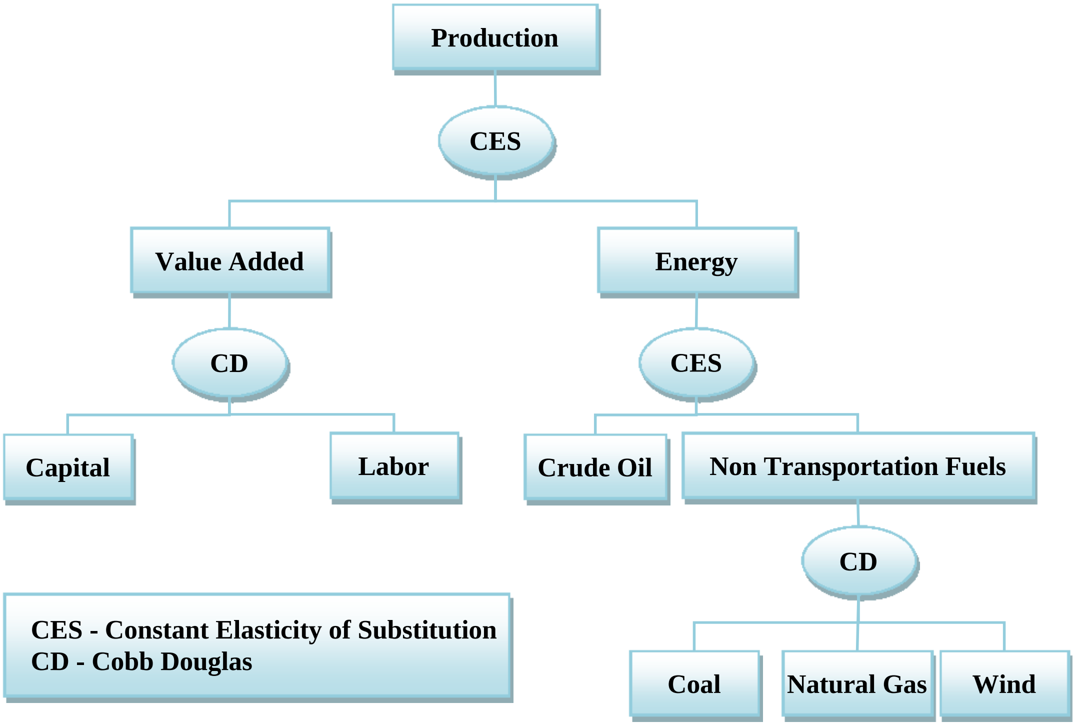
We consider a decentralized economy in a dynamic general-equilibrium framework. All agents are price-takers and have perfect foresight. With money absent, the model is framed in real terms. There are four sectors in the economy – the production sector, the household sector, the public sector and the foreign sector. The first three have an endogenous behavior but all four sectors are interconnected through competitive market equilibrium conditions, as well as the evolution of the stock variables and the relevant shadow prices. All markets are assumed to clear.

The trajectory for the economy is described by the optimal evolution of eight stock and five shadow price variables - private capital, wind energy capital, public capital, human capital, and public debt together with their shadow prices, and foreign debt, private financial wealth, and human wealth. In the long term, endogenous growth is determined by the optimal accumulation of private capital, public capital and human capital. The last two are publicly provided.

2.1. The Production Sector

Figure 1 presents an overview of the production structure of the economy. Aggregate output, Y_t, is produced with a Constant Elasticity of Substitution (CES) technology, as in (Eq. 1), linking value added, VA_t, and aggregate primary energy demand, AGG_E_t. Value added is produced with a Cobb-Douglas technology (Eq. 2), exhibiting constant returns to scale in the reproducible inputs – effective labor, $L_t^d HK_t$, private capital, $K_{p,t}$, and public capital, KG_t. Only the demand for labor, L_t^d, and the private capital stock are directly controlled by the firm, meaning that if public investment is absent then decreasing returns set in. Public infrastructure and the economy-wide stock of knowledge, HK_t, are publicly financed and are positive externalities. The capital and labor shares are $\theta_K$and θ_L, respectively, and $\theta_{KG} = 1 - \theta_K - \theta_L$ is a public capital externality parameter. A is a size parameter.

Figure 1: Overview of the Production Structure



Private capital accumulation is characterized by (Eq. 3) where physical capital depreciates at a rate δ_K. Gross investment, $I_{p,t}$, is dynamic in nature with its optimal trajectory induced by the presence of adjustment costs. These costs are modeled as internal to the firm - a loss in capital accumulation due to learning and installation costs - and are meant to reflect rigidities in the accumulation of capital towards its optimal level. Adjustment costs are assumed to be non-negative, monotonically increasing, and strictly convex. In particular, we assume adjustment costs to be quadratic in investment per unit of installed capital.

The firms' net cash flow, NCF, (Eq. 4), represents the after-tax position when revenues from sales are netted of wage payments and investment spending. The after-tax net revenues reflect the presence of a private investment and wind energy investment tax credit at an effective rate of τ_{ITC} and τ_{ITCR}, respectively, taxes on corporate profits at a rate of τ_{CIT}, and Social Security contributions paid by the firms on gross salaries, $w_t L_t^d HK_t$, at an effective rate of τ_{FSSC}.

Buildings make up a fraction, $0 < (1 - \rho_I) < 1$, of total private investment expenditure. Only this fraction is subject to value-added and other excise taxes, the remainder is exempt. This situation is modeled by assuming that total private investment expenditure is taxed at an effective rate of $\tau_{VATET,I}$. The corporate income tax base is calculated as Y_t net of total labor costs, $(1 + \tau_{FSSC}) w_t L_t^d HK_t$, and net of fiscal depreciation allowances over past and present capital investments, αI_t. A straight-line fiscal depreciation method over $NDEP$ periods is used and investment is assumed to grow at the same rate at which output grows. Under these assumptions, depreciation allowances simplify to αI_t, with α is obtained by computing the difference of two infinite geometric progression sums, and is given by (Eq. 5).

Optimal production behavior consists in choosing the levels of investment and labor that maximize the present value of the firms' net cash flows, (Eq. 4), subject to the equation of motion for private capital accumulation, (Eq. 3). The demands for labor and investment are given by (Eq. 6) and (Eq. 7), respectively, and are obtained from the current-value Hamiltonian function, where q_{t+1}^{K} is the shadow price of private capital, which evolves according to (Eq. 8). Finally, with regard to the financial link of the firm with the rest of the economy, we assume that at the end of each operating period the net cash flow is transferred to the consumers.

2.2. The Energy Sector

We consider the introduction of CO_2 taxes levied on primary energy consumption by firms. This is consistent with the nature of the existing policy environment in which CO_2 permits may now be auctioned to firms. Furthermore, evidence suggests that administrative costs are substantially lower the further upstream the tax is administered. By considering taxation at the firm level, the additional costs induced by CO_2 taxes are transmitted through to consumers and consumer goods in a fashion consistent with the energy content of the good. Not levying the CO_2 tax on consumers therefore avoids double taxation of the carbon content of a good.

The energy sector is an integral component of the firms' optimization decisions. We consider primary energy consumption by firms, AGG_E_t, for crude oil, coal, natural gas and wind energy. Primary energy demand refers to the direct use of an energy vector at the source in contrast to energy resources that undergo a conversion or transformation process. With the taxation of primary energy consumption by firms, costs are transmitted through to consumers and consumer goods in a fashion consistent with the energy content of the good.

Primary energy consumption provides the most direct approach for accounting for CO_2 emissions from fossil fuel combustion activities. The hydrogen and carbon contained in fossil fuels generates the potential for heat and energy production. Carbon is released from the fuel upon combustion; 99.0% of the carbon released from the combustion of petroleum, 99.5% from natural gas, and 98.0% from coal, oxidizes to form CO_2. Together, the quantity of fuel consumed, its carbon factor, oxidation rate, and the ratio of the molecular weight of CO_2 to carbon are used to compute the amount of CO_2 emitted from fossil fuel combustion activities in a manner consistent with the Intergovernmental Panel for Climate Change (2006) reference approach. These considerations suggest a linear relationship between CO_2 emissions and fossil fuel combustion activities. Computation of CO_2 emissions from fossil fuel combustion is given in (Eq. 19).

Aggregate primary energy demand is produced with a CES technology (Eq. 9) in which crude oil, $CrudeOil_t$, and non-transportation fuels, NTF_t, are substitutable at a rate less than unity reflective of the dominance of petroleum products in transportation energy demand and the dominance of coal, natural gas and wind energy, in electric power and industry. Non-transportation fuels are produced with a Cobb-Douglas technology (Eq. 15) recognizing the relatively greater potential substitution effects in electric power and industry. The accumulation of wind energy infrastructure is characterized by a dynamic equation of motion (Eq. 16) where the physical capital, wind turbines, depreciates at a rate of $\delta_{w,t}$ and investment, $I_{w,t}$, is subject to adjustment costs as private capital. Wind energy investment decisions are internal to the firm while coal, natural gas and oil are imported from the foreign sector.

Optimal primary energy demand is derived from the maximization of the present value of the firms' net cash flows as discussed above. The first order condition for crude oil demand and non-transportation energy demand are given by (Eq. 13) and (Eq. 14). In turn, the demand for coal and natural gas are defined through the nested dual problem of minimizing energy costs (Eq. 10) given the production function (Eq. 15) and optimal demand for these energy vectors in electric power and industry. Finally, the variational condition for optimal wind energy investment and optimal demand levels given in (Eq. 13), yielding (Eq. 12). Finally, the variational condition for optimal wind energy investment, given in (Eq. 17), and the equation of motion for the shadow price of wind energy, given in (Eq. 18), are defined by differentiating the Hamiltonian with respect to wind energy investment and its stock.

2.3. The Households

An overlapping-generations specification was adopted in which the planning horizon is finite but in a non-deterministic fashion. A large number of identical agents are faced each period with a probability of survival, γ. The assumption that γ is constant over time and across age-cohorts yields a perpetual youth specification in which all agents face a life expectancy of $\frac{1}{1-\gamma}$. Without loss of generality, the population, which is assumed to be constant, is normalized to one. Therefore, per capita and aggregate values are equal.

The household, aged a at time t, chooses consumption and leisure streams that maximize intertemporal utility, (Eq. 20), subject to the consolidated budget constraint, (Eq. 21). The objective function is lifetime expected utility subjectively discounted at the rate of β. Preferences, $u_{a+v,t+v}$, are additively separable in consumption and leisure, and take on the CES form where B is a size parameter and σ is the constant elasticity of substitution. The effective subjective discount factor is $\gamma\beta$ meaning that a lower probability of survival reduces the effective discount factor making the household relatively more impatient.

The budget constraint, (Eq. 21), reflects the fact that consumption is subject to a value-added tax rate of $\tau_{VAT,C}$ and states that the households' expenditure stream discounted at the after-tax market real interest rate, $1+(1-\tau_r)r_{t+v}$, cannot exceed total wealth at t, $TW_{a,t}$. The loan rate at which households borrow and lend among themselves is $1/\gamma$ times greater than the after-tax interest rate reflecting the probability of survival.

Table 1: The Dynamic General Equilibrium Model - The Model Structure

The Production Sector

$$Y_t = A_t\left(\gamma_{va}\, VA_t^{\rho_{va}} + (1-\gamma_{va})\, AGG\_E_t^{\rho_{va}}\right)^{1/\rho_{va}} \tag{1}$$

$$VA_t = A_{va,t}(L_t^d HK_t)^{\theta_L} K_t^{\theta_K} KG_t^{1-\theta_L-\theta_K} \tag{2}$$

$$K_{p,t+1} = (1-\delta_k)K_{p,t} + I_{p,t} - \mu_k \frac{I_{p,t}^2}{K_{p,t}} \tag{3}$$

$$NCF_t = Y_t - (1+\tau_{fssc})w_t(L_t^d HK_t) - I_{p,t} - I_{W,t} - (1-\rho_I)\tau_{vat,I} I_{p,t} - p_{e,t}E_t - \tau_{cit}\left(Y_t - (1+\tau_{fssc})w_t(L_t^d HK_t) - \alpha I_{p,t} - \alpha I_{w,t} - p_{e,t}E_t\right) + \tau_{itc,I} I_{p,t} + \tau_{itc,RI} I_{w,t} \tag{4}$$

$$\alpha = [1-(1+g)^{-NDEP}]/NDEP[1-(1+g)^{-1}] \tag{5}$$

$$\theta_L \gamma_{VA} A_t\left(\gamma_{va}\, VA_t^{\rho_{va}} + (1-\gamma_{va})AGG\_E_t^{\rho_{va}}\right)^{1/\rho_{va}-1} VA_t^{\rho_{VA}} = (1+\tau_{FSSC})w_t L_t^d HK_t \tag{6}$$

$$\frac{I_{p,t}}{K_t} = \frac{1}{2\mu_I} - \left[1 + (1-\rho_I)\tau_{VAT,I} - \alpha\tau_{CIT} - \tau_{ITC}\right](2\mu_I q_{t+1}^K)^{-1}(1+r_{t+1}) \tag{7}$$

$$q_t^K = (1-\tau_{CIT})\theta_K \frac{Y_t}{K_{p,t}} + \frac{q_{t+1}^K}{1+r_{t+1}}\left[1 - \delta_K + \mu_I\left(\frac{I_{p,t}}{K_{p,t}}\right)^2\right] \tag{8}$$

The Energy Sector

$$AGG\_E_t = A_{E,t}\left(\gamma_E\, Crude\ Oil_t^{\rho_e} + (1-\gamma_E)\, NTF_t^{\rho_e}\right)^{1/\rho_e} \tag{9}$$

$$p_{e,t}E_t = p_{fe,t}FE_t + \left(p_{crude\ oil,t} + emission\_factor_{oil}\tau_{carbon}\right) Crude\ Oil_t \tag{10}$$

$$p_{fe,t}FE_t = \sum_{i=1}^{n}\left(p_{f,i,t} + emission\_factor_f \tau_{carbon}\right)F_{i,t} \tag{11}$$

$$\left(p_{f,i,t} + emission\_factor_f\tau_{carbon}\right)\theta_{f,j}F_{i,t} - \left(p_{f,j,t} + emission\_factor_f\tau_{carbon}\right)\theta_{f,i}F_{j,t} = 0 \tag{12}$$

$$\theta_{FE}\frac{AGG\_E_t}{FE_t}A_t\left(\gamma_{va}\, VA_t^{\rho_{va}} + (1-\gamma_{va})AGG\_E_t^{\rho_{va}}\right)^{1/\rho_{va}-1}(1-\gamma_E)\, A_{E,t}\left(\gamma_E\, Crude\ Oil_t^{\rho_e} + (1-\gamma_E)\, NTF_t^{\rho_e}\right)^{1/\rho_e-1} NTF_t^{\rho_e} - p_{fe,t} = 0 \tag{13}$$

$$\frac{AGG\_E_t}{Crude\ Oil_t}(1-\gamma_{VA})A_t\left(\gamma_{va}\, VA_t^{\rho_{va}} + (1-\gamma_{va})AGG\_E_t^{\rho_{va}}\right)^{1/\rho_{va}-1}\gamma_E\, A_{E,t}\left(\gamma_E\, Crude\ Oil_t^{\rho_e} + (1-\gamma_E)\, NTF_t^{\rho_e}\right)^{1/\rho_e-1} Crude\ Oil_t^{\rho_e} - p_{crude\ oil,t} = 0 \tag{14}$$

$$NTF_t = A_{E2,t}\left(\varphi_{cf}RK\right)_t^{\theta_{RK}}\prod_{i=1}^{n}F_{i,t}^{\theta_{f,i}} \tag{15}$$

$$RK_{t+1} = (1-\delta_{rk})RK_t + I_{w,t} - \mu_{rk}\frac{I_{w,t}^2}{RK_t} \tag{16}$$

$$\frac{I_{w,t}}{RK_t} = \frac{1}{2\mu_{rk}} - \left(1 + (1-\rho_I)\tau_{vat,RI} - \alpha\,\tau_{cit} - \tau_{itcr}\right)(2\mu_{rk}q_{t+1}^{RK})^{-1}(1+r_{t+1}) \tag{17}$$

$$q_t^{RK} = \frac{\partial\pi_t}{\partial RK_t} = (1-\tau_{cit})\theta_{RK}\frac{Y_t}{RK_t} + \frac{q_{t+1}^{RK}}{(1+r)}\left((1-\delta_{rk}) + \mu_{rk}\left(\frac{I_{w,t}}{RK_t}\right)^2\right) \tag{18}$$

$$CarbonEmissions_t = \sum_{f}^{N} emission\_factor_f F_{i,t} + emission\_factor_{oil} Crude\ Oil_t \tag{19}$$

Table 1 (con't): The Dynamic General Equilibrium Model - The Model Structure

The Household Sector

$$U_{a,t} = \frac{\sigma}{\sigma - 1}\sum_{\upsilon=0}^{\infty} \gamma^{\upsilon}\, \beta^{\upsilon} \left[c_{a+\upsilon,t+\upsilon}^{\frac{\sigma-1}{\sigma}} + B\ell_{a+\upsilon,t+\upsilon}^{\frac{\sigma-1}{\sigma}} \right] \tag{20}$$

$$\sum_{\upsilon=0}^{\infty} \gamma^{\upsilon}[1 + (1 - \tau_r)r_{t+\upsilon}]^{-\upsilon}\left(1 + \tau_{VAT,C}\right)C_{a+\upsilon,t+\upsilon} = TW_{a,t} \tag{21}$$

$$TW_{a,t} \equiv HW_{a,t} + FW_{a,t} + PVF_t \tag{22}$$

$$HW_{a,t} = \sum_{m=0}^{\infty} \left(\frac{\gamma}{1 + (1 - \tau_r)r_{t+m}}\right)^{m} \left(\left(1 - \tau_{pit}\right)\left((1 - \tau_{wssc})w_{t+m}\left(\bar{L} - \ell_{a+m,t+m}\right)HK_{t+m} + TR_{t+m}\right) + R_{t+m} - LST_{t+m}\right) \tag{23}$$

$$\begin{aligned} FW_{a,t} = {} & \left(1 + (1 - \tau_r)r_{t-1}^{pd}\right)PD_{t-1} + (1 - \tau_{\pi})NCF_{t-1} - \left(1 + r_{t-1}^{fd}\right)FD_{t-1} + \left(1 - \tau_{pit}\right)\left((1 - \tau_{wssc})w_{t-1}\left(\bar{L} - \ell_{a-1,t-1}\right)HK_{t-1} + TR_{t-1}\right) + R_{t-1} - LST_{t-1} \\ & - (1 + \tau_{vat})C_{a-1,t-1} \end{aligned} \tag{24}$$

$$(1 + \tau_{vat})C_t = [1 - (1 + (1 - \tau_r)r_{t-1})^{\sigma-1}\gamma\beta^{\sigma}](HW_t + (PD_t - FD_t) + PVF_t) \tag{25}$$

$$\ell_t = \left(\frac{B(1 + \tau_{vat})}{(1 - \tau_{wssc})\left(1 - \tau_{pit}\right)w_t(1 - UR_t)HK_t}\right)^{\sigma} C_t \tag{26}$$

The Public Sector

$$U_{public} = \sum_{t}[\left(C_t\ell_t^{p_1}\right)^{\alpha_C}CG_t^{1-\alpha_C}]\;(1 + (1 - \tau_r)r_t^{PD})^{-t} \tag{27}$$

$$PD_{t+1} = (1 + r_t^{PD})PD_t + \left(1 + \tau_{vat,cg}\right)CG_t + \left(1 + \tau_{vat,ig}\right)IG_t + \left(1 + \tau_{vat,ih}\right)IH_t + TR_t - T_t \tag{28}$$

$$T_t = PIT_t + CIT_t + VAT_t + FSSC_t + WSSC_t + LST_t \tag{29}$$

$$KG_{t+1} = \left(1 - \delta_{kg}\right)KG_t + IG_t - \mu_{kg}\frac{IG_t^2}{KG_t} \tag{30}$$

$$HK_{t+1} = (1 - \delta_{hk})HK_t + IH_t - \mu_{hk}\frac{IH_t^2}{HK_t} \tag{31}$$

$$\frac{q_{t+1}^{PD}}{(1 + (1 - \tau_r)r_{t+1}^{PD})} = \frac{q_t^{PD}}{(1 + (1 - \tau_r)r_t^{PD})} \tag{32}$$

$$q_{t+1}^{PD} = (1 - \alpha_c)\left(\frac{C_t\ell^{p_1}}{CG_t}\right)^{\alpha_C} (1 + (1 - \tau_r)r_t^{PD}) \tag{33}$$

$$-q_{t+1}^{PD} = q_{t+1}^{kg}\left(2\mu_{kg}\frac{IG_t}{KG_t}\right) \tag{34}$$

$$q_t^{KG} = \frac{q_{t+1}^{PD}}{(1 + (1 - \tau_r)r_t^{PD})}\left((\tau_{\pi}(1 - \tau_{cit}) + \tau_{cit})\frac{\partial Y_t}{\partial KG_t}\right) + \frac{q_{t+1}^{kg}}{(1 + (1 - \tau_r)r_{t+1}^{PD})}\left(\left(1 - \delta_{kg}\right) + \mu_{kg}\left(\frac{IG_t}{KG_t}\right)^{2}\right) \tag{35}$$

$$-q_{t+1}^{PD} = q_{t+1}^{hk}\left(2\mu_{hk}\frac{IH_t}{HK_t}\right) \tag{36}$$

$$q_t^{HK} = \frac{q_{t+1}^{PD}}{(1 + (1 - \tau_r)r_t^{PD})}\left(\left(\tau_{pit}\left(1 - \tau_{fssc}\right) - (1 - \tau_{\pi})(1 + \tau_{cit})\tau_{fssc} + \tau_{wssc}\right)\frac{\partial Y_t}{\partial HK_t}\right) + \frac{q_{t+1}^{hk}}{(1 + (1 - \tau_r)r_{t+1}^{PD})}\left((1 - \delta_{hk}) + \mu_{hk}\left(\frac{IH_t}{HK_t}\right)^{2}\right) \tag{37}$$

Market Equilibrium

$$(1 - UR_t)LS_t = L_t^d \tag{38}$$

$$Y_t = \sum_{i=1}^{n} p_{f,i,t}F_{i,t} + p_{crude\ oil,t}Crude\ Oil_t + C_t + I_{p,t} + I_{w,t} + CG_t + IG_t + IH_t - NX_t \tag{39}$$

$$FD_{t+1} = \left(1 + r_t^{fd}\right)FD_t + NX_t - R_t \tag{40}$$

$$FW_t = PD_t - FD_t \tag{41}$$

For the household of age a at t, total wealth, $TW_{a,t}$ (Eq. 22), is age-specific and is composed of human wealth, $HW_{a,t}$, net financial worth, $FW_{a,t}$, and the present value of the firm, PVF_t. Human wealth (Eq. 23), represents the present discounted value of the household's future labor income stream net of personal income taxes, τ_{PIT}, and workers' social security contributions, τ_{WSSC}. Labor's reward per efficiency unit is w_t.

The household's wage income is determined by its endogenous decision of how much labor to supply, $LS_t = \bar{L} - \ell_t$, out of a total time endowment of $\bar{L}$, and by the stock of knowledge or human capital, HK_t, that is augmented by public investment on education. Labor earnings are discounted at a higher rate reflecting the probability of survival.

A household's income is augmented by net interest payments received on public debt, PD_t, profits distributed by corporations, NCF_t, international transfers, R_t, and public transfers, TR_t. On the spending side, debts to foreigners are serviced, taxes are paid and consumption expenditures are made. Income net of spending adds to net financial wealth (Eq. 24). Under the assumption of no bequests, households are born without any financial wealth. In general, total wealth is age-specific due to age-specific labor supplies and consumption streams.

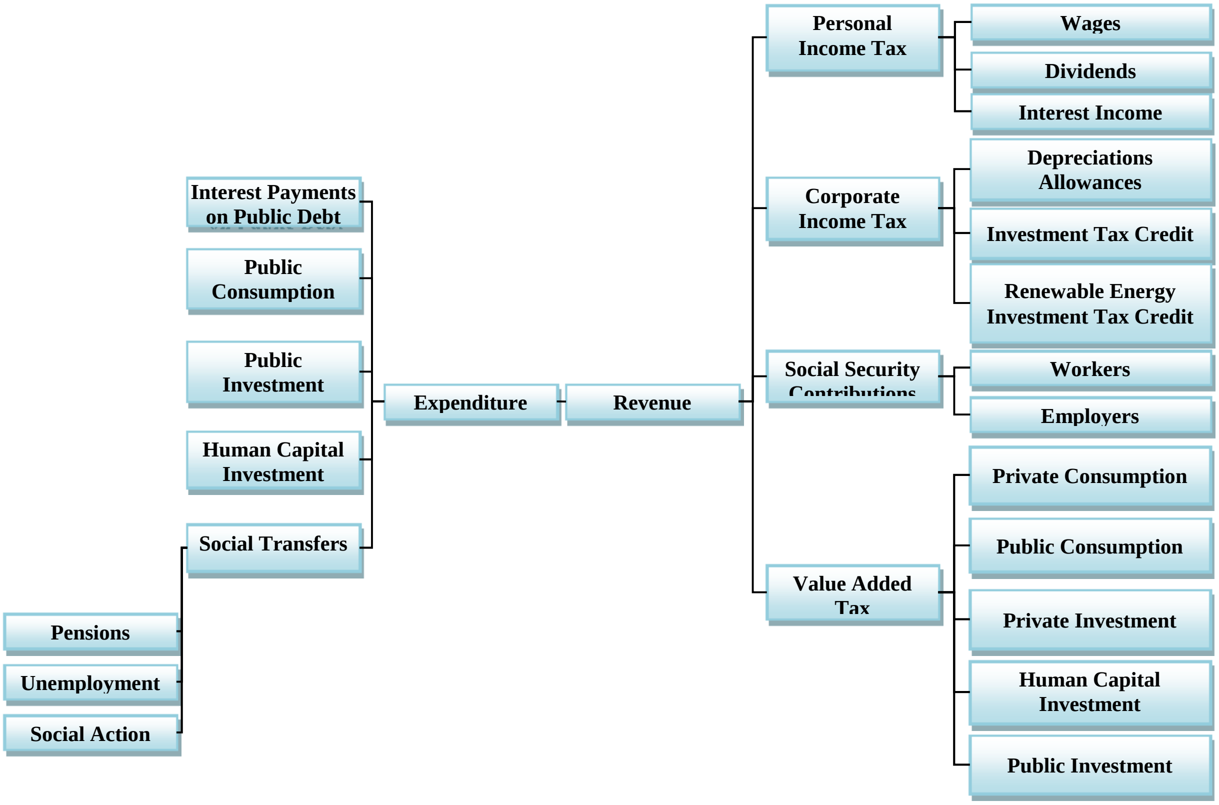
Assuming a constant real interest rate, the marginal propensity to consume out of total wealth is age-independent and aggregation over age cohorts is greatly simplified. Aggregate consumption demand is given by (Eq. 25) and an age-independent coefficient enables us to write the aggregate demand for leisure, (Eq. 26), as a function of aggregate consumption.

2.4. The Public Sector

The equation of motion for public debt, PD_t, (Eq. 28), reflects the fact that the excess of government expenditures over tax revenues has to be financed by increases in public indebtedness. Total tax revenues, T_t, (Eq. 29) include personal income taxes, PIT_t, corporate income taxes, CIT_t, value added taxes, VAT_t, social security taxes levied on firms and workers $FSST_t$ and $WSST_t$. All of these taxes are levied on endogenously defined tax bases. Residual taxes are modeled as lump sum, LST_t, and are assumed to grow at an exogenous rate.

The public sector pays interest on public debt at a rate of r_t^{PD} and transfers funds to households TR_t in the form of pensions, unemployment subsidies, and social transfers, which grow at an exogenous rate. In addition, it engages in public consumption activities, CG_t, and public investment activities in both public capital and human capital, IG_t and IH_t.

Figure 2: Overview of the Public Sector



Public investments are determined optimally, respond to economic incentives, and constitute an engine of endogenous growth. The accumulations of HK_t and KG_t are subject to depreciation rates, δ_{HK} and δ_{HK}, and to adjustment costs that are a fraction of the respective investment levels. The adjustment cost functions are strictly convex and quadratic.

Public sector decisions consist in choosing the trajectories for CG_t, IH_t, and IG_t that maximize social welfare, (Eq. 27), defined as the net present value of the future stream of utility derived from public consumption, parametric on private sector consumption-leisure decisions. The optimal choice is subject to three constraints, the equations of motion of the stock of public debt, (Eq. 28), the stock of public capital, (Eq. 30), and the stock of human capital, (Eq. 31).

The optimal trajectories depend on q_{t+1}^{PD}, q_{t+1}^{KG}, and q_{t+1}^{HK}, the shadow prices of the public debt, public capital, and human capital stocks, respectively. The relevant discount rate is $1 + (1 - \tau_r) r_{t+1}^{PD}$ because this is the financing rate for the public sector. Optimal conditions are (Eq. 32) for public debt, (Eq. 33) for public consumption, (Eq. 34-35) for public investment, and (Eq. 36-37) for investment in human capital.

2.5. The Foreign Sector

The equation of motion for foreign financing, FD_t, (Eq. 40), provides a stylized description of the balance of payments. Domestic production, Y_t, and imports are absorbed by domestic expenditure and exports. Net imports, $-NX_t$, (Eq. 39), are financed through foreign transfers, R_t, and foreign borrowing. Foreign transfers grow at an exogenous rate. In turn, the domestic economy is assumed to be a small, open economy. This means that it can obtain the desired level of foreign financing at a rate, r_t^{FD}, which is determined in the international financial markets. This is the prevailing rate for all domestic agents.

2.6. The Intertemporal Market Equilibrium

The intertemporal path for the economy is described by the behavioral equations, by the equations of motion of the stock and shadow price variables, and by the market equilibrium conditions (Eq. 38-41). The labor-market clearing condition is given by (Eq. 38) where a structural unemployment rate of UR_t is exogenously considered. The product market equalizes demand and supply for goods and services. Given the open nature of the economy, part of the demand is satisfied through the recourse to foreign production, hence (Eq. 39) and (Eq. 40). Finally, the financial market equilibrium, (Eq. 41), reflects the fact that private capital formation and public indebtedness are financed by household savings and foreign financing.

We define the steady-state growth path as an intertemporal equilibrium trajectory in which all the flow and stock variables grow at the same rate g while market prices and shadow prices are constant. There are three types of restrictions imposed by the existence of a steady-state. First, it determines the value of critical production parameters, like adjustment costs and depreciation rates given the initial capital stocks. These stocks, in turn, are determined by assuming that the observed levels of investment of the respective type are such that the ratios of capital to GDP do not change in the steady state. Second, the need for constant public debt and foreign debt to GDP ratios implies that the steady-state public account deficit and the current account deficit are a fraction g of the respective stocks of debt. Finally, the exogenous variables, such as public transfers or international transfers, have to grow at the steady-state growth rate.

2.7. Numerical Implementation

The model is developed conceptually as an infinite horizon model and is implemented numerically as a truncated finite horizon model. In the implementation, terminal conditions are imposed that are dictated by the requirement of a model achieving a steady-state trajectory by the truncation date. In our numerical implementation the truncation is set fifty years into the future.

The model is implemented numerically using non-linear optimization algorithms in the context of the GAMS-MINOS software package. Optimality conditions for the different agents presented in an implicit manner, as well as the equilibrium conditions for the problem and the optimal equations of motion for the stock variables and variational conditions, are interpreted as the constraints to a large scale and highly non-linear optimization problem with an artificial and fixed objective function. Since by definition the non-linear optimization algorithms are particularly well suited to find feasible solutions to the problem, the unique intertemporal solution to our problem, which is also the only feasible solution to the artificial constrained optimization problem, is reached in a rather efficient manner.

2.8. Dataset, Parameter Specification, and Calibration

The model is implemented numerically using detailed data and parameters sets. The dataset is reported in Table 2 and reflects the GDP and stock variable values in 2008; public debt and foreign debt reflect the most recent available data. The decomposition of the aggregate variables follows the average for the period 1990–2008. This period was chosen to reflect the most recent available information and to cover several business cycles, thereby reflecting the long-term nature of the model. Over the past decades, the Portuguese economy has exhibited weak economic growth and soaring levels of public debt. The per worker real growth rate of the economic activity between 1990 and 2008 was 1.763% while the level of public debt reached 85.8% of GDP in 2008, prior even to the recent debt crisis over which public debt has grown to in excess of 115% of GDP. These figures underscore some of the primary concerns of the

Portuguese economy as well as other small oil importing economies exhibiting weak economic growth and high levels of public indebtedness.

In turn, the baseline energy and environmental accounts are presented in Table 3. Primary demand for crude oil in our baseline trajectory grows to 658.8 PJ (65.0% of primary energy demand), coal demand to 169.1 PJ (16.7% of primary energy demand), demand for natural gas to 158.0 PJ (15.6% of primary energy demand), and wind generating capacity to 27.0 PJ (2.7% of primary energy demand) in 2020. These lead to a baseline projection for emissions of 71.9 Mt CO_2 in 2020. The reference trajectory does not incorporate policy constraints on emissions. This stems from the fact that our objective is to evaluate the relative impact of potential policies to be implemented and to achieve emissions reductions goals by 2020.

Parameter values are specified in different ways. Whenever possible, parameter values are taken from the available data sources or the literature. This is the case, for example, of the population growth rate, the probability of survival, the share of private consumption in private spending, and the different effective tax rates.

All the other parameters are obtained by calibration; i.e., in a way that the trends of the economy for the period 1990–2008 are extrapolated as the steady-state trajectory. These calibration parameters assume two different roles. In some cases, they are chosen freely in that they are not implied by the state-state restrictions. They were chosen either using conventional central values or using available data as guidance. For instance, the elasticity of substitution parameters are consistent with those values often applied in climate policy analysis [see, for example, Manne and Richels (1992), Paltsev et al. (2005) and Koetse et al. (2008)].

Table 2: The Dynamic General Equilibrium Model - The Basic Data Set

Domestic spending data (% of Y_0)		
Y_0	GDP (billion Euros)	166.2279
g_0	Long term growth rate (%)	0.01763
VA_0	Value added	83.743
AGG_E_0	Primary energy consumption expenditure	2.557
C_0	Private consumption	62.263
$I_{p,0}$	Private investment	20.312
$I_{w,0}$	Private wind investment	0.064
CG_0	Public consumption	14.652
IG_0	Public capital investment	3.411
IH_0	Public investment in education	6.996
Primary energy demand (GJ as a % of Y_0)		
E_0	Primary fossil energy spending	2.472
NTF_0	Non transportation fuels	0.584
FE_0	Fossil fuels (excluding crude oil)	0.160
$CrudeOil_0$	Quantity of crude oil imports	0.321
$F_{Coal,0}$	Quantity of coal imports	0.082
$F_{Natural\ Gas,0}$	Quantity natural gas imports	0.077
Energy prices (€ per GJ)		
$p_{Crude\ Oil,0}$	Import price of crude oil	6.14
$p_{f,Coal,0}$	Import price of coal	1.89
$p_{f,Natural\ Gas,0}$	Import price of natural gas	4.45
Foreign account data (% of Y_0)		
NX_0	Trade deficit	7.697
$r_0^{FD}FD_0$	Interest payments of foreign debt	3.157
R_0	Unilateral transfers	11.413
CAD_0	Current account deficit	1.913
FD_0	Foreign debt	108.500
Public sector data (% of Y_0)		
T_0	Total tax revenue	41.958
PIT_0	Personal income tax revenue	5.710
CIT_0	Corporate income tax revenue	3.110
VAT_0	Value added tax revenue	13.700
VAT_c	on private consumption expenditure	10.669
VAT_I	on private investment expenditure	1.902
VAT_{cg}	on public consumption expenditure	0.649
VAT_{ig}	on public capital investment expenditure	0.379
VAT_{ih}	on public investment in human capital	0.101
$WSSC_0$	Social security tax revenues	11.700
$WSSC_{1,0}$	employers contributions	5.600
$WSSC_{2,0}$	workers contributions	6.100
$Carbon\ Tax_0$	Carbon tax	0.000
LST_0	Lump sum tax revenue	7.738
TR_t	Social transfers	15.915
$r_0^{PD}PD_0$	Interest payments of public debt	2.497
DEF_0	Public deficit	0.015
PD_0	Public debt	85.800

Table (con't): The Dynamic General Equilibrium Model - The Basic Data Set

Population and employment data (% of POP_0)			
	POP_0	Population (in thousands)	10.586
	L_0	Active population	5.587
	UR_0	Unemployment rate	0.058
Private Wealth (% of Y_0)			
	HW_0	Human wealth	2574.498
	FW_0	Financial wealth	-22.700
	PVF_0	Present value of the firm	1429.101
	NCF_0	Distributed profits	17.930
Prices			
	w_0	Wage rate	0.031
	q_0^{PD}	Shadow price of public debt	-0.883
	q_0^{k}	Shadow price of private capital	1.291
	q_0^{rk}	Shadow price of wind energy capital	1.291
	q_0^{kg}	Shadow price of public capital	1.104
	q_0^{hk}	Shadow price of human capital	5.521
Capital stocks (% of Y_0)			
	K_0	Private capital	215.321
	RK_0	Wind energy capital stock	1.142
	KG_0	Public capital stock	73.415
	HK_0	Human capital stock	226.899

Table 3: Baseline Energy and Environmental Accounts

Primary Energy Demand (PJ)

	2010	**2020**	**2030**	**2040**	**2050**
Crude Oil	553.1	658.8	784.6	934.4	1112.8
Coal	142.0	169.1	201.4	239.9	285.7
Natural Gas	132.7	158.0	188.2	224.1	266.9
Wind Energy	22.3	26.6	31.7	37.7	44.9

CO_2 Emissions from Fossil Fuel Combustion Activities (Mt CO_2)

	2010	**2020**	**2030**	**2040**	**2050**
Crude Oil	40.2	47.8	57.0	67.8	80.8
Coal	12.8	15.3	18.2	21.6	25.8
Natural Gas	7.4	8.8	10.5	12.5	14.9
Total	60.4	71.9	85.6	102.0	121.5

Table 4: The Dynamic General Equilibrium Model – The Structural Parameters

Household parameters		
β	Discount rate	0.003
γ	Probability of survival	0.987
g_{POP}	Population growth rate	0.000
σ	Elasticity of substitution	1.000
p_1	Leisure share parameter	0.331
Production parameters		
θ_L	Labor share in value added aggregate	0.506
θ_{KP}	Capital share in value added aggregate	0.294
θ_{KG}	Public capital share in value added aggregate	0.200
σ_{VA}	Elasticity of substitution between value added and energy	0.400
σ_{Crude}	Elasticity of substitution between oil and other energy	0.400
θ_{KR}	wind energy share in non-transportation fuels	0.146
θ_E	fossil energy share in non-transportation fuels	0.854
φ_{cf}	Wind energy price:quantity capacity utilization factor	0.074
θ_{Coal}	coal share in non-transportation fuels	0.313
θ_{gas}	natural gas share in non-transportation fuels	0.687
γ_{VA}	CES scaling share between value added and energy	1.000
γ_E	CES scaling share between oil and other energy	0.580
δ_k	Depreciation rate - Private capital	0.060
μ_k	Adjustment costs coefficient - Private capital	1.159
δ_{Rk}	Depreciation rate - Wind energy capital	0.028
μ_{Rk}	Adjustment costs coefficient - Wind energy capital	1.952
$\dot{A}_i/A_i$	Exogenous rate of technological progress	0.000
Emissions factor		
$emission\_factor_{oil}$	Emissions factor for oil (tCO_2 per TJ)	72.600
$emission\_factor_{coal}$	Emissions factor for oil (tCO_2 per TJ)	90.200
$emission\_factor_{gas}$	Emissions factor for oil (tCO_2 per TJ)	55.800
Public sector parameters - tax parameters		
τ_{pit}	Effective personal income tax rate	0.104
τ_{π}	Effective personal income tax rate on distributed profits	0.112
τ_r	Effective personal income tax rate on interest income	0.200
τ_{cit}	Effective corporate income tax rate	0.116
$NDEP$	Time for fiscal depreciation of investment	16.000
α	Depreciation allowances for tax purposes	0.735
ρ_I	Fraction of private investment that is tax exempt	0.680
$\tau_{itc,I}$	Investment tax credit rate - Private capital	0.005
$\tau_{itc,RI}$	Investment tax credit rate - Wind energy capital	0.005
$\tau_{VAT,C}$	Value added tax rate on consumption	0.212
$\tau_{vat,I}$	Value added tax rate on investment	0.094
$\tau_{vat,cg}$	Value added tax rate on public consumption	0.044
$\tau_{vat,ig}$	Value added tax rate on public capital investment	0.111
$\tau_{vat,ih}$	Value added tax rate for public investment in human capital	0.014
τ_{fssc}	Firms' social security contribution rate	0.152
τ_{wssc}	Workers social security contribution rate	0.166

Table 4 (con't): The Dynamic General Equilibrium Model – The Structural Parameters

Public sector parameters - outlays parameters		
$1-\alpha_C$	Public consumption share	0.215
δ_{kg}	Public infrastructure depreciation rate	0.020
μ_{kg}	Adjustment cost coefficient	2.392
δ_{hk}	Human capital depreciation rate	0.000
μ_{hk}	Adjustment cost coefficient	13.817
Real interest rates		
r, r^{FD}, r^{PD}	Interest rate	0.0291

It is widely recognized in the literature that the elasticity of substitution between value added and energy as well as among energy inputs play a significant role in a general equilibrium analysis of energy-related matters (e.g. Jacoby et al. 2006; Schubert and Turnovsky 2010; Pereira and Pereira 2011). This is because the appropriate choice for the elasticity of substitution parameters can yield smooth continuous approximations consistent with engineering estimates from bottom up representations of the energy system (Gerlagh et al. 2002; Kiuila and Rutherford 2010). We assume a central elasticity of substitution of 0.4 between crude oil and non-transportation fuels and an elasticity of substitution of 0.4 between energy inputs and capital/labor inputs. The remaining calibration parameters are obtained using the steady-state restrictions.

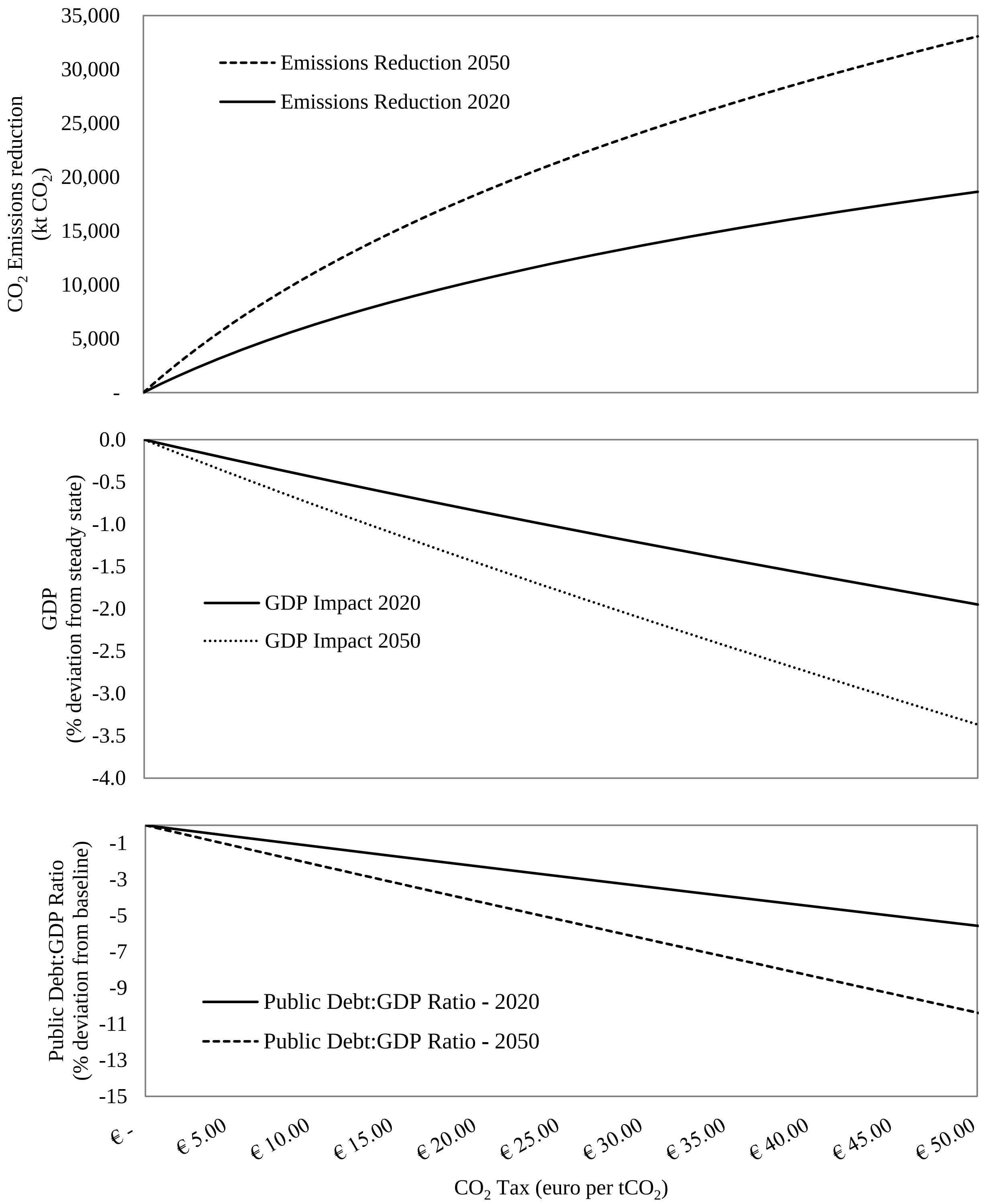
It should be noted that, as it is common in the literature this model is understood and interpreted as a long-term model. It is intended and designed to capture the long term trends of the economy. Hence the model is calibrated to capture exactly the average performance of the Portuguese economy in the last decade. This means that parameters are chosen in a way that the model replicates, by construction, the trends observed for 1990-2008. Furthermore, and also by construction, results from the model are not "contaminated" by business cycle effects.

3. Marginal Abatement Cost Curves for Carbon Dioxide Emissions

The traditional marginal abatement cost curves provide a measure of the environmental effectiveness of CO_2 taxation as a policy instrument for reducing emissions. In the top panel of Figure 3, we present these marginal abatement cost curves for 2020 and 2050 fully incorporating the dynamic feedback between emissions, energy costs, economic activity and the public sector account. Emission abatements are measured in thousands of tons of CO_2 relative to steady state levels and corresponding to tax levels up to 50.00 Euros per tCO_2 in increments of 0.50 Euros. The CO_2 tax revenues revert to the government general revenue fund. As a result, the public sector is free to adjust expenditure patterns optimally.

There are two important characteristics of these marginal abatement cost curves. First, the curvature of these marginal abatement cost curve is consistent with a diminishing marginal reduction in emissions for greater tax levels and is consistent with economic theory. This curvature stems from the convexities built into the model in terms of adjustment costs, the marginal productivity of factor inputs and other rigidities. In turn, the marginal productivities and costs are highly influenced by the elasticity of substitution between value added and energy inputs. Specifically, a greater degree of flexibility by firms to substitute labor and capital inputs, both public and private, for energy inputs allows for larger levels of emissions reductions. This also affects the rate at which increases in the tax level will affect the marginal reduction in emissions. In particular, lower substitution elasticities cause the marginal abatement in emissions to fall at a faster rate. The elasticity of substitution between crude oil and other energy inputs has a negligible impact on the abatement cost curve.

Figure 3 Marginal abatement costs for CO_2 emissions



Second, the marginal abatement cost curve for emissions reductions in 2050 is always above the marginal abatement cost curve for 2020. This results from the fact that a small change in the growth rate of emissions early in the model horizon generates relatively larger long term effects as a result of dynamics of capital accumulation as well as the incentives to reduce the emissions intensity of the economy. The reduction in the emissions intensity of the economy highlights that the immediate introduction of a CO_2 tax results in a growing level of emissions reductions through time relative to steady state emissions growth. The CO_2 tax, however, reduces the growth rate of emissions without achieving zero emissions growth. As such, emissions continue to grow in absolute terms and CO_2 emissions levels in 2050 are greater than in 2020.

The analysis above has focused on the traditional marginal abatement cost curves associated with CO_2 taxes. We now consider two complementary abatement cost curves. The first, in the middle panel of Figure 3, depicts the economic impact of reducing emissions through CO_2 taxes. The second, presented in the bottom panel of Figure 3, depicts the impact on public debt. These complementary curves suggest that, although CO_2 taxes have a meaningful positive impact on CO_2 emissions, they have a negative impact on economic performance, particularly over the long term. In addition, they positively affect the public budget and contribute to reducing public debt, the effects in 2050 being again more pronounced.

4. On the Economic and Budgetary Impact of Achieving 2020 Emissions Targets

4.1. On the Impact of Achieving Current 2020 Emission Targets

We now turn our attention to the details of the economic and budgetary impact of compliance with existing 2020 emissions targets in Portugal, limiting CO_2 emission growth to a one percent increase over 2005 levels as stipulated under Decision No 406/2009/EC [see

European Commission, (2009)]. This provides a benchmark for evaluating the role of CO_2 taxes in their dual role as climate and fiscal policy instruments. It is also essential in understanding the mechanisms through which CO_2 taxes affect the economy and the public sector account. All results are presented in terms of percent deviations from the steady-state growth trajectory of the economy unless otherwise indicated.

The analysis of the marginal abatement cost curves for CO_2 emissions presented above provides us with a bird's eye view of the overall impact of meeting different emissions targets through CO_2 taxation. Specifically, we observe that a tax of 17.00 Euros per tCO_2 has the technical capacity to reduce CO_2 emissions by 9.3 Mt CO_2, limiting emissions to 62.6 Mt CO_2 in 2020, and thereby achieving the climate policy objective in a manner consistent with the share of CO_2 emissions from fossil fuel combustion activities in total greenhouse gas emissions. This tax reduces GDP by 0.7% by 2020 and leads to a 2.7% reduction in public debt, reducing the public debt to GDP ratio to 83.5 by 2020.

Table 5 provides a detailed description of the impact of meeting existing targets through the introduction of a tax of 17.00 Euros per tCO_2. The CO_2 tax works primarily through two mechanisms. First, by affecting relative prices, the CO_2 tax drives changes to the firms' input structure that affects the marginal productivity of factor inputs. Second, the CO_2 tax increases energy expenditure and reduces the firms' net cash flow, household income and domestic demand. These scale and substitution effects are central in defining the impact of CO_2 taxation.

The CO_2 tax increases the price of fossil fuels relative to renewable energy resources and changes the relative price of the different fossil fuels to reflect their carbon content. This has a profound impact on the energy sector, driving a reduction in fossil fuel consumption of 11.6% in 2020 and increasing the stock of wind energy infrastructure by 10.5%. The impact of CO_2

taxation on aggregate fossil fuel demand, however, masks important changes in the fuel mix. In particular, we observe a 34.9% decrease in coal consumption while crude oil demand decreases by 7.7% and natural gas by 3.1%. As such, the CO_2 tax stimulates a shift in the energy mix which favors wind energy at the expense of coal.

The taxes impact on the energy sector reduces CO_2 emissions by limiting the growth rate of emissions in order to satisfy the 2020 emissions targets. Over the long term, however, CO_2 emissions continue to grow reaching 105.1 Mt CO_2 in 2050. This constitutes a 13.5% reduction in emissions from steady-state levels, corresponding to 16.4 Mt CO_2. More ambitious long term targets naturally suggest the need for larger and increasing tax levels.

The CO_2 tax reduces both the emissions intensity of the energy sector and the economy. Indeed, we observe a 12.9% reduction in emissions in 2020 while energy consumption decreases by 8.3%, reflecting a drop in the emissions intensity of the energy sector. The changing composition of primary energy demand in response to the CO_2 tax drives this reduction by stimulating investment in wind energy infrastructure and, more importantly, by heavily penalizing coal consumption. A further reduction in the energy intensity of the economy, through an increase in the share of labor and capital inputs in production, also contributes to reducing the emissions intensity of the economy to 0.3055 tCO_2 per thousand Euros of GDP. This also works to limit the growth in per capita emissions to 5.89 tCO_2 per person.

CO_2 taxation, by increasing energy system costs, has a negative impact on the firms' net cash flow which limits the firms' demand for inputs. Employment fall marginally, less than the associated decrease in capital inputs of 0.9% and substantially less than the decrease in fossil fuel demand of 11.6% in 2020. This is consistent with an overall reduction in input levels coupled with a shift in the firms' input structure away from energy inputs and an increasing role for capital and especially labor. This facet of the substitution mechanisms driving the impact of CO_2 taxation is also seen in changes in public investment in human capital and public capital.

Given the reductions in factor demand, it is no surprise that CO_2 taxation has a negative impact on economic growth and activity levels. The reduction in the firms' net cash flow has a direct impact on household income since it is an integral part of total wealth. This drives down private consumption and initiates an important dynamic feedback between income, consumption and production. As a result, private consumption falls by 1.0%. Consumption smoothing behavior results in relatively stable private consumption levels through time. The net effect of this interaction is a reduction in GDP levels of 0.7% in 2020 and 1.3% in 2050.

We observe an increase in public consumption activities designed to cushion the negative effects of lower private consumption levels and income losses. This drives an overall increase in public expenditure levels of 0.2% in 2020 although part of the 1.1% increase in public consumption results from a shift in public expenditure from investment to consumption. Indeed, public capital investment falls 2.1% and public investment in human capital falls 0.6%. The drop in public investment reduces the stock of public capital infrastructure by 0.7% and slightly reduces the stock of human capital in 2020, consistent again with shifts in the firms' production structure towards employment and capital.

The reductions in income, consumption and private inputs results in contracting tax bases, an effect compounded by the lower levels of investment in public and human capital. Accordingly, we observe a reduction in personal income tax, corporate income tax, and value-added tax revenues and in social security contributions. These reductions are clearly offset by the CO_2 tax receipts, amounting to 0.6% and 1.1% of base year GDP in 2020 and 2050, respectively. As a result, total tax revenue increases by 0.4% in 2020 and increases marginally in 2050. The

Table 5: Impact of a 17.00 Euros per ton CO_2 Tax

(Percent deviations from steady state baseline unless otherwise indicated)

	2010	2020	2030	2040	2050
Energy					
Energy	-9.01	-8.30	-8.04	-7.99	-8.02
Fossil Energy	-11.03	-11.62	-11.92	-12.10	-12.22
Crude Oil	-7.28	-7.68	-7.90	-8.05	-8.17
Coal	-34.14	-34.92	-35.29	-35.48	-35.59
Natural Gas	-1.94	-3.11	-3.65	-3.93	-4.10
Inv. Wind Energy	31.27	22.96	18.91	17.14	16.41
Wind Energy Infrastructure	3.01	10.46	13.90	15.25	15.75
Environmental					
Carbon Dioxide Emissions (Mt CO2)	52.90	62.63	74.33	88.35	105.08
Deviations from Baseline	-12.32	-12.90	-13.19	-13.37	-13.48
Increase over 1990 levels	24.30	47.07	74.56	107.47	146.76
Per Capita Emissions (tCO2 per person)	4.98	5.89	6.99	8.31	9.89
Deviations from Baseline	-12.32	-12.90	-13.19	-13.37	-13.48
Emissions Intensity of the Economy (tCO2 per 1000 euros GDP)	0.3075	0.3055	0.3044	0.3038	0.3034
Deviations from Baseline	-12.32	-12.90	-13.19	-13.37	-13.48
Macroeconomic					
Growth Rate (level)	1.71	1.73	1.74	1.75	1.75
GDP	-0.30	-0.72	-0.97	-1.13	-1.25
Consumption	-1.01	-1.00	-1.00	-0.99	-0.99
Investment	-1.71	-1.61	-1.65	-1.72	-1.79
Private Capital	-0.27	-0.94	-1.28	-1.48	-1.62
Labor Demand	0.13	-0.05	-0.16	-0.23	-0.28
Energy Imports	-8.23	-8.76	-9.04	-9.21	-9.33
Foreign Debt (percent of GDP)	106.58	101.31	97.99	95.97	94.82
Foreign Debt	-1.77	-6.62	-9.69	-11.55	-12.60
Public Sector					
Public Debt (percent of GDP)	85.18	83.50	82.48	81.94	81.71
Public Debt	-0.72	-2.69	-3.86	-4.50	-4.77
Total Expenditure	0.18	0.23	0.25	0.27	0.27
Public Consumption	1.06	1.14	1.19	1.23	1.26
Public Investment	-2.18	-2.09	-2.03	-2.02	-2.07
Human Capital Investment	-0.56	-0.60	-0.64	-0.67	-0.70
Public Capital	-0.17	-0.71	-1.09	-1.36	-1.55
Human Capital	-0.01	-0.03	-0.06	-0.09	-0.12
Total Tax Revenue	0.65	0.38	0.23	0.13	0.07
Personal Income Tax (IRS)	-0.33	-1.08	-1.47	-1.70	-1.85
Corporate Income Tax (IRC)	-0.16	-0.84	-1.18	-1.39	-1.53
Value Added Tax (VAT)	-1.01	-1.00	-1.00	-1.00	-1.01
Social Security Contributions (SSC)	-0.70	-1.12	-1.36	-1.52	-1.64

reduction in tax revenues is particularly pronounced in 2050 with a reduction in personal income tax receipts of 1.9%, in corporate income tax revenue of 1.5% and in value added tax receipts of 1.0% as well as in social security contributions of 1.6%.

4.2. Other Potential 2020 Emission Targets

The EU is presently in the process of considering tighter emissions targets in 2020 as well as longer term emission reductions. An important advantage of constructing wider marginal abatement cost curves is that these provide an effective tool for understanding the implications of alternative targets, specifically with respect to the rate at which the costs, environmental effectiveness and budgetary effects change with the tax level. Accordingly, we now examine the impact of alternative emissions targets in Portugal within the context of the European Union's burden sharing agreement. All targets are presented relative to CO_2 emissions levels in 2005.

Table 6 presents the impact, in 2020, of emissions targets corresponding to a 1.0% increase in emissions (consistent with the current burden sharing agreement and the discussion in the previous section), as well as targets corresponding to a 0.0%, 5.0%, 10.0%, 15.0% and 20.0% reductions in CO_2 emissions by 2020.

Naturally, greater reductions in CO_2 emissions require increasingly larger levels of CO_2 taxation. This results from the decreasing marginal effectiveness of the tax. As discussed above, the current target requires an equilibrium tax of 17.00 Euros per tCO_2. For a tighter target corresponding to stabilizing emissions at 2005 levels, the required tax grows to 18.50 Euros per tCO_2 and up to 69.00 Euros per tCO_2 for a 20.0% reduction in emissions.

Due to the larger tax levels required to achieve greater levels of emissions reduction, more ambitious emissions targets have a larger impact on economic activity. The 0.7% reduction in GDP associated with the current emissions target increases to 0.8% for the 2005 stabilization

Table 6: Impact of Other Potential 2020 Emissions Targets

(Percent deviations from baseline in 2020 unless otherwise stated)

(Changes Relative to 2005)	Emissions Target (kt CO_2)	Carbon Tax (Euros per tCO_2)	GDP	Tax Revenue	Public Debt
+1.0%	62,792.43	17.00	-0.72	0.38	-2.69
0.00%	62,170.72	18.50	-0.78	0.40	-2.91
-5.00%	59,062.19	27.50	-1.13	0.54	-4.26
-10.00%	55,953.65	38.50	-1.54	0.67	-5.86
-15.00%	52,845.12	52.50	-2.03	0.80	-7.83
-20.00%	49,736.58	69.00	-2.59	0.92	-10.10

scenario and up to 2.6% in 2020 for a 20.0% reduction in emissions. Again, the impact in 2050 will be larger than those impacts presented for 2020 because they will reflect the changes in economic growth early in the model horizon and the accumulated impact of lower private and public investment levels through time.

The more aggressive targets and CO_2 taxes also have a larger positive impact on public sector tax receipts. Tax revenues grow to 0.9% with the tightening CO_2 emissions constraint from the current levels to -20.0%. These contribute markedly towards improving the sustainability of the public sector account driving down public debt levels from 2.9% to 10.1% for the 2005 targets and the -20.0% targets, respectively.

5. On the Economic and Budgetary Impact of CO_2 Taxes: A Closer Look

The discussion shows that CO_2 taxes are an effective instrument for reducing emissions while at the same time generating positive budgetary effects. It also shows that these positive effects come at a substantial cost in terms of economic performance. We now turn to the specific mechanisms behind these effects in more detail.

The analysis above is based on the assumption that CO_2 tax revenues accrue to the general government account. The public sector is free to optimally adjust expenditure levels to cushion the impact of increasing energy costs and falling private consumption levels. This is particularly important because in maximizing social welfare the public sector optimally increases public consumption activities. Policies of this nature have been proposed in the context of efforts to use revenues from CO_2 taxation and permit auctions to address potential regressive aspects of the policy and fund social transfer programs. In addition, proposals and measures to alleviate the social welfare effects of fiscal consolidation efforts have been common responses to austerity measures. These optimal public sector behavioral responses mean that our first pass at examining the impact of CO_2 taxes as an instrument for fiscal consolidation is in the context of a package of measures consisting of optimal changes in public spending designed to address the negative impact of increased taxation and to reduce public debt.

In order to appreciate the impact of CO_2 taxes on public revenues and on the public account it is important to understand the impact of public consumption and investment decisions as well as the feedback between tax receipts, CO_2 taxation and public spending decisions. In this vein, we can compare our central model results to simulations designed with i) an exogenous public consumption trajectory consistent with our baseline steady state growth assumptions; ii) an exogenous public investment trajectory consistent with our baseline steady state growth assumptions; and iii) both of the above, i.e., a completely exogenous public sector. Table 7 presents the relevant results in 2020 and 2050.

We first consider exogenous public consumption decisions. Under our central modeling assumptions, we observed an increase in public consumption to mitigate the negative impacts of increased taxation. The exogenous public consumption trajectory implies, therefore, lower public consumption resulting in an overall reduction in public expenditure. Absent the public consumption increase, households allocate a greater portion of their income to private consumption at the expense of private investment which intensifies the negative economic effects of the policy. This contributes to the lower levels of tax revenue. Overall, greater restraint in public consumption activities results in a more substantive reduction in public debt. An exogenous trajectory for public consumption, reflective of political constraints on public spending activities and conscious efforts to stay the course during periods of austerity and not overcompensate to address welfare concerns, increases the reduction in public debt levels to 5.0 percent in 2020 and 13.9 percent in 2050. This is particularly important in an environment in which the increases in public consumption come at the expense of public investment activities and has a negative impact on the fundamentals of long-term growth.

We now turn to the implications of maintaining exogenous public and human investments while allowing public consumption to adjust in an optimal fashion. This eliminates the endogenous growth mechanism. With exogenously determined levels, larger levels of public investment spending provide a boost to firms' productivity and the GDP impact of each emissions target is notably smaller. In particular, the current target implies that GDP is 0.5% lower 2020. Similarly, the tax level required to achieve a particular emissions constraint is larger due to the rebound in domestic final demand. The long term differences are much more pronounced. More importantly, from a budgetary perspective, higher public investment levels, together with increased public consumption levels relative to the steady state, transform the greater tax revenues into lower gains in terms of debt consolidation.

Let’s consider, finally, the effects of a assuming a completely passive public sector. In this case all government spending is exogenously determined and the only effects come from the changes in the revenue side of the budget. Naturally, this scenario combines the two previous scenarios. It shares with the exogenous public consumption case a greater reduction in public

Table 7: How Optimal Public Spending Affects the Results of Achieving 2020 Targets

(Percent deviations from steady state baseline in 2020 unless otherwise indicated)

2020 Emissions Target (Relative to 2005 Levels)	Carbon Tax (€/tCO$_2$)	Emissions Level (kt CO$_2$)		GDP		Tax Revenue		Public Debt	
Central Results									
		2020	**2050**	**2020**	**2050**	**2020**	**2050**	**2020**	**2050**
1.00%	17.00	62,645	105,110	-0.72	-1.25	0.38	0.07	-2.69	-4.77
0.00%	18.50	62,062	104,076	-0.78	-1.35	0.40	0.06	-2.91	-5.17
-5.00%	27.50	58,985	98,607	-1.13	-1.96	0.54	0.04	-4.26	-7.56
-10.00%	38.50	55,925	93,156	-1.54	-2.66	0.67	-0.01	-5.86	-10.41
-15.00%	52.50	52,754	87,491	-2.03	-3.52	0.80	-0.11	-7.83	-13.93
-20.00%	69.00	49,704	82,032	-2.59	-4.47	0.92	-0.26	-10.10	-17.97
Exogenous Public Consumption (1)									
		2020	**2050**	**2020**	**2050**	**2020**	**2050**	**2020**	**2050**
1.00%	17.00	62,604	104,944	-0.79	-1.41	0.33	-0.10	-5.00	-13.92
0.00%	18.50	62,018	103,900	-0.85	-1.52	0.35	-0.11	-5.38	-14.94
-5.00%	27.50	58,925	98,382	-1.23	-2.18	0.47	-0.19	-7.55	-20.62
-10.00%	38.50	55,844	92,888	-1.68	-2.94	0.58	-0.31	-9.96	-26.71
-15.00%	52.00	52,748	87,372	-2.22	-3.82	0.69	-0.46	-12.65	-33.20
-20.00%	68.00	49,734	82,007	-2.82	-4.80	0.78	-0.66	-15.52	-39.83
Exogenous Public Investment (2)									
		2020	**2050**	**2020**	**2050**	**2020**	**2050**	**2020**	**2050**
1.00%	17.00	62,758	105,757	-0.54	-0.64	0.59	0.53	-0.73	-0.68
0.00%	19.00	61,998	104,451	-0.60	-0.71	0.65	0.59	-0.81	-0.76
-5.00%	28.00	59,003	99,307	-0.87	-1.02	0.89	0.79	-1.18	-1.11
-10.00%	39.50	55,898	93,977	-1.19	-1.40	1.16	1.02	-1.64	-1.55
-15.00%	53.50	52,828	88,707	-1.56	-1.83	1.43	1.26	-2.18	-2.07
-20.00%	71.00	49,709	83,356	-1.99	-2.34	1.73	1.51	-2.84	-2.70
Exogenous Public Sector (1+2)									
		2020	**2050**	**2020**	**2050**	**2020**	**2050**	**2020**	**2050**
1.00%	17.00	62,655	105,622	-0.71	-0.77	0.55	0.36	-4.12	-13.41
0.00%	18.50	62,074	104,627	-0.76	-0.83	0.59	0.39	-4.43	-14.39
-5.00%	27.50	59,006	99,379	-1.10	-1.19	0.81	0.53	-6.15	-19.82
-10.00%	39.00	55,835	93,955	-1.50	-1.62	1.06	0.69	-8.10	-25.87
-15.00%	52.50	52,806	88,778	-1.94	-2.10	1.31	0.84	-10.11	-31.98
-20.00%	69.50	49,695	83,464	-2.45	-2.66	1.58	1.00	-12.33	-38.56

debt due to the fact that total public expenditure does not increase as it did in our central case. It shares with the exogenous growth case a larger increase in tax revenue due to smaller contractions in the tax bases. Although the results presented for 2020 suggest a moderate improvement in economic performance, for 2050 we observe a much more pronounced improvement in economic activity due to the effects of higher levels of capital accumulation. Specifically, for the current emission target, GDP losses in 2050 amount to 1.3% in our central case, 1.4% with an exogenous public consumption trajectory, 0.6% with an exogenous public investment trajectory and 0.8% with a completely exogenous public sector.

These results are important both conceptually and methodologically. They highlight the fact that assumptions with respect to public spending patterns are not innocuous. Specifically, for any given emissions target, exogenous public sector behavior suggests substantially smaller GDP and larger tax revenue effects due to changes in public investment spending and substantially larger public debt effects due to the lower levels of public expenditure.

6. Sensitivity Analysis: On the Importance of the Elasticities of Substitution

Table 8 presents the importance of the elasticity of substitution on the economic and budgetary impact of climate policy instruments. The elasticity of substitution between value and energy measures the facility with which firms can substitute capital and labor for energy inputs. The elasticity of substitution between oil and other energy inputs measures the ease with which firms can substitute between oil and non-transportation fuels – coal, natural gas and wind energy. The economic and budgetary effects of CO_2 emissions limits and CO_2 taxation are more sensitive to the specification of the elasticity of substitution between value added and energy than that among energy inputs. In addition, a Cobb-Douglas specification, in which the elasticity of

Table 8: Sensitivity Analysis with respect to the Elasticity of Substitution

(Percent deviations from steady-state baseline unless otherwise indicated)

2020 Emissions Target (Relative to 2005 Levels)	CO_2 Tax (€/tCO_2)	Emissions Level (Mt CO_2)		GDP		Public Debt	
		Central Results					
		2020	**2050**	**2020**	**2050**	**2020**	**2050**
1%	17.00	62.8	105.1	-0.72	-1.25	-2.69	-4.77
0%	18.50	62.2	104.1	-0.78	-1.35	-2.91	-5.17
-5%	27.50	59.1	98.6	-1.13	-1.96	-4.26	-7.56
-10%	38.50	56.0	93.2	-1.54	-2.66	-5.86	-10.41
		Value Added - Energy Elasticity of Substitution - 0.25					
		2020	**2050**	**2020**	**2050**	**2020**	**2050**
1%	24.00	62.8	104.9	-0.88	-1.63	-3.82	-6.78
0%	26.50	62.2	103.8	-0.97	-1.79	-4.21	-7.47
-5%	41.50	59.1	98.1	-1.48	-2.72	-6.54	-11.59
-10%	61.00	56.0	92.3	-2.12	-3.89	-9.53	-16.91
		Value Added - Energy Elasticity of Substitution - 1.0					
		2020	**2050**	**2020**	**2050**	**2020**	**2050**
1%	8.00	62.8	105.6	-0.52	-0.77	-1.27	-2.25
0%	9.00	62.2	104.0	-0.58	-0.86	-1.41	-2.51
-5%	12.50	59.1	98.7	-0.79	-1.17	-1.92	-3.42
-10%	16.50	56.0	93.4	-1.01	-1.50	-2.47	-4.40
		Oil - Other Energy Elasticity of Substitution - 0.25					
		2020	**2050**	**2020**	**2050**	**2020**	**2050**
1%	17.00	62.8	105.2	-0.73	-1.25	-2.68	-4.76
0%	18.50	62.2	104.2	-0.79	-1.35	-2.91	-5.17
-5%	28.00	59.1	98.4	-1.14	-1.96	-4.26	-7.56
-10%	39.00	56.0	93.0	-1.56	-2.70	-5.93	-10.53
		Oil - Other Energy Elasticity of Substitution - 1.0					
		2020	**2050**	**2020**	**2050**	**2020**	**2050**
1%	16.50	62.8	105.1	-0.70	-1.21	-2.61	-4.64
0%	18.00	62.2	104.1	-0.76	-1.32	-2.84	-5.05
-5%	26.50	59.1	98.8	-1.09	-1.89	-4.11	-7.31
-10%	38.00	56.0	93.1	-1.51	-2.62	-5.78	-10.28

substitution between value added and energy is equal to one, yields a change in the economic impact of the CO_2 emissions targets comparable in magnitude to eliminating the mechanisms of endogenous growth in the model.

From the perspective of the 2020 emissions reduction objectives, a lower elasticity of substitution implies that a greater degree of emissions reductions must originate in reduced output as opposed to substitution away from fossil fuels in production. This means that a greater tax is required to achieve the emissions objective and the GDP impacts of the policy are greater. Similarly, the larger tax also means greater revenues and a more positive effect on public debt levels. In contrast, from the perspective of a 17.00 Euros per tCO_2, the greater substitution elasticity implies larger tax interaction effects and larger policy costs. This is a well known result in the taxation literature highlighted by Chamley (1981) who shows that the excess burden of taxation increases as the elasticity of substitution increases.

7. Conclusions and Policy Implications

In this paper, we examine the impact of CO_2 taxation in Portugal as it affects the dual public policy objectives of reducing greenhouse gas emissions and advancing fiscal consolidation efforts. Overall, our results indicate that CO_2 taxes can be an important policy instrument for reducing emissions and promoting fiscal consolidation, although this will come at a cost in terms of economic performance. These results highlight the challenges facing many small, open economies in the EU that must face severe austerity measures designed to promote fiscal consolidation, while simultaneously working to address environmental problems and growth concerns.

We show that a tax of 17.00 Euros per tCO_2 has the technical capacity to limit emissions growth to 62.6 Mt CO_2 in 2020, consistent with the existing climate policy target in Portugal. This value is in line with the current value of forward contracts for 2020 emissions permits in the ICE. This is the price at which the Portuguese Carbon Fund, designed to address any shortfalls in domestic policies, will purchase emissions permits as necessary.

The reduction in emissions associated with CO_2 taxes results from changes in the input structure of the economy that favor capital and labor inputs as well as changes in the energy sector that favor wind energy and reductions in coal demand. The implied increase in energy costs has a negative impact on the firms' net cash flow, household income and domestic demand. These mechanisms lead to a negative impact on economic performance as they result in a 0.7% reduction in GDP by 2020 and of 1.3% in 2050.

The introduction of the CO_2 tax, however, has a positive budgetary impact as it results in a reduction in public debt of 2.7% by 2020. To cushion the negative effects of increased taxation, however, the public sector optimally increases public consumption which results in an overall increase in public expenditure levels. The growing levels of public consumption result, in part, from a shift in expenditure from investment to consumption, which compounds the negative economic impact of the CO_2 tax policy.

Our analysis highlights the fact that limiting the increase in public consumption can contribute to substantially larger reductions in public debt, albeit at a marginally larger cost to economic activity. In turn, we also highlight that reducing public investment, although effective in reducing public debt, produces a much larger negative economic impact. This evokes an important trade-off, particularly pronounced in the present debates regarding austerity measures in the EU, between fiscal consolidation efforts and efforts to promote convergence to EU standards of living. In addition, it highlights the complexity in addressing multiple policy concerns, and those central in understanding the potential for CO_2 taxes to generate public revenues, relevant to many small, energy importing countries facing the need for austerity and budgetary restraint.

Although the results of this paper are important for policy makers in Portugal, the interest is far from parochial. The results in this paper have far reaching policy implications in that CO_2 taxation is not considered in a policy vacuum. We have shown that, overall, achieving reductions in CO_2 emissions through CO_2 taxation seem to result in economic losses but in a more favorable budgetary situation. Accordingly, the policy conditions for the introduction of a CO_2 tax seem to be more favorable in an environment of budgetary stress. A less tight budgetary situation when long-term growth comes to the forefront of the economic policy concerns is a far less conducive environment for the introduction of CO_2 taxes.

In addition, we highlight the importance of a detailed modeling of public sector behavior and of endogenous growth mechanisms. This is critical for the evaluation of the economic and budgetary impacts of CO_2 taxation, an understanding that has been absent in the literature and which can make an enormous difference in terms of the simulation results and their policy implications. The mechanisms of endogenous growth through investment in public capital and human capital have a substantial effect on our understanding of the impacts of CO_2 taxes on social welfare, GDP and public debt. These effects, over the long term, are generally much larger than the effects of increasing the ease with which firms can substitute away from energy inputs in production as defined by the elasticity of substitution parameter, a widely understood factor in the literature.

This paper highlights that endogenous growth is essential in analyzing tax policies because it reflects the actual behavior of the public sector observed in the past. The behavior of the public sector in recent years, and as reflected in our endogenous public sector behavior, has been one of increased public consumption to increase social welfare at the expense of public investment. This has had a detrimental effect on the fundamentals of long term growth and at the cost of increased public debt levels. Fully committing to the austerity measures and not overcompensating in the face of these welfare concerns can substantially influence the costs and trade-off between growth and fiscal sustainability. The implications of these assumptions on the policy are fully examined in the paper and make a substantial difference in understanding the costs of policy. These results highlight the fact that assumptions with respect to public spending patterns are not innocuous. Specifically, for any given emissions target, exogenous public sector behavior suggests substantially smaller GDP effects, larger tax revenue effects and substantially larger budgetary gains.

Finally, this paper opens several interesting avenues for future research and should be regarded as just the starting point of a new line of inquiry. An analysis of the sectoral effects of fiscal instruments in climate policy would provide for the distributional implications of policies and their political economy ramifications. Given the importance of public debt, future research should incorporate endogenous interest rate mechanisms. Finally, due to the importance of employment concerns in the current policy environment, an endogenous unemployment rate would allow for a more detailed analysis of the labor market implications of policies.

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