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DGEP - A Dynamic General Equilibrium Model of the Portuguese Economy: Model Documentation (*)

*Alfredo Marvão Pereira***
The College of William and Mary

Rui M. Pereira
The College of William and Mary

College of William and Mary
Department of Economics
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** Corresponding author

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Alfredo Marvão Pereira
Department of Economics,
The College of William and Mary, Williamsburg, USA
PO Box 8795, Williamsburg, VA 23187
ampere@wm.edu

Rui M. Pereira
Department of Economics,
The College of William and Mary, Williamsburg, USA
PO Box 8795, Williamsburg, VA 23187
rmpereira@wm.edu

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Model Documentation (*)

Alfredo M. Pereira (**)

Dept. of Economics, College of William and Mary, PO Box 8795, Williamsburg, VA 23187
Phone: 804 741 8196 - Email: ampere@wm.edu

Rui M. Pereira

Dept. of Economics, College of William and Mary, PO Box 8795, Williamsburg, VA 23187
Phone: 804 433 0250 - Email: rmpereira@wm.edu

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JEL:

1. Introduction

In this paper we describe the model structure, data, and implementation procedures for the **D**ynamic **G**eneral **E**quilibrium model of the **P**ortuguese Economy, DGEP for short. This model incorporates fully dynamic optimization behavior, endogenous growth, and a detailed modeling of the public sector activities, both tax revenues and consumption and investment spending. Previous versions of this model have been used to evaluate the impact of tax policy [see Pereira and Rodrigues (2002, 2004) and Pereira and Pereira (2011e)], social security reform [see Pereira and Rodrigues (2007)] and, more recently, energy and environmental policy [see Pereira and Pereira (2011a, 2011b, 2011c, 2011d)].

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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, for example, Goulder (1995), Goulder and Bovenberg (1996), Parry (1997), Goulder et al (1999), Parry and Williams (1999), Babiker et al (2003) 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)].

The links between climate policy, the economy and the public budget are fundamental since they directly correlate to some of the most important policy constraints faced in Portugal: the need to enact policies that promote long-term growth and fragile public budgets. These policy constraints are particularly relevant for the less developed energy-importing economies in the EU, such as Greece, Ireland, and Portugal, for example. As EU structural transfers have shifted towards new member states, these countries have been forced to rely on domestic public policies to promote real convergence to EU standards of living. This poses a challenge since growing public spending and, more recently, falling tax revenues and pro-cyclical fiscal policies have contributed to a fast increasing public debt and a sharp need for budgetary consolidation.

In this context of low growth and high public debts, and even more so in light of the austerity policies to be implemented in the foreseeable future in these countries under the auspices of the IMF and the EU, it is imperative to evaluate policies in a framework that captures the relevant policy concerns and designed within the context of the policy environment.

This is particularly pertinent in the context of climate policy analyses in which economic growth and budgetary concerns may appear to make it is easy to dismiss environmental efforts as untimely. Evaluating policies in the appropriate context can provide important insight into whether or not environmental fiscal reform can actually interact positively with the other policy concerns, and – ultimately, whether the current economic and fiscal difficulties should be regarded as a hindrance or as a catalyst for enacting climate policies. This is in line with the recent foremost recommendations of the OECD (2011).

In practice, many of the models used in climate policy analysis developed for the EU, the OECD, and other major national and international institutions contain similar design elements that reflect a distributional and international focus but fail to capture important public debt and economic growth considerations. Models such as the GEM-E3, GEMINI, GREEN, MIT-EPPA and BEAR, among others, have been extensively used in climate policy analysis and share many features. They are each multi-sector, multi-national recursive dynamic with an open economy specification employing Armington trade elasticities. While these features are aptly suited for the analysis of many issues, due to computational complexity, they lack the important dynamics, endogenous growth concerns and a meaningful modeling of the evolution of the stock of public debt and foreign debt, particularly important considerations in the context of weak growth and the need for austerity in a country like Portugal.

The key distinguishing feature of this model in the applied climate policy literature is its focus on endogenous growth and the associated treatment of public sector optimization behavior [see Conrad (1999) and Bergman (2005) for literature surveys]. Productivity enhancing public sector investment in public capital 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 [Greiner (2005) and Gupta and Barman (2009)].

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. This model documentation is based on and expanded from Pereira and Rodrigues (2002).

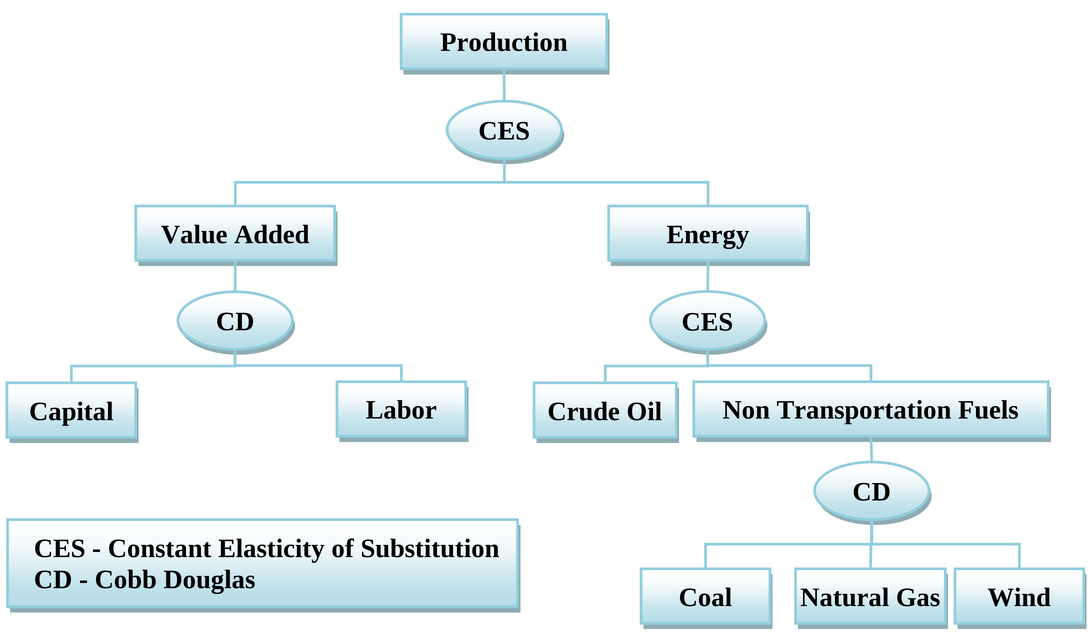
The trajectory for the economy is described by the optimal evolution of eight stock and five shadow price variables - private capital, wind energy capital, public capital, human capital, and public debt together with their shadow prices, and foreign debt, private financial wealth, and human wealth. In 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 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_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.

Private capital accumulation is characterized by (Eq. 3) where physical capital depreciates at a rate δ_K. Gross investment, I_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.

Figure 1: Overview of the Production Structure



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

The energy sector is an integral component of the firms' optimization decisions. Aggregate primary energy demand is produced with CES technology (Eq. 9) in which crude oil, $CrudeOil_t$, and non-transportation fuels, NTF_t are substitutable at a lower rate reflective of the dominance of petroleum products in transportation energy demand and the dominance of coal, natural gas and, to a lesser extent, 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 (Eq. 16) where the physical capital, wind turbines, depreciate at a rate of δ_{RK}. Gross investment in wind energy infrastructure, RI_t, is dynamic in nature and is subject to adjustment costs as private capital.

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 levels given in (Eq. 13), yielding (Eq. 12). Finally, the variational condition for optimal wind energy investment is given in (Eq. 17) and the equation of motion for the shadow price of wind energy is given in (Eq. 18).

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 given in (Eq. 19). These considerations also reinforce the need to state that carbon and CO_2 taxes are identical differing only in their presentation due to the relative molecular weight of the oxidized carbon. The term CO_2 taxation is preferred because it more precisely reflects what is being taxed.

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.

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 in 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.

Table 1: The Model Structure

The Production Sector

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

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

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

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

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

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

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

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

The Energy Sector

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

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

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

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

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

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

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

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

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

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

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

Table 1 (continued): The Model Structure

The Household Sector

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

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

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

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

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

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

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

The Public Sector

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

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

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

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

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

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

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

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

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

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

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

Market Equilibrium

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

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

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

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

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.

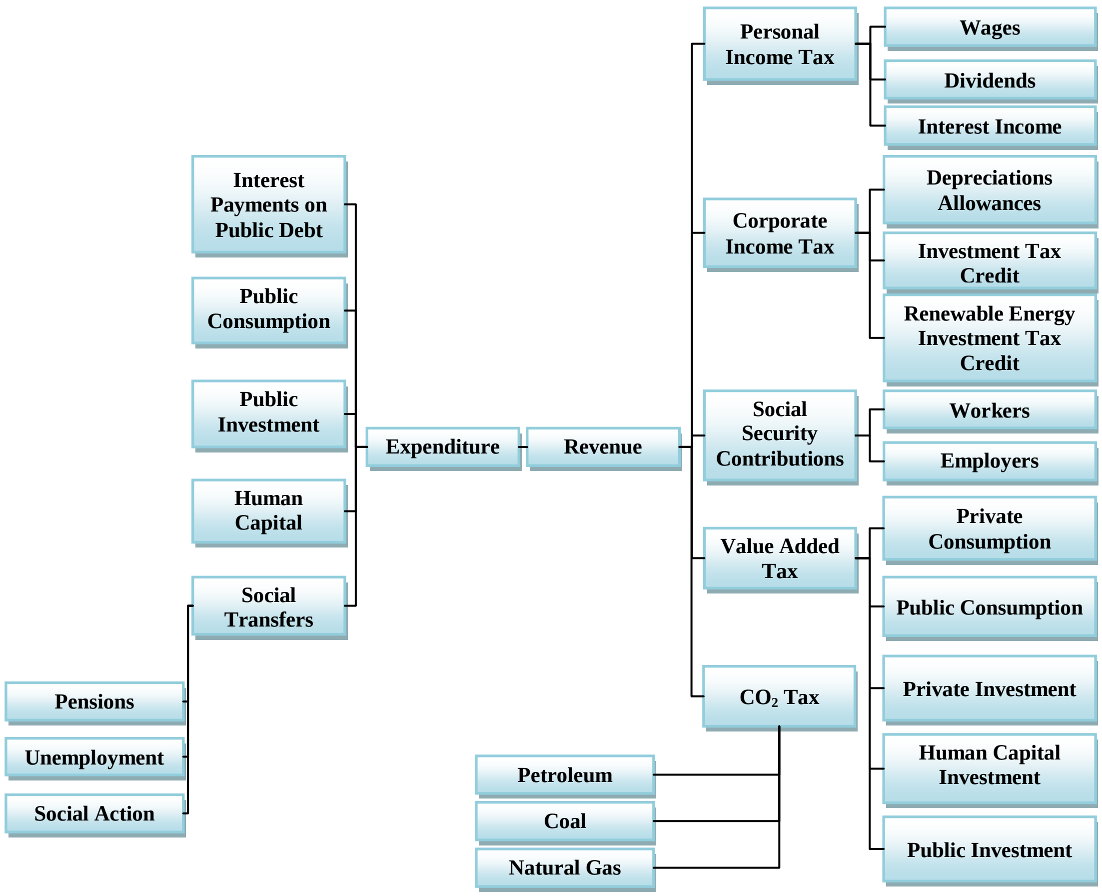
2.4 The Public Sector

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 g. 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, CG_t, and public capital, IG_t, and human capital investment, IH_t.

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.

Figure 2: Overview of the Public Sector



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 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 Computational Implementation and Solution

The dynamic general equilibrium model is fully described by the behavioral equations and accounting definitions and thus constitutes a system of nonlinear equations and nonlinear first order difference equations. No objective function is explicitly specified due to the fact that each of the individual problems (the household, firm and public sector) are set as first order and Hamiltonian conditions. These are implemented and solved using the GAMS (General Algebraic Modeling System) software and the MINOS nonlinear programming solver.

MINOS uses a reduced gradient algorithm generalized by means of a projected Lagrangian approach to solve mathematical programs with nonlinear constraints. The projected Lagrangian approach employs linear approximations for the nonlinear constraints and adds a Lagrangian and penalty term to the objective to compensate for approximation error. This series of subproblems are then solved using a quasi-Newton algorithm to select a search direction and step length.

3. Dataset, Parameter Specification, and Calibration

3.1 General considerations

The model is implemented numerically using detailed data and parameter sets. The data set 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. It allows us to isolate energy use patterns that are not as affected by cyclical variations in the availability of hydrological resources, which will affect thermal electricity generation. In turn, the baseline energy and environmental accounts are presented in Table 3.

Economic data are from the Statistical Annex of the European Economy and budgetary data are from the Portuguese Ministry of Finance (http://www.gpeari.min-financas.pt/analise-economica). Energy sector data are from the Portuguese Directorate General for Geology and Energy (DGGE) of the Ministry of the Economy and Innovation (http://www.dgge.pt). Greenhouse gas emissions data are from greenhouse gas inventories published by the Portuguese Environmental Agency (APA) (http://www.apambiente.pt).

Parameter values are reported in Table 3 and 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 probability of survival, the share of private consumption in private spending, and the different effective tax rates. In turn, consistent with the conditions for the existence of a steady-state, the exogenous variables were set to grow at the observed long-term steady-state growth rate. These parameters play no direct role in the model calibration.

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. This is the case, for example, of the discount rate, the inter-temporal elasticity of substitution, the production elasticities of substitution, the shares for labor and capital, and the public capital externality. Although free, these parameters have to be carefully chosen since their values affect the value of the remaining calibration parameters. Accordingly, they were chosen either using central values or using available data as guidance. The remaining calibration parameters are obtained using the steady-state restrictions.

3.2 Economic Data

Macroeconomic accounts serve as the foundation for the model data. In particular, among the most important pieces of information are contained in the steady state growth rate of the economy and the real long term interest rate. The long term steady state growth rate is computed as the average real growth rate of GDP net of employment growth, yielding the GDP growth rate per employed person.

Figure 3 presents the GDP growth rate per employed person between 1990 and 2008. During this time period, the Portuguese economy grew at an average rate of 2.4% per year, while employment grew by 0.6%. As a result, GDP per employed person grew at an average rate of 1.763% per year. This serves as an appropriate reference period for isolating long term growth trends in the Portuguese economy because we capture periods of high growth, occurring in the early 1990s as well as the recession in 2003 and more recently in 2008.

Table 2 The Basic Data Set

Domestic spending data (% of Y_0)		
Y_0	GDP (billion Euros)	166.228
g_0	Long term growth rate (%)	1.763
VA_0	Value added	85.393
AGG_E_0	Primary energy consumption expenditure	2.557
C_0	Private consumption	62.343
$I_{p,0}$	Private investment	20.312
$I_{w,0}$	Private wind investment	0.064
CG_0	Public consumption	12.285
IG_0	Public capital investment	3.329
IH_0	Public investment in education	7.025
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	6.140
$p_{f,Coal,0}$	Import price of coal	1.890
$p_{f,Natural\ Gas,0}$	Import price of natural gas	4.450
Foreign account data (% of Y_0)		
NX_0	Trade deficit	5.358
$r_0^{FD} FD_0$	Interest payments of foreign debt	2.933
R_0	Unilateral transfers	8.855
CAD_0	Current account deficit	1.908
FD_0	Foreign debt	108.200
Public sector data (% of Y_0)		
T_0	Total tax revenue	39.366
PIT_0	Personal income tax revenue	5.392
CIT_0	Corporate income tax revenue	3.094
VAT_0	Value added tax revenue	12.050
VAT_c	on private consumption expenditure	9.351
VAT_I	on private investment expenditure	1.739
VAT_{cg}	on public consumption expenditure	0.521
VAT_{ig}	on public capital investment expenditure	0.333
VAT_{ih}	on public investment in human capital	0.100
$WSSC_0$	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	7.130
TR_t	Social transfers	15.915
$r_0^{PD} PD_0$	Interest payments of public debt	2.326
DEF_0	Public deficit	1.513
PD_0	Public debt	85.800

Table 2 (continued): The Basic Data Set

Population and employment data (in millions)			
	POP_0	Population	10.608
	L_0	Active population	5.614
	UR_0	Unemployment rate (percent)	5.979
Private Wealth (% of Y_0)			
	HW_0	Human wealth	2827.507
	FW_0	Financial wealth	-22.400
	PVF_0	Present value of the firm	1695.452
	NCF_0	Distributed profits	17.603
Prices			
	w_0	Wage rate	0.034
	q_0^{PD}	Shadow price of public debt	-0.969
	q_0^k	Shadow price of private capital	1.288
	q_0^{rk}	Shadow price of wind energy capital	1.288
	q_0^{kg}	Shadow price of public capital	1.211
	q_0^{hk}	Shadow price of human capital	8.450
Capital stocks (% of Y_0)			
	K_0	Private capital	273.587
	RK_0	Wind energy capital stock	1.381
	KG_0	Public capital stock	97.250
	HK_0	Human capital stock	218.913

Table 3 Baseline Energy and Environmental Accounts

			Primary Energy Demand (PJ)		
	2010	**2020**	**2030**	**2040**	**2050**
Crude Oil	553	659	785	934	1,113
Coal	142	169	201	240	286
Natural Gas	133	158	188	224	267
Wind Energy	22	27	32	38	45
		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 Structural Parameters

Household parameters		
β	Discount rate	0.001
γ	Probability of survival	0.987
g_{POP}	Population growth rate	0.000
σ	Elasticity of substitution	1.000
p_1	Leisure share parameter	0.358
Production parameters		
θ_L	Labor share in value added aggregate	0.520
θ_{KP}	Capital share in value added aggregate	0.290
θ_{KG}	Public capital share in value added aggregate	0.190
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	0.062
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	0.043
μ_k	Adjustment costs coefficient - Private capital	1.473
δ_{Rk}	Depreciation rate - Wind energy capital	0.021
μ_{Rk}	Adjustment costs coefficient - Wind energy capital	2.359
$\dot{A}_i/A_i$	Exogenous rate of technological progress	
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)	90.193
$emission\_factor_{gas}$	Emissions factor for oil (tCO_2 per TJ)	55.820
Public sector parameters - tax parameters		
τ_{pit}	Effective personal income tax rate	0.091
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	0.176
$\tau_{vat,I}$	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	0.144
τ_{wssc}	Workers social security contribution rate	0.157

Table 4 (continued): The Structural Parameters

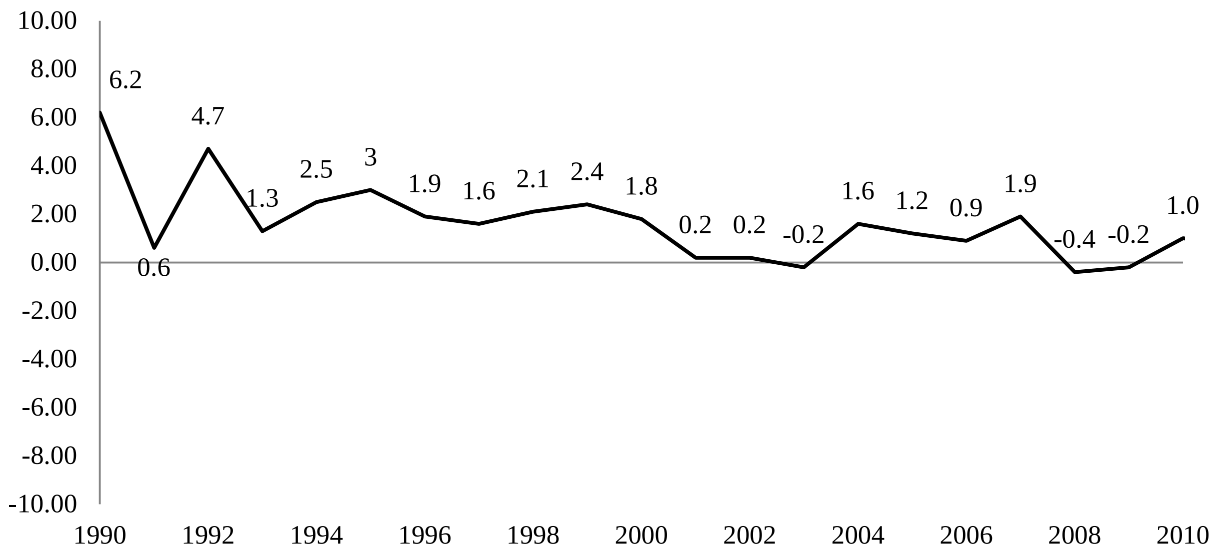
Public sector parameters - outlays parameters		
$1-\ \alpha_C$	Public consumption share	0.182
δ_{kg}	Public infrastructure depreciation rate	0.010
μ_{kg}	Adjustment cost coefficient	3.246
δ_{hk}	Human capital depreciation rate	0.000
μ_{hk}	Adjustment cost coefficient	13.993
Real interest rates		
r, r^{FD}, r^{PD}	Interest rate	2.711

Table 5 presents GDP and its components between 1990 and 2008. Private consumption has been the largest expenditure component over the past ten years, at an average of 64.8% of GDP. Expenditure on fossil fuels is included in the value for consumption and is duly extracted. Gross fixed capital formation follows, accounting for 23.7% of GDP between 1990 and 2008. Gross fixed capital formation includes private investment, public investment as well as wind energy investment. Given the importance of energy in foreign accounts, it is important to highlight that the foreign trade accounts have shown a consistently negative balance with an average trade imbalance valued at 7.8% of GDP.

3.3 Public Sector Data

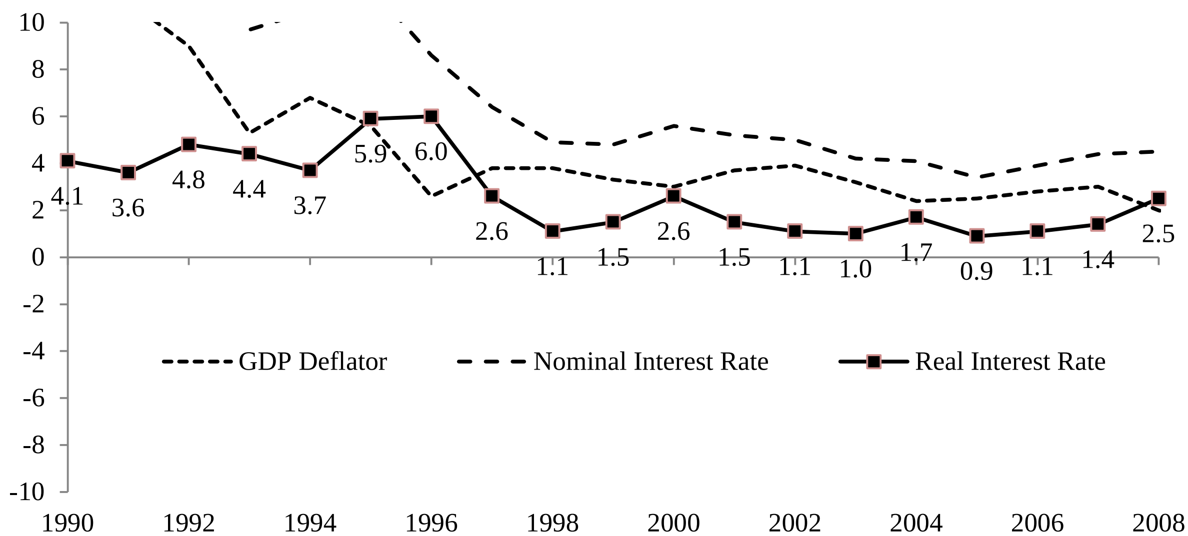
Public deficits in Portugal increased 6.6 percentage points (of GDP) between 2008 and 2009 and has remained high in the years since the financial crisis (Ministry of Finance, 2010). In fact, the recently approved Portuguese State Budget for 2010 considers a reduction in the public deficit to 8.3% of GDP (Ministry of Finance, 2010). Budgetary measures considered with the Stability and Growth Program to promote fiscal consolidation, while focusing on politically difficult policy areas, such as social security and public sector wages, have had a more substantial adverse impact on public investment levels.

Figure 3 GDP Growth Rate per Employed Person



Source: Statistical Annex of the European Economy

Figure 4 Real Long Term Interest Rate



Source: Statistical Annex of the European Economy

Table 5 Economic Data

(millions of Euros at current prices)

	Private Consumption	Gross Fixed Capital Formation	Gross Domestic Production
Average Share	**64.81**	**23.70**	**100.00**
1990	63.4	26.9	69.40
1991	66.0	26.2	79.70
1992	65.5	26.1	77.30
1993	66.5	23.5	80.20
1994	66.1	22.6	87.00
1995	65.3	22.5	92.70
1996	65.2	23.0	98.80
1997	64.3	25.2	105.90
1998	63.5	26.5	114.20
1999	63.8	26.8	122.30
2000	63.9	27.1	129.30
2001	63.3	26.5	135.40
2002	63.0	25.0	138.60
2003	63.4	22.9	144.10
2004	64.1	22.6	149.10
2005	64.9	22.2	155.40
2006	65.4	21.7	163.10
2007	65.0	21.8	166.50
2008	66.5	21.7	163.90
2009	65.8	19.0	166.50
2010	66.2	18.0	170.30

source: Statistical Annex of the European Economy

Public sector accounts in Portugal have been marked by rapidly growing levels of expenditure on social programs and public sector wages. Indeed, public sector tax receipts, clearly vulnerable to economic conditions and business cycle variations, adjust very rapidly to economic conditions, while expenditure levels do not. In addition to these transitory issues, however, there appears to exist structural imbalances with respect to expenditure and financing systems in Portugal. Reflective of this is the fact that the public sector deficit was an average of 4.6% of GDP between 2000 and 2008.

Table 6 Public Spending Data

(Percent of GDP)

	Social Transfers	**Public Consumption**	**Public Capital Investment**	**Public Investment in Education**
Average Share	**15.92**	**19.31**	**3.33**	**7.03**
1990	n.d.	15.4	3.1	n.d.
1991	n.d.	17.2	3.3	n.d.
1992	n.d.	17.3	3.7	n.d.
1993	n.d.	18.0	3.8	n.d.
1994	n.d.	17.8	3.5	n.d.
1995	n.d.	17.9	3.8	n.d.
1996	13.6	18.2	4.2	n.d.
1997	13.5	18.1	4.5	n.d.
1998	13.7	18.3	4.0	n.d.
1999	13.1	18.6	4.1	n.d.
2000	13.5	19.3	3.8	6.7
2001	13.9	19.7	3.9	6.9
2002	14.6	20.0	3.5	7.3
2003	17.0	20.3	3.1	7.4
2004	17.6	20.6	3.1	7.4
2005	18.5	21.4	2.9	7.6
2006	18.8	20.7	2.4	7.1
2007	19.2	20.3	2.3	5.8
2008	19.9	20.8	2.3	n.d.

Source: Statistical Annex of the Portuguese Economy - 2009, Min. Financas, Eurostat

Table 6 presents public sector expenditure activities between 1996 and 2008. The public sector spending data, with the exception public spending on education, are from the Statistical Annex of the European Community; Public education expenditure is taken from the Eurostat data series. On the expenditure side, public consumption and social transfers account for most public spending. Indeed, public consumption, which includes wages and salaries of civil servants, resulted in expenditures equal to 19.3% of GDP and includes 7.0% of GDP as public investment in education. Social transfers, for social security, unemployment and other social programs, accounted for expenditure equal to 15.9% of GDP and public capital investment amounted to 3.3% of GDP.

Table 7 Tax Revenue Data

(Percent of GDP)

	IRS	**IRC**	**VAT and Excise Taxes**	**IVA**	**ISP**	**IA/ ISV**	**Other**	**Social security contributions**
Average Share	**5.39**	**3.09**	**12.05**	**7.35**	**2.05**	**0.84**	**1.82**	**11.8**
1996	5.9	2.8	12.0	6.5	2.6	0.9	2.0	11.0
1997	5.6	3.3	12.1	6.9	2.4	0.9	1.9	11.3
1998	5.5	3.6	12.3	7.0	2.5	1.0	1.8	11.5
1999	5.2	3.5	11.9	6.9	2.2	1.1	1.8	10.8
2000	5.5	3.7	11.5	7.1	1.7	1.0	1.7	11.2
2001	5.5	3.2	11.2	6.9	1.7	0.9	1.7	11.4
2002	5.4	3.3	12.0	7.4	2.0	0.8	1.8	11.7
2003	5.3	2.7	12.3	7.6	2.1	0.7	1.9	12.2
2004	5.1	2.7	11.7	7.2	2.1	0.8	1.7	12.2
2005	5.2	2.5	12.5	7.8	2.0	0.8	1.9	12.5
2006	5.3	2.8	12.7	8.0	2.0	0.8	2.0	12.5
2007	5.5	3.5	12.6	8.1	1.9	0.7	1.8	12.7
2008	5.6	3.6	12.0	8.1	1.5	0.6	1.8	13.0

Source: Portuguese Ministry of Finance and Eurostat

Table 7 presents tax receipts by the Portuguese government between 1996 and 2008 as a percent of GDP. On the revenue side, total tax receipts, excluding social security contributions, were valued at 22.3% of GDP. Indirect taxes, and value added taxes in particular, constitute the largest source of revenue for the public sector. Indirect tax revenue amounted to an average of 12.1% of GDP. The personal income tax contributed revenue equal to 5.4% of GDP, while the remaining tax revenue components accounted for notably smaller values. The corporate income tax accounted for revenue equal to 3.1% of GDP. Social security contributions amounted to 11.8% of GDP, the disaggregation into contributions by employers and employees, together with key tax parameters, follows Pereira and Rodrigues (2001a,2001b).

3.4 Energy Data

Primary energy refers to an energy vector that has not undergone any conversion process (OECD, 2011). Crude oil, therefore, is a primary energy resource while gasoline, diesel, fuel oil and other petroleum derivatives are not. Similarly, electricity is not a primary energy resource. From our standpoint, primary energy demand is the most useful quantity to analyze because we can account for the energy used as well as that lost due to inefficiencies in the transformation process and transmission. For this reason, reference approaches for constructing greenhouse gas emissions inventories rely almost exclusively on primary energy consumption.

Table 8 presents the evolution of primary energy demand in Portugal between 1999 and 2008 in both physical quantities and at current prices. Crude oil dominates, accounting for an average of 79.3% of total primary energy demand in physical units and 66.3% in terms of value. Natural gas has become progressively more important, although accounting for an average of 14.2% of total primary energy demand in physical units. Coal on the other hand has been decreasing in importance. The average share of coal in primary energy demand was 6.6% between 1999 and 2008 in physical units, with a value share that fell from 19.6% to 12.1%. This, together with the increase in the value share for natural gas from 10.2% in 1999 to 21.6% in 2008, provides preliminary evidence for the degree to which natural gas and coal can be substituted in the energy sector.

Primary demand for coal, natural gas, and crude oil is completely satisfied by imported energy resources. This situation results from the fact that Portugal does not produce fossil fuel resources domestically. As such, fossil fuels are imported from abroad and either used directly

Table 8 Primary Energy Demand

	Physical Units / Base Year GDP		
	Coal	**Natural Gas**	**Crude Oil**
Average	**0.082**	**0.077**	**0.321**
1999	0.096	0.049	0.342
2000	0.100	0.054	0.297
2001	0.075	0.057	0.324
2002	0.088	0.069	0.291
2003	0.084	0.067	0.327
2004	0.081	0.084	0.328
2005	0.081	0.098	0.338
2002	0.088	0.093	0.343
2007	0.073	0.095	0.314
2008	0.059	0.105	0.308
	Physical Units (TJ)		
	Coal	**Natural Gas**	**Crude Oil**
1999	159,001	82,175	568,079
2000	166,506	89,632	493,850
2001	123,871	94,766	538,812
2002	146,462	114,735	484,152
2003	140,158	111,197	543,777
2004	134,528	138,898	545,295
2005	135,053	163,453	562,198
2002	146,450	153,834	570,789
2007	121,830	157,975	522,529
2008	97,436	174,303	511,857

Source: www.dgge.pt, balanco energetica and factura energetica.

by firms or processed and refined by domestic firms. As such, the base price of fossil fuels is computed as the import value divided by import quantity.

Crude oil is imported into Portugal at the two ports with refineries, Sines and Porto. 13.4% of the oil imported into Portugal between 2006 and 2008 came from Nigeria. The remaining was imported primarily from Libya (11.6%), Brazil, (11.5%), Algeria (11.1%), and Saudi Arabia (9.9%). Smaller quantities of oil are imported from Iraq, Angola, Iran, Kazakhstan, Norway, Mexico and Venezuela. GALP is the principal importer, refiner and distributer of petroleum and petroleum products in Portugal.

Most of the coal in Portugal is bituminous coal imported from Colombia, accounting for 52.2% of total coal imports. South Africa also exports a significant amount of coal to Portugal, accounting for 31.6% of total coal imports to Portugal. The United States, Norway, Indonesia and the Russian Federation exported smaller quantities of bituminous coal to Portugal between 2006 and 2008.

Natural gas consumption grew in earnest with the completion of the Maghreb-Europe natural gas pipeline in 1996, connecting the Iberian Peninsula to Algerian natural gas resources (DOE, 2011). Between 1994 and 1999, Portugal invested 348 million Euros in natural gas infrastructure, of which 140 million Euros were contributed from the European Regional Development Fund in the framework of the EU Structural and Cohesion Funds (EU, 1999). The Maghreb-Europe natural gas pipeline connects the natural gas fields of Hrassi R'Mel in Sonatrach, Algeria to the natural gas transportation network in the Iberian Peninsula (Galp, 2010). In addition, a liquefied natural gas (LNG) terminal at Sines became operational in 2004 and receives ships with natural gas from Nigeria (REN, 2010). Although the natural gas transportation networks were initially owned by Gas de Portugal, the transmission network was acquired by REN in 2006 from the GALP group.

Wind energy, although still a marginal source of energy has been growing very rapidly over the past ten years due to domestic efforts including both private investment and grants from the Ministry of the Economy and Innovation. In fact, over the five year period between 2004 and 2008, the stock of wind turbines grew by 82.5% per year. This was largely driven by a 51.4 million Euro grant to fund 20 wind projects with a combined installed capacity of 244.5 MW financed by Portugal's Ministry of Economy in 2004. Between 2006 and 2008, wind energy infrastructure grew at an average rate of 22.9% per year, a remarkable rate of growth.

Table 9 Wind Energy Investment

	MW	Value of Stock (million euros)	Investment (Million of euros)	Stock (% GDP)	Investment (% GDP)
Model Data				**1.14**	**0.064**
Stock (Final Year) and Flow (2004- 2008 Avg)	**3,030**	**3,718**	**678**	**2.24**	**0.431**
1997	29	36	13	0.04	0.01
1998	53	65	29	0.06	0.03
1999	57	70	5	0.06	0.00
2000	83	102	32	0.08	0.03
2001	125	153	52	0.12	0.04
2002	190	233	80	0.17	0.06
2003	268	329	96	0.24	0.07
2004	553	679	350	0.47	0.24
2005	1063	1,304	626	0.87	0.42
2006	1699	2,085	780	1.34	0.50
2007	2464	3,023	939	1.85	0.58
2008	3030	3,718	694	2.24	0.42

Source: Direccao Geral de Energia e Geologia (www.dgeg.pt) and Authors' Calculations

Data with respect to wind energy investment is taken as the 2006 value so as not to be overly influenced by the Ministry of Economy investment program. Investment levels are computed by determining the change in the value of the stock in each year. To this effect, a price of 1.227 million dollars per MW of installed capacity was imputed, consistent with estimates for the costs of wind energy technology by the US Department of Energy.

These considerations together with the steady state growth trajectory for the economy result in our reference growth path for fossil fuel demand. Baseline primary demand for crude oil grows to 658.8 PJ, coal demand to 169.1 PJ and demand for natural gas to 158.0 PJ in 2020.

Final energy demand measures the end use of fuels and includes processed fuels such as gasoline, diesel, fuel oil and types of energy that are the result of transformed primary energy resources such as electricity. An analysis of final demand patterns is useful in understanding where each type of energy is being used and in justifying our focus on fossil fuel demand for combustion activities by industry and business.

Petroleum and its derivatives are the dominant energy resources used in Portugal between 1998 and 2008 with the bulk of diesel and gasoline demand in transportation. Electricity demand also constitutes an important component of final energy demand distributed evenly between manufacturing industries, household consumption and services.

Manufacturing energy demand is driven primarily by oil consumption, followed by electricity and natural gas. In fact, oil consumption accounts for 42.3% of final demand in manufacturing, electricity for 39.6% and natural gas for 29.0%. In addition, manufacturing accounts for all of the coal consumption in final demand. The manufacturing industry accounts also for the bulk, 70.1%, of natural gas demand.

The bulk of refined oil products, gasoline and diesel in particular, are consumed in transportation. Transportation demand for oil products is primarily for road transportation. This consists of leisure travel, professional travel and freight transport. The latter two are clearly components of production activities. In addition, professional travel includes commutes to a from the workplace in addition to professional travel activities within the context of particular services and businesses. In fact, 29% of trips by passenger car in the country are by passenger vehicles for professional services, 16% are commutes to and from work, 23% are other passenger vehicle travel and 32% are commercial vehicles (IEP, 1998).

Electric power is produced predominately by the combustion of fossil fuels. Between 1998 and 2008, 73.2% of electric power was produced from thermal sources, particularly coal

Table 10 Thermal Electricity Generation by Fuel Source

Thermal electricity production by source, physical units of fossil fuel input (toe)

	Coal	Natural Gas	Total Petroleum Products	Gasoline	Diesel	Fuel Oil	GPL	Total
1998	2688	362	1864	0	21	1843	0	4914
1999	3255	1285	1852	0	16	1836	0	6392
2000	3206	1095	1135	0	28	1107	0	5437
2001	2948	998	1467	0	28	1439	0	5412
2002	3323	1254	1887	0	28	1858	0	6464
2003	3211	984	852	0	28	823	0	5047
2004	3227	1494	692	0	28	664	0	5413
2005	3320	1941	1357	0	28	1328	0	6618
2006	3277	1760	600	0	18	582	0	5637
2007	2707	1891	541	0	19	522	0	5138
2008	2445	1971	476	0	20	456	0	4891

Share of fossil fuel in thermal electricity production (percent)

	Coal	Natural Gas	Total Petroleum Products	Gasoline	Diesel	Fuel Oil	GPL	Total
1998	54.70	7.37	37.93	0.00	0.42	37.51	0.00	100.00
1999	50.93	20.10	28.97	0.00	0.25	28.72	0.00	100.00
2000	58.97	20.15	20.88	0.00	0.52	20.36	0.00	100.00
2001	54.47	18.43	27.10	0.00	0.52	26.58	0.00	100.00
2002	51.42	19.40	29.19	0.00	0.44	28.75	0.00	100.00
2003	63.62	19.51	16.87	0.00	0.56	16.32	0.00	100.00
2004	59.62	27.60	12.78	0.00	0.52	12.26	0.00	100.00
2005	50.16	29.34	20.50	0.00	0.43	20.07	0.00	100.00
2006	58.13	31.22	10.65	0.00	0.33	10.32	0.00	100.00
2007	52.68	36.79	10.52	0.00	0.37	10.15	0.00	100.00
2008	49.98	40.29	9.72	0.00	0.41	9.31	0.00	100.00

Table 11 Production of Electricity

(Gwh)

Electricity Production

	Thermal Electric	Renewable Energy	Hydroelectric	Wind	Geothermal	Solar	Total
1998	25782	13202	13054	89	58	1	38984
1999	35452	7835	7631	123	80	1	43287
2000	31800	11964	11715	168	80	1	43764
2001	31772	14737	14375	256	105	1	46509
2002	37390	8717	8257	362	96	2	46107
2003	30209	16643	16054	496	90	3	46852
2004	34055	11050	10147	816	84	3	45105
2005	39610	6965	5118	1773	71	3	46575
2006	34559	14482	11467	2925	85	5	49041
2007	32542	14711	10449	4037	201	24	47253
2008	32686	13283	7296	5757	192	38	45969

Share of Electricity Production by Source

	Thermal Electric	Renewable Energy	Hydroelectric	Wind	Geothermal	Solar	Total
1998	66.13	33.87	33.49	0.23	0.15	0.00	100.00
1999	81.90	18.10	17.63	0.28	0.18	0.00	100.00
2000	72.66	27.34	26.77	0.38	0.18	0.00	100.00
2001	68.31	31.69	30.91	0.55	0.23	0.00	100.00
2002	81.09	18.91	17.91	0.79	0.21	0.00	100.00
2003	64.48	35.52	34.27	1.06	0.19	0.01	100.00
2004	75.50	24.50	22.50	1.81	0.19	0.01	100.00
2005	85.05	14.95	10.99	3.81	0.15	0.01	100.00
2006	70.47	29.53	23.38	5.96	0.17	0.01	100.00
2007	68.87	31.13	22.11	8.54	0.43	0.05	100.00
2008	71.10	28.90	15.87	12.52	0.42	0.08	100.00

and natural gas with a diminishing share from fuel oil. Although the shares of electricity generated by wind energy has been growing substantially over the years, hydroelectric power remains the largest source of renewable energy in Portugal driving an average share for renewable energy in electricity production to 28.9%.

4. Concluding Remarks

This paper describes the DGEP model equations, data and parameters. The model is well suited to the analysis of tax reform policies, particularly those under consideration in the context of climate policy in Portugal. It brings together important elements that are imperative in allowing for relevant and contextual policy analysis. In particular, it captures the characteristics of the tax system in great detail, endogenous public sector behavior, incorporates the dynamics of public debt accumulation and features of endogenous economic growth. These features, while unique in applied climate policy analysis, are important in capturing the intersection of environmental, economic and budgetary concerns faced by many small energy importing countries in general and Portugal in particular. Portugal has suffered many years of slow economic growth and soaring public debt levels that have placed increased stress on the economy and the public sector's ability to finance basic operations. These concerns are consistently central in the policy debates in Portugal. Incorporating these concerns is particularly important in contextualizing and ensuring that the evaluation of environmental policies is done in a fashion that is relevant and reflects those concerns that are driving the policy debate.

Despite its many desirable characteristics – dynamics, endogenous growth, detailed public sector accounting – the DGEP model can and should be developed in a variety of directions which will make it even more suitable for policy analysis as applied to the Portuguese case. Some important extensions to this modeling framework include a multi-sector extension [and possibly a multi-country framework as it is typical of many of the institutional general equilibrium models], endogenous unemployment behavior based on nominal rigidities, and endogenous interest rate determination based on idiosyncratic risk premium components.

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