Fossil Fuel Prices and the Economic and Budgetary Challenges of a Small Energy-Importing Economy: The Case of Portugal *

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Abstract

This paper examines the economic and budgetary impacts of fuel prices 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. The fuel price scenarios are based on forecasts by the US Department of Energy (DOE-US) and the International Energy Agency (IEA-OECD) and represent a wide range of projections for absolute and relative fossil fuel prices. In terms of the long term economic impact, our results suggest a 1.9% drop in GDP in the DOE-US scenario and 1.6% in the IEA-OECD scenario. As to the budgetary impact, higher fuel prices lead to lower tax revenues, which, coupled with a reduction in public spending, translate into lower public deficits. Accordingly, increasing fuel prices create an important policy trade off in that they can contribute to reducing the public deficit while hindering economic growth. Finally, our results highlight the importance of public sector spending decisions and the mechanisms of endogenous growth in understanding the impact of fossil fuel prices. Indeed, a scenario of higher fuel prices would, with exogenous public decisions and exogenous economic growth assumptions, result in substantially smaller economic effects and yield adverse budgetary effects.

Keywords: Fuel Prices, Economic Performance, Budgetary Consolidation, Dynamic General Equilibrium, Endogenous Growth, Portugal..

JEL Classifications: : C68, D58, H50, H60, O52, Q43.

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1. Introduction

A great deal of empirical research has highlighted the dynamic relationship between energy prices, energy consumption and economic growth [see, for example, Jorgenson (1998), Hamilton (2003, 2009), He et al. (2010), Korhonen and Ledyaeva (2010), and Tang et al. (2010)]. The literature explores the way in which fossil fuel prices affect economic activity and the mechanisms driving these effects [see, for example, Bruno and Sachs (1985), Backus and Crucini (2000), Brown and Yücel (2002), Esteves and Neves (2004), Sousa (2011)]. What seems to be abundantly clear from this literature is that energy has an important economic impact. As a result, energy prices are acknowledged as an important input for macroeconomic forecasting [see, for example, Esteves and Coimbra (2004), Roeger (2005) and EC (2010)].

The basic mechanism through which imported energy prices affect the economy is through the demand for energy as a basic input to production, with its implications for private investment, labor demand and the overall input mix. In addition, changes in the firms' profitability affect household income, and domestic consumption and savings decisions. These demand responses, in turn, shape the impact of imported energy prices on trade imbalances. Although several other channels have been considered in the literature, the influence of energy as an input to production has been recognized as contributing the most towards explaining the impact of fuel prices on economic performance [see, for example, Borges and Goulder (1984) and Brown and Yücel (2002)]. Indeed, the impact of oil price shocks on a small, oil-importing developing economy has been shown to depend critically on the production structure of the economy [see Schubert and Turnovsky (2010)].

We add to this discussion of the effects of imported fuel prices on economic performance and the trade balance, a focus on the effects of fuel prices on the public sector behavior and account, something that has been largely absent from the literature. Imported fuel prices affect economic performance both in terms of economic growth and of its dynamic feedbacks with the public sector. By affecting economic growth and activity levels, fuel prices affect the size of the tax base and the cost of public funds. This means that any serious forecast of tax revenues has to consider the effects of changing fuel prices. More importantly, by affecting the availability of public funds, fuel prices affect financing for productive public sector education and infrastructure spending, both of which can themselves contribute towards economic growth.

The link between economic growth and the public sector account is fundamental since it directly correlate to some of the most important policy constraints faced by many energy-importing economies in their pursuit of sound policies: 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 European Union (EU). As EU structural transfers have shifted towards new member states, countries such as Ireland, Greece, and Portugal 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 countercyclical policies have contributed to a fast increasing public debt and a sharp need for budgetary consolidation. Furthermore, the need for fiscal responsibility is ever present in the context of the Stability and Growth Programs these countries are subject to in the framework of their participation in the Euro zone and much more so in presence of the EU and IMF led austerity plans these countries are facing.

In this paper we explore the dynamic relationship between imported energy prices, economic performance and the public sector account. Our simulation results are based on a dynamic general equilibrium model which highlights the mechanisms of endogenous growth and provides a detailed specification of public sector activities, both tax revenues and consumption and investment spending. This model is applied to the Portuguese economy, an economy dependent on foreign energy sources and is calibrated to replicate the stylized facts of the Portuguese economy over several business cycles. 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, more recently, energy and environmental policy [see Pereira and Pereira (2011a, 2011b)]. 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. 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 fuel price scenarios are based on forecasts by the US Department of Energy (DOE-US) and the OECD International Energy Agency (IEA-OECD). These forecasts are widely used in policy analysis and macroeconomic forecasting exercises. Indeed, the DOE-US forecasts are commonly used by the US government while the IEA-OECD forecasts are commonly used in the EU. These forecasts correspond to, sometimes dramatically, different scenarios which allow us to examine the impact of differences in relative fossil fuel prices as well as absolute price levels.

The remainder of this paper is organized as follows. Section 2 provides a description of the dynamic general equilibrium model and discusses several implementation issues. Section 3 presents the fuel prices scenarios. Section 4 analyzes the impact of the fossil fuel prices scenarios and provides sensitivity analysis. Finally, section 5 includes a summary and concluding remarks.

2. The Dynamic General Equilibrium Model

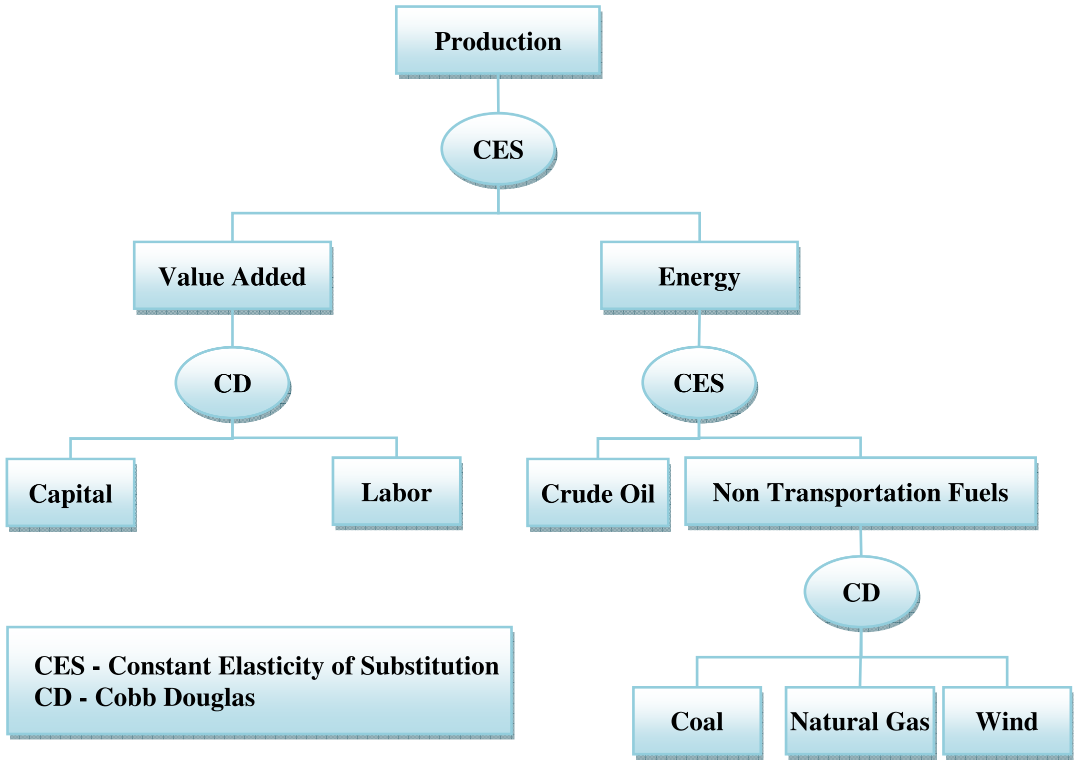
We consider a decentralized economy in a dynamic general-equilibrium framework. All agents are price-takers and have perfect foresight. With money absent, the model is framed in real terms. There are four sectors in the economy – the production sector, the household sector, the public sector and the 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 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.

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_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, where 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).

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. 19), subject to the consolidated budget constraint, (Eq. 20). 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. 20), 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. 21), 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. 22), 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, which is financed 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. 23). Under the assumption of no bequests, households are born without any financial wealth. In

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

The Production Sector

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

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

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

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

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

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

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

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

The Energy Sector

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

$$p_{e,t}E_t = p_{fe,t}FE_t + p_{crude\ oil,t}\, Crude\ Oil_t \tag{10}$$

$$p_{fe,t}FE_t = \sum_{i=1}^{n} p_{f,i,t}F_{i,t} \tag{11}$$

$$p_{f,i,t}\theta_{f,j}F_{i,t} - p_{f,j,t}\theta_{f,i}F_{j,t} = 0 \tag{12}$$

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

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

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

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

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

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

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

The Household Sector

$$U_{a,t} = \frac{\sigma}{\sigma-1}\sum_{v=0}^{\infty}\gamma^{v}\beta^{v}\left[c_{a+v,t+v}^{\frac{\sigma-1}{\sigma}} + B\ell_{a+v,t+v}^{\frac{\sigma-1}{\sigma}}\right] \quad (19)$$

$$\sum_{v=0}^{\infty}\gamma^{v}[1+(1-\tau_r)r_{t+v}]^{-v}(1+\tau_{VAT,C})C_{a+v,t+v} = TW_{a,t} \quad (20)$$

$$TW_{a,t} \equiv HW_{a,t} + FW_{a,t} + PVF_t \quad (21)$$

$$HW_{a,t} = \sum_{m=0}^{\infty}\left(\frac{\gamma}{1+(1-\tau_r)r_{t+m}}\right)^{m}\left((1-\tau_{pit})\left((1-\tau_{wssc})w_{t+m}(\bar{L}-\ell_{a+m,t+m})HK_{t+m} + TR_{t+m}\right) + R_{t+m} - LST_{t+m}\right) \quad (22)$$

$$FW_{a,t} = \left(1+(1-\tau_r)r_{t-1}^{pd}\right)PD_{t-1} + (1-\tau_\pi)NCF_{t-1} - \left(1+r_{t-1}^{fd}\right)FD_{t-1} + (1-\tau_{pit})\left((1-\tau_{wssc})w_{t-1}(\bar{L}-\ell_{a-1,t-1})HK_{t-1}\right) + TR_{t-1} + R_{t-1} - LST_{t-1} - (1+\tau_{vat})C_{a-1,t-1} \quad (23)$$

$$(1+\tau_{vat})C_t = [1-(1+(1-\tau_r)r_{t-1})^{\sigma-1}\gamma\beta^{\sigma}](HW_t + (PD_t - FD_t) + PVF_t) \quad (24)$$

$$\ell_t = \left(\frac{B(1+\tau_{vat})}{(1-\tau_{wssc})(1-\tau_{pit})w_t(1-UR_t)HK_t}\right)^{\sigma}C_t \quad (25)$$

The Public Sector (26)

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

$$PD_{t+1} = (1+r_t^{PD})PD_t + (1+\tau_{vat,cg})CG_t + (1+\tau_{vat,ig})IG_t + (1+\tau_{vat,ih})IH_t + TR_t - T_t \quad (27)$$

$$T_t = PIT_t + CIT_t + VAT_t + FSSC_t + WSSC_t + LST_t \quad (28)$$

$$KG_{t+1} = (1-\delta_{kg})KG_t + IG_t - \mu_{kg}\frac{IG_t^2}{KG_t} \quad (29)$$

$$HK_{t+1} = (1-\delta_{hk})HK_t + IH_t - \mu_{hk}\frac{IH_t^2}{HK_t} \quad (30)$$

$$\frac{q_{t+1}^{PD}}{(1+(1-\tau_r)r_{t+1}^{PD})} = \frac{q_t^{PD}}{(1+(1-\tau_r)r_t^{PD})} \quad (31)$$

$$q_{t+1}^{PD} = (1-\alpha_c)\left(\frac{C_t\ell^{p_1}}{CG_t}\right)^{\alpha_C}(1+(1-\tau_r)r_t^{PD}) \quad (32)$$

$$-q_{t+1}^{PD} = q_{t+1}^{kg}\left(1-2\mu_{kg}\frac{IG_t}{KG_t}\right) \quad (33)$$

$$q_t^{KG} = \frac{q_{t+1}^{PD}}{(1+(1-\tau_r)r_{t+1}^{PD})}\left((\tau_\pi(1-\tau_{cit})+\tau_{cit})\frac{\partial Y_t}{\partial KG_t}\right) + \frac{q_{t+1}^{kg}}{(1+(1-\tau_r)r_{t+1}^{PD})}\left((1-\delta_{kg}) + \mu_{kg}\left(\frac{IG_t}{KG_t}\right)^2\right) \quad (34)$$

$$-q_{t+1}^{PD} = q_{t+1}^{hk}\left(1-\mu_{hk}\frac{IH_t}{HK_t}\right) \quad (35)$$

$$q_t^{HK} = \frac{q_{t+1}^{PD}}{(1+(1-\tau_r)r_t^{PD})}\left((\tau_{pit}(1-\tau_{fssc}) - (1-\tau_\pi)(1+\tau_{cit})\tau_{fssc} + \tau_{wssc})\frac{\partial Y_t}{\partial HK_t}\right) + \frac{q_{t+1}^{hk}}{(1+(1-\tau_r)r_{t+1}^{PD})}\left((1-\delta_{hk}) + \mu_{hk}\left(\frac{IH_t}{HK_t}\right)^2\right) \quad (36)$$

Market Equilibrium (37)

$$(1-UR_t)LS_t = L_t^d$$

$$Y_t = \sum_{i=1}^{n}p_{f,i,t}F_{i,t} + p_{crude\ oil,t}Crude\ Oil_t + C_t + I_{p,t} + I_{w,t} + CG_t + IG_t + IH_t - NX_t \quad (38)$$

$$FD_{t+1} = (1+r_t^{fd})FD_t + NX_t - R_t \quad (39)$$

$$FW_t = PD_t - FD_t \quad (40)$$

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. 24) and an age-independent coefficient enables us to write the aggregate demand for leisure, (Eq. 25), as a function of aggregate consumption.

2.4 The Public Sector

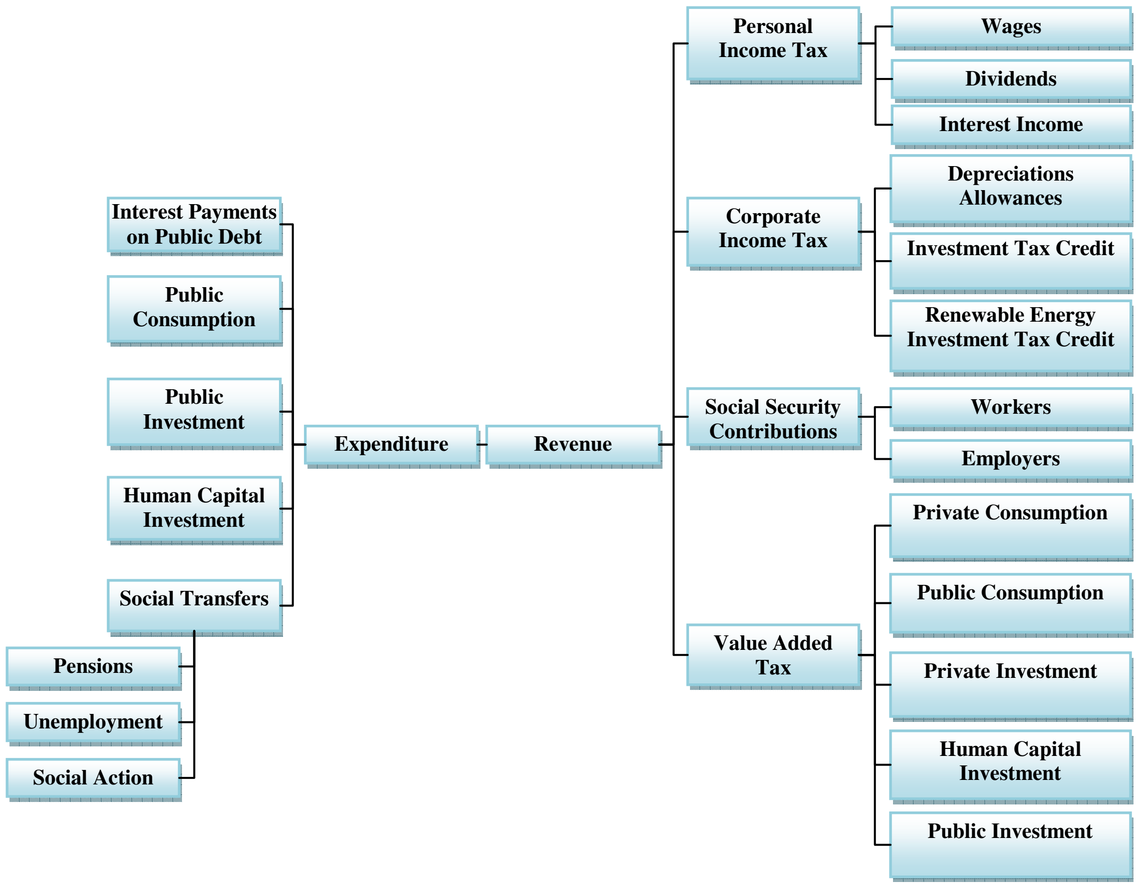
The equation of motion for public debt, PD_t, (Eq. 27), reflects the fact that the excess of government expenditures over tax revenues has to be financed by increases in public indebtedness. Total tax revenues, T_t, (Eq. 28) include personal income taxes, PIT_t, corporate income taxes, CIT_t, value added 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 in both public capital and human capital, IG_t and 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. 26), 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. 27), the stock of public capital, (Eq. 29), and the stock of human capital, (Eq. 30).

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. 31) for public debt, (Eq. 32) for public consumption, (Eq. 33-34) for public investment, and (Eq. 35-36) for investment in human capital.

2.5 The Foreign Sector

The equation of motion for foreign financing, FD_t, (Eq. 39), 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. 38), 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. 37-40). The labor-market clearing condition is given by (Eq. 37) where a structural unemployment rate of UR_t is exogenously defined. 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. 38) and (Eq. 39). Finally, the financial market equilibrium, (Eq. 40), 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

Table 2: The Dynamic General Equilibrium Model - 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 (con't): The Dynamic General Equilibrium Model - The Basic Data Set

Population and employment data (% of POP_0)			
	POP_0	Population (in thousands)	10.608
	L_0	Active population	5.614
	UR_0	Unemployment rate	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

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 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.

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

Table 3: The Dynamic General Equilibrium Model – 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	
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 3 (con't): The Dynamic General Equilibrium Model – 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

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 elasticities of substitution, the shares for labor and capital in production, 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 as discussed above.

3. On the Fuel Price Scenarios

The fuel price scenarios are based on forecasts developed by the US Department of Energy, (DOE-US) and the International Energy Agency (IEA-OECD), through 2035, as

Table 4: Fuel Price Scenarios

(2008=100.00)

	2010	2020	2030	2040	2050
	DOE-US				
Reference Fossil Price Index	97.89	102.11	114.67	128.06	134.42
Petroleum and its Products	98.55	108.75	124.03	140.08	147.81
Coal	99.42	96.72	98.90	102.70	103.80
Natural Gas	93.52	80.18	92.49	105.11	111.33
Coal/Natural Gas Ratio	106.31	120.63	106.93	97.71	93.23
Oil/Natural Gas Ratio	99.12	112.43	125.41	136.40	142.40
	IEA-OECD				
Reference Fossil Price Index	96.79	102.36	116.40	122.17	129.27
Petroleum and its Products	96.91	102.89	118.32	124.67	132.48
Coal	93.00	86.38	90.72	92.51	94.70
Natural Gas	100.39	117.25	135.85	143.50	152.91
Coal/Natural Gas Ratio	92.64	73.67	66.78	64.46	61.93
Oil/Natural Gas Ratio	104.20	119.12	130.43	134.77	139.88

presented in the *Annual Energy Outlook* of the US Department of Energy (2010). After 2035, we assume that prices grow at the average growth rate for the last ten years of the forecast. Table 4 presents the forecasts including a composite energy price index and relative price ratios.

The price scenarios present a range of different level and relative price movements by 2050, including changes in oil prices of 47.8% and 32.5%, in coal prices of 3.8% and -5.3%, and in natural gas prices of 11.3% and 52.9%, in the DOE-US and IEA-OECD scenarios, respectively. Naturally, oil prices tend to dominate the reference fuel price index, relative to coal and natural gas prices, because the demand for oil accounts for more than 65% of primary energy demand and for close to 80% of the value of imported energy. Overall, the reference fossil fuel price index is projected to grow by 34.4% in the DOE-US scenario and by 29.3% in the IEA-OECD scenario by 2050.

In the shorter term we have even more interesting differences. While the change in the composite price index by 2020 is similar for both the DOE-US and IEA-OECD scenarios, these scenarios differ markedly for coal and natural gas prices, with coal prices growing by 20.6%

relative to natural gas prices in the DOE-US scenario and falling by 26.3% relative to natural gas prices in the IEA-OECD scenario. In addition, crude oil prices fall by more in the IEA-OECD scenario and remain lower throughout the forecast horizon. The two forecasts show a very different intertemporal trajectory for coal and natural gas prices. Natural gas prices grow by more than any other fuel in the IEA-OECD forecast while the DOE-US forecast depicts an initial decline and subsequent increase in the price of natural gas, returning to 2008 levels by 2035. Coal prices, on the other hand, show a meaningful drop in price in the IEA-OECD scenario, while remaining relatively stable in the DOE-US scenario.

4. The Impact of Fossil Fuel Prices

The impacts of the price scenarios are presented in Tables 5 and 6. In the discussion below, unless indicated otherwise, all figures are deviations from the steady state baseline.

4.1 The Impact on Energy Demand

Differences in relative prices between the two scenarios are particularly pronounced early in the model horizon. While by 2020 the actual fossil fuel price index based on forecasted demand patterns increases by 1.5% in both the DOE-US and the IEA-OECD scenarios, we observe a 0.6% reduction in fossil fuel demand in the DOE-US scenario and a 1.1% increase in the IEA-OECD scenario. This is due to the larger drop in fuel prices earlier in the model horizon in the IEA-OECD price scenario. By 2050, however, primary demand for fossil fuels falls in both the DOE-US and IEA-OECD scenarios, by 12.2% and 8.8%, respectively.

The differences with respect to the aggregate impact on primary energy demand underscore important differences in the composition of energy demand. In the DOE-US scenario we observe an increase in natural gas consumption of 14.3%. This is due primarily to the 19.8%

drop in natural gas price by 2020 together with the larger array of substitution possibilities for natural gas in industry and electric power. Indeed, the uptake in natural gas demand drives, in part, a 5.4% reduction in coal demand and a 10.6% reduction in 2010 and a 4.1% reduction in 2020 in investment in wind energy, driving an accumulated fall of 2.9% in the stock of wind energy infrastructure by 2020. The demand for crude oil by firms falls by 2.9%. In this scenario, therefore, we observe a shift in the energy mix towards natural gas.

The IEA-OECD scenario considers, on one hand, substantially lower coal prices, falling 13.7% by 2020 and, on the other, much larger natural gas prices, growing 17.3% by 2020. As a result, we observe a 20.6% growth in the demand for coal and a drop in the demand for natural gas of 11.6%. The increase in natural gas prices contributes, in a very important way, to the 14.1% increase in investment in wind energy infrastructure, corresponding to an accumulated increase in the stock of wind turbines of 3.1% in 2020 and of 11.9% in 2050. Oil demand falls by 0.8% due to more limited technological substitution possibilities and smaller crude oil price movements.

4.2 The Macroeconomic Impact

Higher fuel prices and larger expenditures on energy inputs have a negative impact on the firms' net cash flow. Accordingly, businesses reduce private investment by 1.3% and 3.5% in the DOE-US scenario and by 1.2% and 3.0% in the IEA-OECD scenario in 2020 and in 2050, respectively. This is consistent with the larger share of wind investment in the IEA-OECD scenario than in the DOE-US scenario. The reduction in private investment drives down the stock of private capital which in turn has a negative impact on economic growth. The fact that the reduction in the stock of capital is smaller than the reduction in energy consumption suggests

Table 5: Economic and Budgetary Impact of the DOE-US Fossil Fuel Price Scenario

(Deviations from steady state baseline unless otherwise indicated)

	2010	2020	2030	2040	2050
Composite Price Level	97.86	101.52	113.99	127.08	133.18
Energy					
Primary Energy	0.85	-0.93	-5.16	-8.66	-10.16
Fossil Energy	1.12	-0.59	-5.70	-10.16	-12.22
Crude Oil	0.97	-2.92	-8.88	-13.80	-16.10
Coal	-1.65	-5.42	-2.76	-1.78	-1.20
Natural Gas	4.72	14.28	4.38	-3.98	-7.86
Wind Energy Infrastructure	-0.86	-2.86	-2.09	-0.16	1.51
Macroeconomic					
Growth Rate	1.78	1.69	1.68	1.70	1.71
GDP	0.38	0.06	-0.64	-1.38	-1.92
Consumption	-1.22	-1.23	-1.24	-1.25	-1.26
Investment	0.06	-1.33	-2.46	-3.12	-3.52
Private Capital	0.02	-0.25	-0.95	-1.75	-2.41
Investment Wind Energy	-10.55	-4.07	3.32	5.49	5.81
Labor Demand	0.70	0.53	0.13	-0.29	-0.56
Energy Imports	-0.84	2.08	9.74	16.69	19.65
Foreign Debt (percent of GDP)	104.22	86.65	70.65	59.96	54.26
Foreign Debt	-3.68	-19.92	-34.71	-44.58	-49.85
Public Sector					
Public Debt (percent of GDP)	84.25	77.84	72.23	68.50	66.41
Public Debt	-1.81	-9.28	-15.81	-20.16	-22.60
Total Expenditure	-3.04	-3.19	-3.26	-3.26	-3.27
Public Consumption	-4.84	-4.77	-4.59	-4.42	-4.30
Public Investment	-1.45	-2.65	-3.67	-4.32	-4.78
Human Capital Investment	-0.69	-0.75	-0.80	-0.84	-0.88
Public Capital	-0.08	-0.49	-1.07	-1.71	-2.33
Human Capital	-0.01	-0.03	-0.06	-0.08	-0.11
Total Tax Revenue	-0.14	-0.42	-1.01	-1.61	-2.00
Personal Income Tax	0.40	-0.28	-1.65	-3.01	-3.90
Corporate Income Tax	0.62	0.72	-0.13	-1.25	-2.02
Value Added Tax	-1.20	-1.43	-1.62	-1.73	-1.81
Social Security Contributions	0.42	0.01	-0.94	-1.90	-2.55

Table 6: Economic and Budgetary Impact of the IEA-OECD Fossil Fuel Price Scenario

(Deviations from steady state baseline unless otherwise indicated)	2010	2020	2030	2040	2050
Composite Price Level	96.75	101.52	114.75	120.09	126.63
Energy					
Primary Energy	1.82	1.43	-2.52	-4.08	-5.69
Fossil Energy	2.08	1.13	-4.13	-6.48	-8.80
Crude Oil	1.63	-0.79	-6.78	-9.43	-12.06
Coal	6.92	20.56	20.30	20.05	19.76
Natural Gas	-1.18	-11.63	-19.22	-22.57	-25.81
Wind Energy Infrastructure	0.45	3.11	6.60	9.52	11.93
Macroeconomic					
Growth Rate	1.79	1.69	1.71	1.71	1.72
GDP	0.34	0.04	-0.61	-1.10	-1.60
Consumption	-1.01	-1.02	-1.03	-1.04	-1.05
Investment	0.12	-1.23	-1.98	-2.58	-3.01
Private Capital	0.03	-0.22	-0.82	-1.44	-2.02
Investment Wind Energy	6.09	14.05	16.14	17.68	18.19
Labor Demand	0.60	0.43	0.06	-0.20	-0.47
Energy Imports	-1.39	1.64	9.32	12.48	15.85
Foreign Debt (percent of GDP)	104.88	89.47	76.80	67.73	62.42
Foreign Debt	-3.07	-17.32	-29.02	-37.40	-42.31
Public Sector					
Public Debt (percent of GDP)	84.48	78.86	74.35	71.12	69.15
Public Debt	-1.53	-8.08	-13.34	-17.11	-19.40
Total Expenditure	-2.57	-2.70	-2.73	-2.76	-2.77
Public Consumption	-4.09	-4.02	-3.85	-3.74	-3.63
Public Investment	-1.19	-2.30	-3.04	-3.64	-4.09
Human Capital Investment	-0.58	-0.63	-0.67	-0.71	-0.74
Public Capital	-0.07	-0.41	-0.91	-1.43	-1.96
Human Capital	-0.01	-0.03	-0.05	-0.07	-0.09
Total Tax Revenue	-0.09	-0.36	-0.92	-1.30	-1.67
Personal Income Tax	0.35	-0.25	-1.57	-2.45	-3.27
Corporate Income Tax	0.53	0.63	-0.32	-0.92	-1.62
Value Added Tax	-0.98	-1.21	-1.33	-1.44	-1.52
Social Security Contributions	0.39	-0.01	-0.90	-1.51	-2.12

that with growing fuel prices firms substitute capital inputs for energy inputs. Over the long term, energy price increases have a negative impact on employment as well, despite short term employment gains in both the DOE-US and IEA-OECD scenarios. This is, however, consistent with the substitution of labor inputs for energy inputs.

Given the impact of fuel prices on the private inputs (which as we will see next section is mirrored by reductions in public and human capital investment), it is no surprise that higher fuel prices, primarily higher oil prices, have a negative impact on GDP. In 2050, in the DOE-US scenario GDP falls by 1.9% while in the IEA-OECD scenario GDP falls by 1.6%. Short term reductions in fossil fuel prices stimulate a marginal increase in economic activity early in the model horizon in both scenarios. Indeed, the short term increase in GDP in 2020 in the DOE-US scenario is entirely driven by falling natural gas prices while that in the IEA-OECD scenario results from dropping crude oil and coal prices.

The feedback between domestic demand, production and income defines the impact of fuel prices on private consumption. The net effect of this process is a reduction in private consumption of 1.2% in the DOE-US scenario and 1.0% in the IEA-OECD scenario. Consumption smoothing behavior by households implies that these reductions are relatively constant throughout the model horizon.

The net effect of fuel price increases on the trade balance depends on the response of non-energy demand. Expenditure on fossil fuels increases by 2.1% in the DOE-US scenario and 1.6% in the IEA-OECD in 2020 and up to 19.7% and 15.9% in 2050, respectively, which places positive pressure on the trade balance. This increase in fossil fuel expenditure, however, is offset by reductions across the board in domestic final demand. As a result, the net effect of higher energy prices on foreign debt is negative. Although foreign debt as a fraction of the GDP falls, over the long term these remain at 54.3% in the DOE-US scenario and 62.4% in the IEA-OECD.

4.3 On the Budgetary Impact

The impact of fuel prices on activity levels affects the size of the tax bases and public sector tax receipts. Contracting tax bases in the DOE-US and IEA-OECD scenarios drive a 0.4% reduction in tax revenue by 2020 and of 2.0% and 1.7% in 2050. These changes are driven primarily by changes in VAT tax revenues, the largest source of public revenues. These changes in turn are directly related to the changes in private consumption, the largest component of its tax base. The falling share of VAT receipts in both scenarios is accompanied by increasing shares for social security contributions, reflective of the shift towards employment in production. In absolute terms, the reduction in revenues associated with fuel price increases is led by a reduction in VAT revenue of 1.4% in the DOE-US scenario and 1.2% in the IEA-OECD.

On the expenditure side, the public sector optimally adjusts its spending patterns in response to fuel price variations. Total public expenditure falls in the long term by 3.3% and 2.8% in the DOE-US and IEA-OECD scenarios while public consumption itself falls by 4.3% and 3.6%, respectively. Equally important, in the long-term, public capital investment falls by 4.8% in the DOE-US scenario and by 4.1% in the IEA-OECD scenarios while public investment in human capital falls by 0.9% and 0.7%, respectively. This reduction in public investment activities further reinforces the negative effect of declining private inputs on production activities and has a negative impact on economic performance.

Overall despite tax revenue losses, the reduction in expenditure levels reduces public debt levels in 2020 by 9.3% and 8.1% in the DOE-US and IEA-OECD scenarios and by 22.6% and

19.4% by 2050. This leads to public-debt to GDP ratios in the long term of 66.4% in the DOE-US scenario and 69.2% in the IEA-OECD scenario.

4.4 Sensitivity Analysis with respect to Model Structure and Key Model Parameters

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 [see Jacoby et al. (2006), Wissema and Dellink (2007), and Schubert and Turnovsky (2010)]. Here, we start by analyzing how sensitive our results are to the specification of these parameters. Simulation results are reported on Table 7. In general, changes in energy demand due to higher fuel prices are significantly amplified by a greater elasticity of substitution between energy and value added and lower elasticity of substitution among energy inputs. Changes in the economic impact as well as the budgetary impact are, however, less pronounced across different elasticity of substitution assumptions, in particular for that among different energy inputs.

Endogenous growth and endogenous public sector behavior are key features of our model. Table 8 presents the sensitivity of our results to these aspects of the model. The absence of endogenous growth coupled with exogenous public sector behavior greatly affects the evaluation of the impact of fuel prices. Exogenous decisions imply higher levels of investment spending which leads to substantially smaller output losses in the long term – the measured output losses under exogenous public sector decision would be around 40% of the levels identified under our central modeling assumptions. This reduction in the observed GDP loss comes together with a marginal improvement in the trade deficit and the foreign debt position, substantially lower than the one identified in the central case – the observed improvements shrink by a factor of seven. In addition, and naturally, tax revenues decline by a lower amount as

Table 7: Sensitivity Analysis with respect to the Elasticities of Substitution

(percent deviation from baseline in 2050)

Elasticity of Substitution between Value Added and Energy

Elasticity of Substitution	Energy	GDP	Foreign Debt	Public Debt
			DOE-US	
0.1	-1.72	-1.71	-52.53	-23.85
0.4	-10.16	-1.92	-49.85	-22.60
1.0	-26.04	-2.30	-44.62	-20.14
			IEA-OECD	
0.1	1.69	-1.42	-44.22	-20.30
0.4	-5.69	-1.60	-42.31	-19.40
1.0	-19.88	-1.94	-38.54	-17.61

Elasticity of Substitution between Crude Oil and other Energy Sources

Elasticity of Substitution	Energy	GDP	Foreign Debt	Public Debt
			DOE-US	
0.1	-12.09	-1.93	-50.26	-22.77
0.4	-10.16	-1.92	-49.85	-22.60
1.0	-5.65	-1.89	-48.91	-22.19
			IEA-OECD	
0.1	-5.95	-1.60	-42.32	-19.41
0.4	-5.69	-1.60	-42.31	-19.40
1.0	-5.11	-1.60	-42.29	-19.38

Table 8: Sensitivity Analysis with respect to the Model Structure

(percent deviation from baseline in 2050)

	Energy	GDP	Foreign Debt	Public Debt
		DOE-US		
Central Modeling Assumptions	-10.16	-1.92	-49.85	-22.60
Exogenous Public Consumption (1)	-10.13	-1.89	-24.49	5.86
Exogenous Labor (2)	-9.81	-1.54	-31.75	-13.10
Exogenous Public Investment (3)	-9.46	-1.16	-34.45	-16.12
Exogenous Public Sector (1) + (2) + (3)	-9.19	-0.86	-6.64	9.67
		IEA-OECD		
Central Modeling Assumptions	-5.69	-1.60	-42.31	-19.40
Exogenous Public Consumption (1)	-5.50	-1.44	-20.90	4.63
Exogenous Labor (2)	-5.35	-1.28	-26.89	-11.24
Exogenous Public Investment (3)	-5.04	-0.95	-29.31	-13.96
Exogenous Public Sector (1) + (2) + (3)	-4.81	-0.71	-5.79	7.86

well under exogenous public sector decisions. In this case, however, lower tax revenues would directly translate into higher deficits and we would project increases in the public debt to GDP position, not the reduction identified under our central modeling assumptions. Overall, ignoring endogenous public sector decisions and endogenous long-term growth would lead to a serious misrepresentation of the effects on fuel prices on economic activity, GDP and foreign debt position, and on the public budget.

In concluding this sensitivity analysis section, it is important to highlight that the order of magnitude of the changes in the economic and budgetary results due to differences in the elasticities of substitution – a widely understood effect – pale in comparison with the changes generated by the endogenous growth mechanisms and endogenous public sector behavior – effects largely ignored in the literature. This is in sharp contrast to the notion that the effect of oil as an input to production is driven by the share of oil in production and the elasticity of substitution between oil and other inputs [see, Schubert and Turnovsky (2010)].

5. Summary and Concluding Remarks

In this paper, we examine the economic and budgetary impacts of fossil fuel prices 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. Increasing fuel prices, consistent with the DOE-US and the IEA-OECD fuel price scenarios, both dominated over the long term by increasing oil prices, lead to an increase in firms' operating costs which reduces energy consumption, employment and private investment, while shifting the input mix towards labor and capital. These changes lead to a long term drop of 1.9% in GDP by 2050 in the DOE-US scenario and 1.6% in the IEA-OECD scenario. Although the value of fossil fuel imports increases substantially over time, the contraction of economic activity due to higher fuel prices leads to an overall improvement in the foreign account position. Finally, higher fuel prices have an important impact on the public sector account and public investment activities. Contracting tax bases reduce revenues, led by reductions in VAT revenues, while a reduction in public spending, and public investment in particular, further compounds the long-term output and employment losses. These are, however, consistent with an optimally shrinking public sector which leads to a reduction in the deficit and lower public debt to GDP levels.

Fuel prices, by affecting economic performance, directly affect the pursuit of policies to promote long term growth and convergence to EU standards of living. Indeed, our results indicate that higher fuel prices have a negative effect on long-term growth, and likely on real convergence. In addition, fuel prices have a pronounced impact on the public sector and thereby important policy implications in the context of the Stability and Growth Programs in general and the current quest for fiscal consolidation and austerity plans in particular. Two important points emerge. First, through their negative impact on economic performance, increasing fuel prices reduce tax revenues, particularly once the feedbacks with public investment are taken into account. Second, the public sector optimally reduces investment activities. While this further compounds output losses, it alleviates pressure on the budget. Accordingly, increasing fuel prices create an important policy trade off in that they can contribute to reducing the public deficit while hindering real convergence.

The endogeneity of public sector decisions plays an important role in determining the impact of increasing fuel prices. Specifically, tax revenue losses reduce the funds available for productive public sector activities. This affects the level of economic activity and, as a result, the public sector account. By ignoring these feedbacks, exogenous growth assumptions result in substantially smaller GDP losses and lower foreign debt to GDP and public debt to GDP gains in the presence of increasing fuel prices. In particular, in the absence of changes in public expenditure behavior, tax revenues fall substantially less than they otherwise do which reflects a smaller loss in the tax base. In an environment of exogenous public spending decisions characterized by great inertia in reducing spending, however, any changes in tax revenues translate directly into changes in the public deficit. Accordingly, with exogenous public spending, following the status quo patterns one would project a deterioration of the public debt to GDP position with increasing fuel prices while we actually project an improvement.

From a methodological perspective, if the feedback mechanisms on public spending are ignored, any budgetary projections are liable to seriously misrepresent the effects of higher fuel prices. Namely, that higher fuel prices may actually lead to optimal spending adjustments which can improve the budgetary situation.

From a policy perspective, increasing fuel prices, which would require an optimal reduction in public spending, together with the ongoing inability to adjust spending in light of new budgetary conditions, have certainly contributed to the current budgetary woes. More importantly, increasing fuel prices will require even more significant financial consolidation efforts under the current EU and IMF austerity plans if budgetary consolidation is to actually be achieved. Failure to engage in strong fiscal restraint, optimal in the presence of tax revenue losses due to higher fossil fuel prices, i.e., ignoring the impact of fuel prices in this context, may prove to be the best recipe for missing budgetary consolidation targets.

To conclude, it should be mentioned that although the results in this paper are directly relevant for policy making in Portugal, their interest and applicability is far from parochial. Concerns over economic growth and fiscal sustainability are at the forefront of policy discussion in many countries. Furthermore, EU countries such as Greece and Ireland are facing similar budgetary problems and equally difficult austerity plans. Many of the lessons presented here and applicable to Portugal can easily be used to inform policy making in these countries as well.

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