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On the Relative Roles of Fossil Fuel Prices, Energy Efficiency, and Carbon Taxation in Reducing Carbon Dioxide Emissions:

The Case of Portugal (*)

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Abstract

We assess the relative role of fossil fuel prices, energy efficiency and carbon taxation in achieving climate policy goals using a dynamic general equilibrium model of the Portuguese economy with endogenous growth and a detailed modeling of public sector activities. We show that to achieve ambitious domestic reductions in emissions, given the expected evolution of international fossil fuel prices, the roles of promoting energy efficiency and of a new significant carbon tax are fundamental. More importantly, promoting energy efficiency improvements and the new carbon tax have significantly different economic and budgetary effects. Energy efficiency improvements achieve reductions in emissions while promoting economic performance at the risk of increasing public and foreign debt. The new carbon tax in turn achieves reductions in emissions at the risk of jeopardizing economic performance while the effects on public and foreign debt are more favorable. This being the case, the relevance of pursuing both strategies in tandem is clear. Finally, domestic efforts toward promoting energy efficiency and the introduction of a new carbon tax need to be calibrated in function of the expected evolution of international fossil fuel prices. This evolution has significant effects on emissions and thereby on the measure of the additional effects required from the domestic authorities. It also has negative effects on economic performance while it may have more positive effects on the evolution foreign and public debts, which provide important leeway for the implementation of the domestic policies without generating a negative impact on the levels of indebtedness assuming that the public sector curtails spending appropriately in response to the increasing opportunity cost of public funds.

Keywords: Fossil Fuel Prices, Energy Efficiency, Carbon Taxation, Endogenous Growth, Budgetary Consolidation, Portugal.
JEL Classification: D58, H63, O44.

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1. Introduction

The last 20 years in Portugal have been marked by substantial changes in the energy sector and in carbon dioxide emissions from fossil fuel combustion activities, the bulk of greenhouse gas emissions from energy activities and about 70% of total greenhouse gas emissions in the country. In 1990 – a benchmark years for emissions data defined in the context of the United Nations Framework Convention on Climate Change and the Kyoto Protocol – carbon dioxide emissions from fossil fuel combustion activities amounted to 40.9 Mt CO_2. Emissions grew 57% between 1990 and 2005 at which time emissions reached their maximum level over the 20 year period of 64.1 Mt CO_2. The introduction of natural gas in the late 1990s, the effective promotion of renewable energies as well as the European Union Emissions Trading System have allowed for a 25% reduction in emissions between 2005 and 2012 – in part driven by weak economic conditions and the financial crises of recent years – to 45.3 Mt CO_2.

Following these positive outcomes – both in terms of the increased reliance on domestic renewable energies and reductions in greenhouse gas emissions – Portugal, together with the member states of the European Union, has set forth an ambitious program to reduce emissions by 40% relative to 1990 levels, in 2030 [see, for example, the national roadmap to low carbon in 2050 from Agência Portuguesa do Ambiente (2012) or the policy framework for climate and energy for 2020 to 2030 from the European Commission (2014a, 2014b)]. Achieving these goals will require a comprehensive package of policy instruments which will demand a multi-pronged approach – that the country mobilizes its efforts in all the relevant areas. First, it should be clear that because Portugal is dependent on imported fossil fuels to satisfy the bulk of its energy service demand, the evolution of international prices for the different fuels – oil, natural gas, coal – will have an impact on demand and thereby on emissions. Second, there is plenty of evidence suggesting that there is substantial potential for the adoption of cost-effective energy efficiency improvements. Third, and finally, there is the ongoing debate on the possibility of introducing a tax on carbon dioxide emissions.

The purpose of this paper is to identify the relative role of these different drivers of carbon dioxide emissions in achieving environmental goals in Portugal. Our concern is naturally on their effectiveness in reducing emissions. At the same time, we recognize that these three different drivers have very different economic and budgetary repercussions. While increases in fossil fuel prices result in a net loss of resources for the domestic economy, though these price increases can reduce emissions, the same reduction in emissions achieved through a carbon tax generate revenues. Finally, energy efficiency gains provide the potential for a win-win outcome in terms of environmental and economic performance.

We assess the relative role of fossil fuel prices, energy efficiency and carbon taxation in achieving environmental targets using a dynamic general equilibrium model of the Portuguese economy with endogenous growth and a detailed modeling of public sector activities, both tax revenues and social welfare maximizing public consumption and investment spending. The model further captures the small, open, energy-importing, nature of the Portuguese economy. The model is calibrated to replicate the stylized facts of the Portuguese economy over the last two decades. 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, other energy and climate policies [see Pereira and Pereira (2013, 2014a, 2014b, 2014c)].

Naturally, the impact of climate policy on economic performance has been a central part of the policy debate [see, for example, Nordhaus (1993a, 1993b), Babiker et al. (2003), Dissou (2005), Stern (2007), Rivers, (2010), and Morris et al. (2012)]. These impacts have been explored in a general equilibrium framework [see, for example, Barker et al. (1993), Koeppl et al. (1996), Farmer and Steininger (1999), Heijdra et al. (2006) and Conefrey et al. (2013)]. The key distinguishing feature of our methodological approach is our focus on endogenous growth and the associated treatment of public sector behavior [see Conrad (1999) and Bergman (2005) for literature surveys]. Productivity enhancing investments in public and human capital, which have been largely overlooked in applied climate policy [van Zon and Yetkiner (2003) and Carraro et al. (2012)], are, in addition to private investment, the drivers of endogenous growth. Furthermore, the analysis of the interaction between fiscal policies, public capital, economic growth, and environmental performance has garnished little attention and then only in a theoretical framework [Bovenberg and de Mooij (1997), Greiner (2005), Fullerton and Kim (2008), Glomm et al. (2008) and Gupta and Barman (2009)].

This paper is organized as follows. Section 2 presents the dynamic general equilibrium model and its implementation for the Portuguese case. The next three sections are the core of the paper and consider in succession the three different drivers of reduction in emissions. Section 3 focuses on different fossil fuel price scenarios and their impact. This is the most basic exogenous driver of emissions and economic growth outside the realm of direct domestic policy control. Section 4 addresses the incremental effects of energy efficiency gains when considered in addition to the reference fuel price scenario. This recognizes that, given the evolution of international fossil fuel prices, promoting energy efficiency is the most basic tool at the disposal of the domestic economy. Section 5 in turn, focuses on the effects of a carbon tax in an environment subject to the reference international fuel price scenario and energy efficiency gains. Section 6, presents and discusses the relative roles of the three mechanisms under consideration. Finally, section 7 provides a summary and policy implications.

2. The Dynamic General Equilibrium Model of the Portuguese Economy

In this section we present the dynamic general equilibrium model of the Portuguese economy in very general terms. Complete model documentation with detailed descriptions of the model equations, parameters, data, calibration, and numerical implementation, can be found in Pereira and Pereira (2012).

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

Aggregate output is produced with a Constant Elasticity of Substitution (CES) technology, linking value added and primary energy demand. Value added is produced according to a Cobb-Douglas technology exhibiting constant returns to scale in the reproducible inputs – effective labor inputs, private capital, and public capital. Only the demand for labor 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 are publicly financed and are positive externalities. Primary energy demand is produced according to a CES technology using crude oil inputs and non-transportation energy sources. The production of non-transportation energy is defined according to a Cobb-Douglas technology using coal, natural gas and wind energy inputs.

Private capital accumulation is characterized by a dynamic equation of motion where physical capital depreciates. Gross investment 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 represents the after-tax position when revenues from sales are netted of wage payments and investment spending. After-tax net revenues reflect the presence of a private investment and wind energy investment tax credits, taxes on corporate profits, and Social Security contributions paid by the firms on gross salaries.

Buildings make up a fraction of total private investment expenditure. Only this fraction is subject to value-added and other excise taxes, the remainder is exempt. The corporate income tax base is calculated as revenues from the sale of output net of total labor costs and net of fiscal depreciation allowances over past and present capital investments. A straight-line fiscal depreciation method over the periods allowed for depreciation allowances is used and investment is assumed to grow at the same rate at which output grows. Under these assumptions, depreciation allowances simplify proportional to the difference of two infinite geometric sums.

Optimal production behavior consists in choosing the levels of investment and labor that maximize the present value of the firms' net cash flows subject to the equation of motion for private capital accumulation. The demands for labor and investment are obtained from the current-value Hamiltonian function, where the shadow price of private capital evolves according to the respective co-state equation. Finally, with regard to the financial link of the firm with the rest of the economy, we assume that at the end of each operating period the net cash flow is transferred to the consumers.

2.2 The Energy Sector

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

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

Primary energy consumption provides the most direct approach for accounting for CO_2 emissions from fossil fuel combustion activities. Carbon is released from fossil fuel upon combustion. 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.

Fossil fuels are hydrocarbons defined by the relative amounts of carbon and hydrogen in each molecule. In the combustion reaction, the compound reacts with an oxidizing element such as oxygen. Thus, the amount of carbon relative to hydrogen in the fuel will determine the fuels carbon emissions factor, the amount of carbon emitted per unit of energy. The molecular weight of carbon dioxide CO_2 is 44/12 times greater than the weight of the carbon alone (the molecular weight of carbon is 12 and that of oxygen is 16 which give CO_2 a weight of 44 moles and carbon of 12 moles). The fuel's CO_2 emission factor can be computed from the product of its carbon emission factor, in tons of oil equivalent, the fraction of carbon oxidized and the ratio of the molecular weight of carbon dioxide to carbon. The relevant computations are given in Table 1.

Table 1
Carbon Dioxide Emission Factor by Fuel

FUEL TYPES	Unit	Conversion factor (TJ/Unit)	Carbon emission factor (tC/TJ)	Carbon content (Gg C)	Fraction of carbon oxidized	Actual CO_2 emissions (Gg CO_2)
Crude Oil	toe	0.041868	20.00	0.84	0.99	3.04
Bituminous Coal	toe	0.041868	25.10	1.05	0.98	3.78
Natural Gas (Dry)	toe	0.041868	15.30	0.64	1.00	2.34

Crude oil yields 3.04 tCO_2 for each ton of oil equivalent consumed, coal yields 3.78 tCO_2 for each ton of oil equivalent consumed and natural gas yields 2.34 tCO_2 for each ton of oil equivalent consumed.

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

Optimal primary energy demand is derived from the maximization of the present value of the firms' net cash flows as discussed above. In turn, the demand for coal and natural gas are defined through the nested dual problem of minimizing energy costs given the production function and optimal demand for these energy vectors in electric power and industry. Finally, the variational condition for optimal wind energy investment and the equation of motion for the shadow price of wind energy are defined by differentiating the Hamiltonian with respect to wind energy investment and its stock.

2.3 The Households

An overlapping-generations specification was adopted in which the planning horizon is finite but in a non-deterministic fashion. A large number of identical agents are faced each period with a probability of survival. The assumption that the probability of survival is constant over time and across age-cohorts yields a perpetual youth specification. 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 chooses consumption and leisure streams that maximize intertemporal utility subject to the consolidated budget constraint. The objective function is lifetime expected utility subjectively discounted. Preferences are additively separable in consumption and leisure, and take on the CES form. A lower probability of survival reduces the effective discount factor making the household relatively more impatient.

The budget constraint reflects a value-added tax on consumption and states that the households' expenditure stream discounted at the after-tax market real interest rate cannot exceed total wealth. The loan rate at which households borrow and lend among themselves is greater than the after-tax interest rate reflecting the probability of survival.

Total wealth is age-specific and is composed of human wealth, net financial worth, and the present value of the firm. Human wealth represents the present discounted value of the household's future labor income stream net of personal income taxes and workers' social security contributions. The household's wage income is determined by its endogenous decision of how much labor to supply out of a total time endowment and by the stock of knowledge or human capital 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, profits distributed by corporations, international transfers, and public transfers. 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. Under the assumption of no bequests, households are born without any financial wealth. In general, total wealth is age-specific due to age-specific labor supplies and consumption streams.

Assuming a constant real interest rate, the marginal propensity to consume out of total wealth is age-independent and aggregation over age cohorts is greatly simplified and moreover allows us to write the aggregate demand for leisure as a function of aggregate consumption.

2.4 The Public Sector

The equation of motion for public debt reflects the fact that the excess of government expenditures over tax revenues has to be financed by increases in public debt. Total tax revenues include personal income taxes, corporate income taxes, value added taxes, and social security taxes levied on firms and workers. All of these taxes are levied on endogenously defined tax bases. Residual taxes are modeled as lump sum and are assumed to grow at an exogenous rate.

The public sector pays interest on public debt and transfers funds to households in the form of pensions, unemployment subsidies, and social transfers, which grow at an exogenous rate. In addition, it engages in public consumption activities and public investment activities in both public capital and human capital.

Public investments are determined optimally, respond to economic incentives, and constitute an engine of endogenous growth. The accumulations of human capital and public capital are subject to depreciation 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 public consumption, public investment in human capital and public investment in public capital that maximize social welfare, defined as the net present value of the future stream of utility derived from public consumption, parametric on household private consumption-leisure decisions. The optimal choice is subject to three constraints, the equations of motion of the stock of public debt, the stock of public capital, and the stock of human capital. The optimal trajectories depend on the shadow prices of public debt, public capital, and human capital stocks, respectively. Optimal conditions are defined for public debt, for public consumption, for public investment, and for investment in human capital.

2.5 The Foreign Sector

The equation of motion for foreign financing provides a stylized description of the balance of payments. Domestic production and imports are absorbed by domestic expenditure and exports. Net imports incorporate payments by firms for fossil fuels and are financed through foreign transfers and foreign borrowing. Foreign transfers grow at an exogenous rate. 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 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. The labor-market clearing condition incorporates an exogenous structural unemployment rate. The product market equalizes demand and supply for output. Given the open nature of the economy, part of domestic demand is satisfied through the recourse to foreign production. Finally, the financial market equilibrium 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 Dataset, Parameter Specification, and Calibration

The model is implemented numerically using detailed data and parameters sets. Economic data are from the Statistical Annex of the European Community [European Commission (2014c)], budgetary data from the Portuguese Ministry of Finance [GPEARI (2014)] and energy and environmental data from the Portuguese Ministry of Economy [DGEG (2014)]. The decomposition of the aggregate variables follows the average for the period 2000-2013 for macroeconomic data as well as for the energy variables. 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. Public debt and foreign debt, as well as the stocks of capital, reflect the most recent available data, end of 2013.

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

All the other parameters are obtained by calibration; i.e., in a way that the trends of the economy for the period 2000-2013 are extrapolated as the steady-state trajectory. In some cases, the calibration parameters are chosen freely in that they are not implied by the state-state restrictions. 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. For instance, the elasticity of substitution parameters are consistent with those values often applied in climate policy analysis [see, for example, Manne and Richels (1992), Paltsev et al. (2005) and Koetse et al. (2008)]. The remaining calibration parameters are implied by the steady-state restrictions.

3. On the Effects of the Evolution of Fossil Fuel Prices

Fuel prices are important in climate policy due to their impact on CO_2 emissions. Fuel prices directly affect emissions through their impact on energy costs and demand and as drivers in the adoption of new energy technologies. High fossil fuel prices reduce energy demand and can stimulate energy efficiency and the adoption of renewable energy technologies, leading to a reduction in emissions [see Martinsen et al (2007)]. Relative price levels, however, may favor a greater use of coal in electric power and synthetic fuels in transportation, increasing emissions [see van Ruijven and van Vuuren (2009)]. Furthermore, fuel prices also indirectly affect emissions through their impact on economic growth and its dynamic feedbacks with energy demand [see van Ruijven and van Vuuren (2009)]. A great deal of empirical research highlights the dynamic relationship between energy prices, consumption and economic growth [see Hamilton (2009), He et al. (2010), Balcilar et al. (2010) and Korhonen and Ledyaeva (2010)].

3.1 The Fossil Fuel Price Scenarios

We consider three scenarios for the evolution of international prices for coal, oil and natural gas. These fossil fuel price scenarios are the reference forecasts for the Portuguese Commission for Environmental Fiscal Reform [see Comissão para a Reforma da Fiscalidade Verde (2014)] and are developed in great detail in Esteves (2014) and summarized in Table 2.

The fossil fuel price scenarios are based primarily on two sources: The European Commission and futures markets – namely the ICE, the Intercontinental Exchange. These two sources differ both in their temporal scope as well as the magnitude of expected price changes. In general, the EC forecasts suggest higher prices than futures markets. The EC forecast is considered independently (scenario EC). A second scenario based on futures market prices through 2020 and growth in subsequent years as forecasted by the EC (scenario MKT) is also considered. The central fuel price assumptions (reference scenario) are based on an average of the EC forecast and the futures market data appended with growth in prices derived from the EC forecast.

Table 2
Fossil Fuel Price Scenarios

Units: Price Index (2013=1.00)

	2013	2015	2020	2025	2030
European Commission Forecast (EC)					
Crude Oil	1.00	1.10	1.32	1.36	1.38
Coal	1.00	1.17	1.17	1.25	1.25
Natural Gas	1.00	1.12	1.52	1.43	1.61
Crude Oil/Coal Price Ratio	1.00	0.94	1.13	1.09	1.10
Natural Gas/Coal Price Ratio	1.00	0.96	1.30	1.14	1.29
Crude Oil/Natural Gas Price Ratio	1.00	0.98	0.87	0.95	0.86
Reference Case (REF)					
Crude Oil	1.00	1.02	1.06	1.09	1.11
Coal	1.00	1.07	1.13	1.20	1.20
Natural Gas	1.00	1.02	1.19	1.12	1.26
Crude Oil/Coal Price Ratio	1.00	0.95	0.94	0.91	0.93
Natural Gas/Coal Price Ratio	1.00	0.95	1.05	0.93	1.05
Crude Oil/Natural Gas Price Ratio	1.00	1.00	0.90	0.98	0.89
Future Market Case (MKT)					
Crude Oil	1.00	0.94	0.80	0.82	0.83
Coal	1.00	0.98	1.08	1.16	1.16
Natural Gas	1.00	0.92	0.86	0.81	0.91
Crude Oil/Coal Price Ratio	1.00	0.96	0.74	0.71	0.72
Natural Gas/Coal Price Ratio	1.00	0.94	0.82	0.70	0.78
Crude Oil/Natural Gas Price Ratio	1.00	1.02	0.90	1.01	0.92

The different fuel price scenarios imply very different relative prices for oil, coal and natural gas. In the reference scenario, the relative price of coal to natural gas remains relatively unchanged with oil showing a very slight reduction in price relative to natural gas. In contrast, in the EC scenario the price of coal falls substantially relative to natural gas and the price of oil increases relative to natural gas. The MKT price scenario depicts substantially different relative price movements with a large increase in coal prices relative to natural gas and a large reduction in oil prices relative to natural gas. Natural gas prices grow tremendously in the EC scenario while the reduction in coal prices for the MKT price scenario is relatively modest.

3.2 On the Effects of Fossil Fuel Prices – The Reference Scenario

The details of the energy, environmental, economic, and budgetary effects of the reference fossil fuel price scenario are presented in Table 3.

Energy and Environmental Effects

The evolution of fossil fuel prices in international markets suggests an overall reduction in energy demand as fuel prices increase. By 2030, the demand for fossil fuels is 6.2% lower than steady state levels. Changes in relative prices further alter the makeup of the energy sector. The overall increase in the price of fossil fuels relative to renewable energies stimulates investment in wind energy. We observe a 16.6% increase in investment in wind energy and an increase in the stock of wind energy infrastructures by 9.9% in 2030. Similarly, while increasing energy prices reduce demand, the demand for natural gas and coal fall by substantially more than the reduction in crude oil demand. Natural gas consumption is 11.0% lower than steady state levels, 8.3% for coal and 4.5% for crude oil. The reduction in fossil fuel combustion allows for a 6.1% reduction in emissions in 2030 relative to steady state levels.

Economic Effects

The macroeconomic impact of fossil fuel prices is fundamentally defined by the total change in energy system costs as opposed to the fuel mix in the energy system. 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 1.5% relative to steady state levels in 2030. The reduction in private investment drives down the stock of private capital which in turn has a negative impact on economic growth. Energy price increases have a negative impact on employment as well, reducing employment by 0.4% relative to steady state levels in 2050. The smaller reductions in private capital and employment than in energy consumption suggests that with growing fuel prices firms substitute capital and especially labor for energy inputs.

Given the impact of fuel prices on private inputs (which as we will see is mirrored by reductions in public and human capital investment), it is no surprise that higher fuel prices, driven primarily by higher oil prices, have a negative impact on GDP. In 2030, GDP is 0.5% below steady state levels.

The feedback between domestic demand, production and income defines the impact of fuel prices on private consumption and foreign debt. The net effect of this process is a reduction in private consumption of 1.0% in 2030. Consumption smoothing behavior by households implies that these reductions – as a percent of baseline levels – are relatively constant throughout the model horizon. In turn, while there is a marginal increase in the value of imported primary energy, the contractionary effects of higher fuel prices translate into a reduction in foreign debt of 8.5% relative to steady state levels by 2030.

Budgetary Effects

The reduction in economic activity levels due to increasing expenditure on fossil fuels affects the size of the tax bases and thereby public sector tax receipts leading to a 0.6% reduction in tax revenue by 2030. These changes are driven primarily by reductions in VAT receipts. On the expenditure side, the public sector optimally adjusts its spending patterns in response to fuel price variations. Total public expenditure falls by 2.2% while public consumption itself falls by 3.3%. Reductions in public investment activities further reinforce the negative effect of declining private inputs on production activities and have a negative impact on economic performance.

Overall, despite tax revenue losses, the reduction in expenditure levels reduces the public debt to GDP ratio in 2030 by 5.2% relative to steady state levels. The optimal government response to the increasing opportunity cost of public funds is instrumental in driving positive budgetary effects. Absent these, the contracting tax bases yield an increase in public debt levels.

Table 3
On the Energy, Economic and Budgetary Effects of Fossil Fuel Prices – The Central Scenario

(Percent change with respect to steady state levels)

	2020	2025	2030	2050
Energy				
Total Energy Demand	-2.17	-3.11	-3.74	-6.96
Demand for Fossil Fuels	-3.43	-4.99	-6.16	-11.20
Crude Oil	-2.20	-3.47	-4.45	-8.75
Coal	-4.60	-9.92	-8.31	-15.34
Natural Gas	-7.30	-6.02	-10.99	-16.94
Investment in Wind Energy	13.46	14.61	16.60	21.51
Wind Energy Infrastructures	4.98	7.54	9.94	16.98
Carbon Dioxide Emissions from Fossil Fuel Combustion	-3.33	-5.15	-6.07	-11.16
Change as a percent of 1990 levels	-3.99	-6.49	-8.03	-17.98
Economy				
Growth Rate of GDP (Percent Change over Previous Period)	0.95	0.95	0.94	0.94
GDP	-0.02	-0.22	-0.45	-1.45
Private Consumption	-0.95	-0.95	-0.96	-0.98
Private Investment	-0.81	-1.14	-1.47	-2.74
Private Capital	-0.20	-0.42	-0.67	-1.81
Imported Energy	4.23	5.47	6.92	11.96
Foreign Debt	-3.64	-6.09	-8.45	-15.89
Labor Markets				
Employment	0.34	0.24	0.12	-0.38
Wages	-0.46	-0.58	-0.71	-1.28
Public Sector				
Public Debt	-2.29	-3.80	-5.24	-9.62
Public Expenditures	-2.10	-2.13	-2.16	-2.25
Public Consumption	-3.22	-3.18	-3.13	-2.92
Public Investment	-0.66	-0.97	-1.29	-2.54
Investment in Human Capital	-0.49	-0.55	-0.60	-0.80
Public Capital	-0.19	-0.42	-0.67	-1.84
Human Capital	-0.03	-0.06	-0.08	-0.20
Tax Revenues	-0.33	-0.47	-0.64	-1.30
Personal Income Tax (IRS)	-0.22	-0.61	-1.04	-2.63
Corporate Income Tax (IRC)	0.16	-0.04	-0.29	-1.42
Value Added Tax (IVA)	-1.02	-1.08	-1.13	-1.34
Social Security Contributions (TSU)	-0.15	-0.39	-0.68	-1.86

3.3 On the Effects of Fossil Fuel Prices – Alternative Price Scenarios

The two alternative price scenarios produce markedly different environmental, economic and budgetary outcomes than the reference scenario. Details are presented in Table 4. The EC price scenario with higher fossil fuel prices and increasing oil prices relative to gas yield substantially larger reductions in emissions together with more substantial employment and output losses. These contractionary effects translate into smaller levels of foreign debt. In turn, the effects on public debt are not significantly different from the reference case. In contrast, the MKT price scenario, with lower fuel prices and a lower price of oil relative to natural gas, leads to the opposite effects: increases in emissions and employment and output gains. Foreign debt is only marginally improved as the better terms for imported fossil fuels are accompanied by greater imports of other goods. Public debt improves but again to a much smaller degree than the reference case.

Table 4
On the Effects of Fossil Fuel Prices – Alternative Price Scenarios
(Percent change with respect to steady state levels)

	2020	2025	2030	2050
Fossil Fuel Price Scenario: EC				
Carbon Dioxide Emissions	5.29	4.55	3.63	-1.38
GDP	0.60	0.73	0.70	0.19
Labor Demand	0.27	0.32	0.29	0.02
Foreign Debt	0.36	-0.57	-1.78	-6.52
Public Debt	-0.08	-0.76	-1.56	-4.48
Fossil Fuel Price Scenario: Central				
Carbon Dioxide Emissions	-3.33	-5.15	-6.07	-11.16
GDP	-0.02	-0.22	-0.45	-1.45
Labor Demand	0.34	0.24	0.12	-0.38
Foreign Debt	-3.64	-6.09	-8.45	-15.89
Public Debt	-2.29	-3.80	-5.24	-9.62
Fossil Fuel Price Scenario: MKT				
Carbon Dioxide Emissions	-9.36	-11.80	-12.75	-17.93
GDP	-0.58	-1.07	-1.48	-2.93
Labor Demand	0.41	0.17	-0.03	-0.75
Foreign Debt	-7.19	-11.01	-14.39	-24.25
Public Debt	-4.24	-6.50	-8.49	-14.18

4. On the Effects of Energy Efficiency Improvements

Energy efficiency improvements are important in ensuring that energy services are supplied efficiently and using state of the art technologies. The direct effect of an improvement in energy efficiency is a reduction in fuel requirements to satisfy a particular level of demand for energy services. At first glance, this reduces production costs and fuel consumption. Upon closer inspection it is clear that a reduction in production costs increases the firms' net cash flow and disposable income available to families. These have the effect of simulating demand. In addition, because energy resources are more productive, that is, because energy services can be provided at a lower cost relative to other inputs, businesses and corporations have the incentive to shift their input structure towards a greater relative utilization of energy resources. Furthermore, energy intensive industries will benefit more from the reduction in energy system costs, generating the potential for structural changes in the economy. These factors contribute to a behavioral response that limits the reduction in fuel consumption associated with energy efficiency improvements which defines a rebound in energy consumption. The rebound effect has gained increasing attention in recent years [see for example Saunders, 1992, 2000, 2008; Khazzoom, 1980; Brookes, 1990; Grepperud and Rasmussen, 2004; Hanley et al. 2006; Allan et al, 2007; Barker et al., 2007; Hanley et al, 2009; Turner, 2009; and Wei, 2010].

4.1 On the Potential for Energy Efficiency Gains

Improving energy efficiency is widely regarded as a key mechanism for lowering the energy-intensity and carbon-intensity of the economy. Energy efficiency goals have been formalized in a number of EU directives. Most notable is EC Directive 2009/28/EC which sets a legally binding target of increasing energy efficiency by 20% by 2020 relative to 1990 levels and the current working assumptions of energy efficiency gains in primary energy consumption of 21% by 2030 compared to 2007 levels [see, for example, European Commission (2013), (2014a)]. These targets imply an annual increase in energy efficiency of near 1%. Recent legislation and discussions in the EU seem to suggest much more ambitious targets pointing, for example, to a 20% reduction in primary energy use in 2020 relative to projections made in 2007 and to a reduction of 40% in 2030 relative to 1990 as a follow up to the existing 20% target for 2020 [see, for example, European Economy (2014a)]. In both cases, average annual gain in energy efficiency over the next twenty years would have to be closer to 2%.

An analysis of the Portuguese energy system using the TIMES_PT model [see Seixas and Fortes (2014)] suggests that autonomous energy efficiency improvements equivalent to an average annual savings in primary energy consumption of 2.5% per year between 2015 and 2030 are cost-effective in the absence of climate policy and at 2010 energy prices. This means that there are technologies available which are in the best interest of the different economic agents to adopt based on cost considerations independent of environmental concerns or public incentives.

In terms of buildings, both residential and industrial, these technologies include the use of heat pumps, thermal integrity including efficient windows, as well as the use of more efficient equipment and LED lighting. Efficiency gains in transportation stem from the widespread use of increasingly efficient hybrid vehicles and, at a later date, through a great use of electric vehicles. Finally, an increasing use of natural gas in industrial furnaces in place of fuel oil or biomass and an increasing use of cogeneration can reduce energy use.

For the purpose of this study, we assume a reference scenario of an annual gain in energy efficiency of 2% as well as a low scenario of 1.5% and a high scenario of 2.5%. The reference scenario of 2% is in line with the discussions on the matter in the EU as presented above. It is also consistent with the fact that, with just 57 measures in energy efficiency enacted from 1990 to 2011, Portugal ranks 18 in the EU in terms of the numbers of measures – Spain leads the group of 28 countries with 133 measures [see, for example, European Commission (2014d)]. This suggests that Portugal has significant room for improvement.

4.2 On the Effects of Energy Efficiency – An Annual Gain of 2%

The environmental, economic and budgetary effects of exogenous energy efficiency improvements of 2% per year are presented in Table 5.

Energy and Environmental Effects

The exogenous improvements in energy efficiency increase the reduction in emissions in 2030, relative to the steady state, by 10.3 percentage points (p.p.) more than fuel price movements alone. The improvements in efficiency are not biased in favor of specific energy inputs as we observe a reduction in energy demand across the board. Total energy demand declines by an additional 10.4 p.p. and the demand for fossil fuels is an additional 10.3 p.p. lower. Similarly, an increase in energy efficiency reduces investment in wind energy by 14.2 p.p. in 2030.

These effects contrast with the effects previously identified of the evolution of fossil fuel prices. In that case the reduction in emissions of 6.1% was due to a milder reduction in demand for fossil fuels together with a substantial increase in investment in wind energy. Overall energy demand is only by 3.7% lower in 2030.

Economic Effects

Energy efficiency improvements of this nature increase the marginal productivity of energy inputs to production. This lowers production costs and stimulates economic activity. Indeed, we observe that energy efficiency improvements have a positive impact on employment and output. Simulation results suggest that an exogenous improvement in energy efficiency of 2% per year through 2020 increases GDP 0.9 p.p. relative to the reference fuel price scenario in 2030. This improvement in economic performance is induced by a shift into a more capital intensive economy as investment increases 1.8 p.p. by 2030 while employment increases 0.1 percentage point.

Finally, energy efficiency leads to a 1.8 p.p. increase in private consumption. Despite the increase in domestic output and a marginal decline in the value of energy imports the increase in domestic demand leads to an increase in foreign indebtedness by about 1.1 p.p. in 2030.

Table 5

On the Energy, Economic and Budgetary Effects of Energy Efficiency Improvements – An Annual Gain of 2%

(Under the central fossil fuel price scenario)

(Percent change with respect to steady state levels)

	2020	2025	2030	2050
Energy				
Total Energy Demand	-7.65	-9.72	-10.37	-9.94
Demand for Fossil Fuels	-7.95	-9.86	-10.32	-9.49
Crude Oil	-7.98	-9.96	-10.47	-9.75
Coal	-8.00	-9.47	-10.16	-9.05
Natural Gas	-7.77	-9.88	-9.86	-8.88
Investment in Wind Energy	-16.26	-15.18	-14.16	-12.83
Wind Energy Infrastructures	-6.00	-8.92	-10.64	-12.45
Carbon Dioxide Emissions from Fossil Fuel Combustion	-7.96	-9.85	-10.33	-9.50
Change relative to 1990 levels	-9.53	-12.40	-13.67	-15.31
Economy				
Growth Rate of GDP (Percent Change over Previous Period)	1.03	1.00	0.98	0.96
GDP	0.37	0.69	0.91	1.35
Private Consumption	0.96	0.96	0.96	0.97
Private Investment	1.63	1.77	1.82	2.00
Private Capital	0.51	0.85	1.12	1.71
Imported Energy	-8.56	-10.93	-11.75	-11.97
Foreign Debt	3.29	4.82	5.90	8.23
Labor Markets				
Employment	-0.14	0.03	0.14	0.34
Wages	0.75	0.96	1.08	1.26
Public Sector				
Public Debt	1.84	2.69	3.29	4.55
Public Expenditures	1.94	1.92	1.92	1.93
Public Consumption	2.81	2.73	2.69	2.60
Public Investment	1.45	1.61	1.69	1.93
Investment in Human Capital	0.40	0.44	0.47	0.58
Public Capital	0.55	0.91	1.18	1.73
Human Capital	0.03	0.05	0.07	0.15
Tax Revenues	0.55	0.77	0.91	1.17
Personal Income Tax (IRS)	0.46	1.01	1.38	2.05
Corporate Income Tax (IRC)	0.17	0.68	1.02	1.61
Value Added Tax (IVA)	1.14	1.16	1.17	1.20
Social Security Contributions (TSU)	0.64	1.04	1.29	1.75

Budgetary Effects

The subsequent expansions in the tax base lower the opportunity cost of public funds and public expenditures increase substantially as a result, negatively affecting public sector accounts. The increase in economic activity levels due to the energy efficiency improvements enlarges the tax bases and increases tax revenues across the board. Tax revenues increase by 0.9 p.p. in 2030 led by a 1.4 p.p. increase in the personal income tax. On the other side of the public budget, however, public expenditures increases even more by 1.9 p.p. in 2030 led mostly by an increase of 2.7 p.p. in public consumption. Accordingly we observe an increase in public indebtedness over time leading to an increase in the debt to GDP ratio of 3.3 p.p. in 2030.

Table 6
On the Effects of Energy Efficiency – Alternative Scenarios
(Under the central fossil fuel price scenario)

(Percent change with respect to steady state levels)

	2020	2025	2030	2050
Annual Energy Efficiency Improvements: 1.5				
Carbon Dioxide Emissions	-6.14	-7.65	-8.04	-7.38
GDP	0.29	0.54	0.71	1.05
Labor Demand	-0.11	0.02	0.11	0.27
Foreign Debt	2.57	3.77	4.63	6.45
Public Debt	1.44	2.11	2.57	3.56
Annual Energy Efficiency Improvements: 2.0				
Carbon Dioxide Emissions	-7.96	-9.85	-10.33	-9.50
GDP	0.37	0.69	0.91	1.35
Labor Demand	-0.14	0.03	0.14	0.34
Foreign Debt	3.29	4.82	5.90	8.23
Public Debt	1.84	2.69	3.29	4.55
Annual Energy Efficiency Improvements: 2.5				
Carbon Dioxide Emissions	-9.68	-11.90	-12.46	-11.47
GDP	0.45	0.84	1.10	1.62
Labor Demand	-0.17	0.04	0.16	0.41
Foreign Debt	3.95	5.78	7.08	9.87
Public Debt	2.21	3.22	3.94	5.46

4.3 On the Effects of Energy Efficiency – Alternative Scenarios

The two alternative energy efficiency scenarios lead to changes in the environmental, economic and budgetary outcomes that accentuate the effects observed in the central scenario without changing their nature. Higher efficiency gains leads to greater gains in terms of emission reductions and output gains but also larger public and foreign indebtedness. Details are presented in Table 6.

5. On the Effects of Carbon Taxation

Carbon taxation has gained momentum as an important part of a package of policy instruments for reducing greenhouse gas emissions in a cost-effective manner. In particular, we have witnessed a generalized growing concern over mounting public debt in recent years and the need to promote fiscal sustainability. CO_2 taxes and auctioned emissions permits have emerged as potentially important instruments for increasing public revenues (e.g. Metcalf and Weisbach 2008; Galston and MacGuineas 2010; Metcalf 2009, 2010 and Nordhaus 2010).

A CO_2 tax works primarily through two mechanisms. First, by affecting relative prices, the CO_2 tax drives changes to the firms' input structure that affects the marginal productivity of factor inputs. Second, the CO_2 tax increases energy expenditure and reduces the firms' net cash flow, household income and domestic demand. These substitution and scale effects are central in understanding how carbon taxation affects energy consumption, emissions, economic performance and the public sector account.

5.1 On the Level of Carbon Taxation

The choice of the value of the carbon tax is a delicate matter. There are now about fifteen countries which have introduced or are about to introduce carbon taxes. The levels and scope of taxation vary widely from a low of about 1.5 Euros per ton of CO_2 in Japan and about 7 Euros per ton in Iceland – covering 50% and 70% of domestic emissions respectively, to near

115 Euros in the United Kingdom and 125 Euros in Sweden although these cover only about 25% of total emissions in these countries. In about two-thirds of the countries taxes range from 10 to 35 euros per ton of CO_2 and cover between 35% and 70% of emissions, [for details, see, for example, World Bank (2014)].

Another reference point for the price of carbon emissions is given by carbon market carbon in the European Trading System. The average price for CO_2 emissions allowances observed in the EU-ETS between 2006 and 2011 was 15 euros per ton. During this period, the price of carbon reached a maximum of 34 Euros. Prices, however, have shown a great degree of volatility. In particular, the price of carbon fell substantially over weak demand to 8 Euros per tCO_2 in 2012, 4.7 Euros in 2013 and an average of just under 6.0 Euros in 2014. More importantly, from our perspective, 15 Euros is the average reference price for the sectors covered by the EU-ETS for the period from 2015 to 2030 [see, for example, European Commission (2014d)] with the price of carbon growing from the current low levels to 35 Euros in 2030.

Given this evidence we have chosen as the reference point in this study a tax of 15 Euro per tCO_2. This tax level is also consistent with the recommendation in a recent report by the European Environmental Agency [see Anderson et al. (2013)] and is also indicative of the efforts required to meet domestic targets [see Pereira and Pereira (2013)]. We further consider a lower tax level of 5 euros per ton and a higher level of 35 euros per ton. This way we cover in broad terms the bulk of the tax levels observed over the world as well as the boundaries of the current ETS price levels and the levels projected for 2030.

It should be pointed out that in order to evaluate the full potential for carbon pricing policies in the Portuguese economy we assume that every sector of the economy is subject to the tax. This assumption is consistent with the introduction of a CO_2 tax in sectors not covered by the EU-ETS and auctioning permits for those firms participating in the EU-ETS. In this way, firms and sectors not covered by the EU-ETS will face a price signal reflecting the costs of carbon through the tax while those firms and sectors participating in the EU-ETS will face this price signal in the market. Although the current market price for carbon is substantially below 15 Euros per tCO_2, adjustments to the cap and projections undertaken for the EU between 2015 and 2030 suggest, as indicated above, an average value of 15 Euros per tCO_2.

5.2 On the Effects of a Carbon Tax of 15€ per tCO2

The effect of a 15 Euros per tCO_2 tax on energy demand, emissions, economic performance and the public sector account are presented in Table 7.

Energy and Environmental Effects

The CO_2 tax increases the price of fossil fuels relative to renewable energy resources and changes the relative price of the different fossil fuels to reflect their carbon content. This has a profound impact on the energy sector, driving a reduction in fossil fuel consumption of 5.3 p.p. and an increase in investment in wind energy infrastructure of 12.0 p.p. in 2030 The impact of CO_2 taxation on aggregate fossil fuel demand, however, masks important changes in the fuel mix. In particular, we observe a 23.9 p.p. reduction in coal consumption while crude oil falls by 5.7 p.p. and natural gas by 2.0 p.p.. As such, the CO_2 tax stimulates a shift in the energy mix which favors wind energy at the expense of coal. Overall, by 2030, total energy demand declines by 5.3 p.p. and CO_2 emissions decline by 9.1 p.p..

Economic Effects

CO_2 taxation, by increasing energy system costs, has a negative impact on the firms' net cash flow which limits the firms' demand for inputs. Employment falls by 0.4 p.p. in 2030, less than the reduction in private investment of 1.6 p.p. and substantially less than the drop in fossil fuel demand. This is consistent with an overall reduction in input levels coupled with a shift in the firms' input structure away from energy inputs and toward a more labor-intensive economy. Given the reductions in factor demand, it is no surprise that CO_2 taxation has a negative impact on economic activity levels, a reduction of 1.0 p.p. in GDP in 2030 relative to the fuel price and efficiency scenarios.

The reduction in the firms' net cash flow has a direct impact on household income since it is an integral part of total wealth. This drives down private consumption by 0.4 p.p. In turn by 2030, fossil fuel imports are 7.2 p.p. lower. The reduction in domestic demand, coupled with the reduced expenditure on imported energy resources stemming from demand adjustments, suggests that foreign debt levels fall by 3.4 p.p. in 2030.

Budgetary Effects

The carbon tax contributes positively towards fiscal consolidation. Results suggest that a tax of 15 Euros per tCO_2 has a neutral effect on the public debt by 2030 and a favorable effect of marginally reducing the public debt thereafter. These positive effects are due fundamentally to reductions in public expenditures but also due to the increased revenues associated with the introduction of the carbon tax.

On the revenue side, a reduction in income, consumption and private inputs results in contracting tax bases. Accordingly, we observe a reduction in personal income tax, corporate income tax, value-added tax revenues and in social security contributions. These reductions are clearly offset by the CO_2 tax receipts. As a result, total tax revenue is 0.1 p.p. greater in 2030. On the expenditure side, and considering an appropriate policy response to high levels of public indebtedness, public expenditures fall by 1.5 p.p. in 2030. This increase reflects a shift in public expenditure from consumption to investment. Public consumption falls by 2.0 p.p. while public capital investment and human capital investment fall 1.5 p.p. and 0.4 p.p., respectively. The drop in public investment is again consistent with shifts in the firms' production structure towards labor.

Table 7

On the Effects of a Carbon Tax of 15€ per tCO2

(Under the central fossil fuel price scenario and annual energy efficiency gains of 2%)

(Percent change with respect to steady state levels)

	2020	2025	2030	2050
Energy				
Total Energy Demand	-6.26	-5.50	-5.32	-4.60
Demand for Fossil Fuels	-8.78	-8.25	-8.19	-7.31
Crude Oil	-5.94	-5.74	-5.65	-5.23
Coal	-26.38	-23.47	-23.88	-20.46
Natural Gas	-1.75	-2.45	-1.98	-1.92
Investment in Wind Energy	16.55	13.50	12.03	10.11
Wind Energy Infrastructures	8.00	10.10	10.90	10.75
Carbon Dioxide Emissions from Fossil Fuel Combustion	-9.76	-9.10	-9.07	-8.06
Change relative to 1990 levels	-11.70	-11.45	-11.99	-12.99
Economy				
Growth Rate of GDP (Percent Change over Previous Period)	0.99	0.97	0.96	0.95
GDP	-0.70	-0.87	-0.98	-1.21
Private Consumption	-0.36	-0.36	-0.35	-0.32
Private Investment	-1.68	-1.62	-1.58	-1.58
Private Capital	-0.67	-0.95	-1.14	-1.46
Imported Energy	-7.17	-7.14	-7.16	-7.23
Foreign Debt	-1.87	-2.74	-3.36	-4.65
Labor Markets				
Employment	-0.27	-0.34	-0.40	-0.50
Wages	-0.71	-0.78	-0.82	-0.86
Public Sector				
Public Debt	-0.86	-1.25	-1.52	-2.03
Public Expenditures	-1.52	-1.50	-1.49	-1.48
Public Consumption	-2.11	-2.07	-2.04	-1.97
Public Investment	-1.52	-1.49	-1.49	-1.55
Investment in Human Capital	-0.34	-0.36	-0.38	-0.46
Public Capital	-0.75	-1.03	-1.20	-1.47
Human Capital	-0.02	-0.04	-0.06	-0.12
Tax Revenues	0.34	0.21	0.13	-0.02
Personal Income Tax (IRS)	-0.74	-1.01	-1.19	-1.52
Corporate Income Tax (IRC)	-0.67	-0.93	-1.11	-1.42
Value Added Tax (IVA)	-0.65	-0.63	-0.62	-0.60
Social Security Contributions (TSU)	-1.00	-1.16	-1.27	-1.49

5.3 On the Effects of a Carbon Tax – Alternative Scenarios

The two alternative carbon tax scenarios lead to changes in the environmental, economic and budgetary outcomes that accentuate the effects observed in the central scenario without changing their nature. Higher carbon taxes lead to greater gains in terms of emission reductions but also larger losses in terms of output and employment and greater reductions in foreign and public debt. Details are presented in Table 8.

Table 8
On the Effects of a Carbon Tax – Alternative Scenarios
(Under the central fossil fuel price scenario and annual energy efficiency gains of 2%)
(Percent change with respect to steady state levels)

	2020	2025	2030	2050
CO2 Tax of 5€ per tCO2				
Carbon Dioxide Emissions	-3.91	-3.60	-3.59	-3.13
GDP	-0.24	-0.30	-0.34	-0.42
Labor Demand	-0.10	-0.12	-0.14	-0.18
Foreign Debt	-0.65	-0.95	-1.17	-1.61
Public Debt	-0.30	-0.43	-0.52	-0.69
CO2 Tax of 15€ per tCO2				
Carbon Dioxide Emissions	-9.76	-9.10	-9.07	-8.06
GDP	-0.70	-0.87	-0.98	-1.21
Labor Demand	-0.27	-0.34	-0.40	-0.50
Foreign Debt	-1.87	-2.74	-3.36	-4.65
Public Debt	-0.86	-1.25	-1.52	-2.03
CO2 Tax of 35€ per tCO2				
Carbon Dioxide Emissions	-17.69	-16.70	-16.62	-15.07
GDP	-1.51	-1.89	-2.15	-2.66
Labor Demand	-0.58	-0.73	-0.85	-1.10
Foreign Debt	-4.10	-6.01	-7.38	-10.25
Public Debt	-1.89	-2.76	-3.37	-4.52

6. On the Relative Roles of Fossil Fuel Prices, Energy Efficiency, and Carbon Taxes

We have identified important and clearly differentiated environmental, economic and budgetary effects associated with each of the three drivers of reductions in carbon emissions, the evolution of international fossil fuel prices, energy efficiency gains, and carbon taxation. Here we consider the overall picture on how these three mechanisms put together contribute to achieving emission targets and their overall economic and budgetary effects. The summary results are presented in Table 9.

6.1 Carbon Dioxide Emissions

In terms of emissions, we show that by 2030 changing fossil fuel prices under the reference price scenario lead to a reduction of 6.1% in CO_2 emissions relative to steady state levels while an increase in energy efficiency of 2% leads to an additional 10.3 p.p. reduction and a tax of 15 Euros per tCO_2 to a reduction of 9.1 p.p. all relative to baseline levels. Behind these reductions in emissions are important and differentiated changes in the energy sector. In the fuel price scenario there is a significant reduction in the demand for natural gas, in case of the carbon tax reductions in emissions come with a sharp reduction in coal, while in the case of energy efficiency by design there is an even reduction in all fossil fuels. In turn, the increase in investment in wind energy under the carbon tax although not as pronounced as in the reference price scenario contrasts with the sharp decline observed in the efficiency scenario.

The combined effect of these policies in terms of emissions reduction is approximately 25.4% of the projected baseline emissions in 2030 which corresponds to 33.7% of the emissions in 1990. To achieve a higher reduction in emissions vis-à-vis the 1990 levels more in line with the current targets, and given the central case scenario – which naturally the domestic authorities cannot control – would require a greater effort in either the energy efficiency or carbon tax margins or both. Indeed, for example, we project that under the central price scenario the combined effects of a greater achievement in energy efficiency of 2.5% and a carbon tax of 35 Euros per tCO_2 would lead to a combined reduction of 35.2% in 2030 relative to the baseline emissions, which corresponds to about 45% of the emissions in 1990.

6.2 Economic Effects

The economic impacts of these three different drivers are different in very significant ways. We show that the evolution of fuel prices and of a new carbon tax lead to contractions in economic activity, reductions of 0.5% and 1.0% by 2030 – while the increase in energy efficiency has an expansionary effect, a 0.9% increase in GDP by 2030. The combined effect of these three drivers and therefore the economic cost of the reduction in emissions presented above is a reduction of 0.5% in GDP by 2030.

The reductions induced by the carbon tax and the fossil fuel prices come with overall reduction in input demands and with a shift into a more capital intensive economy in the former and labor intensive in the later. In turn, the improvement in economic performance with energy efficiency is induced by a shift into a more capital intensive economy but with a substantial increase in investment activities together with a decline in employment.

In terms of domestic demand, a new carbon taxes but particularly fossil fuel prices drive down private consumption while energy efficiency leads to a very substantial increase. In turn, energy efficiency and the new carbon tax lead to a decline in the value of energy imports while evolution of fuel prices leads to an increase. However, the overall contraction in domestic demand under the fossil fuel prices and carbon tax lead reductions of foreign debt, particularly significant in the first case, while with energy efficiency the expanded domestic demand lead to an increase in foreign debt. Overall, the combined effect of the three drivers is a 5.9% reduction in foreign debt by 2030.

From the perspective of the economic impacts, it is clear that, although both mechanisms are necessary, domestic policy should stress more the advancement of energy efficiency than carbon taxation. A greater share of emissions reduction obtained through energy efficiency would mitigate the negative economic effects we observe. Given our projections, there is enough margin to increase efforts to encourage energy efficiency improvements without jeopardizing the favorable outcome of the combined policies on the evolution of foreign debt

6.3 Budgetary Effects

Finally, the budgetary impacts of these three different drivers are equally very different. With energy efficiency we observe an increase in public indebtedness of 3.3% in 2030 with both public spending and tax revenues increasing. This is opposite of the response to higher fossil fuel prices where public debt declines by 5.2% with both public spending and public revenues shrinking. The carbon tax reduces public debt by 1.5% by 2030. These effects come from both reductions in public expenditures and increases in tax revenues. The combined decline in public indebtedness induced by the three drivers is 3.5% by 2030.

Table 9
Summary of the Relative Roles of Fossil Fuel Prices, Energy Efficiency Improvements and Carbon Taxation
(Under their respective central cases)

(Percent change with respect to steady state levels)

	2020	2025	2030	2050
Carbon Dioxide Emissions				
Total Effect	**-25.23**	**-30.34**	**-33.70**	**-46.28**
Fossil Fuel Prices	-3.99	-6.49	-8.03	-17.98
Energy Efficiency	-9.53	-12.40	-13.67	-15.31
Carbon Tax	-11.70	-11.45	-11.99	-12.99
GDP				
Total Effect	**-0.35**	**-0.39**	**-0.53**	**-1.31**
Fossil Fuel Prices	-0.02	-0.22	-0.45	-1.45
Energy Efficiency	0.37	0.69	0.91	1.35
Carbon Tax	-0.70	-0.87	-0.98	-1.21
Labor Demand				
Total Effect	**-0.07**	**-0.07**	**-0.14**	**-0.55**
Fossil Fuel Prices	0.34	0.24	0.12	-0.38
Energy Efficiency	-0.14	0.03	0.14	0.34
Carbon Tax	-0.27	-0.34	-0.40	-0.50
Foreign Debt				
Total Effect	**-2.23**	**-4.02**	**-5.91**	**-12.31**
Fossil Fuel Prices	-3.64	-6.09	-8.45	-15.89
Energy Efficiency	3.29	4.82	5.90	8.23
Carbon Tax	-1.87	-2.74	-3.36	-4.65
Public Debt				
Total Effect	**-1.30**	**-2.37**	**-3.48**	**-7.10**
Fossil Fuel Prices	-2.29	-3.80	-5.24	-9.62
Energy Efficiency	1.84	2.69	3.29	4.55
Carbon Tax	-0.86	-1.25	-1.52	-2.03

From the perspective of the budgetary effects of these drivers, we find that once again although energy efficiency has undesirable effects on the public budget, these are however neutralized by the favorable effects of fossil fuel prices and to a lesser extent carbon taxes. The fact that the bulk of the reduction in public debt are induced by the evolution of the fossil fuel prices – again something the domestic authorities cannot control – also leaves sufficient leeway to increase the mix of energy efficiency relative to carbon taxation without witnessing a deterioration of the budgetary situation.

7. Summary and Conclusions

We assess the relative role of fossil fuel prices, energy efficiency and carbon taxation in achieving environmental targets using a dynamic general equilibrium model of the Portuguese economy with endogenous growth and a detailed modeling of public sector activities. We have identified important and clearly differentiated environmental, economic and budgetary effects associated each of these three drivers of reductions in carbon emissions.

The consideration of the impacts of the different drivers on energy and emissions, economy and public budget are very informative from a policy perspective. First, to achieve the ambitious emissions reductions goal of 40% compared to 1990 levels and conditional on the expected evolution of international fuel prices, the roles of promoting energy efficiency and of a new significant carbon tax are fundamental and have to be both fully embraced.

Second, and more importantly, promoting energy efficiency and a new carbon tax have significantly different economic and budgetary effects. Energy efficiency achieves reductions in emissions while promoting economic performance but with a risk of increasing public and foreign debt. The new carbon tax in turn achieves reductions in emissions at a risk of jeopardizing economic performance while the effects on public and foreign debt are more favorable. This being the case, the relevance of pursuing both strategies in tandem is clear.

Third, and maybe even from a more basic perspective, while the domestic authorities can affect and control efforts toward promoting energy efficiency and the introduction of a new carbon tax, these efforts need to be calibrated in function of the expected evolution of the international fossil fuel prices. This evolution has significant effects on emissions and thereby on the measure of the additional effects required from the domestic authorities. It also has negative effects on economic performance while it may have more positive effects on the evolution of foreign and public debts, which provide important leeway for the implementation of the domestic policies without seeing a negative impact on the levels of indebtedness.

The results presented in this paper despite, and maybe even because of, their direct relevance for policy making, have to be taken with caution. Indeed, there are a few shortcomings of the analysis which can be understood as directions for future research.

First, projections of international fossil fuel prices are known to vary widely depending on the sources and entities supplying them. Furthermore, we show that different price scenarios may have markedly different impacts on emissions and the economy. Accordingly, a thorough analysis of all relevant fossil fuel price projections is critical to understand the benchmark for domestic policy making.

Second, energy efficiency gains are considered costless in our setting. While this is justifiable since all of the energy technologies are cost-effective and should be adopted by the economy for that reason alone, it is also well understood how difficult these potential energy efficiency gains are to actually implement given the potential alternative uses of those resources. Large investments are often necessary to promote, publicize and subsidize the adoption of these technologies on a large scale. In this sense our projections of the economic effects of energy efficiency can be understood as upper bounds. In terms of emissions, however, a lower rebound effect could lead to an even more favorable outcome and therefore our projections could be thought of as a lower bounds.

Third, in the context of the new carbon tax we have not considered any strategies for recycling revenues raised by the tax, something that is well understood as having the potential to mitigate any adverse effects of the tax besides the potential to be used to promote energy efficiency itself. In this sense, the economic effects of the carbon taxes we project here can be understood as lower bounds – the worst possible outcome. In turn, recycling by mitigating the economic effects would also somewhat reduce the gains in emissions. Accordingly, our projections of the emission effects could be conceptualized as upper bounds.

Finally, it should be mentioned that although this paper is an application to the Portuguese case and is intended to be directly relevant from the perspective of policy making in Portugal, its interest is far from parochial. Naturally, climate and energy are at the center of the policy concerns and objectives in the EU [see, for example, European Commission (2014a, 2014b)] and as such all EU countries need to deal, albeit in different degrees, with these issues. In addition, there is a growing chorus of institutional voices urging the different countries in the direction of environmental fiscal reform [see, for example Eurogroup (2014), IMF (2014), OECD (2014), Parry at al. (2014), and World Bank (2014)]. Furthermore, from the perspective of policy evaluation, the interactions between climate policy, economic growth and the public sector account are fundamental since they correlate to the most important policy constraints faced by less developed energy-importing economies in their pursuit of sound climate policies: the need to enact policies that promote long-term growth and fragile public budgets.

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