Gabinete de Estratégia e Estudos

GEE Paper

123

June 2019

Financing a Renewable Energy Feed-in Tariff with a Tax on Carbon Dioxide Emissions: A Dynamic Multi-Sector General Equilibrium Analysis for Portugal

Rui M. Pereira |Alfredo M. Pereira

Gabinete de Estratégia e Estudos do Ministério da Economia
Office for Strategy and Studies of the Ministry of Economy
Rua da Prata, n.º 8 – 1149-057 Lisboa – Portugal
www.gee.gov.pt
ISSN (online): 1647-6212

Financing a Renewable Energy Feed-in Tariff with a Tax on Carbon Dioxide Emissions: A Dynamic Multi-Sector General Equilibrium Analysis for Portugal

Rui M. Pereira and Alfredo M. Pereira[1]

Abstract

Renewable energy production subsidies alleviate the pressure on electricity prices associated with carbon and energy pricing policies in the process of decarbonization and electrification of the Portuguese economy. Our simulation results show that a feed in tariffs financed by a carbon tax leads to adverse macroeconomic as well as adverse and regressive distributional welfare effects. On the flip side, however, we show that use of the carbon tax revenues to finance a feed in tariff is an improvement over the simple carbon tax case along all the relevant policy dimensions. The feed in tariff mechanism when added to the carbon tax leads to better environmental outcomes at lower costs both in terms of the economic and social justice implications. The policy implications are clear. First, because of its adverse economic and distributional effects a carbon tax should not be used in isolation. The use of the revenues to finance a feed in tariff dominates the simple carbon tax case in all dimensions. Second, the search for the appropriate recycling mechanisms in addition to feed in tariffs is an issue as relevant as the carbon tax itself as it pertains to the potential reversal of the adverse effects of such a tax.

JEL Classification: C68, E62, H23, Q43, Q48.

Keywords: Dynamic General Equilibrium, Renewable Energy, Feed-in Tariff, Carbon Taxation, Macroeconomic Effects, Distributional Effects, Environmental Effects, Portugal

Note: This article is sole responsibility of the author and do not necessarily reflect the positions of GEE or the Portuguese Ministry of Economy.

[1] Department of Economics, William & Mary, Williamsburg, VA 23187

1. Introduction

Policies to encourage the adoption of renewable energies are at the center of efforts to address climate change in Portugal and around in the world (IEA, 2016). This focus is justifiable as decarbonization of the Portuguese economy will necessarily be based on an increasing electrification of energy demand coupled with the production of electricity from green energy.

Renewable energy has made strong progress in Portugal over the past decade and the country has become one of Europe's leaders in terms of use of renewable energy sources (RES). Since 2005, installed capacity for wind energy grew from 3,058 MW in 2008 to 5,313 MW in 2017 and installed capacity for electricity production from solar cells grew from 62 MW in 2008 to 585 MW in 2017 (DGEG, 2019).

These trends are expected to continue over the coming decades. Projections within the context of the National Program for Climate and Energy (PNEC) indicate that renewable energies will grow to dominate the production of electricity through 2030 with 33% - 35% of electricity generated in the country produced from wind turbines, 24-28% from hydroelectric generating units and 22% - 27% from solar power (PNEC, 2019). This expansive growth will require significant investment in infrastructures. The national program for investment (PNI) estimates investment volume of 4,930 million Euros through 2030 while the national program for climate and energy estimates investment volumes between 17,100 million Euros and 18,700 million Euros in the energy sector overall.

Support mechanisms for renewable energy sources are based on feed-in tariff systems, tax benefits and small levels of investment subsidies. The principal instrument for promoting renewable electricity in Portugal is the special production regime, whereby electricity produced from renewable energy benefit from a feed-in tariff. Support costs for renewable energy amount to 781.15 million EUR in 2012 and 977.71 million EUR in 2013 (IEA, 2016).

The objective of this paper is to examine the environmental, economic, and distribution effects of initiatives to support the use of renewable energy resources in the production of electric power. In this paper we consider using auction revenues for permits issued within the context of the European Union Emission Trading System (EU-ETS) in Portugal and a tax on carbon dioxide emissions from fossil fuel combustion activities not covered within the EU-ETS to finance green energy in the production of electricity. This is consistent with the carbon pricing policies in place in Portugal; In 2015, Portugal introduced a tax on carbon dioxide emissions indexed to the price of carbon permits in the EU-ETS (IEA, 2016).

Climate and energy policies that increase the price of fossil fuels or provide funding for the development and deployment of renewable energies raise a number of concerns. On one hand, consumer and producer groups are concerned about the potentially higher costs associated with energy goods in the presence of carbon pricing policies. On the other hand, funding mechanisms needs to be efficiently and fairly designed to support renewable energies.

Both of these concerns are then compounded by social justice concerns surrounding the effects of these policies on lower income households and on industry sectors that are particularly vulnerable. The distributional impact of carbon pricing policies across households is determined by heterogeneity in spending patterns as well as heterogeneity in factor income patterns across income groups and the precise formulation of the policy, that is, how the revenue from the carbon pricing policy are distributed [see, for exmple Fullerton and Heutel, (2010), Rausch et al. (2011) Dissou and Siddiqui (2014), Beck et al, (2015), and Parry, (2015)].

When policies that mandate the use of renewable energies in the production of electric power are financed by surcharges on the power bills of utility customers, renewable energy support policies may also increase the price of electricity (see Bhattacharya, 2017, among others). Rausch and Mowers (2014) find that renewable energy support policies yield highly regressive distributional effects steming from this increase in electricity prices.

Higher electricity prices also increase input costs for firms and, when coupled with the loss in revenue due to lower demand for the firms' products at higher prices, results in losses in profits for firms. Proença and St. Aubyn (2013) find that feed-in tariffs in Portugal were effective in increasing the share of renewable energy sources in electricity production from 19.2% to 45% of electricity supply and reducing carbon dioxide emissions by 31% at a cost of 0.18% of GDP.

Public acceptance, and therefore the political feasibility, of a tax on carbon, depends in large part on how the revenue from the tax is used and how the tax is labeled and the information provided about it and its purpose. Recycling the revenues to purposes and goals important to more narrowly targeted groups, whether these are environmentally motivated or motivated by industry concerns, seems to increase support for taxation (Kallbekken, Kroll and Cherry, 2011). In fact, carbon taxation in Washington State failed to gain sufficient support because it was unpopular with groups concerns about social justice and divided environmental activists, many arguing it did not go far enough in promoting clean energy (Climate News, 2016).

The regressive aspects of renewable energy promotion stemming from higher electricity prices can be attenuated by alternative subsidy financing mechanisms which achieve the same level of electricity generation from renewable energy sources (Bohringer et al., 2016). Kalkuhl et al. (2013) find that smart combinations of carbon prices and renewable energy subsidies can achieve ambitious carbon mitigation targets at moderate additional costs without leading to high energy price increases. These concerns highlight the need to design a politically feasible package of policy instruments to encourage the adoption of green energies and to appropriately price fossil fuels to reflect the external costs these generate.

2. The Dynamic Multi-sector General Equilibrium Model of the Portuguese Economy

What follows is necessarily a very brief and general description of the design and implementation of the new multi-sector, multi-household dynamic general equilibrium model. More detailed information in provided in the Appendix [see also Pereira and Pereira (2017) for further details].

2.1 The General Features

The dynamic multi-sector general equilibrium model of the Portuguese economy incorporates fully dynamic optimization behavior, detailed household accounts, detailed industry accounts, a comprehensive modeling of the public sector activities, and an elaborate description of the energy sectors. We consider a decentralized economy in a dynamic general equilibrium framework. There are four types of agents in the economy: households, firms, the public sector and a foreign sector. All agents and the economy in general face financial constraints that frame their economic choices. All agents are price takers and are assumed to have perfect foresight. With money absent, the model is framed in real terms.

Households and firms implement optimal choices, as appropriate, to maximize their objective functions. Households maximize their intertemporal utilities subject to an equation of motion for financial wealth, thereby generating optimal consumption, labor supply, and savings behaviors. We consider five household income groups per quintile. While the general structure of household behavior is the same for all household groups, preferences, income, wealth and taxes are household-specific, as are consumption demands, savings, and labor supply.

Firms maximize the net present value of their cash flow, subject to the equation of motion for their capital stock to yield optimal output, labor demand, and investment demand behaviors. We consider thirteen production sectors covering the whole spectrum of economic activity in the country. These include energy producing sectors, such as electricity and petroleum refining, other European Trading System sectors, such as transportation, textiles, wood pulp and paper, chemicals and pharmaceuticals, rubber, plastic and ceramics, and primary metals, as well as sectors not in the European Trading System such as agriculture, basic manufacturing and construction. While the general structure of production behavior is the same for all sectors, technologies, capital endowments, and taxes are sector-specific, as are output supply, labor demand, energy demand, and investment demand.

The public sector and the foreign sector, in turn, evolve in a way that is determined by the economic conditions, and their respective financial constraints. All economic agents interact through demand and supply mechanisms in different markets: commodity markets, factor markets, and financial markets.

The general market equilibrium is defined by market clearing in product markets, labor markets, financial markets, and the market for investment goods. The equilibrium of the product market reflects the national income accounting identity and the different expenditure allocations of the output by sector of economic activity. The total amount of a commodity supplied to the economy, be it produced domestically, or imported from abroad, must equal the total end-user demand for the product, including the demand by households, by the public sector, its use as an intermediate demand, and its application as an investment good. Labor supplied by the different households, adjusted by an unemployment rate that is assumed exogenous and constant, must equal total labor demanded by the different sectors of economic activity. There is only one equilibrium wage rate, although this translates into different household-specific effective wage rates based on household-specific levels of human capital which differ by income quintile. Different firms buy shares of the same aggregate labor supply. Implicitly, this means that we do not consider differences in the composition of labor demand among the different sectors of economic activity, in terms of the incorporated human capital levels. Saving by households and the foreign sector must equal the value of domestic investment plus the budget deficit.

The evolution of the economy is described by the optimal and endogenous change in the stock variables – five household-specific financial wealth variables and thirteen sector-specific private capital stock variables, as well as their respective shadow prices/co-state variables. In addition, the evolution of the stocks of public debt and of the foreign debt act as resource constraints in the overall economy. The endogenous and optimal changes in these stock variables – investment, saving, the budget deficit, and current account deficit – provide the endogenous and optimal link between subsequent time periods. Accordingly, the model can be conceptualized as a large set of nonlinear difference equations, where critical flow variables are optimally determined through optimal control rules.

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. 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 while market prices and shadow prices are constant.

2.2 Calibration

The model is calibrated with data for the period 2005-2014 and stock values for 2015. The calibration of the model is ultimately designed to allow the model to replicate as its most fundamental base case, a stylized steady state of the economy, as defined by the trends and information contained in the data set. In the absence of any policy changes, or any other exogenous changes, the model's implementation will just replicate into the future such stylized economic trends. Counterfactual simulations thus allow us to identify marginal effects of any policy or exogenous change, as deviations from the base case.

There are three types of calibration restrictions imposed by the existence of a steady state. First, it determines the value of critical production parameters, such as 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 budget deficit and the current account deficit are a fraction of the respective stocks of debt equal to the steady-state growth rate. Finally, the exogenous variables, such as public transfers or international transfers, have to grow at the steady-state growth rate.

2.3 Numerical Implementation

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

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

2.4 The Reference Scenario

The reference scenario provides a trajectory for the economy through 2050. This scenario serves as a reference for evaluating the impact of policies that follow. The reference scenario embodies several assumptions regarding climate policy and technological progress. The principal climate policy considerations present in our reference scenario are first, that the tax of 6.85 Euro/tCO_2 persists at this level through 2050 and second that the major coal fired power plants in Portugal cease operations at the end of their useful life and no additional coal capacity is installed. Power has two major coal fired power plants, one in Sines and one in Pego which together accounted for 22% of greenhouse gas emissions in Portugal in 2012. The plant in Sines is scheduled to close in 2035 and the plant in Pego in 2040. Third, we assume that fossil fuel prices follow forecasts given by the International Energy Agency (2016). Finally, we assume an increase in energy efficiency in transportation and in electricity usage of 35% by 2030 with marginal improvements thereafter.

These assumptions imply a reference scenario in which greenhouse gas emissions fall 36.8% from 2015 levels, from 64.6 Mt CO_2e in 2015 to 44.3 Mt CO_2e in 2050. This reduction is largely the result of closing the Sines and Pego power plants but is also driven by increasing oil and natural gas prices. The closing of Sines and Pego is also associated with a substantial increase on domestic reliance on renewable energy resources. Renewable energy resources increase from 52.6% of electricity production in 2015 to 86.5% in 2050, a 64.4% increase over 2015 levels. The greatest increase in the importance of renewable energy in electricity production occurs between 2030 and 2040 with the closure of the coal fired power plants in Portugal. Electricity demand is projected to increase in Portugal by 23.9% in 2050 over 2015 levels, from 46.9 Twh 2015 to 58.1 Twh in 2050. This is in large part driven by technological progress in the electric power industry.

3 Simulation Results

3.1 The Simulation Design

The central policy objective we consider is a 60% reduction in carbon dioxide emissions, relative to 1990 levels, in 2050, which we will refer to as the 60/50 scenario. This emissions constraint is introduced to the TIMES energy system model and the energy sector adjusts to meet this constraint in a cost-effective manner, minimizing the cost of the energy system. The shadow price of the emissions constraint identified by the TIMES model measures the marginal cost of carbon dioxide emissions reductions associated with the emissions constraint. Specifically, the marginal costs of CO_2 abatement considered in the central counterfactual scenario grow from current levels to 33 Euro/tCO_2 in 2030, 49 Euro/tCO_2 by 2040 and 183 Euro/tCO_2 by 2050.

In our simulations, the marginal costs from the TIMES model are implemented as a carbon tax, that is, carbon pricing in its most basic and direct form. This policy also reflects the current state of carbon pricing in Portugal in which the carbon tax levied on households and firms not participating the European Union Emissions Trading System (EU-ETS) is indexed to prices in the EU-ETS, thereby generating a single, economy-wide price for carbon.

The carbon tax yields tax revenues that result from a sharply increasing tax rate applied to a less sharply declining tax base. Accordingly, the tax revenues generated are marginal in the early years of the simulations but reaches about 0.8% of the GDP by 2040 and about 1,7% by 2050. The proceeds from this carbon tax are used to finance a renewable energy feed-in tariff for wind and solar power supplied to the national electric power grid. In these simulations, hydroelectric power facilities are not provided this support.

In the tables summarizing the policy experiments we report two sets of results – the effects of financing a renewable energy feed-in tariff with a tax on carbon dioxide emissions and the effects of an equivalent carbon tax without any revenue recycling. Our main purpose is to identify the effects of financing a renewable energy feed-in tariff with a tax on carbon dioxide emissions from the different relevant perspectives – environmental, macroeconomic, and distributional. These results are reported on the top panel of the different tables. In addition, by comparing the results of the carbon tax without revenue recycling to the effects of the carbon tax financing renewable energy feed in tariff we can ascertain the marginal contribution of the feed in tariffs. These results are reported in the bottom panel of all of the tables, Finally, and for the sake of simplicity although we report the simulation results for 2020, 2030, 2040, and 2050, we focus our discussion on the effects by 2050, which we refer to as the long-term effects of the policies. All results are presented as percent change deviations relative to the Reference Scenario.

3.2 The Effects on the Energy Sector and on CO2 Emissions

Table 1 presents the effects on final energy prices. Overall, final energy prices increase by 57.5% in 2050 relative to the reference scenario.

The prices of coal and natural gas are determined in world commodity markets and the increase in prices here reflects the carbon pricing policies in place. As a result, in the long term the increasing tax on carbon will increase the price of coal by 379.0% and the price of natural gas by 40.6% relative to the reference scenario.

The price of petroleum products reflects both the price of oil set in international markets but also the technical details of the refining process and the amount of each refined petroleum product produced at the refinery in Sines and in Matosinhos. The yield of each product from the refining process together with domestic demand for those specific products and international trade in refined products will ultimately define the prices for the refined products. The dominance of diesel products in transportation demand and in agriculture and fisheries ultimately means that prices for these products grow substantially, by 45.2% by 2050. Gasoline prices are expected to grow by 29.7% relative to the reference scenario reflecting both the relatively higher price of gasoline in place as well as the lower levels of demand for gasoline in transportation and domestic production levels in the refineries in Portugal defined by the technical requirements of the distillate towers.

Heating oils (butane, propane and LPG) can be relatively easily replaced for home space heating with centralized heating units running on electric power. This dampens the increase in prices for heating oils given supply conditions.

Electricity prices decrease over the long run by 1.2% relative to the reference scenario due to the substantial subsidies provided by the significant tax on carbon. The feed-in tariff financed by broader based pricing policies for fossil fuels in function of their carbon content allows for a significant reduction in the levelized costs of producing energy from renewable sources and thereby lowers the costs and prices of electric power. Given the substitution possibilities available to residential and commercial consumers for heating, demand responses to the lower electricity prices provide the basis for the equilibrium price responses observed.

Table 2 presents the effects on final energy demand. The increase in energy prices stemming from financing a renewable energy feed in tariff with a tax on carbon dioxide emissions decreases the final demand for energy products relative to the reference scenario. Overall, final energy demand decreases by 10.4% in 2050 relative to the reference scenario.

The pattern of reduced demand reflects the observed increase in prices for each energy product reflecting the carbon content of the fuel as well as domestic supply and demand constraints. Naturally, final demand for coal by households, in industry and in services decreases significantly by nearly 70.6% relative to the reference scenario in 2050. This is possible because of the relatively easily available substitutes for coal products and the substantial increase in the price of coal relative to electricity and, to a lesser extent, natural gas. By 2050, natural gas demand decreases by 27.7% relative to the reference scenario. In contrast, the lower prices for electricity allow for an increase in electricity demand of 1.3% relative to the reference scenario reflective of an increasing electrification of energy demand in Portugal over the long run as part of a pathway to decarbonization.

Reductions to the final demand for transportation fuels reflect the increase in prices and domestic refinery supply constraints. Over the long run, the final demand for diesel fuel decreases by 26.1% relative to the reference scenario and the demand for gasoline falls by 15.9%. Adjustments within the transportation sector reflect an increasing use of transportation services, public transportation, improvements to fuel efficiency, and increased adoption of electric vehicles for passenger transport.

Table 3 presents the effects on the electric power industry. Over the long run, domestic electricity production increases by 0.8% relative to the reference scenario. The feed-in tariff, coupled with increased costs associated with fossil fuel generation units, naturally increases investment in and the use of renewable energies in the production of electric power. The share of renewable energy in electricity production increases 13.8% percent in 2050 relative to the reference scenario. This increase in the employment of renewable energies reflects the costs of these energies to the utilities but also technological constraints on further deployment of specific technologies. The increase in the wind energy is constrained by the fact that the most productive areas for the placement of wind turbines are the first developed and that additional turbines placed in less productive areas will yield a diminishing marginal product for these capital stocks.

The lower prices for electricity for households, commercial applications in services and in industry, together with the available substitutes in home space heating and in industrial applications, allow for an increase in the final demand for electricity. Electricity demand by households increases by 3.3% in the long run and the demand for electricity by firms increases more marginally by 0.1% relative to the reference scenario.

Table 4 presents the effects on carbon dioxide emissions. Carbon dioxide emissions decrease by 25.9% relative to the reference scenario in 2050. Both firms and households reduce their emissions in response to the pricing policies in place for carbon as well as the incentives in place for use of renewable energies in electricity production. Firms reduce their carbon dioxide emissions by 27.1% relative to the reference scenario. The long run 23.4% reduction in carbon dioxide emissions by household are driven by emissions reductions associated with residential demand for fossil fuels. Residential demand for fossil fuels, especially heating oil and natural gas used for space heating as well as in cooking, can be relatively easily replaced by electric power and biomass used in wood-fired heating units and fireplaces. Carbon dioxide emissions from residential fossil fuel demand decreases by 40.9% relative to the reference scenario.

In contrast, reductions in transportation demand for energy are more limited due to the lack of easily accessible substitutes for fossil fuels in these applications. In the long run, carbon dioxide emissions associated with transportation demand for energy decrease by 16.9% relative to reference scenario.

Comparing the results in the top and bottom panels of **Tables 1 - 4** we are able to ascertain the contribution of the feed in tariff to decarbonization and the energy markets. Overall, the feed in tariffs allow for a slightly deeper level of emissions reductions. This is true for both households and producers, with reductions of emissions enhanced in the long-term by 2.9% and 1.0% respectively, for an aggregate improvement of 1.6%. Residential emissions are the most affected with an enhanced reduction of just under 4%.

These improved outcomes in terms of emissions mirror the effects of the feed in tariffs on final energy prices, final energy demand and the electricity sector. Feed in tariffs lead to slightly lower overall final energy prices led by a decline in electricity prices and a corresponding mitigation of the reduction in final energy demand, with electricity increasing substantially its share of the final energy demand. With the feed in tariff, electricity demand increases particularly for households while the share of renewables in electricity production also increases significantly.

Overall, we can say that the use of the revenues from the carbon tax to finance feed in tariffs, deepens the emissions reductions while at the same time mitigates the adverse energy demand effects of the carbon tax itself.

3.3 The Macroeconomic and Budgetary Effects

Table 5 presents the macroeconomic and budgetary effects. The increasing costs of energy – with the notable exception of electric power – impedes the ability of households to purchase consumer goods and increases production costs both of which contribute to decreased domestic demand and consumption. By 2050, private consumption decreases 2.9% relative to the reference scenario. The feed-in tariff, however, facilitates the large scale investment and deployment of new renewable energy infrastructures which increases private investment by 0.7%.

The increase in domestic production costs due to the higher prices for energy products makes domestically produced goods less attractive in international markets and thereby worsens the current account balance in Portugal. Foreign debt increases by 4.0% over the long run relative to the reference scenario led by a 6.1% deterioration in the trade balance due to a close to 8.0% decrease in exports, though weaker domestic demand also contributes to a 2.5% decrease in imports by 2050.

The overall effect of reduced domestic demand and a worsening of the trade balance – despite the moderate uptick in private investment – is overall weaker economic performance. By 2050, GDP is 2.8% lower than the reference scenario.

By design, the financing policy itself is revenue neutral as the increase in revenues associated with the tax on carbon are used exclusively to promote renewable energy use in the electric power industry by financing a feed-in tariff. As a result, the overall effects on the public sector account are driven by second order effects on tax revenues due to economy-wide responses and tax interaction effects. The net result is an increase in public debt levels by 3.9% percent by 2050 relative to the reference scenario.

Comparing the results in the top and bottom panels of **Table 5** we are able to ascertain the contribution of the feed in tariff to the macroeconomic performance. Overall, the allocation of the revenues from the carbon tax to a feed in tariff significantly mitigates the adverse macroeconomic effects of the carbon tax. Naturally, the most direct effect is on private investment, which now increases by 0.7% vis-à-vis the reference scenario while with the simple carbon tax it would decline by 3.6%. This brings with itself a substantial reduction of the adverse effects on employment. As a consequence, GDP now falls by 2.8% in the long term relative to the reference scenario as opposed 3.7% in the simple carbon tax case, a 32% decline in the magnitude of the adverse effect of the carbon tax. Naturally, these marginal effects also reach private consumption, the trade balance, and the CPI, all of which show clearly better outcomes with the feed in tariff.

Overall, we can say that the use of the revenues from the carbon tax to finance feed in tariffs, greatly mitigates the adverse macroeconomic effects of the carbon tax itself.

3.4 The Industry-Specific Effects

Table 6 presents the industry output effects. The overall output decline in the long-term relative to the reference scenario is 0.8%. The specific industry output effects depend on the types of energy used in the production process, the energy intensity of the production process, the industries exposure to international markets and the response of domestic consumers to increasing costs and prices.

Naturally, because the feed-in tariff provides additional revenues to electric utilities and provides a strong incentive to expand production capacity for renewable energy sources, output of the electric power industry increases by 0.8% relative to the reference scenario by 2050. The capacity expansion encourages construction activities and marginally offsets some of the losses to equipment manufacturers. The most significant decreases in output levels are in transportation services for which few alternatives are commercially and technologically viable with a decline of 10.9%, as well as energy intensive industry, notably non-metallic mineral products - rubber, plastic and ceramics with a 9.4% decrease and chemical and pharmaceutical products with a 7.6% reduction relative to the reference scenario.

Comparing the results in the top and bottom panels of **Table 6** we are able to ascertain the contribution of the feed in tariff to the economic performance at the industry level. Although one can say that the adverse effects of the carbon tax are mitigated with a feed in tariff across basically all sectors of activity, clearly the electricity sector and construction are the ones that benefit the most. In both cases, feed in tariffs translate into positive output, employment and investment effects in these sectors while they both would see a decline along all of these dimensions under a simple carbon tax. Other sectors that benefit significantly from the feed in tariff compared to the simple carbon tax case, include, equipment, wood and related, rubber and related, and primary metals, all sectors clearly linked to investment activities.

Overall, we can say that the use of the revenues from the carbon tax to finance feed in tariffs, greatly mitigates the adverse economic effects of the carbon tax itself across all sectors of activity. Clearly as well, the electricity and investment-related sectors stand to benefit the most.

3.5 Household Welfare Effects

Table 7 presents the distributional effects by quintile of income. The reduction in national income reflected in weaker GDP figures for 2050 is further reflected in reductions to the after-tax income for households. As the sources of income vary across income brackets the overall effects are felt in a rather unequal fashion among households. Lower income household groups tend to earn a more substantial amount of their income from labor while wealthier households have additional sources of capital income. As such, the increase in corporate income made possible due to gains among electric utilities and construction firms, both of which feature heavily in the PSI-20 the Portuguese stock market, translate to increases in income among the higher income groups offset by losses in income for the lower income groups.

Consumer price indices reflect the importance of energy products in the households basket of consumer goods. As noted above, energy products broadly and electricity in particular are generally normal and necessary goods which implies that lower income household groups tend to spend a larger fraction of their income on electricity than do wealther household groups – those these higher income groups do tend have higher power bills reflective of the larger home energy requirements for these household groups. The lower prices for electricity therefore contribute to greater gains for households in the lower income quintiles that marginally offsets increases in energy costs among the remaining energy products consumed by households.

Personal automobiles, however, are less prevalent among households at the lowest income group who tend to rely more on public transportation services. As a result, consumer prices for households in the lowest income quintile increase by 3.7% over the long run, just less than those in the second income quintile who are expected to see a 3.9%t increase in consumer prices relative to the reference scenario. After this level of income, a more traditional pattern of consumer price increases reflecting a decreasing expenditure share for energy products in the household budget emerges.

The effects of feed-in tariff financed by a tax on carbon on the after-tax income of households and on the costs of a typical basket of goods and services paid for by each household group contributes towards a regressive effect of the policy reflected in equivalent variations in income that decrease with income level. Households in the lowest income group experience a welfare loss equivalent to a 4.0% percent reduction in well-being relative to the reference scenario while those in wealthiest households experience a 2.2% reduction in welfare relative to the reference scenario by 2050.

Comparing the results in the top and bottom panels of **Table 7** we are able to ascertain the contribution of the feed in tariff at the household distributional level. Overall, the feed in tariffs reduce the welfare losses induced by the carbon tax for the three lowest income groups despite a greater loss by the two highest income groups. This also implies that the feed in tariffs make the distributional effects of the carbon tax less regressive. The factor of regressivity – the adverse effects of the lowest income group over the adverse effects of the highest income groups – is 2.7 in the simple carbon tax case and it is 1.8 under the feed in tariff scheme.

4 Concluding Remarks

The decarbonization of the Portuguese economy will necessarily go hand in hand with an increasing electrification of energy demand coupled with the production of electricity from green energy resources. In this context, the introduction of a sizeable tax on carbon emissions together with matching incentives for renewable electricity production seems to be a natural policy to consider.

In this paper, we evaluate the environmental, economic and distributional effects of such a policy in Portugal in the context of a multi-sectoral dynamic general equilibrium model. We show that a carbon tax eventually growing by 2050 to 183 euros per ton of CO2 emissions couple with the use of the corresponding revenues as a feed-in tariff for the production of electricity from renewable sources allows indeed for a sharp decline in CO2 emissions. In this sense, this policy is an effective policy if environmental concerns are the overriding consideration.

Our simulation results also show that the macroeconomic effects of such policy are less than innocuous as it will lead to a decline in economic performance, GDP, consumption, investment, employment, and trade balance while at the same time it leads to adverse across the broad negative welfare effects which are actually regressive. This means that a carbon tax with revenues recycled to finance feed in tariffs as appealing as it may be from an environmental perspective, it fails to deliver – it has in fact adverse effects - in terms of the macroeconomic efficiency and social justice.

On the flip side however, we show that use of the carbon tax revenues to finance a feed in tariff is an improvement over the simple carbon tax case along all the relevant policy dimensions. The feed in tariff mechanism leads to better environmental outcomes at lower costs both in terms of the economic and social justice implications.

From a policy perspective, these results highlight two very important facts. First, the use of the revenues of a carbon tax to finance feed in tariffs represents an improvement over a simple carbon tax. In this sense, a carbon tax should never be implemented in isolation. Rather, at the very least, it should be combined with such feed in tariff mechanisms. Second, the effects of the combined policies of a carbon tax and feed in tariffs still yield potentially adverse macroeconomic and distributional effects that may be enough to jeopardize support among the citizens and attention from the political actors thereby sowing the seeds of inertia. In this sense, the quest for recycling mechanisms for the carbon tax revenues that may reverse the adverse macroeconomic and distributional effects is wide open.

5 References

Behrens, Paul, Joao F.D. Rodrigues, Tiago Bras, and Carlos Silva. 2016. Environmental, economic and social impacts of feed-in tariffs: A Portuguese perspective 2000-2010. *Applied Energy*. 173:309-319

Bhattacharya, Suparna, Konstantinos Giannakas, and Karina Schoengold. 2017. Market and Welfare Effects of Renewable Portfolio Standards in United States Electricity Markets. *Energy Economics*

Bohringer, Christoph, Florian Landis, Tovar Reanos and Miguel Angel. 2016. Cost-effectiveness and incidence of renewable energy promotion in Germany. Oldenburg Discussion Papers in Economics. No. V-390-16

Direcção Geral de Energia e Geologia, 2018. https://www.dgeg.gov.pt

Dissou, Yazid and Muhammad Shahid Siddiqui. 2014. Can carbon taxes be progressive? *Energy Economics*. 42: 88-100

Energy International Agency, 2018, https://www.eia.gov/outlooks/ieo/pdf/0484(2017).pdf.

Eurostat (2016). "Energy Price Statistics," Brussels. Available: http://ec.europa.eu/ eurostat/statistics-explained/pdfscache/1223.pdf

Frondel, Manuel. Nolan Ritter, Christoph Schmidt, and Colin Vance. 2010. Economic Impacts from the Promotion of Renewable Energy Technologies: The German Experience. *Energy Policy*. 38:4048-4056

Fullerton, Don and Garth Heutel. 2010. Analytical General Equilibrium Effects of Energy Policy on Output and Factor Prices. *NBER Working Paper Series* Working Paper 15788

Fullerton, Don, Garth Heutel and Gilbert Metcalf. 2011. Does the Indexing of Government Transfers Make Carbon Pricing Progressive. *CESifo Working Papers* Working Paper No. 3315

Fullerton, Don. 2008. Distributional Effects of Environmental and Energy Policy: An Introduction. *NBER Working Paper Series* Working Paper 14241

Galinato, Gregmar and Jonathan Yoder. 2010. An integrated tax-subsidy policy for carbon emission reduction. *Resource and Energy Economics*. 32: 310-326

Kalkuhl, Matthias, Ottmar Edenhofer, and Kai Lessmann. 2013. Renewable energy subsidies: Second-best policy or fatal aberration for mitigation? *Resource and Energy Economics*. 35:217-234

Kallbekken, Steffen, Stephan Kroll and Todd Cherry. 2011. Do you not like Pigou, or do you not understand him? Tax aversion and revenue recycling in the lab. *Journal of Environmental Economics and Management*. 62:53-64

Parry, Ian and Roberton Williams III. 2010. What are the Costs of Meeting Distributional Objectives for Climate Policy? *NBER Working Paper Series*. Working Paper 16486

Pereira, Alfredo and Rui Pereira, 2017. The Role of Electricity for the Decarbonization of the Portuguese Economy – DGEP Technical Report, https://mpra.ub.uni-muenchen.de/id/eprint/84782

Portugal National Statistics Institute (INE), 2019. www.ine.pt

Rausch, Sebastian and Giacomo Schwarz. 2016. Household heterogeneity, aggregation, and the distributional impacts of environmental taxes. *Journal of Public Economics* 138: 43-57

Rausch, Sebastian and Matthew Mowers. 2012. Distributional and Efficiency Impacts of Clean and Renewable Energy Standards for Electricity. *MIT Joint Program on the Science and Policy of Global Change.* Report No. 225.

Table 1 Effects on Final Energy Prices

(Percent Change Relative to the Reference Scenario)

	2020	2030	2040	2050
Green Energy Feed-in Tariff Financed by Carbon Tax				
Composite Energy Price Index	3.163	18.915	23.054	57.564
Coal	23.695	131.692	157.499	379.031
Natural Gas	2.669	14.661	17.202	40.638
Butane, Propane and LPG	1.636	9.350	11.271	26.887
Gasoline	1.690	9.852	12.202	29.710
Diesel	2.521	14.453	18.015	45.197
Electricity	-0.719	-0.796	-2.978	-1.174
Biomass	-0.264	0.478	-0.015	1.626
Carbon Tax w/o Revenue Recycling				
Composite Energy Price Index	3.350	19.410	23.912	58.863
Coal	23.695	131.692	157.499	379.031
Natural Gas	2.669	14.661	17.202	40.638
Butane, Propane and LPG	1.777	9.799	12.070	28.155
Gasoline	1.744	9.910	12.260	29.752
Diesel	2.482	14.408	17.968	45.134
Electricity	0.541	3.006	3.483	8.273
Biomass	0.062	0.929	0.621	2.427

Source: Authors' Calculations

Table 2 Effects on Final Energy Demand

	2020	2030	2040	2050
Green Energy Feed-in Tariff Financed by Carbon Tax				
Final Energy Demand	-0.717	-4.267	-4.281	-10.398
Coal	-15.406	-48.417	-52.797	-70.622
Natural Gas	-2.417	-12.330	-14.225	-27.649
Butane, Propane and LPG	-1.474	-7.535	-9.101	-18.741
Gasoline	-1.264	-6.338	-7.602	-15.860
Diesel	-1.967	-10.582	-12.721	-26.059
Electricity	0.606	0.781	2.683	1.262
Biomass	0.060	0.334	0.429	0.747
Share of Electricity in Final Energy Demand	1.570	6.389	8.751	15.624
Carbon Tax w/o Revenue Recycling				
Final Energy Demand	-1.157	-5.866	-6.927	-14.126
Coal	-14.859	-47.698	-51.804	-69.764
Natural Gas	-2.496	-12.239	-13.952	-27.121
Butane, Propane and LPG	-1.456	-7.494	-9.043	-18.589
Gasoline	-1.146	-6.207	-7.462	-15.671
Diesel	-2.010	-10.643	-12.798	-26.090
Electricity	-0.390	-2.339	-2.653	-6.028
Biomass	0.341	1.126	1.718	2.536
Share of Electricity in Final Energy Demand	0.902	4.404	5.245	10.707

Source: Authors' Calculations

Table 3 Effects on the Electric Power Industry

(Percent Change Relative to the Reference Scenario)

	2020	2030	2040	2050
Green Energy Feed-in Tariff Financed by Carbon Tax				
Electricity Production	0.494	0.544	2.133	0.786
Thermal	-1.373	-5.584	-12.883	-23.665
Hydroelectric	-0.119	-0.401	-0.735	-1.128
On-shore Wind	5.431	17.328	30.175	44.161
Solar Photovoltaic	2.453	8.158	14.873	22.735
Percent of RES in Electricity Production	2.073	6.902	8.962	13.774
Net Imports of Electricity	-1.204	-2.118	-5.489	-1.961
Exports	1.384	1.525	5.966	2.249
Imports	-0.400	-0.449	-1.621	-0.677
Electricity Demand by Household	0.324	1.418	2.810	3.292
Electricity Demand by Sector	0.521	0.322	1.941	0.144
Carbon Tax w/o Revenue Recycling				
Electricity Production	-0.351	-2.083	-2.347	-5.311
Thermal	-1.080	-5.006	-10.826	-21.123
Hydroelectric	0.233	0.686	1.098	1.455
On-shore Wind	0.217	0.646	1.044	1.393
Solar Photovoltaic	0.117	0.377	0.654	0.927
Percent of RES in Electricity Production	0.756	3.148	4.503	8.220
Net Imports of Electricity	0.844	5.869	5.046	10.805
Exports	-0.996	-5.578	-6.355	-14.161
Imports	0.308	1.606	1.888	4.573
Electricity Demand by Household	-0.002	-0.194	-0.241	-1.179
Electricity Demand by Sector	-0.438	-2.513	-2.853	-6.336

Source: Authors' Calculations

Table 4 Effects on Carbon Dioxide Emissions

(Percent Change Relative to the Reference Scenario)

	2020	2030	2040	2050
Green Energy Feed-in Tariff Financed by Carbon Tax				
Carbon Dioxide Emissions	-1.862	-8.546	-13.583	-25.923
Carbon Dioxide Emissions by Households	-3.073	-11.720	-13.533	-23.365
Residential	-7.532	-24.967	-27.867	-40.897
Transportation	-1.525	-6.663	-8.099	-16.930
Carbon Dioxide Emissions by Firms	-1.480	-7.632	-13.606	-27.116
Carbon Tax w/o Revenue Recycling				
Carbon Dioxide Emissions	-1.806	-8.457	-13.278	-25.525
Carbon Dioxide Emissions by Households	-2.665	-11.221	-12.906	-22.710
Residential	-6.953	-23.996	-26.463	-39.324
Transportation	-1.165	-6.247	-7.656	-16.478
Carbon Dioxide Emissions by Firms	-1.534	-7.655	-13.445	-26.841

Source: Authors' Calculations

Table 5 Effect on Macroeconomic Performance

(Percent Change Relative to the Reference Scenario)

	2020	2030	2040	2050
Green Energy Feed-in Tariff Financed by Carbon Tax				
Gross Domestic Product	-0.019	-0.937	-1.092	-2.782
Private Consumption	-0.484	-1.112	-1.361	-2.827
Gross Fixed Capital Formation	2.566	2.029	2.195	0.655
Exports	-0.609	-3.103	-3.772	-7.974
Imports	0.056	-0.967	-1.086	-2.508
GDP Deflator	0.178	0.560	0.597	1.373
Employment	0.216	-0.244	-0.313	-1.173
Foreign Debt	0.446	1.504	2.778	3.995
Current Account Deficit	14.214	19.545	16.661	12.466
Trade Deficit	1.197	2.785	3.348	6.056
Public Debt	0.416	1.238	2.341	3.853
Carbon Tax w/o Revenue Recycling				
Gross Domestic Product	-0.276	-1.436	-1.784	-3.732
Private Consumption	-0.114	-0.708	-0.961	-2.442
Gross Fixed Capital Formation	-0.222	-1.300	-1.610	-3.588
Exports	-0.723	-3.545	-4.527	-9.060
Imports	-0.308	-1.422	-1.625	-3.111
GDP Deflator	0.120	0.652	0.820	1.801
Employment	-0.137	-0.717	-0.891	-1.874
Foreign Debt	0.086	0.842	2.361	4.405
Current Account Deficit	3.334	14.673	14.233	18.381
Trade Deficit	0.395	2.199	3.011	5.889
Public Debt	-0.280	-2.846	-7.111	-12.874

Source: Authors' Calculations

Table 6 Output Effects by Sector of Economic Activity

	2020	2030	2040	2050
Green Energy Feed-in Tariff Financed by Carbon Tax				
Total	-0.019	-0.937	-1.092	-2.782
Petroleum Refining	-1.474	-7.535	-9.101	-18.741
Electricity Production	0.494	0.544	2.133	0.786
Biomass	0.060	0.334	0.429	0.747
Agriculture	-0.220	-1.144	-1.454	-3.216
Equipment Manufacturing	-0.334	-2.189	-3.110	-6.209
Construction	2.046	1.478	1.598	0.075
Transportation	-0.780	-4.281	-4.964	-10.884
Textiles	-0.464	-1.699	-2.061	-4.260
Wood, pulp and paper	-0.237	-1.620	-1.953	-4.439
Chemicals and pharmaceuticals	-0.606	-3.007	-3.474	-7.575
Rubber, plastic and ceramics	-0.412	-3.611	-4.239	-9.434
Primary metals	-0.213	-1.831	-2.350	-5.201
Other	-0.054	-0.489	-0.635	-1.517
Carbon Tax w/o Revenue Recycling				
Total	-0.276	-1.436	-1.784	-3.732
Petroleum Refining	-1.456	-7.494	-9.043	-18.589
Electricity Production	-0.351	-2.083	-2.347	-5.311
Biomass	0.341	1.126	1.718	2.536
Agriculture	-0.236	-1.239	-1.641	-3.507
Equipment Manufacturing	-0.747	-3.118	-4.549	-8.131
Construction	-0.218	-1.257	-1.548	-3.427
Transportation	-0.778	-4.320	-5.056	-11.001
Textiles	-0.340	-1.712	-2.240	-4.639
Wood, pulp and paper	-0.509	-2.349	-3.155	-6.084
Chemicals and pharmaceuticals	-0.648	-3.317	-4.066	-8.398
Rubber, plastic and ceramics	-0.949	-4.593	-5.666	-11.192
Primary metals	-0.627	-2.778	-3.833	-7.162
Other	-0.109	-0.625	-0.820	-1.837

Source: Authors' Calculations

Table 7 Distributional Effects on Households: Equivalent Variation in Income

(Percent Change Relative to the Reference Scenario)

	2020	2030	2040	2050
Green Energy Feed-in Tariff Financed by Carbon Tax				
First Quintile (Lowest Income)	-0.370	-1.457	-1.727	-3.986
Second Quintile	-0.389	-1.452	-1.748	-3.972
Third Quintile	-0.493	-1.195	-1.454	-3.060
Fourth Quintile	-0.564	-1.010	-1.246	-2.414
Fifth Quintile (Highest Income)	-0.495	-0.906	-1.137	-2.221
Carbon Tax w/o Revenue Recycling				
First Quintile (Lowest Income)	-0.263	-1.498	-1.910	-4.358
Second Quintile	-0.247	-1.425	-1.828	-4.207
Third Quintile	-0.124	-0.834	-1.121	-2.797
Fourth Quintile	-0.034	-0.395	-0.602	-1.755
Fifth Quintile (Highest Income)	-0.032	-0.367	-0.559	-1.627

Source: Authors' Calculations

APPENDIX

DGEP Model Description and Implementation

1. Model Description

Household Behavior

We consider five household income groups per quintile. While the general structure of household behavior is the same for all household groups, preferences, income, wealth and taxes are all household-specific, as are consumption demands, savings, and labor supply.

Household h chooses consumption and leisure streams that maximize intertemporal utility, subject to the consolidated budget constraint. The objective function is lifetime expected utility, subjectively discounted at the rate of β. Preferences, are additively separable in consumption and leisure, and take on the CES form, where σ is the constant elasticity of substitution.

C_h denotes the total consumption by household *h*, including both expenditure on goods and services. P_h is a household-specific price index which reflects consumption levels of individual goods and services as well as their prices. The household-specific price index reflects the individual basket of goods and services that each household selects. The amount of time the household spends in leisure and recreational activities is denoted by ℓ_h.

The budget constraint 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, $TW_{h,t}$. For the household h, total wealth, $TW_{h,t}$, is composed of human wealth, $HW_{h,t}$, and net financial wealth, $A_{h,t}$.

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. Labor earnings are discounted at a higher rate reflecting the probability of survival.

The effective wage rate, wHK_h, accomodates differences in income levels for the same number of work hours, by accounting for differences in worker productivity reflected in differences in the level of human capital each household has accumulated. The level of human capital for each household reflects differences in education and experience among the various household groups. In this version of the model the household-specific HK is fixed or exogenously given.

A household's labor income is augmented by international transfers, R_t, and public transfers, TR_t as well as capital income - interest payments received on public debt, PD_t, net of payments made on foreign debt, and profits distributed by corporations, NCF_t, where s_{ht} is the share of household *h* of the aggregate market portfolio.

On the spending side, taxes are paid and consumption expenditures are made. Income, net of spending, adds to net financial wealth in the form of savings. To allocate aggregate consumption to specific commodities, goods and services, consumers maximize utility from consumption subject to their budget constraint:

$$\max_{\mathbf{QH_h}} \left[\, U^h(\mathbf{QH_h}) \;\middle|\; PC_h QC_h \;\geq\; (\mathbf{1}+\boldsymbol{\tau}_{\mathbf{vat}})(\mathbf{PQ}+\boldsymbol{\tau}_{\mathbf{unit}}) \times \mathbf{QH_h} \right]$$

where $\boldsymbol{PQ}$ and $\boldsymbol{QH_h}$ denote a vector of price (\$/unit) and quantity (physical units) of a good consumed over the course of a year, respectively. $PC_{ht}QC_{ht}$ represents total expenditure on goods and services by the household h at time t. Expenditure on goods and services is subject to product and service-specific value-added tax rates, $\tau_{\text{vat,c}}$, and other unit taxes, $\tau_{\text{unit,c}}$, including the tax on petroleum and energy products (ISP). At optimality, the marginal rate of substitution is equal to the market opportunity cost. The exchange rate for the individual household required to maintain a given level of utility is exactly equal to the rate at which the household can exchange these goods in the marketplace.

This general framework is applied at two different levels. First, it is applied to determine the optimal allocation of total consumption spending among the three main category of goods: transportation services, residential energy, other goods and services. Second, it is applied to determine the optimal allocation within more specific categories within each one of these three main groups.

Producer Behavior

We consider thirteen production sectors. While the general structure of production behavior is the same for all sectors, technologies, capital endowments, and taxes are sector-specific as are output supply, labor demand, energy demand, and investment demand.

Firms maximize the present value of the firm which serves as a source of financial wealth for households. The firm maximizes the present value Hamiltonian which reflects the firm's net cash flow and is subject to the equation of motion for private capital, and renewable energy capital, specified for hydroelectric, wind and solar power infrastructures.

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

The corporate income tax base is calculated as revenues net of total labor costs, $(1 + \tau_{FSSC})w_t L_t^d$, as well as spending in energy and materials and is net of fiscal depreciation allowances over past and present capital investments, αI_t.

Output is produced using capital, labor, energy and material inputs. The production technology describes the level of output possible for the use of inputs to production employed by the firm. The production technology is assumed to be continuous and twice differentiable and thus, by the appropriate choices for the elasticity of substitution in production yields a smooth, continuous approximation to the discrete choice of processes, activities and equipment made at the plant level.

Capital, labor and energy inputs are separable into two broader categories, value added and energy inputs. Value added includes capital and labor inputs to production. A Constant Elasticity of Substitution technology is used to describe the level of value added produced from capital and labor inputs. Energy inputs consist of coal, natural gas, crude oil, refined oil products and electricity. These are aggregated according to a constant elasticity of substitution technology. The conditional demand for these inputs is defined from efforts by the firm to minimize the costs of producing the composite quantity required at the higher levels for the nested production structure.

Material inputs are goods and services produced by other industries needed in production. These material inputs are used in fixed proportions to the level of output. The firm cannot substitute among materials in production. The firm may, however, through its organization of assembly and manufacturing operations, substitute between material inputs and capital, labor and energy in production according to a constant elasticity of substitution production technology.

Private capital accumulation is characterized by the equation of motion for capital 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.

Optimal production behavior consists in choosing the levels of output supply, labor demand, aggregate energy demand, aggregate demand for intermediate materials, and demand for investment that maximize the present value of the firms' net cash flows, subject to the equation of motion for private capital accumulation.

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 netted of investment spending is transferred to the consumers as return on their ownership of the firms.

Investment Supply and Demand

The output of various industries is used in the production of capital goods used by firms. Construction, equipment manufacturing, primary metals and other goods and services are used in the production of plant and equipment for firms. These industry determine the supply of investment goods. The supply of the investment good is a CES composite of the different types of investment goods available in the economy.

Demand for individual component of the investment good is determined by the minimization of the cost of producing the desired amount of the investment good in the economy at time t. In turn, the demand for investment by firms is determined by the firms' maximization problem described above.

Financing for investment is available from savings by private households and foreign transfers reflected in the current accounts deficit and is affected by public deficits whereby reductions in tax revenues or unfinanced increases in expenditures increase the public deficit and crowd out private investment.

The Foreign Sector

The current account deficit reflects the balance of payments with the foreign sector and incorporates both the trade balance and financial flows from abroad. Because of the nature of the currency markets where the economy finds itself, we assume that the foreign exchange rate is exogenous and fixed. This means that in the absence of import and export duties, the import and export prices for the same commodity would be the same.

Net imports 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.

Domestic production and imports are absorbed by domestic expenditure and exports. Domestic demand is satisfied by domestic production and imports from abroad following an Armington specification. Goods produced domestically are supplied to both the national (domestic) market and exported internationally and follow a Constant Elasticity of Transformation (CET) specification

The Public Sector

The equation of motion for public debt reflects the fact that the excess of government expenditures over tax revenues, i.e., the public deficit, has to be financed by increases in public debt. Given the nature of our approach, the evolution of public debt is determined by the endogenous evolution of the tax revenues or more specifically by the endogenous evolution of the different tax bases. Specifically, no behavioral changes on the expenditure side are considered.

Tax revenues include personal income taxes, corporate income taxes, value added taxes as well as other product-specific taxes, social security taxes levied on firms and workers, as well as duties levied on imports and/or exports. All of these taxes are levied on endogenously defined tax bases. Residual taxes are modeled as lump sum, obtained by calibration and are assumed to grow at an exogenous rate.

On the expenditure side, the public sector engages in public consumption and public investment activities. In addition, the public sector transfers funds to households - in the form of pensions, unemployment subsidies, and social transfers also at an exogenous growth rate. Because these expenditures consistent primarily of expenditures on compensation of public sector employees and on social transfers, these expenditures are assumed to grow at an exogenous rate g. Finally, the public sector pays interest on outstanding debt

The allocation of public consumption spending among the different goods and services in the economy is responsive to relative prices and is obtained through the solution to the public sector's cost minimization problem of achieving the desired aggregate consumption level. While aggregate consumption in volume is determined exogenously, public consumption expenditure is affected by endogenous changes in prices determined by the model supply and demand considerations.

2. Data

General Data Sources

Data are from Statistics Portugal (www.ine.pt). The data are based on the Portuguese National Accounts (ESA 2010, base 2011). These data include A – main aggregates for the Portuguese economy, including 1) Gross Domestic Product and its components, 2) Income, Saving and Net Lending/ Borrowing, 3) External Balances, 4) Employment and 5) Goods and Services account. These further include B – Institutional Sectors including, the Government, Households and the Rest of the World (the Foreign Sector). We further consider specific tables by industries including Gross Value Added – Compensation of Employees, Gross Operating Surplus and Taxes/Subsidies on Production, as well as Production and Intermediate Consumption by the

A38 classification of economic activity described below. We further use detailed supply and use tables to construct the social accounting matrix for Portugal.

Data for household expenditure are taken from two surveys. The first is the Inquérito ao Consumo de Energia no Sector Doméstico, a one-time survey conducted in 2010. The second is the Inquérito às Despesas das Famílias, a survey conducted every five years. The model largely employs data from the 2010/2011 survey in allocating income to household by income group and describing the expenditure patterns for each household type.

The Energy Sector

Portugal imports fossil fuels and has a large potential for renewable energy resources, namely wind, solar and hydropower. Renewable energy resources accounted for 25.9% of domestic primary energy consumption in Portugal in 2014, primarily used in the production of electricity. Petroleum and petroleum products accounted for 43.4% of primary energy consumption in Portugal in 2014. Natural gas (16.7% and coal (12.8%) are important sources of energy as well.

Transportation demand for energy amounted to 36.3% of the total final demand for energy in 2014, followed closely by industry (31.2%). Diesel is the dominant fuel in transportation in Portugal (4.072 Mtep in 2014), followed by gasoline (1.136). Residential demand for energy amounted to 16.8% of the total and demand in services accounted for 12.8%. The remaining 2.8% constitutes final energy demand in agriculture. With respect to electricity, services (36.7%) and industry (34.5%) are much more important as is residential demand for electricity (26.4% of the total). Agriculture (1.8%) and transportation (0.7%) do not use electricity extensively.

Renewable energies have made substantial advances in Portugal since 2005. In 2005, thermal electricity general amounted to 85% of the total and renewable energies, including hydroelectric, wind, geothermal and solar power, amounted to 15% of electricity generation. By 2014, electricity generation grew to account for 56.4% of electricity generated in continental Portugal lead by a substantial increase in wind energy generation which accounted for 23.4% of electricity production in 2014, a year with very favorable hydrological conditions which allowed for electricity from hydroelectric facilities to account for 31.9% of total electricity produced. The increased reliance on domestic, renewable energy sources has contributed towards a reduction in emissions factor for the electric power industry from 462 tCO_2 per Gwh in 2005 to 217 tCO_2 per Gwh in 2014.

Installed capacity in the electric power industry consisted of approximately 11.8 GM of renewable energy, including 6.0 GW of hydroelectric capacity, 5.0 GW of wind energy, 0.5GW of solar power and 0.3 GW of other renewable energy resources including biomass, wave energy and geothermal energy, approximately 63.8% of installed capacity. Projections based on the cost effectiveness of the various energy technologies and there evolution in the coming decade suggest that installed capacity of renewable energies are expected to grow to between 25.7 and 28.8 GW, of which hydroelectric facilities make up 9.0 GW, wind energy between 8.0 and 9.2 GM, solar power between 8.1 and 9.9 GW and other renewable energies make up between 0.6 and 0.7 GW, approximately 90% of installed capacity (PNEC, 2018).

In 2008 and 2009 the final demand for electricity in Portugal fell 1.2% and 0.9%, respectively. During the crisis that followed, electricity demand fell 8.8%, from 48.9 Twh in 2010 to 44.6 Twh in 2014, falling 3.0% in 2011 and 4.1% in 2012, respectively. This reduction in emissions is likely attributable to low levels of economic output and consumer confidence during the crisis (Eurostat, 2017)

Energy products in Portugal are subject to value added taxation and product specific taxes. Since January 1, 2011 the value added tax (IVA) rate on energy products is 23% (Lei nº51-A/2011, de 30 de Setembro), up from 19% in 2005. Energy products are subject to a specific tax on petroleum products (ISP) and to carbon taxation. Industrial use of natural gas is exempt from carbon taxation. The carbon tax rate for 2017 is based on an average price in the EU-ETS of 6.85 Euro/tCO_2 (Portaria nº 10/2017, de 09/01).

The Portuguese Economy

The Portuguese economy was dramatically affected by the sovereign debt crisis experienced in many parts of Europe since 2011. The late 1990s was a period of substantial growth in Portugal during which time the Portuguese economy grew at an average annual rate of 4.2%. During the early 2000s, the Portuguese economy began to stagnate and grew at an average annual rate of 1.5% between 2000 and 2004. Since 2005, growth in Portugal has been very weak. The real annual rate of growth of economic activity between 2005 and 2014 was -0.2%. In fact, since the financial crisis Portugal lost 6.8% of its national income between 2010 and 2013. Growth has picked up over that the last few years with the real growth rate of estimated for 2015 at 1.6%.

Gross domestic product consists of private consumption (66.44%), public consumption (19.94%), investment (19.66%) and net exports (-8.21), the difference between exports (28.75%) and imports (36.96%). From the income side, employment made up 46.23% of GDP between 2005 and 2014 while gross operating surplus for firms amounted to 41.44% of GDP. These figures imply that labor income made up 52.73% of income and capital income accounted for 47.27% of income.

The largest sectors of economic activity, in terms of employment levels between 2005 and 2014, were Wholesale and retail trade (15.6%), construction (9.3%), agriculture (7.5%), the public sector, accommodation and food services (5.8%), and manufacturing of textiles, wearing apparel and leather products (4.9%).The principal exports in Portugal are automobiles and transportation equipment with exports from the manufacturing of transport equipment accounting for 3.2% of GDP followed by the manufacturing of textiles, wearing apparel and leather products which exported products valued at 3.1% of GDP between 2005 and 2014. Other energy intensive manufacturing industries, including basic metals and fabricated metal products (2.3%), non-metallic mineral products (2.0%) and wood and paper products (1.8%), have also been very important tradable sectors in the Portuguese economy. (Source: Statistics Portugal)

Household Income and Expenditure

Households consume energy to satisfy demand for transportation services and for residential use. Residential energy consumption accounted for 3.91% of household expenditure while energy demand for personal transportation accounted for 4.55% of household expenditure. Diesel fuel is the dominant source of fuel for automobile transportation in Portugal, accounting for 56.9% of energy consumption in transportation. Residential energy demand includes the use of electricity for heating (11.1% of expenditure) and cooling (0.7%) the residence, heating water (27.4%), energy consumption in the kitchen (39.7%), associated with electrical appliances (15.0%) and lighting (6.1%). Residential demand for energy is dominated by electricity consumption which accounts for 42.5% of consumption and 62.5% of expenditure on energy across households. Butane, propane and liquefied petroleum gases (LPG) are also an important source of energy in residences accounting for 18.0% of consumption and 24.3% of expenditure. These are particularly important sources of energy for hot water furnaces and for use in cooking in the kitchen. Natural gas use in residences has increased in recent years but remains relatively modest accounting for 9.3% of consumption and 6.1% of expenditures. Coal is used in small amounts in households and almost exclusively for cooking.

Patterns of energy consumption across household groups at different income levels tend to suggest that energy services are normal goods, whose consumption increases with income, and that these are necessary goods, that they tend, generally to make up a larger share of a household's budget at lower levels of income than at higher levels of income. This pattern of consumption is particularly apparent for electricity demand. Expenditure on electricity amounted to 4.04% (3.91%) of expenditure for households in the lowest income quintile in 2010, 3.49% (3.11%) for those in the second quintile, 3.07% (2.69%) for those in the third quintile, 2.63% (2.26%) for those in the fourth quintile and 2.25% (1.70%) for those in the highest income quintile. Natural gas consumption tends to follow a similar pattern of expenditures, though expenditures in the lowest income quintile are slightly lower (0.42% of income) than those in the second (0.56%) and third (0.45%) of income. Expenditure on natural gas for households in the highest two income quintile is somewhat lower, at 0.29% and 0.10% of income, respectively.

Much of Portugal, and the larger cities of Lisbon and Porto, in particular, is equipped with a well-developed public transportation system which includes buses, trains, boats and light rail networks. The availability of this public transportation network coupled with high gasoline and diesel prices, lower salaries, and the relatively compact city structures have contributed towards making cars something of a luxury, though expenditure shares vary little across income groups. Diesel and gasoline consumption together account for 4.32% of expenditure among low income households, 4.49% among households in the second income quintile, 4.55% among those in the third income quintile, 4.63% among those in the fourth income quintile and 4.57% among those in the highest income quintile.

The Public Sector

Since 2005, public debt has exploded from 67.4% of GDP to 130.6% of GDP in 2014. Public deficits in Portugal reached 6.8% of GDP in 2009 and 8.2% of GDP in 2010.

The tax burden in Portugal amounted to 34.5% of GDP in 2015. In recent years, the increase in taxation in the context of austerity measures to address high levels of public indebtedness have focused on increases in the corporate income tax, the value added tax and social security contributions. The tax burden in Portugal was below the EU28 average of 39.0% in 2015. Taxes on income, including personal income taxes (9.27%) and social security contributions (7.98% of GDP from employers and 3.74% from workers) are the largest source of revenue for the Portuguese government. Value added and excise taxes are the second largest source of income for the Portuguese government. Revenues from the value added tax amounted to 8.0% of GDP between 2005 and 2014 and product specific excise taxes, including taxes on energy products amounted to 4.37% of GDP.

GEE Papers

1: Evolução do Comércio Externo Português de Exportação (1995-2004)
João Ferreira do Amaral

2: Nowcasting an Economic Aggregate with Disaggregate Dynamic Factors: An Application to Portuguese GDP
Antonio Morgado | Luis Nunes | Susana Salvado

3: Are the Dynamics of Knowledge-Based Industries Any Different?
Ricardo Mamede | Daniel Mota | Manuel Godinho

4: Competitiveness and convergence in Portugal
Jorge Braga de Macedo

5: Produtividade, Competitividade e Quotas de Exportação
Jorge Santos

6: Export Diversification and Technological Improvement: Recent Trends in the Portuguese Economy
Manuel Cabral

7: Election Results and Opportunistic Policies: An Integrated Approach
Toke Aidt | Francisco Veiga | Linda Veiga

8: Behavioural Determinants of Foreign Direct Investment
Ricardo Pinheiro-Alves

9: Structural Transformation and the role of Foreign Direct Investment in Portugal: a descriptive analysis for the period 1990-2005
Miguel de Freitas | Ricardo Mamede

10: Productive experience and specialization opportunities for Portugal: an empirical assessment
Miguel de Freitas | Susana Salvado | Luis Nunes | Rui Costa Neves

11: The Portuguese Active Labour Market Policy during the period 1998-2003 - A Comprehensive Conditional Difference-In-Differences Application
Alcina Nunes | Paulino Teixeira

12: Fiscal Policy in a Monetary Union: Gains from Changing Institutions
Susana Salvado

13: Coordination and Stabilization Gains of Fiscal Policy in a Monetary Union
Susana Salvado

14: The Relevance of Productive Experience in the Process of Economic Growth: an Empirical Study
Diana Vieira

15: Employment and Exchange rates: the Role of Openness and Technology
Fernando Alexandre | Pedro Bação | João Cerejeira | Miguel Portela

16: Aggregate and sector-specific exchange rate indexes for the Portuguese economy
Fernando Alexandre | Pedro Bação | João Cerejeira | Miguel Portela

17: The Macroeconomic Determinants of Cross Border Mergers and Acquisitions and Greenfield Investments
Paula Neto | Antonio Brandao | António Cerqueira

18: Does the location of manufacturing determine service sectors' location choices? Evidence from Portugal
Nuno Crespo | Maria Paula Fontoura

19: A hipótese do Investment Development Path: Uma Abordagem por Dados em Painel. Os casos de Portugal e Espanha
Miguel Fonseca | António Mendonça | José Passos

20: Outward FDI Effects on the Portuguese Trade Balance, 1996-2007
Miguel Fonseca | António Mendonça | José Passos

21: Sectoral and regional impacts of the European Carbon Market in Portugal
Margarita Robaina Alves | Miguel Rodriguez | Catarina Roseta-Palma

22: Business Demography Dynamics in Portugal: A Non-Parametric Survival Analysis
Alcina Nunes | Elsa Sarmento

23: Business Demography Dynamics in Portugal: A Semi-parametric Survival Analysis
Alcina Nunes | Elsa Sarmento

24: Digging Out the PPP Hypothesis: an Integrated Empirical Coverage
Miguel de Carvalho | Paulo Júlio

25: Regulação de Mercados por Licenciamento
Patrícia Cerqueira | Ricardo Pinheiro Alves

26: Which Portuguese Manufacturing Firms Learn by Exporting?
Armando Silva | Óscar Afonso | Ana Paula Africano

27: Building Bridges: Heterogeneous Jurisdictions, Endogenous Spillovers, and the Benefits of Decentralization
Paulo Júlio | Susana Peralta

28: Análise comparativa de sobrevivência empresarial: o caso da região Norte de Portugal
Elsa Sarmento | Alcina Nunes

29: Business creation in Portugal: Comparison between the World Bank data and Quadros de Pessoal
Elsa Sarmento | Alcina Nunes

30: The Ease of Doing Business Index as a tool for Investment location decisions
João Zambujal Oliveira | Ricardo Pinheiro Alves

31: The Politics of Growth: Can Lobbying Raise Growth and Welfare?
Paulo Júlio

32: The choice of transport technology in the presence of exports and FDI
José Pedro Ponte | Armando Garcia Pires

33: Tax Competition in an Expanding European Union
Ronald Davies | Johannes Voget

34: The usefulness of State trade missions for the internationalization of firms: an econometric analysis
Ana Paula Africano | Aurora Teixeira | André Caiado

35: The role of subsidies for exports: Evidence from Portuguese manufacturing firms
Armando Silva

36: Criação de empresas em Portugal e Espanha: análise comparativa com base nos dados do Banco Mundial
Elsa Sarmento | Alcina Nunes

37: Economic performance and international trade engagement: the case of Portuguese manufacturing firms
Armando Silva | Oscar Afonso | Ana Paula Africano

38: The importance of Intermediaries organizations in international R&D cooperation: an empirical multivariate study across Europe
Aurora Teixeira | Margarida Catarino

39: Financial constraints, exports and monetary integration - Financial constraints and exports: An analysis of Portuguese firms during the European monetary integration
Filipe Silva | Carlos Carreira

40: FDI and institutional reform in Portugal
Paulo Júlio | Ricardo Pinheiro-Alves | José Tavares

41: Evaluating the forecast quality of GDP components
Paulo Júlio | Pedro Esperança | João C. Fonseca

42: Assessing the Endogeneity of OCA conditions in EMU
Carlos Vieira | Isabel Vieira

43: Labor Adjustment Dynamics: An Application of System GMM
Pedro Esperança

44: Corporate taxes and the location of FDI in Europe using firm-level data
Tomás Silva | Sergio Lagoa

45: Public Debt Stabilization: Redistributive Delays versus Preemptive Anticipations
Paulo Júlio

46: Organizational Characteristics and Performance of Export Promotion Agencies: Portugal and Ireland compared
Inês Ferreira | Aurora Teixeira

47: Evaluating the forecast quality of GDP components: An application to G7
Paulo Júlio | Pedro Esperança

48: The influence of Doing Business' institutional variables in Foreign Direct Investment
Andreia Olival

49: Regional and Sectoral Foreign Direct Investment in Portugal since Joining the EU: A Dynamic Portrait
Irina Melo | Alexandra Lopes

50: Institutions and Firm Formation: an Empirical Analysis of Portuguese Municipalities
Simão Arouca

51: Youth Unemployment in Southern Europe
João Leão | Guida Nogueira

52: Financiamento da Economia Portuguesa: um Obstáculo ao Crescimento?
João Leão | Ana Martins | João Gonçalves

53: O Acordo de Parceria Transatlântica entre a UE e os EUA constitui uma ameaça ou uma oportunidade para a Economia Portuguesa?
João Leão | Guida Nogueira

54: Prescription Patterns of Pharmaceuticals
Ana Gonçalves

55: Economic Growth and the High Skilled: the Role of Scale Eects and of Barriers to Entry into the High Tech
Pedro Gil | Oscar Afonso | Paulo Brito

56: Finanças Públicas Portuguesas Sustentáveis no Estado Novo (1933-1974)?
Ricardo Ferraz

57: What Determines Firm-level Export Capacity? Evidence from Portuguese firms
Ana Gouveia | Ana Luisa Correia

58: The effect of developing countries' competition on regional labour markets in Portugal
Tiago Pereira

59: Fiscal Multipliers in the 21st century
Pedro Brinca | Hans Holter | Per Krusell | Laurence Malafry

60: Reallocation of Resources between Tradable and Non-Tradable Sectors in Portugal: Developing a new Identification Strategy for the Tradable Sector
Ana Fontoura Gouveia | Filipa Canas

61: Is the ECB unconventional monetary policy effective?
Inês Pereira

62: The Determinants of TFP Growth in the Portuguese Manufacturing Sector
Daniel Gonçalves | Ana Martins

63: Practical contribution for the assessment and monitoring of product market competition in the Portuguese Economy – estimation of price cost margins
Luis Folque

64: The impact of structural reforms of the judicial system: a survey
Ana Gouveia | Silvia Santos | Corinna Herber

65: The short-term impact of structural reforms on productivity growth: beyond direct effects
Ana Gouveia | Silvia Santos | Inês Gonçalves

66: Assessing the Competitiveness of the Portuguese Footwear Sector
Fábio Batista | José Matos | Miguel Matos

67: The empirics of agglomeration economies: the link with productivity
Ana Gouveia | Silvia Santos | Marli Fernandes

68: Determinants of the Portuguese GDP stagnation during the 2001-2014 period: an empirical investigation
Carlos Figueira

69: Short-run effects of product markets' deregulation: a more productive, more efficient and more resilient economy?
Ana Gouveia | Silvia Santos | Gustavo Monteiro

70: Portugal: a Paradox in Productivity
Ricardo Pinheiro Alves

71: Infrastructure Investment, Labor Productivity, and International Competitiveness: The Case of Portugal
Alfredo Pereira | Rui Pereira

106: Integration of Small Technology-Based Firms in Aeronautics
Anabela Reis | Joana Mendonça | Ligia Urbina

107: The Effects of Highway Tolls on Private Business Activity – Results from a Natural Experiment
João Pereira dos Santos | David B. Audretsch | Dirk Dohse

108: Competition and Firm Productivity: Evidence from Portugal
Pedro Carvalho

109: Do Exchange Traded Funds (ETFs) Outperform the Market? Evidence from the Portuguese Stock Index
Carlos Manuel Pinheiro | Hugo Hilário Varela

110: Assessing the Competitiveness of the Portuguese Chemical Sector
Ana Rita Marques | Cátia Silva

111: A General Equilibrium Theory of Occupational Choice under Optimistic Beliefs about Entrepreneurial Ability
Michele Dell'Era | Luca David Opromolla | Luis Santos-Pinto

112: O Mercado Segurador em Portugal: O Papel dos Gestores na Constituição de Provisões
Soraia de Sousa Bornett | Carlos Manuel Pinheiro

113: Exploring the implications of di erent loan-to-value macroprudential policy designs
Rita Basto | Sandra Gomes | Diana Lima

114: The Determinants of TFP Growth in the Portuguese Service Sector
Ana Martins | Tiago Domingues | Catarina Branco

115: Agglomeration and Industry Spillover Effects in the Aftermath of a Credit Shock
José Jorge | Joana Rocha

116: Entrepreneurial Human Capital and Firm Dynamics
Francisco Queiró

117: Global Value Chains and Vertical Specialization: The case of Portuguese Textiles and Shoes exports
Tiago Domingues

118: Firm heterogeneity and exports in Portugal: Identifying export potential
Frederico Oliveira Torres

119: Vantagens Comparativas Reveladas e suas Determinantes: Uma Aplicação à Economia Portuguesa
Guida Nogueira e António Portugal Duarte

120: A Look at the main channels of Potential Impact of Brexit on the Portuguese Economy
Guida Nogueira e Paulo Inácio

121: How internationalization and competitiveness contribute to get public support to innovation? The Portuguese case
Anabela Santos, Michele Cincera, Paulo Neto and Maria Manuel Serrano

122: Grande Guerra e Guerra Colonial: Quanto Custaram aos Cofres Portugueses?
Ricardo Ferraz

123: Financing a Renewable Energy Feed-in Tariff with a Tax on Carbon Dioxide Emissions: A Dynamic Multi-Sector General Equilibrium Analysis for Portugal
Rui M. Pereira and Alfredo M. Pereira

Gabinete de Estratégia e Estudos