EVALUATING THE IMPACT OF THE INTRODUCTION OF A CARBON TAX IN PORTUGAL USING INPUT-OUTPUT BASED MODELS

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Abstract

This paper presents the methodology and results for the evaluation of the macroeconomic, fiscal and environmental impact of the introduction of a carbon tax in Portugal, using a multisectoral (input-output based) model (MODEM 7) combined with an input-output (I-O) price model, considering different levels and scopes for this tax as well as alternative ways of recycling the additional corresponding public revenue.

MODEM 7 is a multisectoral model (with 85 industries), which includes an input-output based block (determining output, employment and taxes and subsidies on products, as well as imports by products, assuming that supply is determined by final demand, in line with the input-output Leontief quantity model). All components of final demand are exogenous, with the exception of private consumption, which is determined by private disposable income. The model includes also macroeconomic equations determining private disposable income and consumption, GDP, total employment, the unemployment rate and fiscal variables which allow the determination of public deficit and debt. In alternative, a fiscal policy rule may be included in model simulations, imposing, for example, no deterioration of public deficit compared to a reference scenario and making the adjustment through a chosen fiscal variable. All variables are defined at current prices, assuming that, for each model simulation, there are no price changes within each year. All equations are static, except for public debt. The model determines also CO_2 emissions through the application of emission coefficients to each product's output and to households' consumption. Model coefficients were estimated on the basis of a system of I-O tables for Portugal, 2008, as well as of other data from Portuguese national accounts and from the environmental satellite accounts. Most of the equations (702) are simultaneously determined.

A carbon tax applied to CO_2 emissions resulting from fossil fuel combustion implies, as a primary effect, the increase in fossil fuel prices. An input-output price model (disaggregated into 85 products and calibrated with the same system of I-O tables used for MODEM 7) was used to estimate the direct and indirect effects of this tax on each product's basic price, as well as on purchaser's price for the various demand components and products, using a cost-push assumption for price determination.

The price effects simulated with the price model for each carbon tax scenario (tax level and scope) were subsequently used to re-estimate MODEM's nominal input-output coefficients, assuming that I-O coefficients for intermediate consumption remained unchanged in real terms. Final exogenous demand was assumed to remain constant in nominal terms (equal to the, before-tax, reference scenario), except for Change in Inventories, which was assumed to remain constant in volume for each product. After these adjustments, simulations were performed, with the adjusted MODEM, for various levels and scopes of the carbon tax, with no fiscal policy rule (without recycling additional tax revenue) as well as with a fiscal policy rule imposing an unchanged public deficit (compared to the reference scenario) and making the adjustment through various alternative variables: other tax cuts (households or company income taxes) or the increase in different types of expenditure (Education, R&D, investment in infrastructures and incentives to private investment), i.e., considering alternative ways of recycling the additional net revenue resulting from the carbon tax introduction.

The impacts of the new carbon tax were obtained, for each alternative simulation, from the comparison between the scenario "with the new carbon tax" and the reference scenario (without this carbon tax). These comparisons were made both in nominal and in real terms (after deflating the results from the scenarios "with tax" with the appropriate price deflators, obtained from the I-O price model simulation).

The results from this study suggest that, while the introduction of a carbon tax without recycling the additional public revenue has a negative impact on the economy, recycling this revenue through the reduction of direct taxes may not be enough to totally reverse this negative effect and that better economic global effects may be achieved if this revenue is recycled through certain types of public expenditure such as those having simultaneously a low unit (direct plus indirect) import content (and, therefore, a positive significant impact on GDP in the short-term), and also contributing to the increase in total factor productivity, such as investment in human capital and in R&D (with a positive long-term effect on potential output).

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1. INTRODUCTION

This paper presents the methodology and results for the evaluation of the macroeconomic, fiscal and environmental impact of the introduction of a new carbon tax in Portugal, using a multisectoral (input-output based) model (MODEM 7) combined with an input-output price model, considering different levels and scopes for this tax as well as alternative ways of recycling the additional corresponding public revenue.

This evaluation was first developed in 2014, in the Portuguese Environment Agency (APA) (Dias[1], 2014), responding to a solicitation from the Commission for Green Fiscal Reform (Comissão para a Reforma da Fiscalidade Verde, CRFV, appointed by the Portuguese Government) and it was updated in January 2015 (in the General Secretary of the Ministry of Environment, Spatial Planning and Energy: SG-MAOTE), after the exact terms of the Green Fiscal Reform (implemented by the Government in 2015) were known. Besides the presently described methodology and evaluation, other three models were used with the same purpose (evaluation of the impact of a new carbon tax in Portugal) by other modeling teams and a comprehensive report was made including a summary of the methodologies and results from the four models (Pereira, coord., 2014).

Section 2 describes MODEM 7 and section 3 presents the input-output price model and its use for the estimation of the effect of a new carbon tax on production (basic) prices and on purchaser's prices for the various products as well as on final demand and GDP deflators. Section 4 explains the method and presents the results for the evaluation of the economic, fiscal and environmental impact of a new carbon tax and, finally, section 5 presents some concluding remarks. Appendixes 1 to 7 show details regarding MODEM 7 and the price model.

2. MODEM 7

2.1. General features

MODEM is a multisectoral (input-output based) model which was developed for Portugal with the purpose of evaluating the macroeconomic impact of public policies and of other exogenous demand and income shocks at the national, sectoral and regional levels, as well as the impact on public finance variables. Previous versions of this model are described in Dias and Lopes (2010b), for MODEM 6C and, in English, in Dias and Lopes (2009), for MODEM 6A.

Versions 1 (1992) to 6C (2010) were developed in the Portuguese Department of Foresight and Planning (DPP[2]) while version 7 was developed by the author in APA, in 2014.

The logic of the model is that supply is determined by demand, in line with the input-output, demand-pull, Leontief quantity model (Blair and Miller, 2009; Leontief, 1986) and all components of final demand are exogenous except private consumption, which is determined by disposable income.

[1] With the collaboration of Manuela Dias.

[2] DPP, a Portuguese Government department with functions in the areas of strategic and macroeconomic planning and policy evaluation, was abolished in 2012. Part of its functions were transferred to APA and, later on (in 2014), to the Prospective and Planning Services (SPP) of SG-MAOTE.

The model is annual and all equations are static, except for public debt. The variables are defined at current prices and there are no price variables in the model, assuming that, for each model simulation, there are no price changes within each year.

The model contains a national block, used for impact simulation at the national level, and a regional block which permits to estimate the breakdown by regions of the national impacts simulated in the national block.

For the present exercise only the national block of the model was used and therefore only this block will be described in detail in this paper. A description of the regional block can be found in Dias and Lopes (2009) and in Dias and Lopes (2010b).

The main differences between MODEM 7 and MODEM 6A are:

- A new product disaggregation (85 products/homogeneous industries, instead of 59, of which six are energy products);
- A more detailed modeling of indirect taxes and of subsidies;
- Modeling of labor supply and of unemployment;
- Endogenisation of public expenditure with unemployment benefits;
- A new modeling approach for company disposable income;
- Introduction of environmental equations, determining CO_2 emissions;
- Use of more updated data for model calibration (including a system of input-output tables estimated for 2008).

2.2. The national block of MODEM 7

The main variables determined by MODEM 7's national block are:

- Sectoral (for 85 industries) and total Output, Gross Value Added and Employment (in full-time equivalents);
- GDP, disposable income, private consumption and imports (total and by products);
- Labor supply, total employment (number of individuals) and unemployment rate;
- Fiscal revenue, decomposed into direct and indirect taxes and social contributions;
- Public expenditure with subsidies on products, unemployment benefits and interest;
- Public deficit and debt;
- CO_2 emissions associated to combustion processes by industry, households and total.

The national block contains 810 equations, of which 702 are simultaneously determined. The following paragraphs describe model specification. The lists of model equations, variables and coefficients are presented in Appendixes 2 and 3 while the list of MODEM 7 products/industries is presented in Appendix 1.

2.2.1. Sectoral (input-output based) equations:

Output (equations 1), Imports (equations 11), Taxes on Products (equations 22) and subsidies on products (equations 30) are determined, for each product, by the corresponding (intermediate and final) demand, using matrices of technical coefficients decomposed into domestic production, import, tax and subsidy coefficients. Exceptions are the output for agricultural, forest and fishery products (sectors 1 to 3 of MODEM 7), which is exogenously determined, the adjustment between demand and supply for these products being made through imports (equations10).

Output of trade services (products 39 to 41 of MODEM 7) and output and imports of land and water transport services (products 42 and 43) have a specific treatment in the model concerning the determination of its final demand, considering that part of these services' output corresponds to trade and transport margins and so the output of these services is also determined by demand (at purchaser's prices) addressed to all products which include a trade or a transport margin in their purchaser's price.

Each component of final demand is decomposed into 85 products (corresponding to the activity sectors considered in the model) and, for each product, into five parts: the part satisfied by domestically produced goods at basic prices, the part corresponding to imported goods CIF; the parts corresponding to taxes and to subsidies on products (the last ones with a negative sign); and the parts corresponding to trade and to transport margins. This decomposition can be made using coefficients estimated from systems of input-output matrices for the Portuguese economy. However, alternative coefficients may be used in the simulation of demand and price shocks, allowing for a different breakdown by products of demand and/or a different import or tax content of the demand for each product, compared to the reference scenario.

Gross value added (GVA) in each industry is obtained by multiplying the corresponding domestic output by a product transformation coefficient (equations 19).

Employment in each industry (full-time equivalent) is obtained through the division of the respective GVA by the labor productivity estimated for that industry (equations 20).

Total output, imports, GVA and employment (fte) are obtained through the summation of the respective values across all products (equations 34 to 37).

2.2.2. Labor market equations:

Total employment (number of individuals, equation 56) is obtained multiplying the volume of total employment (fte) by an exogenously determined factor.

Labor supply (PA, equation 55) is determined, not only by exogenous demographic factors (such as the size of labor age population and trends in the activity rate) but also by the existing labor opportunities (proxied by the level of total employment), which encourage or not the search for a job and migration movements.

Unemployment (equation 57) is obtained through the difference between labor supply and total employment (number of individuals).

2.2.3. Private consumption, disposable income and GDP:

Residents' private consumption, (CONS, equation 45), is determined by private (Households and Non-Profit Institutions Serving Households, NPISH) disposable income. Households'Final Consumption on the Territory (CT, equation 46) is obtained from CONS through the addition of Tourism Balance and the subtraction NPISH's consumption.

The equation for private disposable income (YD, equation 53) is an identity based on the fact that this income is equal to the difference between National Disposable Income (GDP plus the balances of factor income and of current transfers with the Rest of the World), and the sum of Government and Companies' disposable incomes.

Current transfers with the Rest of the World are exogenous (TREG, TREO, TD2S, ZPC, OZC, OTC) with the exception of taxes on products paid to the European Union (TPC, equation 62), which are modeled decomposed into Value Added tax and other taxes.

Value Added Tax paid to the EU (IVAC, equation 63) is determined by the final demand components representing the main basis of incidence of non-deductible VAT (Households consumption, GFCF and Changes in Valuables) multiplied by an exogenously determined factor.

Other taxes on products paid to the EU (OTPC, equation 64), which are taxes on imports, are a function of total imports.

A part of the balance of factor income with the RoW (equation 54) is an exogenously defined fraction of interest on public debt (the part that is paid abroad).

Companies' disposable income (YDSOC, equation 51) depends on Gross Operating Surplus (EBE) and on company direct taxation (TDSC).

Governments' disposable income is obtained from the difference between Government's total current revenue and total current expenditure (with the exception of public consumption).

Total Gross Operating Surplus (EBE, equation 52) is obtained residually, from the difference between total Gross Value Added and the sum of total compensations of employees with other taxes (net of other subsidies) on production.

GDP at market prices (Y) is obtained from the sum of final demand components and deduction of total imports (equation 50). GDP is also calculated through the sum of total GVA at basic prices with total taxes (net of subsidies) on products (equation 50a). Model specification and the method of calculation of model coefficients theoretically ensure that the results of both methods for GDP calculation are equal but this equation is included in the model simulation as a test (assigning a different name to the dependent variable), with the purpose of detecting any possible errors in model programming or in coefficient estimation.

2.2.4. Public finance equations:

The model has also a fiscal block allowing the simulation of the impact of policy or other shocks on public deficit and debt or, in alternative, the definition of a fiscal policy rule such as establishing a fixed amount for public deficit and making the adjustment through one of the existing variables in the model for public revenue or expenditure. The following paragraphs present the standard version of the equations in the fiscal block, used for the reference simulations, without a fiscal policy rule.

Government Total Balance (SGG, equation 74) is obtained through the difference between total revenue and total expenditure.

Public expenditure components are all exogenous with the exception of unemployment benefits, subsidies on products and interest on public debt.

Total public expenditure with unemployment benefits (SUBDES, equation 71) is obtained from the multiplication of the number of unemployed by an exogenously defined average benefit per unemployed.

The value of subsidies on products paid by the Government (ZPG, equation 67) is calculated through the difference between the global value of subsidies on products (equation 44), obtained from the sum, across all products, of subsidies simulated for each product and the subsidies on products paid by the EU (ZPC, an exogenous variable).

Interest expenditure on public debt (JURG, equation 73) depends on the level of public debt and on an average interest rate, defined exogenously.

Government capital transfers (TRKG) and current transfers with the rest of the world (TREG) are only considered in balance (revenue less expenditure) and are both exogenous.

The other components of public revenue (taxes, social contributions and property income) are all endogenous with the exception of capital taxes (TK) which are practically insignificant and so were made exogenous. Taxes and contributions are functions of the corresponding tax basis (or a proxy of it) multiplied by exogenous tax rates. Taxes are decomposed into four categories: direct taxes on Households plus NPISH, company direct taxes, taxes on products and other taxes on production.

Direct taxes on Households plus NPISH (TD, equation 58) and company direct taxes (TDSC, equation 59) are functions of the respective disposable incomes.

The value of taxes on products received by the Government (TPG, equation 61) is calculated through the difference between the global value of taxes on products (TP, equation 43), obtained from the sum, across all products, of taxes on products simulated for each product, and the taxes on products received by the EU (TPC, equation 62, explained above).

Other taxes on production received by the Government (OTG, equation 65) are calculated from the difference between the total amount of these taxes (OT, equation 42, obtained from the sum of these taxes across all industries) and the part of these taxes that is paid to the EU (OTC), which is treated as exogenous, given its insignificant value. For each industry, other taxes on production are calculated through the application of a tax coefficient to the respective output (equations 21).

Social contributions received by the Government (CSOCG, equation 88) are a function of total compensation of employees (REM, equation 41), which, in turn, are calculated from the aggregation of the respective values across all industries, obtained from the application of wage coefficients to each industry's output.

Government Property Income plus Gross Operating Surplus (REPG, equation 69) is a function of total Gross Operating Surplus generated in the economy.

The change in public debt (DIV, equation 72) depends on government total balance and on an exogenously defined variable (DAT) reflecting the flows affecting public debt but not public deficit.

The above description corresponds to the standard version of the model, used in reference simulations. For variant simulations using a fiscal policy rule, equation 74 is rearranged, with public deficit becoming an exogenous variable (moved to the right-hand side of the equation) and with the variable chosen for adjustment becoming the dependent variable (on the left-hand side of the equation).

2.2.5. Environmental equations:

Carbon dioxide emissions associated to combustion processes (ECO2, equations 75 to 77) are obtained through the application of emission factors to each industry's output and to households' consumption.

2.3. Model calibration and reference simulation

2.3.1. General features

Model coefficients are normally estimated for each of the years for which model simulations are necessary, on the basis of available statistical information from National Accounts (for past and present years) and considering scenarios for the Portuguese economy (for future years).

After estimating all the model coefficients for the national block, for a specific year, a model reference simulation is performed for that year using the national block in order to check the correctness of model specification and coefficients estimation, through the comparison of simulated and actual (or projected) values for each variable. Model calibration for each year is only accepted when all values match.

For the present exercise MODEM 7 was calibrated with 2008 data, on the basis of a system of symmetric input-output tables (85×85 products) estimated for Portugal for that year (Dias and Domingos, 2011), which was the most recent system of I-O tables available for Portugal at the time, and of other data from National Accounts, including the Environment Satellite Accounts, and a reference simulation was performed for that year (2008).

Further details regarding the methodology used for model calibration may be found in Appendix 5.

2.3.2 Estimation of the equation for Labor Supply

An econometric estimation was performed for the labor supply equation (equation 55 in Appendix 2), in order to estimate the parameter (cpand) relating labor Supply (PA) and total Employment (ND), using observed data for Portugal from 1981 to 2013. The main results of this estimation are presented in Appendix 4. For this estimation several explanatory variables were used which are exogenous in MODEM 7 (time: T, working age population: P1564 and the combination of both: P1564*T) besides total employment (ND), which is endogenous. Therefore, the following equation was estimated:

$PA = \alpha_0 + \alpha_1 \times \log(T) + \alpha_2 \times P1564 + \alpha_3 \times P1564*T + \alpha_4 \times ND + \varepsilon$

where ε is a residual stochastic variable with expected value equal to zero.

The equation for labor supply included in the model is: PA = PA0+cpand×ND, where PA0 represents the exogenous component of PA, i.e., comparing with the above formulation of the estimated equation:

$PA0 = \alpha_0 + \alpha_1 \times \log(T) + \alpha_2 \times P1564 + \alpha_3 \times P1564*T$ and $cpand = \alpha_4$

The estimated value for cpand is approximately 0.477, representing the increase in labor supply induced by one unit increase in total employment.

2.4. Policy evaluation with MODEM

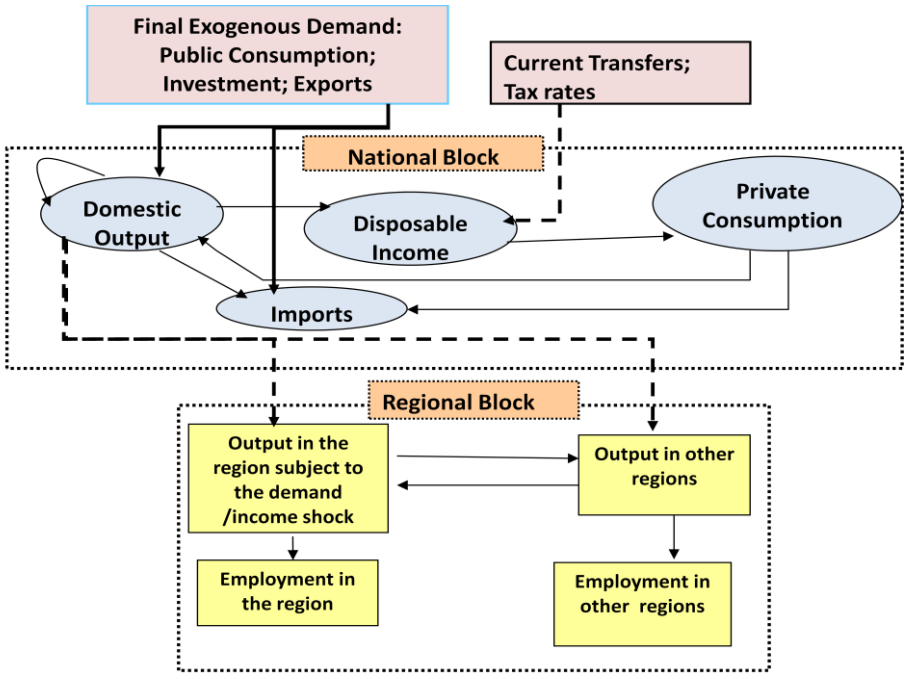
The various versions of MODEM have been used in the past in the evaluation of demand and income shocks on the Portuguese economy, including those induced by large projects and public investment programs, including those co-financed by the European Union.

Examples of such studies are, at the national level, the evaluation of the impact of EXPO'98, which took place in Lisbon (DPP, 1996; Proença *et al.*, 1998) and of the Government Investment and Development Programs, PIDDAC (Dias and Lopes, 2004), and, at the national and regional levels, the evaluations of the National Strategic Reference Framework implemented in 2008-2009 (Dias, Lopes and Martins, 2011) and of Regional Operational Programs (Dias and Lopes, 2001 and 2005).

Figure 1 presents a simplified model diagram showing the main channels of influence of exogenous demand and income shocks on macroeconomic variables.

Figure 1

MODEM and the evaluation of the impact of exogenous demand and income shocks - a simplified diagram



Impact evaluation at the national level is made through the comparison of the results of two model simulations for each of the years to which the impacts refer to:

- a reference simulation, reproducing the observed or projected performance for the Portuguese economy;
- a simulation corresponding to what would happen to the economy in the absence (presence) of the exogenous shock subject to evaluation (depending whether the shock is already included or not in the reference simulation). This simulation is performed after revising the values of the exogenous variables in order to exclude (include) the direct effect of the shock on them.

The macroeconomic impact of the shock is measured through the percent deviation between the two simulations for each model variable.

3. THE INPUT-OUTPUT PRICE MODEL AND THE EVALUATION OF THE IMPACT OF A NEW CARBON TAX ON PRICES

A carbon tax applied to CO_2 emissions resulting from fossil fuel combustion implies, as a primary effect, the increase in fossil fuel prices.

As MODEM does not include price variables, an input-output price model was used to estimate the direct and indirect effects of this tax on prices and, subsequently, recalculate MODEM coefficients (at current prices), make new model simulations and compare the results from the new simulations with those from the reference simulation, at both current and reference scenario prices.

The input-output (I-O) Leontief price model is the dual of the input-output Leontief quantity model and while, in the quantity model, output is determined by final demand (demand-pull), in the price model, prices are determined by unit costs (cost-push). A basic description of the quantity and price I-O Leontief models is presented in chapter 2 of Miller and Blair (2009). Martins (2002) presents a more detailed description of the I-O price model.

The I-O price model allows us to determine the impact of an increase in the price of primary inputs (imported inputs, taxes and subsidies on inputs and value added) on production (basic) prices and on purchasers' prices for the various products.

In the present study we have used the price model to determine the impact of an increase in taxes on fossil fuels on prices.

Appendix 6 presents the details of the price model used in this study. The basic equation of the model is, for the case of a fiscal shock (equation 8 of Appendix 6):

$$p' = UFS'(I–AN)^{-1}$$

where p' is the row-vector for production (basic) percent price increases resulting from the new tax, UFS' is a row-vector for unit fiscal shocks (total tax increase on inputs per unit of output, in each industry) and $(I–AN)^{-1}$ is the so-called "Leontief inverse" (matrix of output multipliers) (see Appendix 6 for a more detailed explanation).

In order to calculate the impact on prices of the new tax, is was necessary to estimate the UFS vector. The AN matrix had already been calculated with the purpose of MODEM 7 calibration.

The j^{th} element of UFS is (equation 7 of Appendix 6):

$$UFS_j = (\underset{i}{\Sigma}\Delta T_{ij})/X_j$$

where ΔT_{ij} is the additional tax charged on input i, used by industry j as a result of the new carbon tax and X_j is the output of product j, in the reference scenario (before the introduction of the new tax).

In order to calculate the fiscal shocks (ΔT_{ij}), resulting from a new carbon tax and as this tax is calculated as a certain amount of euros per ton of CO2 emissions (in combustion processes), the first step was to estimate CO2 emissions associated to fossil fuel consumption for each one of the fossil fuels used for combustion that were considered in the model (products 4: coal; 17:

coke and refined petroleum products; and 33: natural gas distributed), for Portugal, in 2008 (the base year for MODEM 7 calibration).

This estimation was made using data on energy consumption (in Terajoules), per type of fuel, for Portugal, 2008 (from the Portuguese Environment Satellite Accounts, source: Portuguese Statistical office, INE, October 2013), converted into CO2 emissions using emission factors per type of fuel provided by the Portuguese Environment Agency, APA). Total values of emissions per type of fuel were subsequently ventilated by industries and by households' consumption proportionately to the respective fuel consumption at basic prices (using data on Total Flows, at basic prices, for Portugal, 2008, disaggregated by 431 products and 85 industries, calculated from data provided by INE).

Subsequently, and considering several possible values for the carbon tax rate (between 5 and 35 euros per ton of CO2 emissions), combined with different assumptions in terms of the carbon tax incidence (applied to all sectors or excluding those under the EU-ETS, or applied only to those that are not exempt from ISP – the already existing tax on petroleum and energy products), an estimation was made for the additional amount of tax on products to be paid by each industry and by households. The carbon tax was also combined with the additional amount of VAT resulting from it (at the existing rate of 23%), considering, for each industry, the share of non-deductible VAT, estimated from the input-output tables for 2008.

For the cases of application only to Non-ETS or only to ISP payers, it was necessary to estimate their share on CO2 emissions in each one of the 85 industries considered in the model, which was done using data for ETS GHG emissions, provided by the Portuguese Environment Agency, and for CO2 emissions from ISP exempt installations (source: CRFV, 2014, table 14).

After all this information was collected, we could estimate the impact of the new carbon tax on production and purchasers' prices for each product and on final demand (for each demand component) and GDP deflators, using the formulas presented in Appendix 6, for each value of the carbon tax rate and level of its sectoral incidence.

4. EVALUATION OF THE ECONOMIC, FISCAL AND ENVIRONMENTAL IMPACT OF THE INTRODUCTION OF A NEW CARBON TAX

4.1. General features

After the calculation of the impact of each option for the carbon tax on prices, we revised MODEM 7 nominal input-output coefficients (at current prices) for each one of the carbon tax alternatives, assuming that I-O coefficients remained unchanged in real terms, using the methodology described in Appendix 7.

The different versions of recalibrated MODEM 7 were then used for the simulation of the scenarios with the new carbon tax.

In the simulations with the recalibrated MODEM we assumed that the output of industries 1 to 3 (Agriculture, Forestry and Fishing) , which is exogenous in the model, would remain unchanged in volume and so the respective nominal values were updated considering the estimated increases in the production prices for these industries.

For final demand, we assumed that it would remain unchanged in nominal terms, except for Households' Consumption (which is endogenously determined by the model) and for Change in Inventories (because it is an adjustment variable between supply and demand and so we assumed it would remain constant in volume and determined its total nominal value through the multiplication by the respective deflator).

The justification for keeping the other components of final demand constant in nominal terms may be either by the assumption of a price elasticity of demand = -1 (for example, in the case of Exports) or by the existence of a budget restriction (in the case of Public Consumption and Investment).

Besides the different options for the level and sectoral incidence of the carbon tax (which affect prices and MODEM 7 nominal coefficients), we considered different options for recycling the additional revenue derived from this tax, including a reduction in other taxes or an increase in certain types of public expenditures:

- No revenue recycling, implying a reduction in public deficit and debt, compared to the reference scenario;
- Reduction in personal income tax;
- Reduction in social security contributions;
- Reduction in company taxes;
- Increase in transfers to households;
- Increase in Other Subsidies to Production;
- Increase in expenditure with R&D;
- Increase with expenditure with education services (investment in human capital);
- Increase in investment in infrastructures;
- Increase in incentives to private investment.

For the "No revenue recycling" option we used the standard version of MODEM 7 for simulation while for the other options we used the version with a fiscal policy rule (see last paragraph of section 2.2.5) which consisted in fixing the value of public deficit equal to the observed/simulated value from the reference scenario (*i.e.*, SGG, in equation 74, becoming an exogenous variable) and calculating residually (endogenizing) the adjustment (tax or expenditure) variable.

Tables 1 to 3 and 5 presents a summary of the evaluation of different options for the carbon tax, made in 2014 to support the work from the Portuguese Commission for Green Tax Reform (CRFV – see section 1) to prepare a proposal for the Government. Tables 6 and 7 present the results of new simulations, made in January 2015, after the green tax reform was actually implemented, considering the terms of this law.

The impacts on prices (deflators of GDP and of final demand components) presented in tables 5 to 7 are based on the calculations from the input-output price model, with adjustments made after MODEM 7 simulations to change the territorial concept (used in the price model) to the residents' concept for households' consumption and for exports.

The evaluations presented in tables 3 to 6 were made using as a reference scenario the values observed for the Portuguese economy in 2008 (the latest year for which we had detailed input-output tables for Portugal) and the parameters estimated for that year.

However, some projections were made for the impacts of different options of the carbon tax on real GDP, on public debt and on employment for the period 2015 to 2030 (deviations from a reference scenario), assuming that the tax was introduced in 2015 (as it was effectively the case) and that it was maintained at the same rate along 2015-2030, with an annual impact on public primary balance and on nominal GDP (in euros) similar to those simulated for 2008 and with an impact on GDP deflator (percent deviation from the reference scenario) inversely proportional to the level of projected nominal GDP (compared to its value for 2008) in a defined reference scenario. Regarding employment (in full-time equivalents), we assumed that the impact of the carbon tax was equal to the impact simulated for 2008 divided by an index of nominal labor productivity (2008=1), defined in the reference scenario. This reference scenario was established using observed data for the Portuguese economy until 2013, combined with IMF projections for Portugal until 2019 (IMF, 2014) and assuming values for the years from 2020 to 2030 equal to those implicit in the IMF scenario for 2019, regarding the annual growth rates of nominal GDP, nominal labor productivity and the implicit interest rate on public debt (3.6%, 3% and 4%, respectively).

The results of these projections (relative to the simulations presented in table 5) are presented on tables 1 and 2, for 2015 and 2030. These projections are particularly important, concerning public debt, for the options of "no revenue recycling", as the impact on public debt reduction will increase along the years as a result of cumulated reductions in annual primary deficits combined with the reduction in interest expenditure.

4.2. Impact of a new carbon tax without revenue recycling

The introduction of a new carbon tax without recycling the additional public revenue implies a reduction in real total domestic disposable income as the new tax boosts prices while final exogenous demand (at purchasers' prices) remains unchanged in nominal terms (except, by assumption, the change in inventories), therefore maintaining the level of nominal output and of GDP at market prices relatively unchanged.

Value added at basic prices decreases, even in nominal terms, because the share of value added in the total value of output at basic prices shrinks as the price of output goes up (due to the increase in the cost of intermediate inputs, motivated by the increase in taxes on inputs) while (by assumption) the "price" of value added remains unchanged.

The nominal decrease in total value added implies a nominal reduction in private disposable income (both for households and for companies), causing a decrease in nominal private consumption which is even greater when evaluated in real terms. As a result, real GDP and total employment go down.

Total additional fiscal revenue is lower than the one coming from the new tax because the revenue obtained from all the other taxes and contributions is lower due to the reduction in the general level of economic activity. On the other hand, there is an increase in public expenditure with unemployment benefits as the number of unemployed increases. Therefore, the impact of the new tax on public deficit reduction is much lower than the revenue obtained with the new tax.

CO_2 emissions decrease, but mainly due to the decrease in the level of global activity and of private consumption.

In the specific case of a carbon tax of 15€/tCO2 applied to all sectors (designed, ahead, shortly, as the 15Tsr option - see third column of figures in table 5 for a summary of results) we estimated real impacts (in the year of the introduction of the carbon tax) of -0.5% on GDP (with a symmetric impact on the GDP deflator), -0.8% on Private Consumption and -0.5% on Imports (both nominal and real in this case since the carbon tax does not have any effect on import CIF prices). Assuming that Exports remained unchanged in nominal terms (considering a price elasticity of exports = -1), this would imply a slight improvement on the Balance of Goods and Services (+0.2 percentage points of GDP). Considering the same assumption and the estimated average increase in export prices of +0.4%, real exports would decrease by a similar amount, with the greater real decreases occurring for the products facing a greater export price increase (electricity, non-metallic mineral products, land and air transports and other mining products. *i.e.*, those products incorporating a greater amount of CO2 emissions and, therefore, of carbon tax, per unit of output).

In terms of public finance, the revenue obtained with this new tax (15Tsr option) is estimated to be 848 million euros (using 2008 parameters) but the impact on all other taxes and contributions will be negative and expenditure with unemployment benefits will increase, implying a net impact on the reduction of public deficit of about 510 million euros. Public debt as a percentage of GDP would be reduced by 0.3 percentage points in the year of the introduction of the carbon tax (see table 1). Assuming that the new tax was introduced in 2015 and using the method described in section 4.1, the impact of this 15€ carbon tax applied to all sectors with no revenue recycling on public debt would be a reduction of 3.6 pp of GDP in 2030.

Table 1
Impact of a carbon tax without revenue recycling - projection to 2030

		deviations from the reference scenario			
tax rate (€/tCO2)	Sectoral incidence	2015		2030	
		Real GDP (%)	Public Debt (pp of GDP)	Real GDP (%)	Public Debt (pp of GDP)
5 €	Non-ETS	-0.1	-0.1	-0.1	-0.7
15 €	Non-ETS	-0.3	-0.2	-0.2	-2.2
15 €	All sectors	-0.5	-0.3	-0.3	-3.6

The impacts of other tax rates with the same sectoral incidence are roughly proportional to the rate level (and exactly proportional in terms of impacts on prices), *i.e.*, for example, the impact of a 15€ tax is about three times the impact of a 5€ tax.

The impact of a certain tax rate applied only to non-ETS sectors is estimated to be about 63% of the impact of the same tax applied to all sectors in which concerns real GDP.

4.3. Impact of different options of recycling the revenue of a new carbon tax of 15€/tCO2 applied to all sectors

We first simulated different options of revenue recycling for a carbon tax of 15€/tCO2 applied to all sectors, the results of which are summarized in the 4th to 10th columns of table 5.

We verified that three of the options of revenue recycling listed in section 4.1 had exactly the same macroeconomic, environmental and public debt impacts: reduction in personal income tax; reduction in social security contributions, and increase in transfers to households. Therefore, we only present on the tables one of these options (reduction in personal income tax). The identity of impacts for these three options of revenue recycling results from MODEM 7 specification. In fact these three options may have different impacts in a number of variables that are not contemplated in the model, such as income distribution effects and social security sustainability. Another issue is that there is no differentiation, in this model version, between workers' and owners' social security contributions, which should be the object of future model improvements, as the impacts of changes in each one of them are, in reality, different from a macroeconomic point of view.

Table 2 presents the ranking of the various options of revenue recycling that were tested for the case of 15€/tCO2 applied to all sectors, in terms of their impact on GDP, on public debt in percentage of GDP and on employment, projecting their effects for 2015 and 2030 (assuming that the new tax was introduced in 2015 and maintained at the same rate until 2030).

The best options of revenue recycling are, from an economic point of view, among those that were tested, the expenditure with education and training services (investment in human capital), followed by the expenditure in Research and Development and by investment in infrastructures, with positive impacts on GDP, in the year of the introduction of the new tax, of, respectively, +0.6, +0.4 and +0.2%. Concerning public accounts, it should be stressed that, in terms of its level in euros, all options of revenue recycling have a zero impact on public debt for each year of application of the carbon tax, as we impose a zero impact on public global balance in the model programming (model version with a fiscal policy rule) as a way to ensure the revenue recycling (see sections 4.1 and last paragraph of 2.2.4). However in terms of the ratio of public debt to GDP, the impacts may be significantly high due to the changes in the denominator.

Table 2
Impact of different strategies of revenue recycling for a carbon tax of 15€/tCO2 (applied to all sectors) – projection to 2030

deviation from the reference scenario

Ranking	Revenue recycling option (a)	2015			(a)	2030		
		Real GDP (%)	Public Debt (pp of GDP)	Employment (%)	CO_2 (%)	Real GDP (%)	Public Debt (pp of GDP)	Employment (%)
1	Education (investment in human capital)	0.6	-1.4	0.6	-0.1	0.3	-0.6	0.4
2	R&D	0.4	-1.1	0.2	-0.2	0.2	-0.4	0.1
3	Investment in infrastructures	0.2	-0.9	0.2	0.3	0.1	-0.4	0.1
4	Reduction in personal income tax	-0.1	-0.6	-0.1	-0.1	0.0	-0.2	0.0
5	Other subsidies to production	-0.2	-0.4	-0.2	-0.3	-0.1	-0.2	-0.1
6	Incentives to Private Investment (equip. - metal products)	-0.2	-0.3	-0.2	-0.4	-0.1	-0.1	-0.1
7	Reduction in public deficit (no revenue recycling)	-0.5	-0.3	-0.5	-0.7	-0.3	-3.6	-0.3
8	Reduction in company taxes	-0.5	0.0	-0.5	-0.7	-0.3	0.0	-0.3

(a) using in the reference scenario the levels and coefficients of CO_2 emissions observed for Portugal in 2008.

The other options tested for revenue recycling do not succeed in totally compensating the negative effects of this new tax on GDP, resulting in a negative effect on this variable of -0.1% for the reduction in personal income tax, -0.2% for increase subsidies to production and for incentives to private investment and of -0.5% for the reduction in company taxes.

The worst option for revenue recycling would be, according to MODEM simulations, the reduction in company taxes. In fact, the impacts on the economy and on CO2 emissions are similar to those obtained with the "no revenue recycling" option (see tables 2 and 3), but in the first case there is no reduction in public debt as it happens in the second case. The explanation is that the reduction in companies' tax burden does not, in itself, necessarily generate an increase in final demand, which is (according to MODEM's logic) the driver of economic activity.

The better results obtained with the recycling through expenditure in Education, in R&D or in investment in infrastructures, compared, for example, with the reduction in the tax burden on households, can be explained by the fact that those expenditures represent an increase in final demand implying an immediate (direct) positive effect in domestic output of the industries supplying those goods and services (education services, R&D services and construction/civil engineering, which have a null direct import content and relatively low indirect import contents: 3%, 7% and 21%, respectively, according to the values estimated for 2008[3] and presented in table 3), to which add the indirect and induced effects. It should be stressed that, when we speak of an increase in expenditure with education and R&D we assume that it is a volume increase (in the quantity and/or quality of the services supplied) and not a price increase (that would result from, for example, a simple increase in teachers' wage rates).

Concerning a reduction in personal income tax rates, its impact on the level of economic activity is not direct, resulting only from the additional private consumption induced by the increase in households' disposable income. It should be stressed that the impact of this tax reduction may vary according to the marginal propensity to consume by the households benefiting from the tax reduction as well as according to the import content (direct plus indirect) of this consumption.

The option of revenue recycling through incentives to private investment was firstly tested (in the results presented in tables 2 and 5) assuming that this investment was made in equipment in metal products (because it is the type products mostly used in equipment for the production of wind energy). We estimated for this option (in the 15€/tCO2 applied to all sectors case) a global negative impact on GDP of -0.2% in the year of introduction of this tax due to the relatively significant import content (direct plus indirect) of this type of investment (estimated in 55% for 2008 – see table 3).

The ranking of the impacts of the different types of public expenditure (with incidence on final demand) on GDP is related to the domestic value added content (direct plus indirect) per unit of each type of expenditure and this is the reason (considering the logic of MODEM) for the lower impact of revenue recycling through incentives to private investment in equipment, compared to expenditure in Education, in R&D and in infrastructures, due to the higher import content of first (and therefore lower value added and GDP contents) compared to the other type of expenditures.

[3] Calculations made by the author, on the basis of the system of symmetric input-output tables (85*85 products) for Portugal, 2008 (Dias and Domingos, 2011) and using a methodology similar to the one described in Dias (2010 and 2011). These calculations and the updated methodology will be the object of a forthcoming publication.

Table 3
Primary input contents of final demand

Products code		Type of final demand	Primary input contents (direct and indirect) (%) (a)			
MODEM7	NPCN06		Imports	Gross Value Added	Taxes less subsidies on products	GDP
23	25	Investment in equipment (metal products)	55.0	41.3	3.7	45.0
23 to 28; 31;36;53	25 to 30; 33;41;62	Investment in energy efficiency projects	45.9	47.2	6.9	54.1
37	42	Investment in infrastructures	20.5	68.2	11.2	79.5
63	72	Public consumption - R&D	6.8	88.9	4.2	93.2
74	85	Public consumption - Education services	3.4	94.6	2.0	96.6
All	All	Private consumption	27.9	58.4	13.6	72.1
(a) estimated on the basis of I-O tables for Portugal, 2008						

Table 4 presents the relative impacts (ratio of percent deviations from the reference scenario) Employment/GDP and CO2 emissions/GDP for the cases of revenue recycling with a higher impact on GDP (education expenditure, R&D and investment in infrastructures).

The relative impact Employment/GDP is inversely related to the average labor productivity implicit in the expanding output associated to each option of revenue recycling, which explains why investment in infrastructures has the highest value and R&D the lowest, given the differences in the average level of labor qualification (and therefore productivity) in each one of these activities.

Table 4
Relative impacts of different strategies of revenue recycling for a carbon tax of 15€/tCO2 (applied to all sectors)

ratio of percent deviations from the reference scenario

	Employment /GDP	CO2 emissions /GDP
Education (Investment in Human Capital)	1.11	-0.20
R&D	0.55	-0.47
Investment in infrastructures	1.29	1.56

Concerning the relative impact on CO2 emissions compared to GDP, the most favorable situation occurs with R&D expenditure and the worst with investment in infrastructures, which is related with the relative carbon intensity of the activities expanded in each case.

It should be stressed that the investment in infrastructures option for revenue recycling is the worst of all revenue recycling options tested in terms of CO2 emissions, even in absolute terms (see table 4). In fact this is the only option that implies an increase in CO2 emissions compared to the reference scenario (+0.3% for a carbon tax of 15€ applied to all sectors, for the year of introduction of the tax), which is related to the high unit content of emissions of this type of expenditure (including the indirect effects of some of the materials used such as non-metallic mineral products which have high CO2 emissions per unit of output).

Table 5

Impact of the introduction of a new carbon tax in Portugal
Evaluation with MODEM 7, combined with an I-O price model

deviation from the reference scenario

tax rate (€/tCO2):	5 €	15 €								
sectoral incidence	Non-ETS	All sectors								
revenue recycling options (a)	Reduction in public deficit (no revenue recycling)			other tax reduction		Increase in public expenditure				
				Personal Income Tax	Company tax	Subsidies to Production	R&D	Education (invest. In human capital)	Invest. in Infrastruct.	Incentives to private investment (equip. - metal products)
ECONOMIC IMPACT (percent deviation):										
Real Impact (volumes):										
GDP	-0.11	-0.33	-0.52	-0.05	-0.52	-0.22	0.36	0.59	0.18	-0.25
Private Consumption	-0.17	-0.52	-0.78	0.22	-0.78	-0.14	-0.13	0.09	-0.30	-0.58
Public Consumption	-0.03	-0.09	-0.15	-0.15	-0.15	-0.15	2.92	3.48	-0.15	-0.15
Investment (GFCF)	-0.07	-0.20	-0.29	-0.29	-0.29	-0.29	-0.29	-0.29	2.36	1.48
Exports	-0.06	-0.19	-0.39	-0.39	-0.39	-0.40	-0.39	-0.39	-0.39	-0.39
Imports	-0.11	-0.33	-0.54	-0.07	-0.54	-0.24	-0.13	-0.07	-0.03	0.07
Employment	-0.10	-0.29	-0.46	-0.08	-0.46	-0.22	0.20	0.65	0.23	-0.18
Impact on prices (deflators):										
GDP	0.11	0.32	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52
Private Consumption	0.10	0.29	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
Public Consumption	0.03	0.09	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Investment (GFCF)	0.07	0.20	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Exports	0.06	0.19	0.40	0.41	0.41	0.41	0.41	0.41	0.41	0.41
Impact on the Balance of Goods and Services (deviation in percentage points of GDP):										
	0.05	0.14	0.23	0.07	0.23	0.13	0.14	0.14	0.08	0.00
IMPACT ON PUBLIC ACCOUNTS (deviation in million euros):										
Revenue:										
Total Tax revenue	134	401	653	28	163	947	957	958	947	752
of which:										
Fossil fuel taxes	176	527	848	884	848	871	879	883	901	863
Outher indirect taxes	-27	-81	-124	12	-123	-36	6	17	29	-78
Direct taxes on households and	-8	-23	-36	-865	-35	29	30	52	13	-16
Company taxes	-7	-22	-35	-2	-526	83	40	5	5	-18
Social security Contributions	-20	-59	-95	-19	-94	-46	53	227	50	-37
Other revenue	-6	-18	-27	-2	-27	65	32	4	4	-14
Expenditure:										
Public consumption (b)	0	0	0	0	0	0	1062	1255	0	0
GFCF (public or incentives to private	0	0	0	0	0	0	0	0	1026	685
Unemployment benefits	10	29	46	8	46	22	-20	-65	-23	18
Subsidies to products	-1	-2	-3	-1	-3	-2	-1	-1	-2	-3
Other subsideis to production	0	0	0	0	0	946	0	0	0	0
Interest on public debt	-4	-13	-22	0	0	0	0	0	0	0
Global Balance	104	310	510	0	0	0	0	0	0	0
IMPACT ON CO_2 EMISSIONS (percent deviation):										
	-0.14	-0.40	-0.67	-0.14	-0.67	-0.33	-0.17	-0.12	0.28	-0.41

(a) imposing a public deficit equal to the reference scenario.

(b) R&D expenditure will be considered as GFCF with the introduction of ESA 2010, instead of consumption.

4.4. New simulations considering the actually implemented green fiscal reform

When the green fiscal reform was implemented (with effects from 1 January 2015 onwards) new simulations were made for the evaluation of the impact of the new carbon tax, considering the terms established in the law. According to this law, the rate for the new carbon tax in year *t* is calculated through the average of ETS prices observed from July(t-2) to June(t-1) and it is applied only to non-ETS sectors that are not exempt from the already existing tax on petroleum

and energy products (ISP). This law also established the principle of fiscal neutrality (revenue recycling) through the reduction of personal income tax or the increase in fiscal incentives to projects promoting energy efficiency.

The main results for these simulations are presented in tables 6 and 7 for the cases of, respectively, 5€ (the rate that was calculated for application in 2015, from the average of ETS prices observed from July 2013 to June 2014) and 35€/tCO2 (the ETS price projected for 2030 in: European Commission, 2014).

These tables present various options for revenue recycling besides those considered in the green fiscal law, including most of the previously tested options, presented in tables 2 and 4, as well as the "no revenue recycling" option.

The option of revenue recycling through the "increase in fiscal incentives to projects promoting energy efficiency" was tested in the model assuming that these incentives would generate additional investment (GFCF) in equipment, buildings and computer programming services (products 23 to 28, 31, 36 and 53 of MODEM 7 nomenclature – see appendix 1) in the same proportion as observed for GFCF in these products for Portugal in 2008. The idea is that projects of energy efficiency may concern investment in any of the abovementioned products.

The results from the new simulations implied the same ranking for the different options for revenue recycling obtained from the previous exercise (see table 2) although the option that was now considered for the incentives to private investment gives relatively more favorable results (but with a still estimated net negative impact on GDP) than the previously considered option that assumed investment in equipment in metal products only, with a higher import content (and, therefore, lower unit GDP content, which is equal to 1 minus the unit import content) than the assumption for investment now considered (see table 3).

The sectoral incidence of the carbon tax defined in the green fiscal reform imply that the impacts on GDP are about 55% of those that would occur if the tax was applied to all sectors.

Given the level of the tax rate for 2015 (5€/tCO2) and that the revenue recycling will be made through a reduction in personal income tax, the estimated net impact on GDP for this year is close to zero (-0.01%, see column 2 on table 6). Without revenue recycling the impact would be more negative (-0.1%).

The simulated impacts presented in table 7, for a tax rate of 35€/tCO2, are roughly proportional to those from table 6 concerning a 5€ rate, *i.e.*, about seven times these impacts, but this is true only because we assumed unchanged technologies and patterns of consumption. Improvements in energy efficiency and reductions in the carbon intensity of the economy should progressively reduce the economic impact of this tax as CO2 emissions tend to fall.

The simulations with MODEM 7 were based on the observed parameters for the Portuguese economy in 2008. Considering projections for CO2 emissions for 2015, compared to those observed for 2008, we estimated that the additional revenue from taxes on fossil fuels resulting from this new carbon tax might be around 128 million euros instead of the 156 millions presented on the second column of table 6 and therefore the other economic impacts should adjust proportionately.

Table 6

Impact of the Green Fiscal Reform in Portugal - Carbon Tax

(Tax rate = 5€/tCO2, applied to non-ETS, not exempt from tax on oil products)

Evaluation with MODEM 7, combined with an I-O price model

deviation from the reference scenario

	Revenue recycling options (a)						
		Tax reduction (b)		Increase in public expenditure (c)			
	Reduction in public deficit (no revenue recycling)	Personal Income Tax	Company tax	Education (investment in human capital)	R&D (d)	Investment in Infrastructures	Fiscal incentives to investment in energy eficiency
ECONOMIC IMPACT (percent deviation):							
Real Impact (volumes):							
GDP	-0.10	-0.01	-0.09	0.10	0.06	0.02	-0.03
Private Consumption	-0.15	0.02	-0.15	0.00	-0.04	-0.07	-0.11
Public Consumption	-0.02	-0.02	-0.02	0.60	0.50	-0.02	-0.02
Investment (GFCF)	-0.06	-0.06	-0.06	-0.06	-0.06	0.40	0.28
Exports	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
Imports	-0.09	-0.01	-0.09	-0.01	-0.02	0.00	0.01
Employment	-0.08	-0.02	-0.08	0.11	0.03	0.03	-0.02
Impact on prices (deflators):							
GDP	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Private Consumption	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Public Consumption	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Investment (GFCF)	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Exports	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Impact on the Balance of Goods and Services (deviation in percentage points of GDP):							
	0.04	0.01	0.04	0.02	0.02	0.01	0.00
IMPACT ON PUBLIC ACCOUNTS (deviation in million euros):							
Revenue:							
Total Tax revenue	114	6	30	166	166	163	138
of which:							
Fossil fuel taxes	151	156	151	156	156	159	154
Outher indirect taxes	-24	-1	-24	0	-2	2	-11
Direct taxes on households and	-7	-149	-6	9	5	2	-2
Company taxes	-6	-1	-91	0	7	0	-3
Social security Contributions	-17	-4	-17	38	8	8	-5
Other revenue	-5	-1	-5	0	5	0	-2
Expenditure:							
Exogenous expenditure (c)	0	0	0	215	182	176	130
Unemployment benefits	8	2	8	-11	-3	-3	2
Subsidies to products	-1	0	-1	0	0	0	-1
Interest on public debt	-4	0	0	0	0	0	0
Global Balance	88	0	0	0	0	0	0
IMPACT ON CO_2 EMISSIONS (percent deviation):							
	-0.11	-0.02	-0.11	-0.02	-0.03	0.05	-0.05

(a) imposing a public deficit equal to the reference scenario.

(b) before deduction of fiscal benefits.

(c) including fiscal benefits.

(d) R&D is still treated in this table according to ESA95 conventions.

Table 7

Impact of the Green Fiscal Reform in Portugal - Carbon Tax
(Tax rate = 35€/tCO2, applied to non-ETS, not exempt from tax on oil products)
Evaluation with MODEM 7, combined with an I-O price model

deviation from the reference scenario

	Revenue recycling options (a)						
		Tax reduction (b)		Increase in public expenditure (c)			
	Reduction in public deficit (no revenue recycling)	Personal Income Tax	Company tax	Education (investment in human capital)	R&D (d)	Investment in Infrastructures	Fiscal incentives to investment in energy efficiency
ECONOMIC IMPACT (percent deviation):							
Real Impact (volumes):							
GDP	-0.66	-0.10	-0.66	0.67	0.39	0.17	-0.24
Private Consumption	-1.07	0.13	-1.06	-0.03	-0.28	-0.49	-0.77
Public Consumption	-0.17	-0.17	-0.17	4.17	3.51	-0.17	-0.17
Investment (GFCF)	-0.39	-0.39	-0.39	-0.39	-0.39	2.79	1.95
Exports	-0.31	-0.31	-0.31	-0.31	-0.31	-0.31	-0.31
Imports	-0.64	-0.07	-0.64	-0.07	-0.15	-0.02	0.06
Employment	-0.59	-0.13	-0.58	0.75	0.20	0.24	-0.14
Impact on prices (deflators):							
GDP	0.64	0.64	0.64	0.64	0.64	0.64	0.64
Private Consumption	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Public Consumption	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Investment (GFCF)	0.39	0.39	0.39	0.39	0.39	0.39	0.39
Exports	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Impact on the Balance of Goods and Services (deviation in percentage points of GDP):							
	0.27	0.08	0.27	0.16	0.17	0.09	0.01
IMPACT ON PUBLIC ACCOUNTS (deviation in million euros):							
Revenue:							
Total Tax revenue	791	44	205	1158	1157	1149	964
of which:							
Fossil fuel taxes	1048	1094	1049	1093	1089	1117	1073
Outher indirect taxes	-167	-5	-166	2	-11	15	-75
Direct taxes on households	-46	-1040	-45	60	34	13	-16
Company taxes	-45	-5	-633	3	46	3	-18
Social security Contributions	-118	-28	-117	268	58	55	-35
Other revenue	-35	-4	-35	3	36	3	-14
Expenditure:							
Exogenous expenditure (c)	0	0	0	1504	1274	1233	905
Unemployment benefits	58	13	58	-75	-20	-24	14
Subsidies to products	-5	-1	-5	-2	-2	-3	-4
Interest on public debt	-26	0	0	0	0	0	0
Global Balance	611	0	0	0	0	0	0
IMPACT ON CO_2 EMISSIONS (percent deviation):							
	-0.80	-0.16	-0.79	-0.13	-0.19	0.34	-0.38

(a) imposing a public deficit equal to the reference scenario.

(b) before deduction of fiscal benefits.

(c) including fiscal benefits.

(d) R&D is still treated in this table according to ESA95 conventions.

5. CONCLUDING REMARKS

In this study we made the evaluation of the macroeconomic, fiscal and environmental impact of the introduction of a new carbon tax in Portugal, using a multisectoral (input-output based) macroeconomic model (MODEM 7) combined with an input-output price model, both developed for Portugal and calibrated using the most recent system of detailed symmetric input-output tables available for Portugal (for 2008).

MODEM 7 considers 85 products/industries, of which six are energy products (of which three are fossil fuels used in combustion processes, subject to the new carbon tax: coal, oil products and natural gas). Although the model's sectoral block is inspired in the classical Leontief quantity input-output model, it has several differences as output is determined by total final demand (addressed to both domestic and imported products) at purchaser's prices (and not only by final demand at basic prices addressed to domestic output) and it determines also imports, taxes and subsidies on products for each product on the basis of the same concept of final demand. To evaluate the impact of final demand on domestic output vs imports the model considers implicitly the domestic and imports unit contents of final demand at both direct and indirect levels. On the other hand, sectoral equations interact with macroeconomic and public finance equations allowing the simultaneous determination of disposable income for the various economic agents (households, companies and the Government), private consumption, employment, unemployment and public finance variables. Variables are defined at current prices, assuming that there are no price changes for each simulation, within each year.

As the introduction of a carbon tax motivates a change in prices, an input-output price model was used to calculate the direct and indirect impact of the new tax on the price of each product and subsequently re-estimate MODEM 7 nominal input-output coefficients, to be used in the simulations "with" the new tax. The impact of the new tax was then estimated through the comparison of these new simulations with the reference simulation, at both current and constant (reference scenario) prices.

Several options were tested for this new tax, concerning the level of the tax rate, its sectoral incidence and the ways of recycling the additional net public revenue obtained from it. The various options of revenue recycling were tested through the introduction of a fiscal policy rule in MODEM 7 which imposed a null variation of public deficit compared to the reference scenario, calculating residually the adjustment (tax or expenditure) variable.

The results from this study suggest that, while the introduction of a carbon tax without recycling the additional public revenue has a negative impact on the economy, recycling this revenue through the reduction of direct taxes may not be enough to totally reverse this negative effect and that better global economic effects may be achieved if this revenue is recycled through certain types of public expenditure representing an increase in final demand with a low unit (direct plus indirect) import content (and, therefore, a high unit GDP content), such as investment in human capital and in R&D.

The simulations made with MODEM 7 suggest that, for a revenue recycling through final demand expenditure to imply a net positive impact of the carbon tax on GDP, the GDP unit content of this expenditure should be higher than 72.2% (or, equivalently, it should have an import content, direct plus indirect, lower than 27.8%).

Concerning the reduction of personal income tax (or the increase in transfers to households), its impact on the economy is not direct, resulting only from the increase in private consumption induced by additional households' disposable income. However, the impact of this type of

revenue recycling may vary according to the marginal propensity to consume and to the import contents of the additional consumption made by the households benefiting from these measures, with better effects on GDP being obtained if the marginal propensity to consume is high and if the import contents of this consumption is low.

Concerning revenue recycling through expenditure in Education or in R&D it should be stressed that these types of expenditure have not only a positive (demand-pull) short-term effect on the economy but also positive long-term effects (through the increase in total factor productivity), which are not considered in MODEM 7, but were treated in another model, HERPOR (Dias and Lopes, 2010a), which was also developed in the Portuguese Department of Foresight and Planning (DPP, see section 2.1), as it was the case for the previous versions of MODEM.

HERPOR is a macro-econometric dynamic model for the Portuguese economy which considers both demand and supply side mechanisms, allowing the evaluation of impacts in the short, medium and long terms. According to the HERPOR 3 simulations made to evaluate the impact of different types of public expenditure co-financed by EU structural funds (Dias and Lopes, 2010a, pages 15-18), investment in human capital (which, in HERPOR, includes expenditure in Education, training and R&D) would be, among the types of expenditure that were tested, the one with the highest cumulated long-term multiplier effect on GDP (4 euros per euro of public expenditure, which compare to 0.3 euros concerning incentives to private investment and 1.3 euros for investment in infrastructures), which interestingly gives the same ranking as obtained in the present study with MODEM when testing the same types of expenditure as options for recycling the carbon tax additional revenue (see table 2).

In conclusion we recommend that the revenue recycling for carbon tax should be done through an expenditure with a high unit content of GDP (low unit import content), to enable a positive short-term impact on GDP, and having also expected positive long-term effects, in both economic and environmental terms.

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APPENDIX 1 – Products/industries considered in MODEM 7

M7	NPCN06	Product description
1	01	Products of agriculture, hunting and related services
2	02	Products of forestry, logging and related services
3	03	Fishing products; aquaculture products; support services to fishing
4	05	Coal and lignite
5	061	Crude petroleum
6	062	Natural gas produced
7	07+08+09	Other mining and quarrying products
8	10	Food products
9	11	Beverages
10	12	Tobacco products
11	13	Textiles
12	14	Wearing apparel
13	15	Leather and related products
14	16	Wood and cork products, except furniture; art. straw and plaiting materials
15	17	Paper and paper products
16	18	Printing and recording services
17	19	Coke and refined petroleum products
18	20	Chemicals and chemical products
19	21	Basic pharmaceutical products and pharmaceutical preparations
20	22	Rubber and plastics products
21	23	Other non-metallic mineral products
22	24	Basic metals
23	25	Fabricated metal products, except machinery and equipment
24	26	Computer, electronic and optical products
25	27	Electrical equipment
26	28	Machinery and equipment n.e.c.
27	29	Motor vehicles, trailers and semi-trailers
28	30	Other transport equipment
29	31	Furniture
30	32	Other manufactured goods
31	33	Repair and installation services of machinery and equipment
32	351+353	Electricity, steam and air conditioning
33	352	Natural gas distributed
34	36	Natural water; water treatment and supply services
35	37+38+39	Sewerage and waste services; materials recovery
36	41	Buildings and building construction works
37	42	Constructions and construction works for civil engineering
38	43	Specialised construction works
39	45	Wholesale and retail trade and repair serv. of motor vehic. and motorcycles
40	46	Wholesale trade services, except of motor vehicles and motorcycles
41	47	Retail trade services, except of motor vehicles and motorcycles
42	49	Land transport services and transport services via pipelines
43	50	Water transport services
44	51	Air transport services
45	52	Warehousing and support services for transportation
46	53	Postal and courier services
47	55	Accommodation services
48	56	Food and beverage serving services
49	58	Publishing services
50	59	Motion picture, video and TV progr. prod. Serv., sound rec. and music publ.
51	60	Programming and broadcasting services
52	61	Telecommunications services
53	62	Computer programming, consultancy and related services
54	63	Information services
55	64	Financial services, except insurance and pension funding
56	65	Insurance and pension funding serv., except compuls. Soc. security
57	66	Services auxiliary to financial services and insurance services
58	6801+6802	Real estate services (except imputed rents of owner-occupied dewllings)
59	6803	Imputed rents of owner-occupied dewllings
60	69	Legal and accounting services
61	70	Services of head offices; management consulting services
62	71	Architectural and engineering services; technical testing and analysis services
63	72	Scientific research and development services
64	73	Advertising and market research services
65	74	Other professional, scientific and technical services
66	75	Veterinary services
67	77	Rental and leasing services
68	78	Employment services
69	79	Travel agency, tour operator and related services
70	80	Security and investigation services
71	81	Services to buildings and landscape
72	82	Office administrative, office support and other business support services
73	84	Public administration and defence services; compuls. Soc. Security serv.
74	85	Education services
75	86	Human health services
76	87	Residential care services
77	88	Social work services without accommodation
78	90	Creative, arts and entertainment services
79	91	Library, archive, museum and other cultural services
80	92	Gambling and betting services
81	93	Sporting services and amusement and recreation services
82	94	Services furnished by membership organisations
83	95	Repair services of computers and personal and household goods
84	96	Other personal services
85	97	Services of households as employers of domestic personnel

APPENDIX 2

EQUATIONS OF MODEM 7 – NATIONAL BLOCK

Note: Unless otherwise specified, indexes *i* and *j* (identifying products/industries) assume the values 1 to 85 (corresponding to MODEM 7 products/industries listed in Appendix1). Summations are across all index values, unless otherwise specified. **Exogenous** variables are presented in **bold** characters.

1. SECTORAL EQUATIONS

1.1. Output, Expenditure and Employment

Domestic Output (except for Agriculture, Forestry and Fishing):

(1) $X_i = \sum_j an_{ij} \times X_j + CTN_i + GN_i + CS15N_i + IN_i + VEN_i + ACOVN_i + EXN_i \quad (i = 4,..,85)$

Private Consumption (households) of domestic goods and services:

(2) $CTN_i = an_{iC} \times CT \qquad (i = 1 \text{ to } 38 \text{ and } 42 \text{ to } 85)$ and:

$$CTN_k = \sum_{i \neq k} tmcc_i^k \times (a_{iC} \times CT) + (a_{kc} - at_{kc} - az_{kc} - am_{kc}) \times CT \qquad (k = 39 \text{ to } 41)$$

Consumption of domestic goods and services by Non-Profit Institutions Serving Households (NPISH):

(3) $CS15N_i = an_{ics15} \times \mathbf{CS15} \qquad (i = 1,...,85)$

Public Consumption of domestic goods and services :

(4) $GN_i = qn_{iG} \times \mathbf{G_i} \qquad (i = 1 \text{ to } 38 \text{ and } 42 \text{ to } 85)$ and

$$GN_k = \sum_{i \neq k} tmcg_i^k \times \mathbf{G_i} + [(a_{kG} - at_{kG} - az_{kG} - am_{KG})/(a_{KG})] \times \mathbf{G_k} \qquad (k = 39 \text{ to } 41)$$

Gross Fixed Capital Formation (GFCF) of domestic goods and services:

(5) $IN_i = qn_{iI} \times \mathbf{I_i} \qquad (i = 1 \text{ a } 38 \text{ and } 44 \text{ to } 85)$ and:

$$IN_k = \sum_{i \neq k} tmci_i^k \times \mathbf{I_i} + [(a_{kI} - at_{kI} - az_{kI} - am_{kI})/(a_{KI})] \times \mathbf{I_K} \qquad \text{for } k = 39 \text{ to } 41$$

$$IN_k = \sum_{i \neq k} tmtni_i^k \times \mathbf{I_i} + [(a_{kI} - at_{kI} - az_{kI} - am_{kI} - amtm_{kI})/(a_{kI})] \times \mathbf{I_k} \qquad \text{for } k = 42, 43$$

Change in Inventories of domestic goods:

(6) $VEN_i = an_{iVE} \times \mathbf{VE} \qquad (i = 1,...,85)$

Net Acquisition of Valuables of domestic goods:

(7) $ACOVN_i = an_{iv} \times \mathbf{ACOV} \qquad (i = 1 \text{ to } 38 \text{ and } 42 \text{ to } 85)$ and:

$$ACOVN_k = \sum_{i \neq k} tmcv_i^k \times (a_{iV} \times \mathbf{ACOV}) + [a_{kV} - at_{kV} - az_{kV} - am_{kV}] \times \mathbf{ACOV} \quad \text{for } k = 39 \text{ to } 41$$

Exports of domestic goods and services at basic prices:

(8) $EXN_i = qn_{iEX} \times EX_i$ (i =1 to 38 and 42 to 85) and:

$EXN_k = \sum_{i \neq k} tmcx_i^k \times EX_{\mathbf{i}} + [(a_{kEX} - at_{kEX} - az_{kEX} - am_{kEX})/(a_{kEX})] \times EX_{\mathbf{k}}$ for k =39 to 41

Exports FOB:

(9) $EX_i = \mathbf{EXS_i} + w_i \times qacif \times MT$ (i = 1,...,85)

Imports of products of Agriculture, Forestry and Fishing:

(10) $M_i = \sum_j a^*_{ij} X_j + a^*_{iC} \times CT + (a^*_{iI}/a_{iI}) \times \mathbf{I_i} + a^*_{iCS15} \times \mathbf{CS15} + GM_i +$

$+GN_i + VEN_i + VEM_i + ACOVN_i + ACOVM_i + EXN_i + EXM_i - \mathbf{X_i}$ (i = 1,2,3)

Imports of other goods and services:

(11) $M_i = \sum_j am_{ij} X_j + CTM_i + CS15M_i + GM_i + IM_i + VEM_i + ACOVM_i + EXM_i$ (i =4,...,85)

Private Consumption (households) of imported goods and services:

(12) $CTM_i = am_{iC} \times CT$ (i = 1,...,85)

Consumption of imported goods and services by NPISH:

(13) $CS15M_i = am_{ics15} \times \mathbf{CS15}$ (i = 1,...,95)

Public Consumption of imported goods and services:

(14) $GM_i = am_{iG} \times \mathbf{G}$ or (14') $GM_i = qm_{iG} \times \mathbf{G_i}$ (i = 1,...,85)

GFCF of imported goods and services:

(15) $IM_i = qm_{iI} \times \mathbf{I_i}$ for $i \neq 42, 43$ and

$IM_k = \sum_{i \neq k} tmtmi_i^k \times \mathbf{I_i} + [(a_{kI} - at_{kI} - az_{kI} - an_{kI} - amtn_{kI})/(a_{kI})] \times \mathbf{I_k}$ for k = 42,43

Change in Inventories of imported goods:

(16) $VEM_i = am_{iVE} \times \mathbf{VE}$ (i = 1,...,85)

Net Acquisition of Valuables of imported goods:

(17) $ACOVM_i = am_{iv} \times \mathbf{ACOV}$ ou (17') $ACOVM_i = qm_{iv} \times \mathbf{ACOV_i}$ (i = 1,...,85)

Exports of imported goods:

(18) $EXM_i = qm_{iEX} \times EX_i$ (i = 1,...,85)

Gross Value Added:

(19) $VAB_j = av_j \times X_j$ (j = 1,...,85)

Employment (full-time equivalent):

(20) $N_j = VAB_j / \mathbf{PROT_j}$ (j = 1,...,85)

1.2. Indirect taxes and subsidies

Other taxes on production:

(21) $OT_i = aot_i \times X_i$ (i = 1,...,85)

Taxes on products:

(22) $TP_i = \sum_j at_{ij} \times X_j + CTP_i + CS15TP_i + GTP_i + ITP_i + VETP_i + ACOVTP_i + EXTP_i$ (i = 1,...,85)

Taxes on products for Households' private consumption:

(23) $CTTP_i = at_{iC} \times CT$ (i = 1,...,85)

Taxes on products for NPISH' Consumption:

(24) $CS15TP_i = at_{iCs15} \times CS15$ (i = 1,...,85)

Taxes on products for Public Consumption:

(25) $GTP_i = qtp_{iG} \times \mathbf{G_i}$ (i = 1,...,85)

Taxes on products for GFCF:

(26) $ITP_i = qtp_{iI} \times \mathbf{I_i}$ (i = 1,...,85)

Taxes on products for Change in Inventories:

(27) $VETP_i = at_{iVE} \times \mathbf{VE}$ (i = 1,...,85)

Taxes on products for Net Acquisition of Valuables:

(28) $ACOVTP_i = at_{iV} \times \mathbf{ACOV}$ (i = 1,...,85)

Taxes on products for Exports:

(29) $EXTP_i = (at_{iEX}/a_{iEX}) \times EX_i$ (i = 1,...,85)

Subsidies on products:

(30) $ZP_i = \sum_j az_{ij} \times X_j + CZP_i + IZP_i + EXZP_i$ (i = 1,...,85)

Subsidies on products for Households' private consumption:

(31) $CTZP_i = az_{iC} \times CT$ (i = 1,...,85)

Subsidies on products for GFCF:

(32) $ITP_i = qzp_{iI} \times \mathbf{I_i}$ (i = 1,...,85)

Subsidies on products for Exports:

(33) $EXZP_i = (az_{iEX}/a_{iEX}) \times EX_i$ (i = 1,...,85)

2. SUMMING UP EQUATIONS

(34) $X = \Sigma X_i$ **Total Output**

(35) $VAB = \Sigma VAB_i$ **Total Gross Value Added**

(36) $N = \Sigma N_i$ **Total Employment (full-time equivalent)**

(37) $MT = \Sigma M_i$ **Total Imports CIF (excluding Tourism)**

(38) $IT = \Sigma \mathbf{I_i}$ **Total GFCF**

(39) $G = \Sigma \mathbf{G_i}$ **Public Consumption**

(40) $EXT = \Sigma EX_i$ **Exports (excluding Tourism)**

(41) $REM = \Sigma arem_i \times X_i$ **Compensation of Employees**

(42) $OT = \Sigma OT_i$ **Other taxes on production**

(43) $TP = \Sigma TP_i$ **Taxes on products**

(44) $ZP = -\Sigma ZP_i$ **Subsidies on products**

3. MACROECONOMIC EQUATIONS

3.1. GDP, Disposable Income and Final Expenditure:

(45) $CONS = \beta \times YD$ **Residents' Private Consumption (Households + NPISH)**

(46) $CT = CONS - CPE - \mathbf{CS15} + \mathbf{CEP}$ **Households' Consumption on the Territory**

(47) $CPE = \alpha \times CONS$ **Tourism Imports**

(48) $EX = EXT - qacif \times MT + CEP$ **Exports FOB (incl. Tourism)**

(49) $MF = MT \times (1 - qacif) + CPE$ **Imports FOB (incl. Tourism)**

(50) $Y = CONS+G+IT+\mathbf{VE}+\mathbf{ACOV}+ EX-MF$ **GDP (obtained from Expenditure)**

(50a) $Y = VAB + TP - ZP$ **GDP (obtained from Value Added)**

(51) YDSOC = ryds × EBE - TDSC **Companies' Disposable Income**

(52) EBE = VAB – REM – OT +**OZG** + **OZC** **Gross Operating Surplus**

Private Disposable Income (Households + NPISH):

(53) YD =REM+EBE+RF+**TREO**–YDSOC–TD–TDSC–CSOCG –REPG + TRIG + JURG

(54) RF=**RF0** - rf1×JURG **Balance of factor income with the RoW**

3.2 Labor Market

(55) PA = **PA0** + cpand×ND **Labor Supply**

(56) ND = ndn×N **Employment (number of individuals)**

(57) DESEMP = PA – ND **Unemployment**

3.3. Public Finances

(58) TD = rtdyd × YD **Direct Taxes on Households + NPISH**

(59) TDSC = rtdsy × YDSOC **Company Direct Taxes**

(60) TIG = TPG+OTG; **Indirect taxes received by the Government**

(61) TPG=TP-TPC **Taxes on products received by the Government**

(62) TPC=IVAC+OTPC **Taxes on products received by the EU**

(63) IVAC=rivac*(CT+I+ACOV); **VAT received by the EU**

(64) OTPC=rotpc*MT; **Other taxes on products received by the EU**

(65) OTG=OT-OTC; **Other taxes on production received by the Government**

(66) SUBG=ZPG+**OZG**; **Total Subsidies on production paid by the Government**

(67) ZPG=ZP-**ZPC**; **Subsidies on products, paid by the Government**

(68) CSOCG=tcsocg ×REM **Social Contribuitions received by the Government**

(69) REPG = repge × EBE **Government Gross Operating Surplus+Net Property Income**

(70) TRIG=**TRIG0**+SUBDES **Balance of Current transfers from the Government to private agents**

(71) SUBDES = **SUBU**×DESEMP **Unemployment Benefits**

(72) DIV = DIV(-1) – SGG + **DAT** **Public Debt**

(73) JURG = **RG** × DIV **Interest on public debt**

Government Total Balance:

(74) SGG = TD + TDSC + **TD2S** + CSOCG + TIG - SUBG + REPG – **G** – TRIG + **TREG** – JURG + **TK** + **TRKG** – **IG**

4. ENVIRONMENTAL EQUATIONS

CO_2 emissions, associated to combustion processes, resulting directly from productive ativities:

(75) $ECO2_i = cco2_i \times X_i$ (i= 1,…,85)

CO_2 emissions resulting directly from households' comsumption:

(76) $ECO2_c = cco2_c \times CT$

Total CO_2 emissions, associated to combustion processes:

(77) $ECO2 = {}_i\Sigma\, ECO2_i + ECO2_c$

APPENDIX 3

LIST OF MODEL VARIABLES AND COEFFICIENTS – NATIONAL BLOCK

Notes: The variables that are not identified as exogenous (in brackets) are endogenous. For simplification indexes (referring to products/industries - i,j,k) have been omitted in most cases.

Index F is used as a generic designation for final demand components: C (Households' final consumption in the territory), CS15 (NPISH's final consumption), G (Government final consumption), I (GFCF), VE (Change in inventories), V (Net acquisition of valuables) and EX (Exports FOB, from the territorial point of view).

1. VARIABLES:

ACOV – Net Acquisition of valuables **(exogenous)**

ACOVTP – Taxes on Net Acquisition of Valuables

ACOVN – Net Acquisition of Valuables of domestic goods at basic prices

ACOVM – Net Acquisition of Valuables of imported goods (CIF)

CEP – Exports of Tourism (**exogenous** by products)

CONS – Residents' Private Consumption (Households + NPISH)

CPE – Imports of Tourism

CS15 – Consumption of Non-Profit Institutions Serving Households (NPISH) **(exogenous)**

CS15TP – Taxes on Final Consumption by NPISH

CS15M – Consumption of imported goods by NPISH (CIF)

CS15N – Consumption of domestically produced goods by NPISH, at basic prices

CSOCG – Social Contributions received by the Government

CT – Households' Private Consumption on the Territory at purchasers' prices

CTM – Households' Private Consumption of imported goods (CIF), on the Territory

CTN – Households' Private Consumption of domestically produced goods, on the Territory, at basic prices

CTTP – Taxes on Households' Private Consumption on the Territory

CTZP – Subsidies on Households' Private Consumption on the Territory

DAT – Change in public debt not associated to public deficit **(exogenous)**

DESEMP – Number of unemployed

DIV – Public debt

EBE – Total Gross Operating Surplus (including mixed income)

ECO2 – Total carbon dioxide emissions, associated to combustion processes, directly associated to production and to households' final consumption.

$ECO2_c$ – Carbon dioxide emissions, associated to combustion processes, directly associated to households' final consumption.

$ECO2_i$ – Carbon dioxide emissions, associated to combustion processes, directly associated to production of product *i*.

EX_i – Exports (FOB) of product *i*

EX – Total Exports FOB, including Tourism

EXM_i – Exports of imported goods CIF (product *i*)

EXN_i – Exports of domestically produced goods at basic prices (product i)

EXS_i – Exports of product *i* after deducting CIF/FOB adjustment **(exogenous)**

$EXTP_i$ – Taxes on Exports of product *i*

EXT – Total exports (excluding Tourism)

$EXZP_i$ – Subsidies on Exports of product *i*

G – Public Consumption **(exogenous** by products**)**

GM – Public Consumption of imported goods, CIF

GN – Public Consumption of domestically produced goods at basic prices

GTP_i – Taxes on Public Consumption of product *i*

I – GFCF at purchasers' prices **(exogenous** by products**)**

IG – Public investment (GFCF) **(exogenous)**

IM – GFCF in imported goods, CIF

IN – GFCF in domestically produced goods, at basic prices

IT – Total GFCF at purchasers'prices

ITP_i – Taxes on product i used for GFCF.

IVAC – VAT paid to the EU.

IZP_i – Subsidies to product i used for GFCF.

JURG – Interest on public debt

M_i – Imports CIF of product *i*

MF – Total Imports FOB, including Tourism

MT – Total Imports CIF, excluding Tourism

N – Employment (Full-time equivalents)

ND – Employment (number of individuals)

OT – Other taxes on production (excluding taxes on products)

OTC – Other taxes on production received by the EU (**exogenous**).

OTG – Other taxes on production received by the Government.

OTPC – Other taxes on products (excluding VAT) received by the EU.

OZC – Other subsidies on production (excluding subsidies on products) paid by EU **(exogenous).**

OZG – Other subsidies on production (excluding subsidies on products) paid by the Government **(exogenous).**

PA – Labor supply.

PA0 – Exogenous component of PA **(exogenous).**

PROT – Labor productivity **(exogenous)**

REM – Compensation of employees

REPG – Government Gross Operating Surplus+Net Property Income

RF – Balance of factor income with the Rest of the World (RoW).

RF0 – Exogenous component of RF.

RG – Interes rate on public debt **(exogenous)**

SGG – Government Total Balance

SUBDES – Total value of unemployment benefits (paid by the Government).

SUBG – Subsidies to production paid by the Government (total).

SUBU – Average unemployment benefit per unemployed (**exogenous**).

TD – Direct Taxes on Households+NPISH

TDSC – Direct taxes on companies.

TD2S – Balance of direct taxes with the RoW (received by the Government and payed by Households) **(exogenous)**

TIG – Indirect taxes received by the Government (total).

TK – Capital taxes **(exogenous).**

TP – Taxes on products

TPC - Taxes on products received by the EU.

TPG - Taxes on products received by the Government.

TRE – Balance of private current transfers with the RoW **(exogenous)**

TREG – Balance of current transfers between the Government and the RoW (received less paid by the Government) **(exogenous).**

TREO - Balance of other current transfers with the RoW (received less paid by the national economy, excluding TREG, TD2S and transfers of indirect taxes and subsidies) **(exogenous).**

TRIG – Balance of current transfers between the Government and other internal agents (payed less received by the Government) **(exogenous).**

TRIG0 – Exogenous component of TRIG **(exogenous).**

TRKG – Balance of Government Capital transfers (received less paid) **(exogenous)**

VAB – Gross Value Added at Basic prices.

VE – Change in Inventories at purchasers' prices **(exogenous)**

VETP – Taxes on Change in Inventories.

VEM – Change in Inventories of imported goods CIF

VEN – Change in Inventories of domestically produced goods at basic prices.

X – Domestic Output at basic prices.

Y – Gross Domestic Product (GDP) at market prices.

YD – Private Disposable Income (Households + NPISH)

2. COEFFICIENTS:

$\mathbf{a^*_{iF}}$ – Share of product *i* (at basic prices) in total final demand of type F (at purchasers' prices) ($a^*_{iF} = an_{iF} + am_{iF}$);

$\mathbf{a^*_{ij}}$ – quantity of product *i* (at basic prices) necessary to produce one unit of product *j* (at basic prices) ($a^*_{ij} = an_{ij} + am_{ij}$);

$\mathbf{a_{iF}}$ - Share of product *i* (at purchasers' prices) in total final demand of type F (at purchasers' prices).

$\mathbf{a_{ij}}$ - Total technical coefficient of order (i, j), representing the quantity of product *i* (at purchasers' prices) necessary to produce one unit of product *j* (at basic prices).

$\mathbf{am_{iF}}$ - Share of imported product good *i* (CIF) in total final demand of type F (at purchasers' prices);

$\mathbf{am_{ij}}$ - Quantity of imported product *i* (CIF) used to produce one unit of product *j* (at basic prices);

$\mathbf{amc_{iF}}$ - Trade margin coefficient of order (i,F), representing the weight of trade margins on product *i* in total value of final demand of type F (at purchasers' prices).

$\mathbf{amc_{ij}}$ - Trade margin coefficient of order (i,j), representing the weight of the trade margin on intermediate product *i* in total value of production of product *j* (at basic prices).

$\mathbf{amt_{iF}}$ - Transport margin coefficient of order (i,F), representing the weight of transport margins on product *i* in total value of final demand of type F (at purchasers' prices).

$\mathbf{amt_{ij}}$ - Transport margin coefficient of order (i,j), representing the weight of transport margins on intermediate product *i* in total value of production of product *j* (at basic prices).

$\mathbf{amtm_{kF}}$ - Simetric of the share of transport margins satisfied by imports in total final demand of type F (at purchasers' prices).

$\mathbf{amtn_{kF}}$ - Simetric of the share of transport margins satisfied by domestic output in total final demand of type F (at purchasers' prices)

$\mathbf{an_{iF}}$ - Share of domestically produced good *i* (at basic prices) in total final demand of type F (at purchasers' prices);

$\mathbf{an_{ij}}$ - Quantity of domestically produced good *i* (at basic prices) used to produce one unit of product *j* (at basic prices);

$\mathbf{aot_i}$ - Share of Other Taxes on Production in the value of domestic output of product *i*, at basic prices.

$\mathbf{arem_i}$ - Share of compensations of employees in the value of domestic output of product *i*, at basic prices.

$\mathbf{at_{iF}}$ - Share of taxes on products paid for product *i* in total final demand of type F (at purchasers' prices).

at_{ij} - Share of taxes on inputs of product *i* in the value of domestic output of product j (at basic prices).

av_i - Product transformation coefficient for product *i* (share of GVA in the value of domestic output of product *i*, at basic prices).

az_{iF} – Share of subsidies on product i, in total final demand of type F (at purchasers' prices).

az_{ij} – Share of subsidies on inputs of product *i* in the value of domestic output of product j (at basic prices).

$cco2_i$ - CO2 emission coefficient (combustion) of industry i (kgCO2 per euro of output at basic prices).

$cco2_c$ - CO2 emission coefficient of households' final consumption (kgCO2 per euro of households' total consumption).

cpand – change in labor supply per unit of change in total employment (estimated coefficient).

ndn – ratio between Employment (number of individuals, ND) and Employment (full-time equivalent, N) .

qacif – CIF/FOB adjustment coefficient.

qm_{iF} – Share of Imports CIF in the value (at purchasers' prices) of final demand of type F for product *i*

qn_{iF} – Share of domestic output (at basic prices) in the value (at purchasers' prices) of final demand of type F for product *i* .

qtp_{iF} –Share of taxes in the value (at purchasers' prices) of final demand of type F for product *i*.

qzp_{iF} – Share of subsidies in the value (at purchasers' prices) of final demand of type F for product *i* .

repge – Share of REPG in total Gross Operating Surplus (EBE).

rf1 – Share of the interest on public debt that is paid to the RoW on total interest on public debt.

rivac – Ratio between VAT paid to the EU and its main basis of incidence (Households' consumption + GFCF + ACOV).

rotpc – Ratio between other taxes on products received by the EU (OTPC) and total imports CIF (MT).

rtdsy – Ratio between company direct taxes (TDSC) and company's disposable income (YDSOC).

rtdyd – Ratio between direct taxes (TD) and Households+NPISH' disposable income (YD)

tcsocg – Share of Social Contributions paid to the Government (CSOCG) in total Compensation of Employees (REM).

$tmcc_i^k$ – Trade margin rate of type k on households'consumption of product i.

$tmcg_i^k$ – Trade margin rate of type k on public consumption of product i.

$tmci_i^k$ – Trade margin rate of type k on GFCF of product i.

$\mathbf{tmcv}_i^k$ – Trade margin rate of type k on Net Acquisition of valuables of product i.

$\mathbf{tmcx}_i^k$ – Trade margin rate of type k on Exports of product i.

$\mathbf{tmtni}_i^k$ – Transport margin of type k on GFCF of product i, satisfied by domestic output.

$\mathbf{tmtmi}_i^k$ – Transport margin of type k on GFCF of product i, satisfied by imports.

$\mathbf{w_i}$ – Share of product *i* in total CIF/FOB adjustment

α – Share of Tourism Imports (CPE) in Private Consumption (CONS).

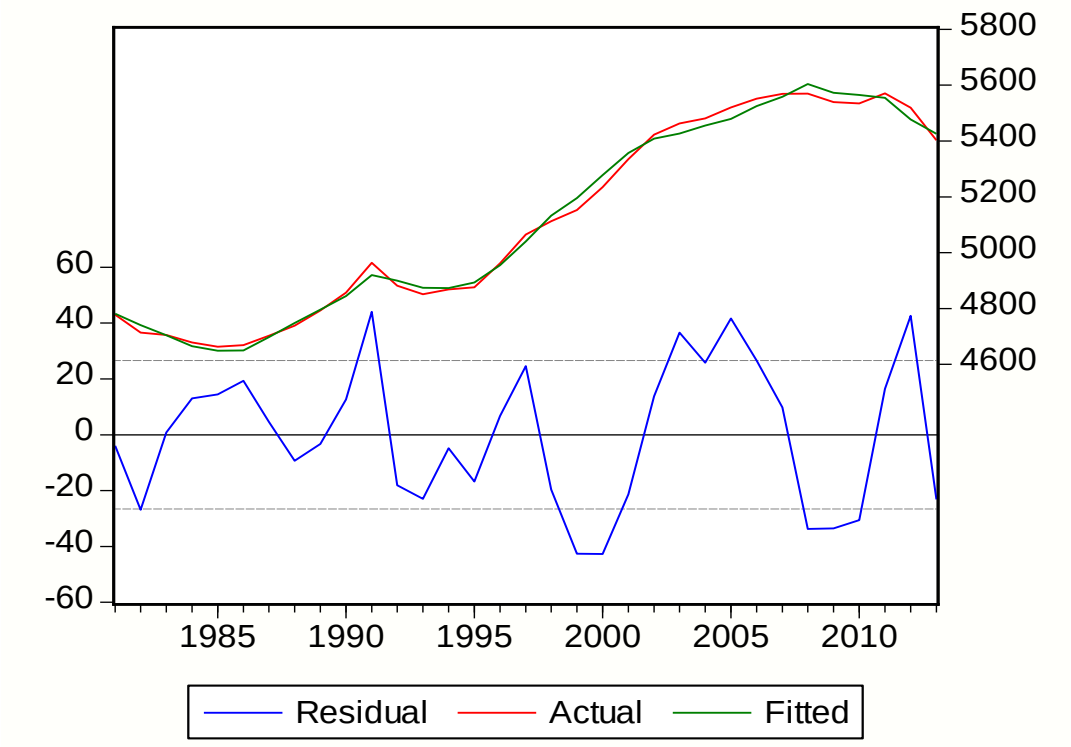
β – Average propensity to consume.

APPENDIX 4
ESTIMATED EQUATION FOR LABOR SUPPLY

Dependent Variable: PA
Method: Least Squares
Date: 03/25/14 Time: 17:18
Sample: 1981 2013
Included observations: 33

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3760.522	124.6593	30.16639	0.0000
LOG(T)	-699.1392	51.38528	-13.60583	0.0000
P1564*T	0.007605	0.000322	23.62053	0.0000
ND	0.477171	0.025399	18.78699	0.0000

R-squared	0.994597	Mean dependent var	5113.465
Adjusted R-squared	0.994039	S.D. dependent var	344.6832
S.E. of regression	26.61310	Akaike info criterion	9.513897
Sum squared resid	20539.46	Schwarz criterion	9.695292
Log likelihood	-152.9793	F-statistic	1779.613
Durbin-Watson stat	1.122522	Prob(F-statistic)	0.000000



APPENDIX 5

DETAILS OF MODEL CALIBRATION
(NATIONAL BLOCK OF MODEM 7 AND PRICE MODEL)

For the national block of MODEM 7 (in order to be used in the reference simulation) and for the input-output price model, **technical coefficients** for 2008 were calculated from the following set of symmetric input-output tables of 85 by 85 products and seven final demand categories (Dias and Domingos, 2011):

- FT : Total Flows at purchasers'prices;
- PN: Domestic Output at basic prices;
- M : Imports CIF;
- T: Taxes on products;
- Z: Subsidies, on products (with negative signs for each subsidy);
- MCk: Trade Margins of type k, for (using the numbering of MODEM 7 products, presented in the first column of Appendix 1) k =39 (trade of motor vehicles), 40 (other wholesale trade) and 41 (other retail trade) (three I-O tables);
- MCT: Total trade margins (MCT = MC39+MC40+MC41);
- MTNk: Transport Margins of type k, satisfied by domestic output, for k= 42 (land transport) and 43 (water transport) (two I-O tables);
- MTMk: Transport Margins of type k, satisfied by imports, for k = 42 and 43 (two I-O tables);
- MTT: Total transport margins (MTT= MTN42+MTN43+MTM42+MTM43).

Let MAT_{ij} or MAT_{iF} represent the elements of order (i,j) or (i,F) of the corresponding input-output table for MAT= the abovementioned I-O tables, X_j = domestic output of product j at basic prices, F= one of the seven final demand categories: C (Households' consumption), CS15 (NPISH's final consumption), G (Government final consumption), I (GFCF), VE (Change in inventories), V (Net acquisition of valuables), EX (Exports) and Ftot= total value (at purchasers' prices) of final demand of type F.

Technical coefficients were calculated using the following formulas (see Appendix 3 for coefficients definition/description):

$a_{ij}=FT_{ij}/X_j$

$a_{iF}=FT_{iF}/Ftot$

$an_{ij}=PN_{ij}/X_j$

$an_{iF}=PN_{iF}/Ftot$

$am_{ij}=M_{ij}/X_j$

$am_{iF}=M_{iF}/Ftot;$

$amc_{ij}=MCT_{ij}/X_j$

$amc_{iF}=MCT_{iF}/Ftot$

$amt_{ij} = MTT_{ij}/X_j$

$amt_{iF} = MTT_{iF}/Ftot$

$a^*_{ij} = an_{ij} + am_{ij}$

$a^*_{iF} = an_{iF} + am_{iF}$

$at_{ij} = T_{ij}/X_j$

$at_{iF} = T_{iF}/Ftot$

$av_i = VAB_i/X_i$

$arem_i = REM_i/X_i$

$aot_i = OT_i/X_i$

$amtm_{kF} = MTMk_{kF}/Ftot = (-\sum_{i \neq k} MTMk_{iF})/Ftot$

$amtn_{kF} = MTNk_{kF}/Ftot = (-\sum_{i \neq k} MTNk_{iF})/Ftot$

$az_{iF} = Z_{iF}/Ftot$

$az_{ij} = Z_{ij}/X_j$

It was also necessary to calculate **trade and transport margins' rates** for each product and component of final demand. These rates are used for the simulation of the output of industries supplying trade services (39 to 41) and of output and imports[4] of land (42) and water (43) transport services whenever the structure of some final demand components is different from the reference structure (based on I-O tables). This need derives from the fact that margin rates have a wide variation across the 59 product considered in the model (for example, they are null for Construction and Services).

Trade margin rate of type k on final demand of type F for product *i* was calculated by the following formula:

$tmcF_i^k = MCk_{iF} / FT_{iF}$ for F=C, G, I, V, EX; k = 39, 40, 41; $i \neq k$

Transport margin rates of type k on final demand of type F for product *i* , satisfied, respectively by domestic output and by imports wer calculated by the following formulas:

$tmtnF_i^k = MTNk_{iF} / FT_{iF}$ (satisfied by domestic output)

$tmtmF_i^k = MTMk_{iF} / FT_{iF}$ (satisfied by imports)

for F = C, I; k = 42, 43; $i \neq k$

The **shares** of **domestic output**, **imports**, **taxes** and **subsidies on** the value (at purchasers'prices) of each product's **final demand** are calculated by the following formulas:

$qn_{iF} = PN_{iF}/FT_{iF}$ (for i = 1 to 38 and 42 to 85);

[4] It should be noted that, while trade margins are entirely satisfied by domestic output, this may not be the case for transport margins, which can be partially satisfied by imports.

$qm_{iF} = M_{iF}/FT_{iF}$ (for i = 1 to 40 and 42 to 85);

$qtp_{iF} = T_{iF}/FT_{iF}$ (for i = 1 to 85);

$qzp_{iF} = Z_{iF}/FT_{iF}$ (for i = 1 to 85).

Labor productivity in each industry was calculated dividing the respective observed GOS by the corresponding observed employment volume (in full-time equivalent):

$PROT_i = VAB_i / N_i$

For the years for which this data is not available, productivities are estimated/projected on the basis on other available information or on scenarios for the Portuguese economy.

Carbon dioxide coefficients were calculated, for the present exercise, by the following formulas:

$cco2_i = ECO2_i / X_i$

$cco2_c = ECO2_c / CT$

The values for X_i and CT were taken from the symmetric I-O tables for Portugal, 2008 (Dias and Domingos, 2011), while the values for carbon dioxide emissions ($ECO2_i$ and $ECO2_c$) were estimated by the process described on section 3.

APPENDIX 6
DETAILS OF THE INPUT-OUTPUT PRICE MODEL

A.6.1. Impact of primary input price increases on production (basic) prices

The value of production (at basic prices) in each industry is equal to the sum of the respective intermediate consumptions with this industry's Gross Value Added.

Considering the terminology used for MODEM 7 and for its calibration (see appendixes 3 and 5), we can write the following equation for each industry j:

(1) $X_j = \sum_i (PN_{ij} + M_{ij} + T_{ij} + Z_{ij}) + VAB_j$

where X_j is the output (at basic prices) of industry (product) j, PN_{ij} is the intermediate consumption of domestically produced good i (at basic prices) by industry j, M_{ij} is the intermediate consumption of imported good i (CIF) by industry j, , T_{ij} and Z_{ij}, are, respetively, taxes and subsidies on intermediate consumption of good i (domestically produced and imported) by industry j and VAB_j is the Gross Value Added generated in industry j.

M_{ij}, T_{ij}, Z_{ij} and VAB_j are the so-called "primary inputs": imported inputs, taxes and subsidies on inputs and value added.

Dividing both members of equation (1) by X_j we obtain the equation for unit costs (technical coefficients), which add up to 1:

(2) $1 = \sum_i (an_{ij} + am_{ij} + at_{ij} + az_{ij}) + av_j$

In case of a price increase in any of the primary inputs, the input-output price model allows us to calculate its impact on each product's production (basic) and purchaser's price, assuming that production technical coefficients remain unchanged in real terms.

Let p_j, pm_{ij}, pt_{ij}, pz_{ij} and pv_j be the percent price increases for, respectively, industry (product) j's domestic output, imported inputs, taxes and subsidies on inputs and value added. We assume that each product's basic production price is the same irrespectively of its use and so we can write the following equation, pre-multiplying each term of equation (2) by the respective price increase:

(3) $p_j = \sum_i (p_i \times an_{ij} + pm_{ij} \times am_{ij} + pt_{ij} \times at_{ij} + pz_{ij} \times az_{ij}) + pv_j \times av_j$

Rearranging equation (3), we obtain, equivalently:

(4) $p_j - \sum_i (p_i \times an_{ij}) = \sum_i (pm_{ij} \times am_{ij} + pt_{ij} \times at_{ij} + pz_{ij} \times az_{ij}) + pv_j \times av_j$

Considering a system of equations similar to equation (4) for all products and using matrix notation, with **p** and **pv** being column vectors (n×1) for respectively p_j and pv_j values, ***i*** a unit vector (n×1), **pm**, **pt** and **pz** matrices (n×n) for all pm_{ij}, pt_{ij}, and pz_{ij} values, AN, AN, AM, AT and AZ matrices (n×n) for all an_{ij}, am_{ij}, at_{ij}, and az_{ij} coefficients, diag(AV) a diagonal matrix (n×n) for all av_j coefficients, the symbols ◦ and ' representing, respectively, Hadamard product

and matrix transposition, and suppressing some multiplication signs for simplification, we obtain :

(5) $p'(I-AN) = i'[pm \circ AM + pt \circ AT + pz \circ AZ] + pv'diag(AV)$

and finally:

(6) $p' = \{i'[pm \circ AM + pt \circ AT + pz \circ AZ] + pv'diag(AV)\}(I-AN)^{-1}$

Equation (6) expresses the general formula of the input–output price model for the determination of production price changes as a function of primary input price changes.

$(I-AN)^{-1}$ is the so-called "Leontief inverse", which is the matrix of output multipliers. The element of order (i,j) of this matrix represents the quantity of output of product i necessary to satisfy one unit of final demand for product j (domestically produced), considering both at basic prices.

In the case of the present study, equation (6) can be simplified as we assume that the only primary input prices that have changes are those for taxes on inputs. Therefore, pm, pz and pv are, in this case, null matrices and equation (6) becomes:

(6a) $p' = i'(pt \circ AT)(I-AN)^{-1}$

The element of order (i,j) of matrix $(pt \circ AT)$ is $(pt_{ij} \times at_{ij})$, where pt_{ij} is the percent increase in the "price" of taxes over the input i used by industry j. Considering a fixed volume of output by industry j (X_j) and a fixed coefficient at_{ij} (in real terms), pt_{ij} is the percent increase in the value of taxes charged over the input i used by industry j, i.e., $pt_{ij} = \Delta T_{ij}/T_{ij}$.

As $at_{ij} = T_{ij}/X_j$, $pt_{ij} \times at_{ij}$ is equal to $\Delta T_{ij}/X_j$, which is the additional tax charged on input i, used by industry j, per unit of output of product j. It should be noted that, in the matter of taxes on products, it is very convenient to calculate directly $pt_{ij} \times at_{ij}$, instead of starting with the calculation of pt_{ij} because, when we consider a new tax, or a tax which incidence is enlarged to more products or industries than in the basic (reference) scenario, we have some initial values of T_{ij} that are equal to zero and so we cannot calculate pt_{ij} (because its denominator is zero), but we can calculate $pt_{ij} \times at_{ij} = \Delta T_{ij}/X_j$.

Therefore, we can rewrite equation (6a) as:

(6b) $p' = [i'\Delta T\ diag(X)^{-1}](I-AN)^{-1}$

where ΔT is a (n×n) matrix for all ΔT_{ij}, and $diag(X)^{-1}$ is a (n×n) diagonal matrix which element of order (i,i) is $(1/X_i)$.

The matrix resulting from the operations $[i'\Delta T\ diag(X)^{-1}]$, in the second member of equation (6b), is a row-vector representing unit fiscal shocks (UFS'), which element of order j (UFS_j) represents the total increase in taxes on inputs per unit of output of industry j:

(7) $UFS_j = (\sum_i \Delta T_{ij})/X_j$

Therefore, equation (6b) can be rewritten as:

(8) $p' = UFS'(I–AN)^{-1}$

For each product j, equation (8) becomes (designating the element of order (i,j) of $(I–AN)^{-1}$ by b_{ij}):

(8a) $p_j = \sum_i (UFS_i \times b_{ij})$

Equation (8a) means that the percent increase in the basic price of product j, resulting from a given increase in taxes on products, is equal to the sum, across all products i, of the unit fiscal shock observed in each industry i (additional tax paid on all inputs per unit of output of product i) multiplied by the quantity of this industry's output necessary to satisfy one unit of final demand for product j (domestically produced).

A.6.2. Impact of primary input price increases on final demand and GDP deflators

After calculating the impacts of primary input price increases on production prices, we can estimate the impacts on final demand deflators using the following formula:

(9) $pft = p'\times ANF + pmf'\times AMF + ptf'\times ATF + pzf'\times AZF$

where pft is a scalar representing the percent change of the (global) deflator of final demand of type F (at purchasers' prices), ANF, AMF, ATF and AZF are column-vectors (n×1) for the an_{iF}, am_{iF}, az_{iF} and az_{iF} coefficients (see appendixes 3 and 5 for coefficients' definition and method of calculation) and pmf, ptf and pzf are column-vectors (n×1) for the percent changes in the prices of, respectively, imports, taxes and subsidies for final demand of type F.

In the case of the present study pmf and pzf are null vectors and so equation (9) simplifies to:

(9a) $pft = p'\times ANF + ptf'\times ATF$

On the other hand, $ptf'\times ATF$ is, in fact, total additional tax paid per unit of final demand of type F and so we can rewrite equation (9a) as:

(9b) $pft = p'\times ANF + (\sum_i \Delta T_{iF})/Ftot$

where ΔT_{iF} is additional tax on final demand of type F for product i and Ftot is total final demand of type F in the reference scenario (before the tax increase), at purchasers' prices.

The percent increase in the deflator of a given component of final demand (ptf) derived from an increase in taxes on products includes, therefore, a direct effect ($ptf'\times ATF$), resulting from additional tax on final demand and an indirect effect ($p'\times ANF$) associated to production price increases resulting from taxes on inputs.

The impact on GDP deflator is subsequently calculated by the formula:

(10) $py = \{\sum_F (pft\times Ftot) - \sum_i [\sum_j (pm_{ij}\times M_{ij})]\}/Y$

for F = all components of final demand and Ftot, M_{ij} and Y the values of final demand, imports of inputs and GDP in the reference scenario.

In the case of the present study, we assume that all pm_{ij} are zero and so, equation (10) simplifies to:

(10a) $py = [\sum_{F}(pft \times Ftot)]/Y$

A.6.3. Impact of primary input price increases on each product's purchasers' price, by types of final demand

After calculating the impact of primary input price increases on production (basic) prices, we can also calculate the impact on each product's purchasers' price, using the following formula:

(11) $pf' = p' \times QNF + pmf' \times QMF + ptf' \times QTF + pzf' \times QZF$

where pf', pmf', ptf' and pzf' are row vectors (1×n) for the percent changes of each product' s price for, respectively, final demand of type F, imports, taxes and subsidies on products (falling upon final demand of type F) and QNF, QMF, QTF and QZF are square matrices (n×n) representing unit direct contents of, respectively, domestic output, imports, taxes and subsidies for final demand of type F. The element of order (i,j) of each one of these matrices (qnf_{ij}, qmf_{ij}, qtf_{ij}, qzf_{ij}) represent, respectively, domestic output (at basic prices), imports (CIF), taxes and subsidies on product i, per unit of final demand of type F (at purchaser's prices) for product j (direct contents).

While QTF and QZF are diagonal matrices, QNF and QMF have some off-diagonal elements which are different from zero, in the rows corresponding to trade (rows 39 to 41 – see Appendix 1) and (land and water) transport (rows 42 and 43) products (for QNF) and to (land and water) transport products (for QMF), to account for the direct effects of final demand of a product, with trade and/or transport margins included in its purchaser's price, on the output (and also on imports, in the case of transports) of trade and transport products.

The elements of these matrices were calculated, for the present exercise, using the same system of input-output tables (for Portugal, 2008) used to calibrate MODEM 7 (Dias and Domingos, 2011). The methodology used for calculating these matrices is similar to the one presented in Dias (2011), with the necessary adaptations resulting from the change in products nomenclature and from the separation between Taxes and Subsidies on products made in this study.

It should be stressed that the diagonal elements of these matrices are also present in MODEM 7 specification, but using a slightly different terminology (on the right-hand side of the following identities, for F = G, I, V, EX):

$qnf_{ii} \equiv qn_{iF}$ (for i = 1 to 38 and 42 to 85);

$qmf_{ii} \equiv qm_{iF}$ (for i = 1 to 40 and 42 to 85);

$qtf_{ii} \equiv qtp_{iF}$ (for i = 1 to 85);

$qzf_{ii} \equiv qzp_{iF}$ (for i= 1 to 85).

For the trade and transport rows in the QNF matrix, we used the following method of calibration (using the methodology described in Dias, 2011, with the necessary adaptations):

qnf_{ii}= (PN_{iF} +MCi_{iF})/FT_{iF} for i = 39 to 41 (direct domestic output content of final demand addressed to trade sectors that does not correspond to trade margins[5])

qnf_{ij} =MCi_{jF}/FT_{jF} (trade margin rate of type i on final demand of type F for product j), for i ≠ j and i = 39 to 41 (trade sectors)

qnf_{ii}=(PN_{iF} +$MTNi_{iF}$)/FT_{iF} for i=42, 43 (direct domestic output content of final demand addressed to land and water transport sectors that does not correspond to transport margins[6])

qnf_{ij} =$MTNi_{jF}$/FT_{jF} (transport margin rate of type i on final demand of type F for product j), for i ≠ j and i = 42,43 (land and water transport sectors)

Similarly, and considering that one part of of the imports of land and water transport services corresponds to transport margins (satisfied by imports), we calculated the elements of the land and water transport rows in the QMF matrix in the following way:

qmf_{ii}=(M_{iF}+$MTMi_{iF}$)/FT_{iF} for i = 42, 43 (import contents of final demand addressed to land and water transport sectors which do not correspond to imported transport margins [7])

qmf_{ij} =$MTMi_{jF}$/FT_{jF} (transport margin rate of type i, satisfied by imports, on final demand of type F, for product j), for i ≠ j and i = 42, 43 (land and water transports).

Comparing the elements of QNF and QMF which correspond to trade and transport margins, we have following equivalence with MODEM 7 parameters:

$qnf_{ij} \equiv tmcF_j^i$ for i ≠ j and i = 39 to 41 (trade sectors)

$qnf_{ij} \equiv tmtnF_j^i$ for i ≠ j and i = 42, 43 (land and water transports)

$qmf_{ij} \equiv tmtmF_j^i$ for i ≠ j and i = 42, 43 (land and water transports)

In the case of the present study, **pmf** and **pzf** are null vectors and so equation (11) simplifies to:

(11a) pf' = p'×QNF + ptf'×QTF

QTF is a diagonal matrix which element of order (i,i) is:

(12) qtf_{ii} = $T_{i,F}$ /F_i (share of taxes, $T_{i,F,}$ on the value, at purchasers' prices, of final demand of type F for product i, F_i, in the reference scenario, before the tax increase)

[5] Note that MCi_{iF} and $MTNi_{iF}$ have negative values when i = trade/transport sectors, which are equal to the symmetric of the total value of the respective margins applied to the various products (*vide* Dias, 2009, page 4, 3rd paragraph). Therefore the sums (PN_{iF} +MCi_{iF}) and (PN_{iF} +$MTNi_{iF}$) represent the part of sector i's domestic output that does not correspond to margins of type i.

[6] *Vide* previous note.

[7] Note that $MTMi_{iF}$ has a negative value when i = land and water transport sectors, which is equal to the symmetric of the total value of the respective transport margins (satisfied by imports) applied to the various products (*vide* Dias, 2009, page 4, 3rd paragraph). Therefore the sum (M_{iF} +MTM_{iF}) represents the part of sector i's imports that does not correspond to imported transport margins of type i.

Therefore, the i^{th} element of the row-vector obtained from the operation ptf'×QTF is:

(13) $ptf_i \times qtf_{ii} = \Delta T_{iF}/F_i$

APPENDIX 7
METHODOLOGY FOR MODEM7 RECALIBRATION AFTER A PRICE SHOCK

After the calculation of the impact of an increase in the price of primary inputs on production prices, we can revise MODEM 7 nominal input-output coefficients (at current prices), assuming that I-O coefficients remain unchanged in real terms, through the following formulas (using the upper index 0 for original values and 1 for revised values, used in the simulations with the carbon tax) (see appendixes 3 and 5 for coefficients definition/description and for the method of their calculation for the reference scenario):

$an_{ij}^{1} = an_{ij}^{0} \times (P_i/P_j)$ (coefficients for domestic *inputs*);

$am_{ij}^{1} = am_{ij}^{0} \times (PM_{ij}/P_j)$ (coefficients for imported inputs);

$az_{ij}^{1} = az_{ij}^{0} \times (PZ_{ij}/P_j)$ (coefficients for subsidies on products);

$at_{ij}^{1} = at_{ij}^{0} \times (PT_{ij}/P_j) = (at_{ij}^{0} + \Delta T_{ij}/X_j^{0})/P_j$ (coefficients for taxes on products);

$a_{ij}^{1} = an_{ij}^{1} + am_{ij}^{1} + at_{ij}^{1} + az_{ij}^{1} + amc_{ij}^{0} + amt_{ij}^{0}$ (total technical coefficients);

$av_j^{1} = av_j^{0} \times PV_j/P_j$ (value added coefficients);

$arem_j^{1} = arem_j^{0} \times PREM_j/P_j$ (coefficients for compensation of employees);

$aot_j^{1} = aot_j^{0} \times POT_j/P_j$ (coefficients for other taxes on production)

$tmcF_i^{k(1)} = tmcF_i^{k(0)} \times (a_{iF}^{0} / a_{iF}^{1})$ (trade margin rates)

for: i = (1,…,85); j = (1,…,85; F) with F (final demand component) = C, G, CS15, I, V, VE, EX; P_i and P_j = production (basic) price indexes for product *i* or *j* or final demand (of type F) deflator (at purchasers' prices) in the scenarios with the increase in primary input prices (considering the prices in the reference scenario =1; note that $P_i = 1+ p_i$); PM_{ij}, PT_{ij}, PZ_{ij} , PV_j , $PREM_j$ and POT_j are the price indexes (considering the prices in the reference scenario =1; note that $PM_{ij}=1+pm_{ij}$, etc., etc.) for, respectively, the following primary inputs: imports, taxes, subsidies, value added, labor (evaluated through the compensation of employees) and other taxes on production, relative to input i for industry (or final demand) j; ΔT_{ij} = additional tax on product i used by industry (or final demand component j (estimated direct effect); X_j^{0} = output of industry j, at basic prices (or total values of final demand of type F, at purchasers prices), in the reference scenario; $amc_{ij}^{0} + amt_{ij}^{0}$ = coefficients of trade and transport margins for product i, used by industry (or final demand) j, calculated for the reference scenario.

Note that the above formulas, combined with the method for production and final demand price determination in the input-output price model (equations 3 and 9 in Appendix 6) , ensure that the revised technical coefficients still add up to one in each industry and for each final demand component:

$\sum_i (an_{ij}^{1} + am_{ij}^{1} + at_{ij}^{1} + az_{ij}^{1}) + av_j^{1} = 1$ (sum for i=1 to 85), for all j.

In the case of the **present study** all **price indexes for primary inputs are** equal to **1 except for taxes (PT_{ij})** and so the above formulas simplify accordingly.