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## Fiscal limits on first-best climate policy: A CGE analysis for Europe

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**Abstract**:
We use a standard computable general equilibrium model to explore the fiscal implications of stringent carbon dioxide emission reduction in Europe. Both the immediate targets (20-30% by 2020) and the medium-term targets (80-90% by 2050) for abatement can be met with a carbon tax that is modest to sizeable. Imposing budget neutrality, a carbon tax that would allow all other taxes to fall by 5% (20%) would cut emissions by about 40% (80%). For 80% emission reduction, the carbon tax would only be the third largest tax in terms of revenue. A 40% emission reduction would cost about 1.5% of GDP. Costs are roughly exponential in abatement. The economic impact of emission reduction is minimized if the carbon tax revenue is preferentially used to reduce taxes on intermediates and import tariffs; such taxes, however, bring in little revenue at present. Emission reduction in Europe affects trade patterns across the world. It hampers the economies of West Asia and Africa, but has stimulating effect elsewhere. Economies everywhere outside Europe become more carbon-intensive. About one in four of emissions avoided in Europe are emitted elsewhere.

**JEL Classification:** H23, Q54

**Key Words:** carbon tax, tax reform, greenhouse gas emission reduction

## 1. Introduction

A carbon tax is generally agreed to be the best way to reduce greenhouse gas emissions (Baumol 1972;Weitzman 1974). The carbon tax revenue can be used to reduce other taxes, which would offset at least part of the costs of emission reduction (Goulder 1995b). At the same time, revenue neutrality poses an upper limit on the carbon tax (unless emissions are cut by 100% at a lower carbon tax). The Leviathan tax is the maximum carbon tax that can be levied without expanding total tax revenue. (Tol 2012) shows that the Leviathan tax falls below the tax required to meet the declared long-term goals of climate policy. (Tol 2012), however, assumes that neither emissions nor the economy responds to tax reform. We here reassess the Leviathan tax in general equilibrium, focusing on Europe, the leader in climate policy.

There have been many studies on greenhouse gas emission reduction (Weyant 1993), and a first-best solution is often among the policy scenarios. Many papers study the implications of adopting a particular target (Clarke et al. 2008;Fischer and Morgenstern 2006;Kuik et al. 2009). We instead explore the feasibility of deep emission cuts. There are also many papers on tax reform, particularly the double dividend (Bovenberg and de Mooij 1994;Bovenberg and Goulder 1996;Bovenberg and van der Ploeg 1998;Goulder 1995a;Goulder 1995b;Parry et al. 1999). These papers explore allocative inefficiencies. We instead focus on the structure of tax revenue.

The paper proceeds as follows. Section 2 presents the model, its closure, and the scenarios. Section 3 discusses the results. Section 4 concludes.

## 2. The model and scenarios

### *2.1 Model*

The GTAP model (Global Trade Analysis Project) is a popular multi-regional CGE model of the global economy (Hertel 1997).[1] Created in the early 1990s to analyse the effects of trade liberalization, the model is operated with data compiled by a team of researchers with base at Purdue University. The GTAP database collects input-output tables, bilateral trade- and tariff data for most countries in the world, for a given year, and provides estimates for all the model parameters (elasticities). In its most recent version (V8), which refers to 2007, data are available for 129 regions, 57 production sectors or commodities and 5 primary factors (Narayanan et al. 2012). GTAP users can aggregate regions, sectors and factors according to their needs.

The core of the model's structure is a two-tier demand system based on the representative household concept (McDougall 2003). At the upper level, regional income (i.e., a region's GDP) is allocated to private consumption, government consumption (households' consumption of publicly provided goods) and savings so as to maximize per capita utility. At the lower level, private expenditure is governed by the Constant Difference of Elasticities (CDE) function (Hanoch 1975), which is non-homothetic (i.e., budget shares vary with income), while government expenditure is derived from a Cobb-Douglas utility function.

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[1] The model is fully documented in Hertel (1997). Also, most comprehensive and up-to-date information and resources are on GTAP's website, www.gtap.agecon.purdue.edu/.

On the sources side, regional income is given by the sum of net returns to primary factors and tax receipts net of subsidies. Furthermore, constant returns to scale technology and perfect competition are assumed. In particular, production is represented with multi-tier CES (Constant Elasticity of Substitution) functions. Other defining features of the GTAP model are the "Global Bank" and the Armington approach to international trade. The first is a mechanism through which investment flows across regions to meet the demands for savings. The second refers to the assumption that, for firms and consumers, good A imported from region X is not a perfect substitute for good A imported from region Y.

A number of adaptations of the standard model have been developed over the years in order to better address specific issues. For the analysis of energy and climate policies, GTAP-E is the model to use (Burniaux and Truong 2002;McDougall and Golub 2007) and, thus, the one deployed in this study. GTAP-E modifies the production structure of the standard GTAP model in order to more closely mimic the ability of firms to substitute among alternative fuels as well as between primary factors and energy. Similarly, private and government consumption functions exhibit greater flexibility, as they distinguish between different types of energy and non-energy commodities. GTAP-E incorporates $CO_2$ emissions from the combustion of fossil fuels and allows one to simulate both regional carbon taxes and international emissions trading.

### *2.2 Data*

We use the GTAP V7 database (113 regions, 57 sectors, 5 factors), which depicts the global economy in 2004. The aggregation we have chosen – always a compromise between economic sense and computational convenience – corresponds to the following sets:

- Regions (*REG*): EU27 & EFTA; North America; Rest of America; Africa; East Asia & Oceania; West Asia & Rest of Europe;
- Sectors (*PROD*): Agriculture; Coal; Crude oil; Gas; Energy intensive industries; Other industries & Services; Petroleum products; Electricity; Capital goods;
- Commodities (*TRAD*): Agriculture; Coal; Crude oil; Gas; Energy intensive industries; Other industries & Services; Petroleum products; Electricity; and
- Primary factors (*ENDW*): Land; Labour; Capital; Natural Resources.

In GTAP, each sector only produces one tradeable good or service. Sets *PROD* and *TRAD* are not identical only for the presence of "Capital goods" in the former. "Capital goods" is the sector that "produces" investment, which is not a tradeable good.

Levels and composition of both $CO_2$ emissions and fiscal revenues are central to the analysis conducted in this paper. Thus, we report summary statistics of these for the region "EU27 & EFTA", the one we are focused on. Table 1 shows the amounts of $CO_2$ emissions associated, respectively, with final (households') and intermediate (firms') consumption of energy commodities, in base year 2004.[2] In the first case, emissions are presented by commodity, in the second by sector; in both cases, emissions due to consumption of domestically produced commodities are distinguished from those associated with consumption of imports.

[TABLE 1 HERE]

[2] Data on $CO_2$ emissions for GTAP V7 are by (Lee 2008).

In GTAP, taxes/subsidies are represented as ad valorem equivalents of the actual applied rates and are appropriately weighted in the aggregation procedure. Table 2 shows the detail with which taxes/subsidies enter the database and, thus, the model. The "dimension" of a tax here indicates the number of rates that are associated with it. This number is given by the product of the sets over which the tax in question is specified (e.g., *ENDW*, *TRAD*, *PROD*, *REG*). For example, the dimension of "income taxes" is 24 (i.e., there are 24 rates for direct taxation), since *ENDW* and *REG* have 4 and 6 elements, respectively.

[TABLE 2 HERE]

Each tax rate, applied to its own tax base, generates a yield (negative in the case of a subsidy). For region "EU27 & EFTA", these receipts are conveniently aggregated and reported in Table 3.

[TABLE 3 HERE]

More than a third (34%) of all tax revenues come from taxation of primary factors and 96% of these revenues come from taxation of labour (not shown). 28% of all tax revenues come from direct taxation and 79% of these revenues are from taxation of labour income.[3] Taxes on final consumption make 19% of total tax revenues.

Subsidies are observed for the primary sector, "Agriculture". Specifically, we observe subsidies to production (output), use of land and capital (primary factors), use of non-energy commodities (intermediate factors) and exports. Sectors "Coal" and "Oil" are also subsidised, for production and exports, respectively.

### *2.3 Closure*

In the CGE jargon, a model's closure refers to the choice of which variables are endogenous (i.e., endogenously determined by the model) and which are exogenous (all the others). For the closure to be valid, the number of endogenous variables must be equal to the number of equations and, also, exogenous variables must be independent (i.e., not linked by equations). The one or more variables that represent the simulated policy reform or, more generally, any "shock" to the system, must be exogenous and the values they are given represent the magnitude of the shock. All other exogenous variables remain unchanged. As the GTAP model is specified in percentage variations, this means all exogenous variables that are not shocked are equal to zero.

In our simulations we adopt the standard general equilibrium closure of the GTAP model, whereby prices, quantities of commodities and regional incomes are endogenous variables, while policy variables, technical change variables, primary factors and population are exogenous. In particular, full employment (labour supply being fixed or perfectly inelastic) and perfectly flexible wages are assumed. Moreover, global investment responds to changes in the relative rates of return across regions. While this does not affect productive capital stocks, it does impact on savings and, hence, on current account balances.

This type of closure is generally interpreted as representing the long run: a time period sufficiently long for the existing capital to move across sectors and regions. At the same time, we

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[3] The average tax rate applied to labour income is almost four times as high as the one applied to capital income: 26.1%vs 7.3%.

keep technologies and endowments constant. In that sense, the model results represent the short run.

Table 4 reports the full model closure as just described. Note, however, that in all our simulation scenarios we endogenize the carbon tax rate (originally among the exogenous variables, in Table 4) and, at the same time, impose revenue neutrality (for the government's budget) by fixing the share of total fiscal revenues in GDP (originally among the endogenous variables). We discuss this closure swap in the next section.

[TABLE 4 HERE]

### *2.4 Scenarios*

We consider two sets of simulations. The first one comprises three scenarios, in which all tax rates in the "EU27 & EFTA" region are reduced by the same proportion: 5%, 10% and 20%. For example, if a tax rate is 30%, a 20% cut results in a 24% rate. At the same time, we endogenize the carbon tax rate and fix the share of total fiscal revenues in GDP so as to ensure revenue neutrality – after all markets have found a new equilibrium.[4] The main purpose of this exercise is to identify an approximate upper boundary for carbon pricing in Europe which, given the model's closure, may be valid for the medium run (as explained above, intended as a 3 to 5 year horizon, approximately).

With the second set of simulations, we run six scenarios, one for each type of taxation that is in the model, namely, taxation of: 1) final consumption; 2) income; 3) output; 4) use of primary factors; 5) use of intermediate factors; 6) imports and exports (cf. Tables 2 and 3). This time, we shock all taxes corresponding to the type of taxation under consideration. Moreover, we only consider 5% reductions in tax rates, and not also 10% and 20% as we do in the first set of simulations. The closure swap, however, between the carbon tax rate and the share of total revenues in GDP remains there as before. The purpose of these scenarios is to contrast alternative options of environmental tax reform whereby revenue neutral carbon taxation is implemented by cutting specific taxes. As all such options involve the same proportional cut in rates (5%), the resulting carbon tax and, thus, emissions and GDP depend, in the first place, on the size of the revenues generated by the tax that is cut and, secondly, on how distortive the same tax is.

## 3. Results

### *3.1. All taxes reduced by same percentage*

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[4] This is the economically correct definition of budget neutrality. In reality, politicians are more likely to opt for budget neutrality without taking price responses into account. Recall that CGE models must be homogenous of degree zero in prices. In other words, purely nominal effects, such as a generalized homogenous variation in prices, must not determine real effects (i.e., must have no impact on quantities). Here, the carbon tax rate is swapped with a "real" variable – the share of total fiscal revenues in GDP – and not a nominal one, as the change in fiscal revenues or government budget would be, in order to preserve this property.

Table 5 shows key impacts of a tax reform. A carbon tax of \$133/t$CO_2$ would allow for a reduction of all other taxes by 5%. It would cut carbon dioxide emissions by 42% (from baseline), and reduce GDP by 1.4% (from baseline).

Table 5 also shows key sensitivities, halving the carbon tax revenue and halving it again, and doubling the revenue and doubling it again. If other taxes were cut by half (double) the amount, the carbon tax would fall (rise) by more than half; emission reduction would fall (rise) by less than half; and GDP loss would fall (rise) by less than half.

If all taxes are cut by 20%, the carbon tax would be \$1289/t$CO_2$. This compares to a Leviathan tax of \$1352/t$CO_2$ if we assume that the economy does not respond to tax reform and emissions do not respond to carbon taxation (Tol 2012).

[TABLE 5 HERE]

The qualitative pattern of emissions and total costs are intuitive. The cheapest options for emission reduction are realized first. Doubling the emission reduction effort would therefore less than double the emission reduction as more expensive options need to be deployed. See Figure 1.

By the same token, doubling the effort would more than double the costs of emission reduction. At the same time, the benefits of revenue recycling would less than double because the tax system becomes progressively less distortionary. See Figure 2.

GDP loss is more than linear in emission reduction (Figure 2) but it appears to be almost linear – or rather slightly less so – in the carbon tax. See Figure 3. A (near) linear relationship between total cost (GDP loss) and marginal cost (carbon tax) implies that the total cost function is (almost) exponential.

The relationship between other taxes cut and the level of the carbon tax requires some more thought. The initial carbon tax is zero. In the scenario where other taxes are reduced by $\alpha$, the carbon tax revenue is $\alpha\tau Y$, where $\tau$ is the relative tax take and $Y$ is GDP. The carbon tax revenue also equals $tE$, where $t$ is the carbon tax and $E$ emissions. The carbon tax is therefore $t=\alpha\tau Y/E$. This suggests a linear relationship between $t$ and $\tau$. However, that would be the case if the elasticities were zero. If GDP and emissions respond to the changes in the tax code, $t=\alpha\tau Y(1-\varepsilon(t))/E(1-\eta(t))$, where $\varepsilon$ and $\eta$ measure the sensitivities of GDP and emissions, respective, to a carbon tax. As we can see from Table 5 (and as we would expect), $\eta>>\varepsilon$ and therefore $\delta t/\delta\alpha>1$. In words, a doubling of the effort, measured in the proportional reduction of other taxes, leads to more than a doubling of the carbon tax.

Table 3 shows that, in the most extreme scenario where emissions are reduced by 80% and climate policy brings in 20% of all tax revenue, the carbon tax is still only the third-largest contributor to the exchequer. The carbon tax therefore does not appear to be unbearably large from a tax composition perspective. Dynamically, however, climate policy requires that the carbon tax revenue goes from zero to 20% and, as emissions are phased out, back to zero again. But as this would need to happen over 20 or more electoral cycles, the scale of the carbon tax should not pose insurmountable problems.

Figure 4 confirms this. It shows the histogram of proportional annual changes in the tax rates on products and income in 30 European countries over the 17 to 41 year period ending in 2011. An 80% emission reduction by 2050 requires a carbon tax that would offset 20% of all other taxes. This corresponds to a proportional tax reduction of 0.5% per year. Although tax reform typically is slower than that – see the blue, central bars in Figure 4 – faster tax reform is not uncommon at all.

### 3.2. *Different types of taxes reduced by 5%*

Table 5 also shows the impacts of specific tax reforms. We in turn reduced the revenue of taxes on final consumption, income, output, primary factors, intermediate products, and imports and exports – see Table 2 – by 5% and levied a carbon tax so as to keep total tax revenue constant.

The resulting carbon taxes vary strongly, from ¢2/t$CO_2$ to \$42/t$CO_2$. This reflects the composition of the tax revenue: Income taxes raise most money, and import tariffs very little. See Table 3.

Figure 1 shows carbon dioxide emissions as a function of the carbon tax. The response is monotonic, almost linear but slightly less than proportional.

The picture is completely different for GDP loss. The relationship is non-monotonic, at least for low carbon taxes. If the carbon tax is used to reduce taxes on intermediate goods and services, GDP even grows: a strong double dividend. A reduction of other taxes does not bring a strong double dividend.[5]

Table 5 aggregates the impacts of the 6 specific tax reforms (the sum) and compares the results to the general tax reform (the whole), all at the 5% level. The whole is smaller than the sum for carbon dioxide emission reduction. This is as expected: A carbon tax first exhausts the cheap and easy options to reduce emissions before moving on to more expensive options. A low carbon tax thus has a higher impact, per unit of tax, than a high carbon tax.

For the same reason, the cost of the whole package (measured in GDP loss) is larger than the sum of the costs of its components. The benefits of tax relief roughly add up, but the costs of emission reduction escalate.

The sum of the carbon taxes is smaller than the whole because carbon emissions respond more strongly to carbon taxes than the economy (see above).

### 3.3. *Structure of production and trade*

We now return to the scenario in which all taxes are reduced by 5%. Table 6 shows the change in output by commodity, and the change in exports and imports. Table A1 shows the changes in trade by commodity and region.

Table 6 shows that output shrinks in all sectors, consistent with the overall drop in GDP. Some sectors are hit particularly hard: coal, gas, petroleum products, electricity. This is as expected:

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[5] The model does not show a strong double dividend for a low carbon tax either. A key reason is that taxes on primary factors (including labour) are the largest source of tax revenue in Europe; see Table 3. However, labour supply is price inelastic in GTAP, and one of the main distortions of wage taxation is thus assumed away. Taxes on income (including capital) are the second largest source of tax revenue. Although lower taxation of capital income has a positive effect on the returns on capital, the increase in savings and the extra influx of foreign investment does not materialize as new capital stock in a static computable general equilibrium model (although the investment does count in GDP).

Carbon dioxide results from fossil fuel combustion. Energy intensive industry sees a sharper decline than other manufacturing and services.

The pattern of changes in output is matched by the pattern of changes in import. Fossil fuel imports fall. Imports of electricity rise (but from a small base) since emissions from electricity generated elsewhere are unconstrained. Import of energy-intensive products fall but by less than domestic output, and by less than GDP. This again indicates a substitution from domestic emissions to emissions abroad. Other imports fall too.

The pattern in the change of export follows. Fossil fuel exports rise as the domestic market is lost. The export of energy-intensive products, electricity and agriculture falls as the carbon tax raises the domestic price relative to the foreign price. The export of other products and services increases, as domestic demand falls and the relative price with it.

### *3.4. Leakage*

Table 6 shows that climate policy in Europe affects international trade across the world. Consequently, economic activity and emissions elsewhere are affected too. Table 7 shows how.

The rest of Europe, West Asia and Africa strongly depend on the EU plus EFTA as an export market, particularly for energy. Reduced economic activity and reduced energy demand in Europe thus hurts the economies of these regions. This is shown in Table 7. The rest of the world, however, benefits from lower energy prices and new export opportunities that arise from Europe's losses.

Table 7 also shows that carbon dioxide emissions rise everywhere else, but particularly in East Asia, in response to Europe's climate policy. This is because fossil fuel prices fall on the world market, and energy-intensive production shifts to non-regulated regions. In EU plus EFTA, carbon dioxide emissions fall by 470 thousand tonnes of $CO_2$. Elsewhere, emissions rise by 106 thousand tonnes of $CO_2$. The leakage rate is thus 23%. Global emissions fall by 5%.

## 4. Discussion and conclusion

This paper explores the fiscal implications of ambitious carbon dioxide emission reduction in Europe, using a standard computable general equilibrium model with a long-term closure (for capita). We find that both the immediate targets (20-30% by 2020) and the medium-term targets (80-90% by 2050) for emission reduction in the EU can be achieved with a carbon tax that is modest to sizeable. Imposing budget neutrality, a carbon tax that would allow all other taxes to fall by 5% (20%) would cut emissions by about 40% (80%). A 40% emission reduction would cost about 1.5% of GDP. Emission reduction costs are roughly exponential in emission reduction. The economic impact of emission reduction is minimized if the carbon tax revenue is preferentially used to reduce taxes on intermediates and import tariffs; such taxes, however, bring in little revenue at present. Emission reduction in Europe affects trade patterns across the world. It hurts the economies of West Asia and Africa, but stimulates economies elsewhere. Economies everywhere outside Europe become more carbon-intensive. About 1 in 4 of emissions avoided in Europe is emitted elsewhere.

There are a number of caveats to these results. GTAP-E has a reasonably detailed representation of the energy sector compared to most computable equilibrium models, but is crude compared to engineering models. Labour supply is assumed to be inelastic and changes in savings and investment have no impact on the capital stock in a static model. As most tax revenue comes from these factors, the scope for a double dividend is limited. Our analysis is comparative static. Although the closure is long-term for capital, we do not account for changes in patterns of demand or productivity. We consider the effect on the taxation in general, but we do not consider the distribution of taxes, either between industries or across the income distribution. It would therefore make sense to repeat the above simulations with other models.

We find that a 20% emissions cut – the EU target for 2020 – requires a carbon tax that would raise 5% of all tax revenue. An 80% emissions cut – the EU target to 2050 – would imply that 20% of all tax revenue comes from a carbon tax. While a tax reform of this scale is feasible, it would require a considerable political effort. In the long run, carbon dioxide emissions will need to be eliminated. That is, after scaling up the carbon tax to 20% of tax revenue by the middle of the century, other taxes would need to be raised again as greenhouse gases are phased out. Political controversy is easy to imagine.

If tradable permits are the instrument of choice, the permit market would be worth 2% of GDP in 2020 and 8% in 2050 (as 41% of EU+EFTA GDP is paid in taxes). That is a sizeable market. If other forms of regulation are used to reduce emissions, the economic footprint would be larger still.

We thus find that stringent climate policy is fiscally challenging but certainly not impossible – at least in Europe. Future research should explore whether this holds for other regions too.

**Acknowledgments**

An earlier version of this paper was presented to the Department of Economics at the University of Sussex. Attendees had useful comments.

Table 1. Carbon dioxide emissions (in 1000 tonne carbon) by commodity (household) and sector (firms), domestic (dom) and imported( imp) in the base year (2005) in EU+EFTA.

| | Households | | | Firms | |
|---|---|---|---|---|---|
| Commodity | dom | Imp | Sector | dom | Imp |
| 1 Agricultural products | 0 | 0 | 1 Agriculture | 17 | 4.6 |
| 2 Coal | 6.1 | 2.5 | 2 Coal | 0.4 | 0.1 |
| 3 Oil | 0 | 0 | 3 Oil | 3.5 | 0.9 |
| 4 Gas | 49.6 | 41.3 | 4 Gas | 4.9 | 0.4 |
| 5 Energy intensive products | 0 | 0 | 5 Energy intensive production | 46.7 | 45.5 |
| 6 Other manufactures and services | 0 | 0 | 6 Other manufacturing and services | 240.7 | 102.4 |
| 7 Petroleum products | 115.9 | 36.1 | 7 Refining | 10.5 | 6.9 |
| 8 Electricity | 0 | 0 | 8 Electricity | 211.4 | 163.5 |
| | | | 9 Capital goods | 0 | 0 |
| Total | 171.7 | 79.9 | Total | 535.1 | 324.2 |

Table 2. Types and number of taxes in the GTAP data and model.

| Type of taxation | Variable | Description | Dimension (per region) |
|---|---|---|---|
| Taxes on final consumption | tpd | private domestic | TRAD x REG = 48 (8) |
| | tpm | private import | TRAD x REG = 48 (8) |
| | tgd | government domestic | TRAD x REG = 48 (8) |
| | tgm | government import | TRAD x REG = 48 (8) |
| Income taxes | to | | ENDW x REG = 24 (4) |
| Output taxes | to | | PROD x REG = 54 (9) |
| Taxes on primary factors | tf | | ENDW x PROD x REG = 216 (36) |
| Taxes on intermediate factors | tfd | Domestic | TRAD X PROD x REG = 432 (72) |
| | tfm | Import | TRAD X PROD x REG = 432 (72) |
| Taxes on imports and exports | txs | Export | TRAD x REG x REG = 288 (48) |
| | tms | Import | TRAD x REG x REG = 288 (48) |

Table 3. Composition of tax revenue in EU+EFTA in the base year (2005) and the most extreme scenario.

| | $bln (2004$) | Share | Share* |
|---|---|---|---|
| Taxes on final consumption | 1,076 | 0.19 | 0.15 |
| Income taxes | 1,620 | 0.29 | 0.23 |
| Output taxes | 244 | 0.04 | 0.03 |
| Taxes on primary factors | 1,924 | 0.34 | 0.28 |
| Taxes on intermediate factors | 687 | 0.12 | 0.10 |
| Taxes on imports and exports | 42 | 0.01 | 0.01 |
| Total | 5,593 | 1.00 | 0.80 |

* Share of total tax take if the carbon tax brings in 20% of the total and all other taxes are reduced by the same proportion.

Table 4. Model closure.

| Exogenous variables | Description |
|---|---|
| *Pop* | Population |
| *ams atm atf ats atd aosec aoreg afcom afsec afreg afall aoall atall* | Technical change variables |
| *to tp tm tms tx txs tf tfd tfm tgd tgm tpd tpm toe te tl tll tk* | Policy variables |
| *Qoe* | Supply primary factors or endowments |
| *Pfactwld* | World price of endowments - Numeraire |
| *tradslack endwslack cgdslack profitslack incomeslack psaveslack* | Slack variables |
| *au dppriv dpgov dpsave* | Distribution parameters |
| *NCTAXB pemp* | Carbon tax rate; power of emissions purchases (for emissions trading) |
| All other variables endogenous | |

Table 5. Summary of scenario results.

| Indicator | Tax | CO2 | GDP |
|---|---|---|---|
| Scenario | $/tCO$_2$ | % | % |
| Taxes on final consumption by 5% | 11.4 | -8.87 | -0.091 |
| Income taxes by 5% | 42.0 | -24.11 | -0.484 |
| Output taxes by 5% | 3.2 | -2.71 | -0.008 |
| Taxes on primary factors by 5% | 26.0 | -17.68 | -0.300 |
| Taxes on intermediate factors by 5% | 9.0 | -7.04 | +0.004 |
| Taxes on imports and exports by 5% | 0.0 | -0.03 | 0.000 |
| *Total* | *91.8* | *-60.44* | *-0.879* |
| All taxes by 1.25% | 22.3 | -15.52 | -0.210 |
| All taxes by 2.5% | 52.3 | -26.95 | -0.540 |
| All taxes by 5% | *132.8* | *-42.26* | *-1.430* |
| All taxes by 10% | 378.3 | -60.98 | -3.750 |
| All taxes by 20% | 1332.4 | -80.47 | -9.830 |

Table 6. The impact of a 5% tax reform on output, export and import.

| **Commodity** | **Output** | **Export** | **Import** |
|---|---|---|---|
| 1 Agricultural products | -1.5 | -2.0 | -0.3 |
| 2 Coal | -56.3 | 4.9 | -55.7 |
| 3 Oil | -3.4 | 1.3 | -18.7 |
| 4 Gas | -27.9 | 46.7 | -15.5 |
| 5 Energy intensive products | -3.4 | -4.7 | -1.4 |
| 6 Other manufactures and services | -1.0 | 1.2 | -2.1 |
| 7 Petroleum products | -18.2 | -18.5 | -20.1 |
| 8 Electricity | -11.9 | -33.0 | 10.7 |

Table 7. The impact of a 5% tax reform on emissions and GDP.

| **Region** | **Emissions** (%) | **GDP** (%) |
|---|---|---|
| 1 EU27+EFTA | -42.26 | -1.43 |
| 2 North America | 1.23 | 0.03 |
| 3 Other America | 1.59 | 0.06 |
| 4 West Asia and Other Europe | 2.69 | -0.52 |
| 5 East Asia and Oceania | 1.43 | 0.05 |
| 6 Africa | 5.56 | -0.02 |

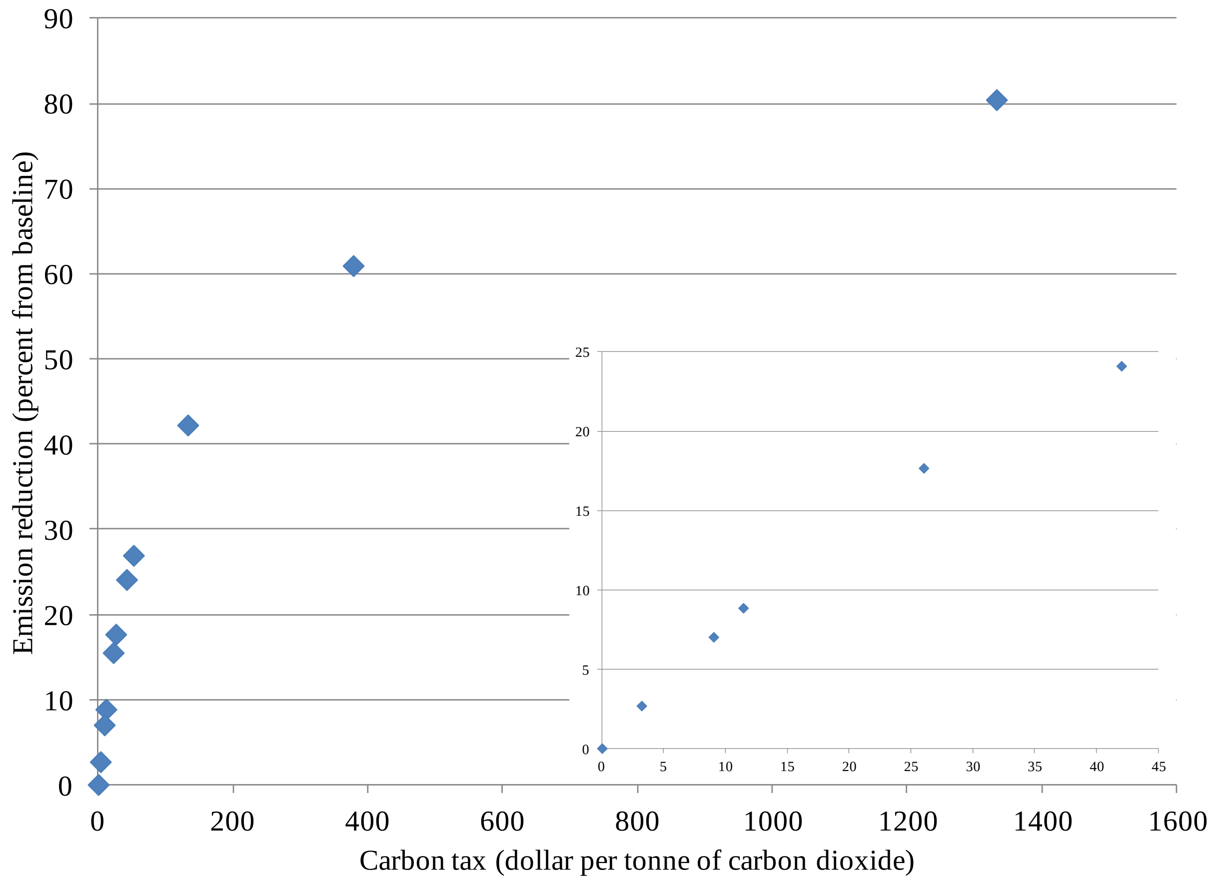


Figure 1. Emission reduction as a function of the carbon tax (the inset enlarges the bottom left corner).

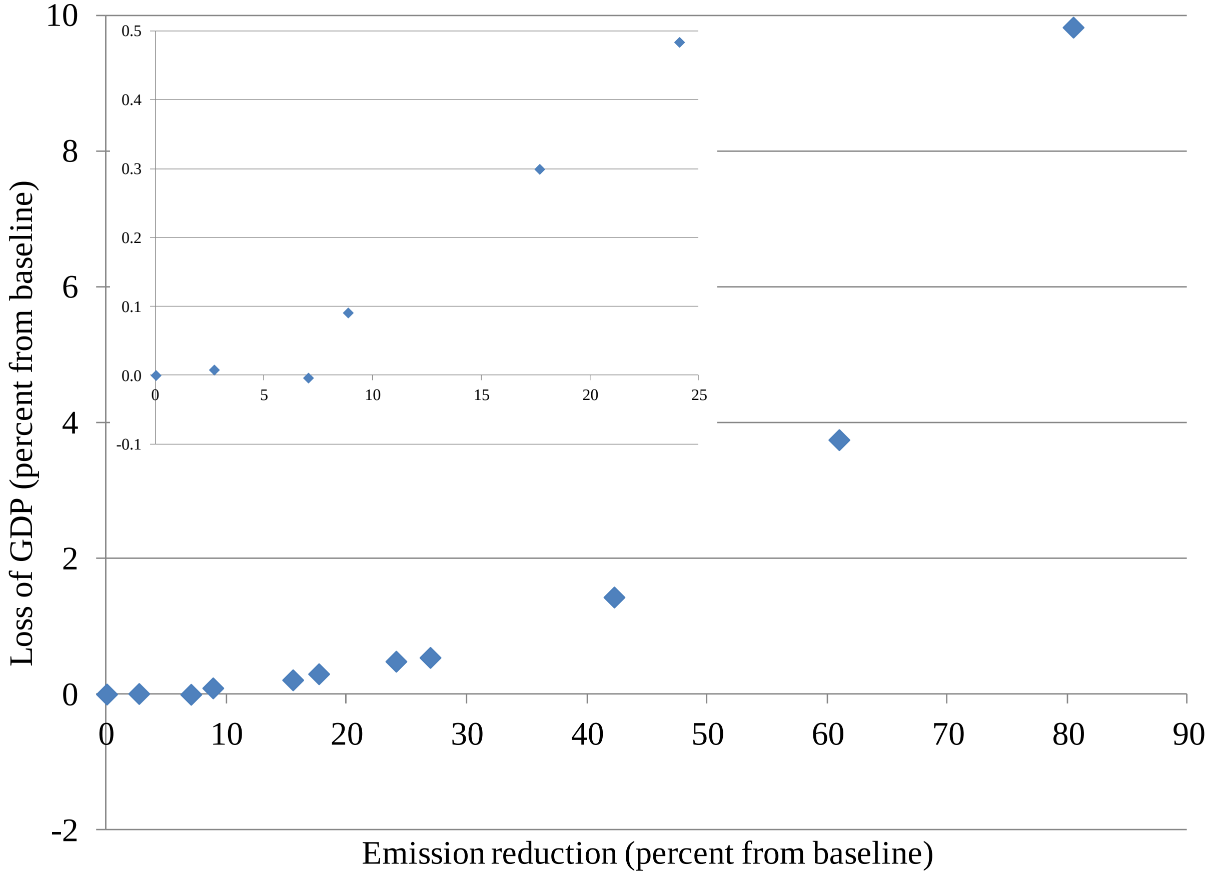


Figure 2. Loss of GDP as a function of emission reduction (the inset enlarges the bottom left corner).

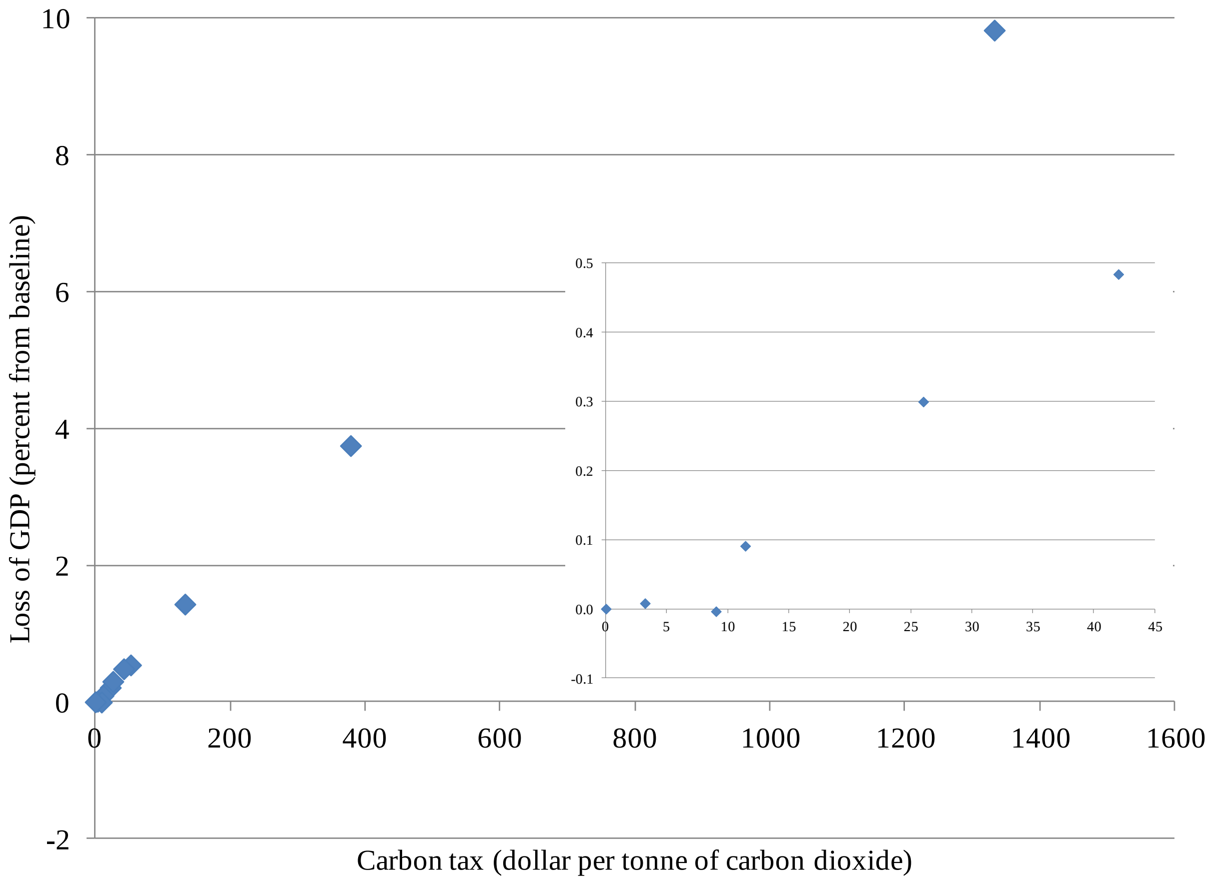


Figure 3. Loss of GDP as a function of the carbon tax (the inset enlarges the bottom left corner).

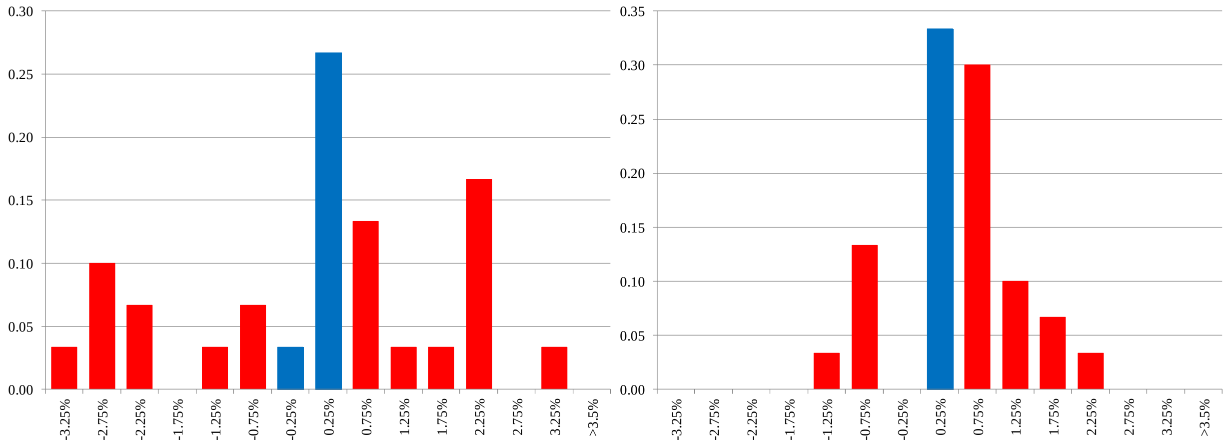


Figure 4. Histogram of the average annual proportional change in tax rates on products (left panel) and income (right panel) in European countries over the period for which EuroStat has data; the blue bars fall below the tax reform rate dictated by the emission targets in 2020 and 2050.

Table A1. The impact of a 5% tax reform on imports and exports by region and commodity.

| Exports | Destination | | | | | | |
|---|---|---|---|---|---|---|---|
| Commodity | E Asia | W Asia | N America | L America | EU27+EFTA | Africa | World |
| 1 agriculture | -0.9 | -3.5 | -0.5 | -0.4 | -2.0 | -2.4 | -2.0 |
| 2 coal | 302.9 | 173.4 | 208.0 | 249.0 | -0.9 | 98.4 | 4.9 |
| 3 oil | 25.5 | 23.5 | 28.3 | 29.7 | -6.4 | 23.9 | 1.3 |
| 4 gas | 650.1 | 538.2 | 1035.6 | 965.3 | 33.2 | 259.0 | 46.7 |
| 5 energy int | -7.1 | -7.0 | -5.7 | -5.8 | -3.9 | -6.4 | -4.7 |
| 6 other goods and services | 5.6 | 1.5 | 6.0 | 5.6 | -0.6 | 2.5 | 1.2 |
| 7 petroleum | -9.2 | -9.3 | -6.6 | -7.0 | -23.9 | -8.5 | -18.5 |
| 8 electricity | -68.0 | -69.7 | -73.7 | -71.0 | -24.0 | -71.4 | -33.0 |
| Total | 3.4 | -0.8 | 3.9 | 2.6 | -1.7 | 0.2 | -0.4 |
| Imports | Origin | | | | | | |
| Commodity | E Asia | W Asia | N America | L America | EU27+EFTA | Africa | World |
| 1 agriculture | 0.4 | 4.0 | 0.8 | 2.5 | -2.0 | 1.9 | -0.3 |
| 2 coal | -73.9 | -67.3 | -73.9 | -61.5 | -0.9 | -54.7 | -55.7 |
| 3 oil | -29.4 | -23.2 | -31.1 | -30.6 | -6.4 | -22.8 | -18.7 |
| 4 gas | -84.1 | -81.7 | -89.9 | -88.5 | 33.2 | -61.4 | -15.5 |
| 5 energy int | 5.5 | 11.5 | 3.5 | 4.0 | -3.9 | 8.3 | -1.4 |
| 6 other goods and services | -5.5 | 0.1 | -6.9 | -4.8 | -0.6 | -1.4 | -2.1 |
| 7 petroleum | -15.1 | -12.8 | -16.4 | -17.2 | -23.9 | -11.9 | -20.1 |
| 8 electricity | 208.3 | 234.1 | 203.3 | 204.3 | -24.0 | 248.0 | 10.7 |
| Total | -4.5 | -5.8 | -5.2 | -2.2 | -1.7 | -8.6 | -2.8 |

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