# Background Note Q-Tool Extensions

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Competitiveness Implications of European Leadership in Climate Policy

## 1 Introduction

The term “competitiveness” has turned into a catchword in virtually every political debate on new regulatory proposals. However, the notion of competitiveness varies widely and is subject to controversial judgments. As a prominent opponent to the inflationary use of the catchword “competitiveness”, Krugman (1994) states that „competitiveness is a meaningless word when applied to national economies. And the obsession with competitiveness is both wrong and dangerous”. On the other hand, national governments and international organizations seek to assess policy interference with respect to some constructive indicators on “competitiveness”. Within the European Union, the European Council started the so-called Lisbon process in 2000 which established the issue of competitiveness as a priority area for EU policy. The seventh edition of the Commissions Report on European Competitiveness (EU 2003) understands “competitiveness to mean high and rising standards of living of a nation with the lowest possible level of involuntary unemployment, on a sustainable basis”.

Reflecting the policy priorities within the EU, there is the need to measure regulatory decisions against their effects on competitiveness. In first place, this requires the definition of measurable indicators for competitiveness: An issue that can not be clearly measured will be difficult to improve. In second place, it is inevitable to apply methodologies which allow for an appropriate systematic and consistent quantification of competitiveness implications associated with different regulatory options.

In this paper, we provide an overview of various definitions of the term “competitiveness”. We then present several indicators that can be used to quantify specific aspects of competitiveness. In order to demonstrate how such indicators can be operated within an economy-wide quantitative framework, we perform an illustrative policy analysis on EU leadership in climate policy (i.e. the EU is assumed to adopting stricter carbon emission regulation as compared to other regions): Selected indicators of competitiveness are implemented into the core static version of the PACE general equilibrium model which has been developed under the auspices of the I.Q. Tools project. At hand of this model framework, we are not only able to quantify the impacts of policy regulation on competitiveness indicators such as Terms of Trade (ToT) or Revealed Comparative

Advantages (RCA) but also for important macroeconomic indicators such as real consumption, sectoral output etc.

The remainder of this paper is structured as follows. Section 2 gives an overview on the concept of competitiveness at the firms, sector, as well as country level; furthermore commonly used indicators at the respective levels are presented. Section 3 provides a more detailed discussion of selected indicators at the sector level which can be directly implemented within the computable general equilibrium approach. Section 4 provides an illustrative policy application on unilateral EU carbon emission restrictions based on the PACE model. A detailed algebraic description of the static core model version is given in the appendix.

## 2 Notions of Competitiveness

The concept of competitiveness originates from the application to individual firms. Beginning in the sixties, many attempts were made to define the concept on a higher aggregated level, i.e., for sectors or even for whole countries.

At the firm level, there is a relatively well established literature on indicators for competitiveness. As Martin (2004) puts it: "At the firm, or micro-economic, level there exists a reasonably clear and straightforward understanding of the notion of competitiveness based on the capacity of firms to compete, to grow, and to be profitable. At this level, competitiveness resides in the ability of firms to consistently and profitably produce products that meet the requirements of an open market in terms of price, quality, etc. Any firm must meet these requirements if it is to remain in business, and the more competitive a firm relative to its rivals the greater will be its ability to gain market share."

With respect to indicator systems for measuring competitiveness one can generally distinguish between ex-ante indicators which are input- or policy-based and ex-post indicators which are based on what is observed on the market. The latter are also called output- or performance- based indicators. At the firm level, examples for policy-based indicators include R&D expenditures, innovation potential, cost structure, or human capital stock. Firm characteristics like market share, profitability or productivity may serve as examples for performance-based indicators.

Competitiveness at the sectoral level is an important policy issue since many countries feature a limited number of sectors which appear most relevant for the economic performance. For example, the automobile industry is perceived as a key industry in several EU countries. As a consequence, the European Competitiveness Report has a separate chapter on the automobile industry. The eight edition of the European Competitiveness Report (EU 2004) also provides what could be interpreted as a definition of competitiveness for the sectoral level: „The analysis of competitiveness […] focuses on the ability to defend and/or to gain market shares in open, international markets by relying on price and/or the quality of goods. This ability is affected by a wide range of factors and conditions ranging from production costs to technological and organizational innovation, from the regulatory framework to macroeconomic developments”. Policy-based indicators for the competitiveness of a whole sector are similar to the ones used at the firm level, such as R&D expenditures, innovation potential or investment flow (e.g. foreign direct investment). Among the performance-based indicators – next to profitability and productivity – there are measures such as the “Relative World Trade Share” (RWA), “Revealed Comparative Advantages” (RCA) or the “Constant Market Shares” (CMA) measure. The two latter concepts are also employed to assess competitiveness at the national level.

Concepts of competitiveness at the national level are very controversial. Krugman (2004) explains his very critical view as follows: „The idea that a country’s economic fortunes are largely determined by its success on world markets is a hypothesis, not a necessary truth, and as a practical, empirical matter, that hypothesis is flatly wrong.” In contrary to such fundamental criticism, concepts of competitiveness at the national level are widely used thereby incorporating various aspects of competitiveness at the levels below. Table 1 provides a selection of indicators at the national level according to four wide-spread classifications (“abilities”): (i) the ability to “sell”, (ii) the ability to “earn”, (iii) the ability to “attract”, and (iv) the ability to “adjust”.

Obviously, it may be difficult to distinguish to which ability a certain indicator belongs to. For some areas, especially within the “ability to adjust”, it can be hard to find meaningful indicators at all.

Table 1: List of competitiveness indicators at the national level

| Ability to sell | Ability to earn | Ability to attract | Ability to adjust |
|---|---|---|---|
| • Current account<br>• Terms of trade<br>• Real exchange rate<br>• World market share (CMS)<br>• Revealed comparative advantage (RCA) | • Per capita income<br>• [Technological competitiveness]<br>• (Labor-) productivity<br>• [Human capital] | • Net foreign direct investment<br>• Corporate tax burden<br>• Level of wages<br>• [Infrastructure]<br>• [Labor market regulation]<br>• Unemployment rate | • [Adjustment to new supply / demand structure]<br>• [Flexibility of wages]<br>• [Flexibility of exchange rates] |

N.B.: Entries in brackets show areas where a number of indicators can be defined but are not further specified here.

As to numerical model-based analysis, the question which of the indicators at the level of firms, sectors, or countries can be implemented depends on the specific modeling framework. In the extension and application of our standard multi-sector, multi-region CGE framework, we will compulsorily focus on indicators for sectoral competitiveness but also report standard indicators of competitiveness at the national level such as terms-of-trade or national income.

## 3 Selected Competitiveness Indicators for CGE Analysis

We discuss three ex-post output-based indicators – "Relative Word Trade Share" (RWA), "Revealed Comparative Advantage" (RCA) and "Constant Market Share" (CMA) – established in the broader literature on competitiveness that are directly amenable to CGE-based policy analysis.

### 3.1 Revealed Comparative Advantages (RCA)

RCA is sometimes called the "empirical counterpart of the theoretical concept of comparative advantages". In practice, RCA values are based on trade data, relating export with import data. Following Balassa (1965), the RCA index based on two dimensions (country, sector) is defined as:

$$RCA_{ij} = \frac{X_{ij} / M_{ij}}{\sum_j X_{ij} / \sum_j M_{ij}}$$

where:

- $i$:= is the index for regions,
- $j$:= is the index for sectors,
- $X_{ij}$:= denotes exports of sector $j$ by region $i$,

and

- $M_{ij}$:= refers to the imports of sector $j$ in region $i$.

Within the RCA, the ratio of exports by a specific sector over its imports is related to the ratio of exports over imports across all sectors of the region. If the sectoral export-import ratio is identical to the economy-wide ratio, the RCA value takes the neutral value of one. If the sectoral ratio is larger than one, it is meant to reflect (ex-post) a certain comparative advantage of this sector, which is exporting more then other sectors on average.

There is a range of slightly different RCA measures and normalization approaches (for mapping the index to the range between zero and one). For our illustrative analysis presented in section 4, we will stick to the simple definition given above.

### 3.2 Relative World Trade Shares (RWA)

A similar attempt to quantify sector-specific competitiveness is the one that uses relative world trade shares (RWA). This index compares the share of a country's exports in a certain sector with the share of the country's overall exports:

$$RCA_{ij} = \frac{X_{ij} / \sum_j X_{ij}}{\sum_j X_{ij} / \sum_i \sum_j X_{ij}} .$$

### 3.3 Constant Market Shares (CMS)

The CMS method is also based on world market shares. It compares the actual development of exports against the development that would have been necessary to keep the world export share constant. Typically, the development of exports is additively or multiplicatively decomposed into a growth effect and a competitiveness effect. In the simplest additive (tautological) decomposition the CMS reads as:

$$(x^t - x^0) = r \cdot x^0 + (x^t - x^0 - r \cdot x^0) .$$

where:

$x^t :=$ denotes exports of a country at time $t$,

$x^0 :=$ indicates exports of a country in the base year,

$j :=$ is the sector index,

$k :=$ is the country index,

and

$r :=$ denotes the change (growth rate) of world exports between the base year and time $t$.

The first term rx$^0$ is referred to as growth effect, while the second term $(x^t - x^0 - r \cdot x^0)$ can be viewed as the global competitiveness effect. If the competitiveness effect is zero, then the change in exports of the country (sector) matches the change in the rest of the world which implies that the share in world exports remained constant. If the competitiveness effect is positive, then the world market share has increased as compared to the reference period. The CMS in the form cited above is not capable to reflect any sectors specific contributions to the changes. This can be overcome by a more sophisticated decomposition into four parts: (i) a growth effect, (ii) a sectoral effect, (iii) a regional effect, and (iv) a competitiveness effect. This can be formalized as follows:

$$(x^t - x^0) = r \cdot x^0 + \sum_j x_j^0 (r_j - r) + \sum_j \sum_k x_{jk}^0 (r_{jk} - r_j) + \sum_j \sum_k (x_{jk}^t - x_{jk}^0 - r_{jk} \cdot x_{jk}^0) .$$

If a country specializes in sectors with a high growth potential then this indicator would show a high structural effect, while a specialization in export regions with a high growth potential would lead to a higher regional effect. In this framework the competitiveness effect is meant to reflect the export changes which are not due to sectoral or regional changes.

The decomposed CMS is widely used as an indicator for competitiveness (see Trabold (1995) or Reichel (1999)). The OECD, for example, uses a slightly extended five-step decomposition of the general CMS approach (OECD (2001)).

# 4 Policy Application: EU Leadership in Climate Policy

## 4.1 Policy Background

International concern about climate change has led to the signature of the Kyoto Protocol in 1997 aiming at emission targets for industrialized countries to be achieved during the commitment period 2008-2012. Initially, the Protocol – being in force after Russia's ratification since early 2005 – was celebrated as a breakthrough in international climate protection. However, the U.S. withdrawal from the Protocol and full tradability of emission entitlements that the former Eastern Bloc has been conceded in excess of its anticipated future business-as-usual emissions (so-called hot air) implies that the first commitment period of the Kyoto Protocol is likely to accomplish very little in terms of global emission reduction (see e.g. Böhringer (2002)). Moreover, it has not yet been negotiated which abatement targets to what parties will apply after the first commitment period 2008-2012.

The apparent "failure" of the Kyoto Protocol with respect to environmental effectiveness does not come much as a surprise from the perspective of standard economic theory given the lack of a supranational authority and the huge free-riding incentives in global public good provision. The rationale behind free-riding in climate policy is to save abatement costs while benefiting from abatement efforts of other countries. Although all countries could be better off if they behaved in a cooperative way, each country has an incentive to take a free-ride. This may lead to the well-known "tragedy of the commons". Despite of this prisoners' dilemma situation there might be reasons for single countries to take a leading role and act unilaterally. For example, a country may decide to make short-term sacrifices in the expectation of long run benefits from an increase in the number of signatory countries. Another motivation which is especially relevant in the EU context could be the domestic political environment where voters demand concrete environmental action. As a matter of fact, the EU is viewing itself as the key promoter of climate protection activities the firm willingness to unilateral action. At the same time, EU policy makers fear negative impacts on international competitiveness of key energy-intensive industries when adopting (much) stricter emission regulation as compared to trading partners.

Apart from adverse implications of unilateral emission regulation on EU industries, there is a potentially important environmental dimension to sub-global action regarding climate change: Unilateral abatement may lead to an increase in emissions in non-abating regions, reducing the global environmental effectiveness. This phenomenon is referred to as "leakage". Emission leakage in the case of EU unilateral carbon abatement can be measured as the increase in non-EU emissions relative to the reduction in EU Member States. There are three basic channels through which carbon leakage can occur (Felder and Rutherford, 1993). First, leakage can arise when in countries undertaking emission limitations energy-intensive industries lose in competitiveness and the production of emission-intensive goods relocates raising emission levels in the non-participating regions (trade channel). Secondly, cut-backs of energy demands in a large region due to emission constraints may depress the demand for fossil fuels and thus induce a drop in world energy prices, which in turn could lead to an increase in the level of demand (and its composition) in other regions (energy channel).

Thirdly, carbon leakage may be induced by changes in regional income (and thus energy demand) due to terms of trade changes. Leakage rates reflect the impact of sub-global emission abatement strategies on comparative advantage.

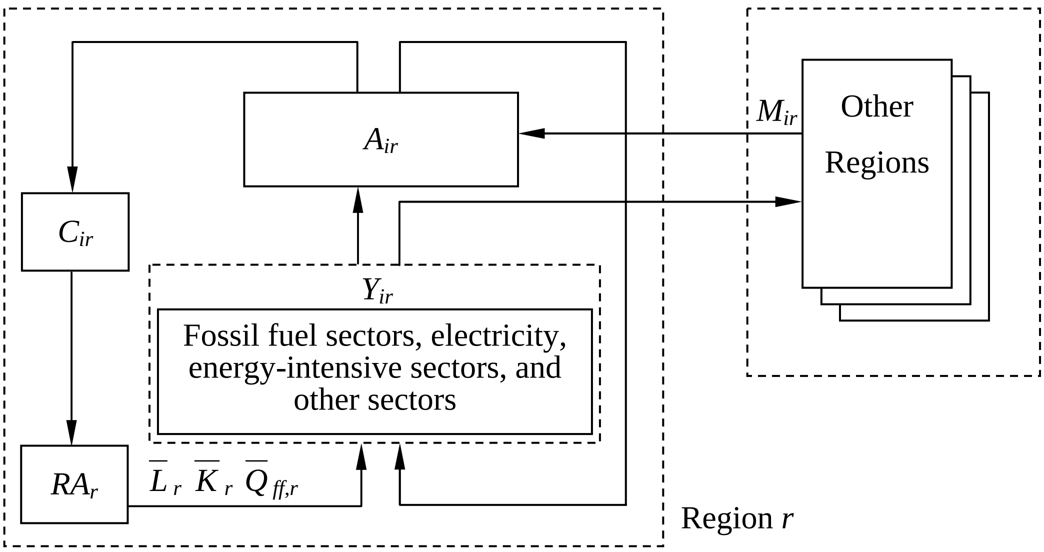
To reduce leakage and improve cost-efficiency of unilateral action, exemptions or tax-breaks for energy- and export-intensive industries are a commonly adopted strategy. However, an appropriate tax differentiation scheme would call for a careful accounting of embodied emissions in imports and exports. Otherwise, the cost of meeting a specific reduction target may increases substantially because the marginal cost of emission reduction are no longer equalized across sectors. At the practical level, the risk of potentially costly tax breaks to energy- and export-intensive sectors is apparent as managers of these politically influential industries use the leakage argument to push forward wide-ranging exemptions.

### 4.2 Non-technical Summary of the CGE Framework (PACE)

To investigate the implications of EU leadership in climate policy on sectoral competitiveness, gross economic welfare (abstracting from benefits of changes in environmental quality), and global carbon emissions we make use of the static multi-sector, multi-region model PACE for the world economy.

Figure 1 lays out the diagrammatic structure of the core model. Primary factors of a region *r* include labor, capital, and resources of fossil fuels *ff* (crude oil, coal, and gas). The specific resource used in the production of crude oil, coal and gas results in upward sloping supply schedules. Production $Y_{ir}$ of commodity *i* in region *r*, other than primary fossil fuels, is captured by aggregate production functions which characterize technology through substitution possibilities between various inputs.

Figure 1: Diagrammatic overview of the model structure



Nested constant elasticity of substitution (CES) cost functions with several levels are employed to specify the substitution possibilities in domestic production sectors between capital, labor, energy, and non-energy intermediate inputs.

Final demand $C_{ir}$ of the representative agent $RA_r$ in each region is given as a CES composite which combines consumption of an energy aggregate with a non-energy consumption bundle. The substitution patterns within the non-energy consumption bundle as well as the energy aggregate are described by nested CES functions. $CO_2$ emissions are associated with fossil fuel consumption in production, investment, and final demand.

All goods used on the domestic market in intermediate and final demand correspond to a CES composite $A_{ir}$ of the domestically produced variety and a CES import aggregate $M_{ir}$ of the same variety from the other regions, the so-called Armington good. Domestic production either enters the formation of the Armington good or is exported to satisfy the import demand of other regions. Endowments of primary resources are fixed exogenously. In the core simulations, we assume competitive factor and commodity markets such that prices adjust to clear these markets. Within our static framework, macroeconomic investment is fixed at the benchmark level (alternatively we might introduce a marginal propensity to save or a model specification where the marginal costs of investment equals the return to investment given myopic expectations).

The model is based on most recent consistent accounts of production, consumption, bilateral trade and energy flows for 87 countries and 57 sectors provided by the GTAP 6 data base for the base year 2001 (Dimaranan and McDougall (2006)).

Table 4: Model dimensions

| Production sectors | Regions and primary factors |
|---|---|
| *Energy* | *Regions* |
| Coal | European Union (EUR) |
| Crude oil | Non-EU OECD (OEC) |
| Natural gas | Rest of World (ROW) |
| Refined oil products (OIL) | |
| Electricity | |
| *Non-Energy* | *Primary factors* |
| Energy-intensive sectors (EIS) | Labor |
| Rest of industry and services (OTH) | Capital |
| Savings good | Fixed factor resources for coal, oil and gas |

For the sake of compactness, we have aggregated the GTAP countries to 3 major regions: European Union (EUR), Non-EU OECD (OEC), and Rest of World (ROW). The sectoral aggregation in the model has been chosen to distinguish carbon-intensive sectors from the rest of the economy. It captures key dimensions in the analysis of greenhouse gas abatement, such as differences in carbon intensities and the degree of substitutability across carbon-intensive goods. The primary and secondary energy goods identified in the model are coal, natural gas, crude oil, refined oil products, and electricity. Important carbon-intensive and energy-intensive non-energy industries that are potentially most affected by carbon abatement policies are aggregated within a composite energy-intensive sector. The remaining manufacturers and services are aggregated to a composite industry that produces a non-energy-intensive macro good. The primary factors in the model include labor, physical capital, and fossil-fuel resources. Table 2 summarizes the regional, sectoral, and factor aggregation of the model.

### 4.3 Scenarios and Results

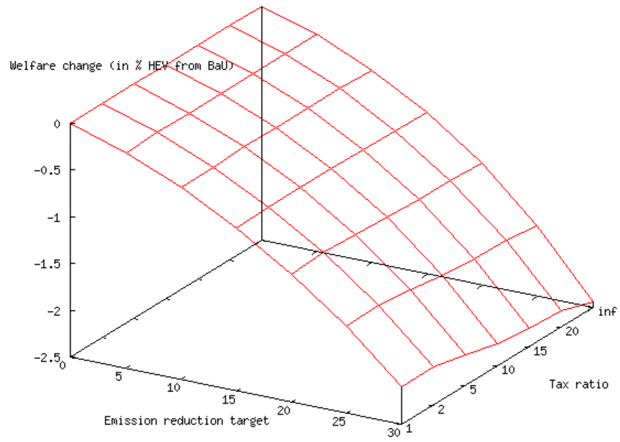
In order to illustrate the consequences of the European Union moving forward in terms of global climate policy we assume unilateral emission abatement within the EU while trading partners abstain from any comparable carbon emission regulation.

We differentiate the unilateral EU policy along two central dimensions: Firstly, the degree of leadership measured in terms of the unilateral reduction target of EU emissions vis-à-vis the benchmark situation where no effective emission abatement policy applies; the emission reduction target is set subsequently at 5 %, 10 %, 15 %, 20 %, 25 %, and 30 % of the base year emission level. Secondly, the level of tax differentiation between carbon-intensive (non-electric) industries – EIS and OIL – and the rest of the economy; the ratio of implicit tax rates to achieve the exogenous EU emission reduction target ranges from unity (i.e. uniform carbon taxes), via factors of 2, 5, 10, and 20 to full exemption of the carbon-intensive industries. Ratios higher than one indicate that taxes are discriminated in favor of carbon-intensive industries – for example a ratio of 20 implies that the carbon tax rate in the rest of the economy is twenty times higher than for carbon-intensive industries.

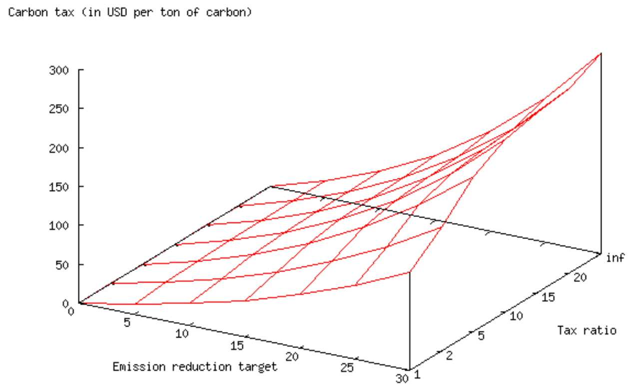
We use contour plots over the unilateral emission abatement target and the tax ratio to visualize our results. Note that in the graphs we refer to the case of full tax exemptions of carbon intensive industries with a label “inf” for the associated *infinite* tax ratio. Figures 2a.-d. report the implications of unilateral EU carbon policies for economic welfare, implied carbon taxes, terms of trade, and carbon leakage. Neglecting environmental benefits from carbon abatement, unilateral emission constraints impose non-negligible welfare losses for the EU economy which increase towards higher reduction targets and more pronounced tax differentiation in favor of carbon-intensive industries. In our core simulations, welfare losses – measured as reduction in real consumption (here:. Hicksian equivalent variation) – may amount to as much as 2.5 % for the case of fully exempting carbon-intensive industries and emission targets of 30 %. The associated carbon values for the rest of the economy are displayed in Figure 2b which also yields – by means of the tax ratio – the lower carbon value for carbon-intensive industries. In the case of full tax exemptions to carbon-intensive industries, the carbon value imposed on the rest of the economy ranges up to several hundreds of $US per ton of carbon which explains the excess cost of discriminating policy regulations due to foregone cheap abatement options in the carbon-intensive segments of the economy.

Figure 2: Economic and environmental implications of EU carbon emission constraints

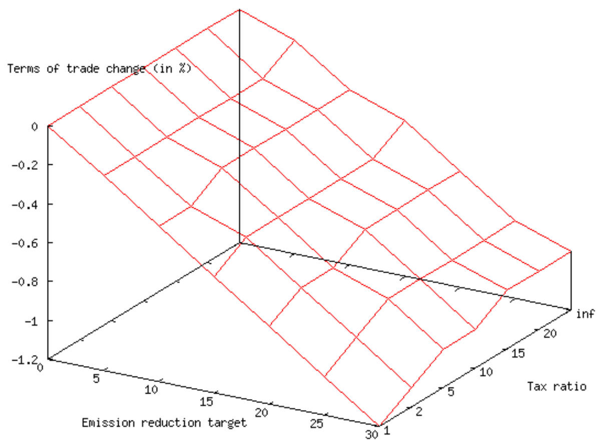
a. Welfare (% HEV from BaU)




b. Carbon tax for rest of economy ($/t of C)




c. Terms of trade (in %)




d. Leakage (in %)

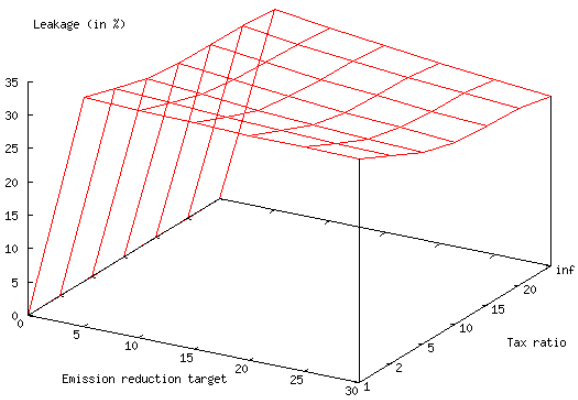



Figure 2c. reports the changes in the terms of trade, i.e. the index of the price of EU's exports in terms of its imports. The terms of trade deteriorate as that index falls.

Referring to the central theme of our analysis both indicators, i.e. changes in real consumption (income) as well as changes in the terms of trade, signal a loss in EU competitiveness at the national level due to unilateral policy action. For both indicators, the implications of more stringent unilateral emission reduction targets for competitiveness are unambiguously negative. However, there is a qualitative difference between the two indicators regarding the implications of tax differentiation. While more pronounced tax differentiation in favor of carbon-intensive industries clearly induces additional consumption losses, the terms of trade may improve due to the possibility of tax burden shifting via higher export prices of carbon-intensive products. Figure 2d. illustrates the problems of unilateral action in climate policy regarding global environmental effectiveness. For our model parameterization, a substantial part of EU abatement – around 30 % – is offset through increased emissions of non-regulating trading partners. Leakage rates are relatively robust with respect to the level of the emission reduction target. As expected, leakage rates decline with tax discrimination of carbon- and export-intensive industries – however, the magnitude of leakage reduction turns out to be rather small

Figures 3a.-c. summarize the impacts of unilateral EU carbon policies on sectoral production of different industries. Imposition of carbon constraints induces structural change which inevitably goes at the expense of carbon-intensive industries. Towards higher emission reduction targets, the output losses for these industries may become drastic – in particular for the mineral oil industry. In turn, tax cuts may offset the adverse output effects for carbon-intensive industries to a large extent. While tax breaks are clearly beneficial for carbon-intensive industries, they go at the expense of the remaining industries (OTH) which are subject to relatively higher carbon tax rates to meet the exogenous overall emission reduction target. Output losses for these industries may substantially increase towards strong preferential tax treatment of carbon-intensive industries.

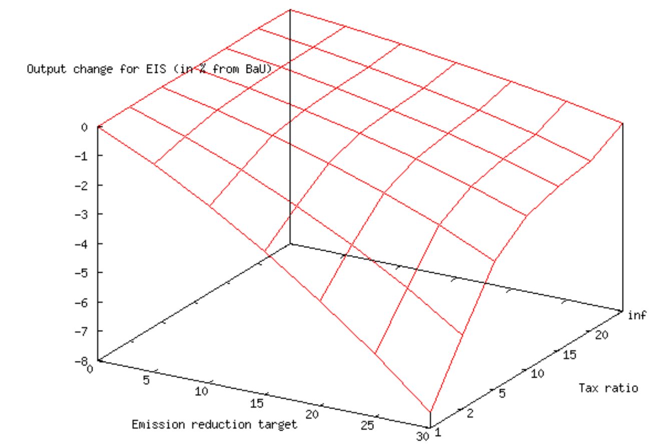
The competitiveness effects at the sectoral level are reported in Figures 4a.-c. in terms of changes of RCA. The changes of RCA reflect changes in comparative advantage across sectors due to policy interference. With uniform (tax) treatment, sectors which are relatively carbon-intensive lose competitiveness whereas relatively carbon-extensive sectors gain in competitiveness. Losses and gains are reinforced with the magnitude of unilateral emission reduction targets. However, tax differentiation in favor of carbon-intensive industries can largely “neutralize” the implications of emission constraints on sectoral competitiveness.

Our results highlight the critical significance of competitiveness indicators at the sectoral level. For a balanced view, it is important to account for changes across the various sectors of the domestic economy rather than focusing on a very narrow segment of the economy which might be most affected by policy-induced structural change. In addition, sectoral implications must be traded off with economy-wide impacts. Obviously, improvements in competitiveness for some industries may not only work at the expense of competitiveness of other industries but induce an overall loss in national competitiveness measured in terms of real income.

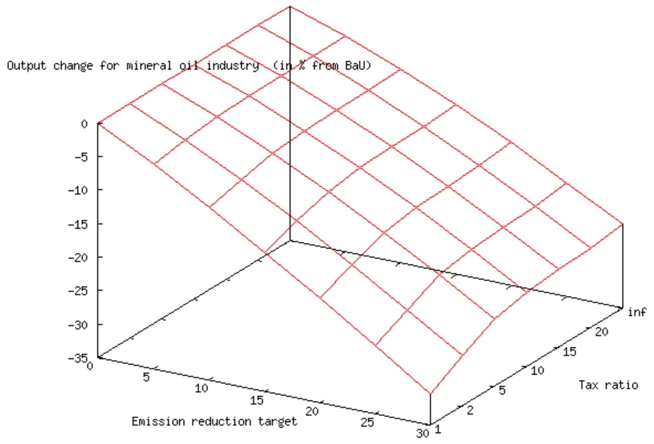
Figures 5a.-c. provide further insights into the economy-wide cost implications of unilateral abatement policies. Figure 5a. indicates the additional costs the EU would have to undergo in order to compensate for carbon leakage. The cost increase amounts to roughly 50 % to 100 % of a strategy without leakage compensation depending on the level of the unilateral emission target and the chosen tax differentiation. Figures 5b. and 5c. illustrate the cost implications of tax differentiation (i) for the realistic case when leakage is not compensated and (ii) for the rather unrealistic case of leakage compensation. If we do not account for leakage, larger tax differentiation may be costly in particular for higher unilateral reduction targets (although at lower reduction targets there might be some limited scope for exploiting terms of trade effects through tax discrimination vis-à-vis uniform taxation). If leakage must be compensated for, some degree of tax discrimination in favor of carbon-intensive industries may in fact be beneficial as compared to uniform taxation.

Figure 3: Changes in sectoral production of EU industries

a. Energy-intensive industries (EIS)




b. Mineral oil industries (OIL)




c. Other industries and services (OTH)

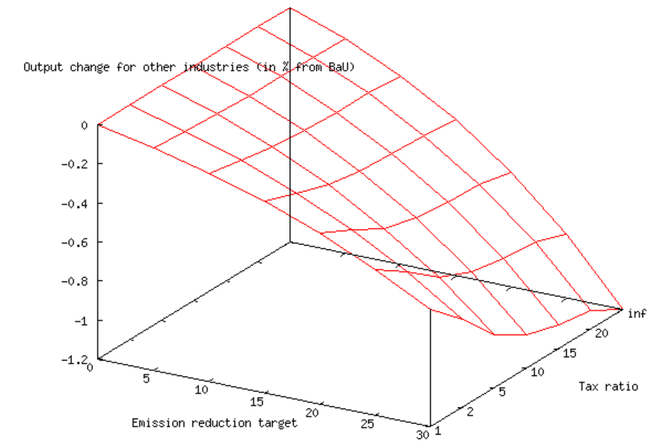
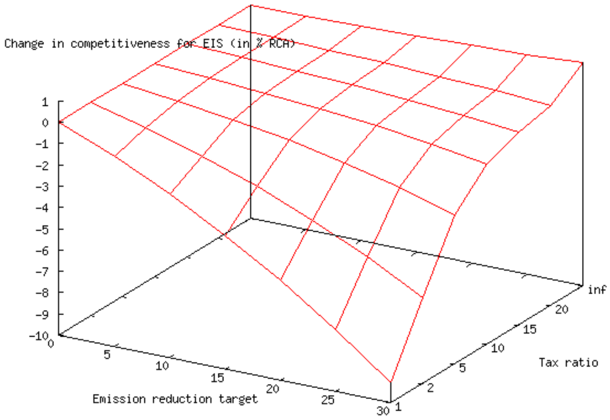
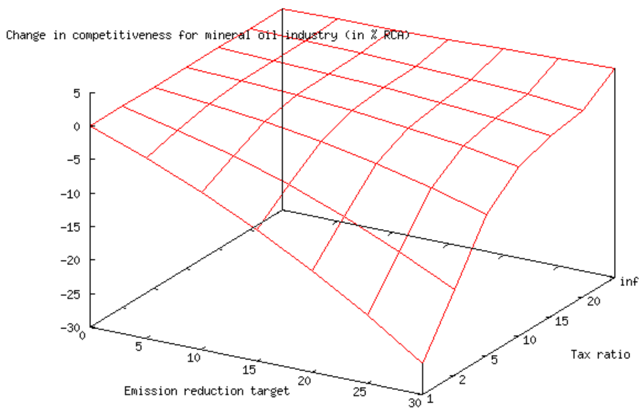


Figure 4: Changes in sectoral competitiveness of EU industries – RCA (in % from BaU)

a. Energy-intensive industries (EIS)




b. Mineral oil industries (EIS)




c. Other industries and services (OTH)

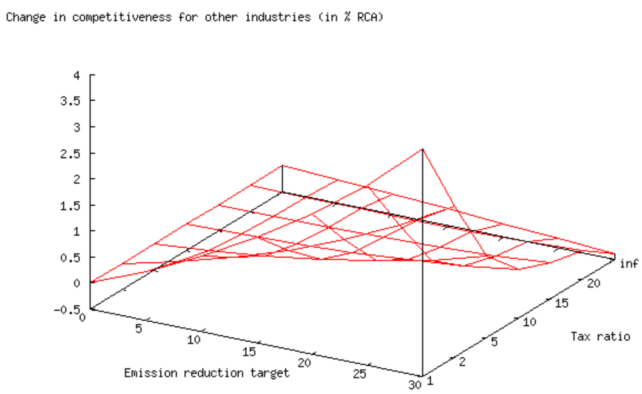
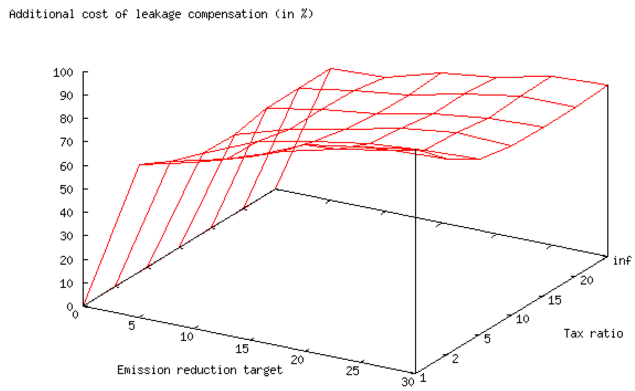
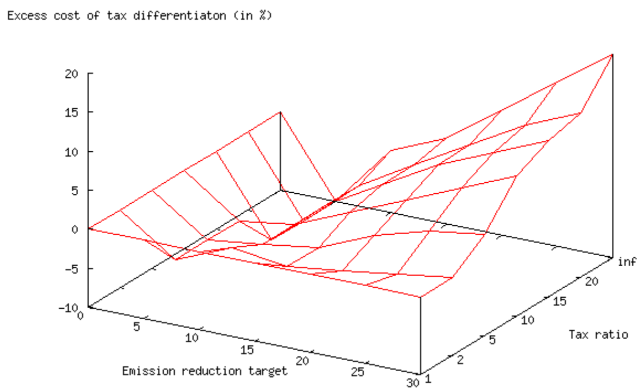


Figure 5: Cost implications of unilateral carbon restrictions for the EU

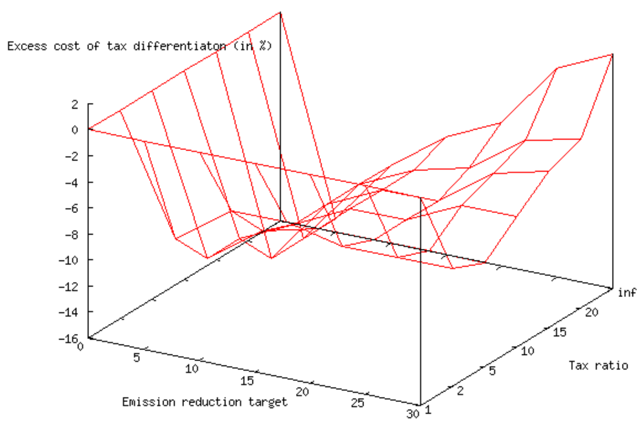
a. Additional cost of leakage compensation (in % of cost without leakage compensation)




b. Cost of tax differentiation without leakage compensation (base: uniform taxation)




c. Cost of tax differentiation with leakage compensation (base: uniform taxation)



## 5 Conclusions

Since the European Council started the Lisbon process in 2000, the issue of competitiveness is an area of high and rising priority within EU policy. However, the notion of competitiveness often remains rather vague and therefore is difficult to address through rigorous economic analysis.

In this paper, we have discussed alternative definitions of the term "competitiveness" complemented by indicators that can be used to quantify specific aspects of competitiveness at the level of firms, sectors, or countries. We have then illustrated how indicators of sector- and country-specific competitiveness can be operated in a conventional CGE framework along the example of EU leadership in climate policy.

Our analysis warrants the careful and complementary use of alternative competitiveness indicators. When assessing competitiveness impacts of policy regulation at the sectoral level, it is important to trade off changes across all the sectors of the domestic economy rather than focusing on only a few branches which might be most exposed at first glance to policy measures. In addition, sectoral implications must be weighted against economy-wide impacts. As a matter of fact, improvements in competitiveness for some industries may not only work at the expense of competitiveness of other industries but induce an overall loss in national competitiveness.

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## Appendix: Algebraic Model Summary

Two classes of conditions characterize the competitive equilibrium for our model: zero profit conditions and market clearance conditions. The former class determines activity levels and the latter determines price levels. In our algebraic exposition, the notation $\Pi_{ir}^{z}$ is used to denote the profit function of sector *j* in region *r* where *z* is the name assigned to the associated production activity. Differentiating the profit function with respect to input and output prices provides compensated demand and supply coefficients (Hotelling's lemma), which appear subsequently in the market clearance conditions.

We use *i* (aliased with *j*) as an index for commodities (sectors) and *r* (aliased with *s*) as an index for regions. The label *EG* represents the set of energy goods and the label *FF* denotes the subset of fossil fuels. Tables A.1 – A.6 explain the notations for variables and parameters employed within our algebraic exposition. Figures A.1 – A.4 provide a graphical exposition of the production and final consumption structure. Numerically, the model is formulated as a mixed complementarity problem (MCP) in GAMS.

*Zero Profit Conditions*

1. Production of goods except fossil fuels:

$$\prod_{ir}^{Y} = \left(\theta_{ir}^{X} p_{ir}^{X^{1-\eta}} + (1-\theta_{ir}^{X}) p_{ir}^{1-\eta}\right)^{\frac{1}{1-\eta}} - \sum_{j \notin EG} \theta_{jir} p_{jr}^{A} - \theta_{ir}^{KLE}\left[\theta_{ir}^{E} p_{ir}^{E\ 1-\sigma_{KLE}} + (1-\theta_{ir}^{E})\left(w_r^{\alpha_{jr}^{L}} v_r^{\alpha_{jr}^{K}}\right)^{1-\sigma_{KLE}}\right]^{\frac{1}{1-\sigma_{KLE}}} = 0 \qquad i \notin FF$$

2. Production of fossil fuels:

$$\prod_{ir}^{Y} = \left(\theta_{ir}^{X} p_{ir}^{X^{1-\eta}} + (1-\theta_{ir}^{X}) p_{ir}^{1-\eta}\right)^{\frac{1}{1-\eta}} - \left[\theta_{ir}^{Q} q_{ir}^{1-\sigma_{Q,i}} + (1-\theta_{ir}^{Q})\left(\theta_{Lir}^{FF} w_r + \theta_{Kir}^{FF} v_r + \sum_{j}\theta_{jir}^{FF} p_{jr}^{A}\right)^{1-\sigma_{Q,i}}\right]^{\frac{1}{1-\sigma_{Q,i}}} = 0 \qquad i \in FF$$

3. Sector-specific energy aggregate:

$$\prod_{ir}^{E} = p_{ir}^{E} - \left\{\theta_{ir}^{ELE} p_{\{ELE,r\}}^{A^{1-\sigma_{ELE}}} + (1-\theta_{ir}^{ELE})\left[\theta_{ir}^{COA} p_{\{COA,r\}}^{A^{1-\sigma_{COA}}} + (1-\theta_{ir}^{COA})\left(\prod_{j \in LQ} p_{jr}^{A^{\beta_{jir}}}\right)^{1-\sigma_{COA}}\right]^{\frac{1-\sigma_{ELE}}{1-\sigma_{COA}}}\right\}^{\frac{1}{1-\sigma_{ELE}}} = 0$$

4. Armington aggregate:

$$\prod_{ir}^{A} = p_{ir}^{A} - \left[\left(\theta_{ir}^{A} p_{ir}^{1-\sigma_A} + (1-\theta_{ir}^{A}) p_{ir}^{M^{1-\sigma_A}}\right)^{\frac{1}{1-\sigma_A}} + t_r^{CO2} a_i^{CO2}\right] = 0$$

5. Aggregate imports across import regions:

$$\prod_{ir}^{M} = p_{ir}^{M} - \left(\sum_{s} \theta_{isr}^{M} p_{is}^{X\ 1-\sigma_M}\right)^{\frac{1}{1-\sigma_M}} = 0$$

6. Household consumption demand:

$$\prod_{r}^{C} = p_{r}^{C} - \left(\theta_{Cr}^{E} p_{Cr}^{E\ 1-\sigma_{EC}} + (1-\theta_{Cr}^{E})\left[\prod_{i \notin FF} p_{ir}^{A^{\gamma_{ir}}}\right]^{1-\sigma_{EC}}\right)^{\frac{1}{1-\sigma_{EC}}} = 0$$

7. Household energy demand:

$$\prod_{Cr}^{E} = p_{Cr}^{E} - \left[ \sum_{i \in FF} \theta_{iCr}^{E} \, p_{ir}^{A\;1-\sigma_{FF,C}} \right]^{\frac{1}{1-\sigma_{FF,C}}} = 0$$

*Market Clearance Conditions*

8. Labor:

$$\overline{L}_r = \sum_i Y_{ir} \frac{\partial \Pi_{ir}^{Y}}{\partial w_r}$$

9. Capital:

$$\overline{K}_r = \sum_i Y_{ir} \frac{\partial \Pi_{ir}^{Y}}{\partial v_r}$$

10. Natural resources:

$$\overline{Q}_{ir} = Y_{ir} \frac{\partial \Pi_{ir}^{Y}}{\partial q_{ir}} \qquad i \in FF$$

11. Output for domestic markets:

$$Y_{ir} \frac{\partial \Pi_{ir}^{Y}}{\partial p_{ir}} = \sum_j A_{jr} \frac{\partial \Pi_{jr}^{A}}{\partial p_{ir}}$$

12. Output for export markets:

$$Y_{ir} \frac{\partial \Pi_{ir}^{Y}}{\partial p_{ir}^{X}} = \sum_s M_{is} \frac{\partial \Pi_{is}^{M}}{\partial p_{ir}^{X}}$$

13. Sector specific energy aggregate:

$$E_{ir} = Y_{ir} \frac{\partial \Pi_{ir}^{Y}}{\partial p_{ir}^{E}}$$

14. Import aggregate:

$$M_{ir} = A_{ir} \frac{\partial \Pi_{ir}^{A}}{\partial p_{ir}^{M}}$$

15. Armington aggregate:

$$A_{ir} = \sum_j Y_{jr} \frac{\partial \Pi_{jr}^{Y}}{\partial p_{ir}^{A}} + C_r \frac{\partial \Pi_{r}^{C}}{\partial p_{ir}^{A}}$$

16. Household consumption:

$$C_r \, p_r^{C} = w_r \overline{L}_r + v_r \overline{K}_r + \sum_{j \in FF} q_{jr} \overline{Q}_{jr} + t_r^{CO2} \overline{CO2}_r + p_{CGD,r} \overline{Y}_{CGD,r} + \overline{B}_r$$

17. Aggregate household energy consumption:

$$E_{Cr} = C_r \frac{\partial \Pi_{r}^{C}}{\partial p_{Cr}^{E}}$$

18. Carbon emissions:

$$\overline{CO2}_r = \sum_i A_{ir} a_i^{CO2}$$

*Table A.1: Sets*

| | |
|---|---|
| I | Sectors and goods |
| J | Aliased with i |
| R | Regions |
| S | Aliased with r |
| EG | All energy goods: Coal, crude oil, refined oil, gas and electricity |
| FF | Primary fossil fuels: Coal, crude oil and gas |
| LQ | Liquid fuels: Crude oil and gas |

*Table A.2: Activity variables*

| | |
|---|---|
| $Y_{ir}$ | Production in sector *i* and region *r* |
| $E_{ir}$ | Aggregate energy input in sector *i* and region *r* |
| $M_{ir}$ | Aggregate imports of good *i* and region *r* |
| $A_{dir}$ | Armington aggregate for demand category *d* of good *i* in region *r* |
| $C_r$ | Aggregate household consumption in region *r* |
| $E_{Cr}$ | Aggregate household energy consumption in region *r* |

*Table A.3: Price variables*

| | |
|---|---|
| $p_{ir}$ | Output price of good *i* produced in region *r* for domestic market |
| $p_{ir}^{X}$ | Output price of good *i* produced in region *r* for export market |
| $p_{ir}^{E}$ | Price of aggregate energy in sector *i* and region *r* |
| $p_{ir}^{M}$ | Import price aggregate for good *i* imported to region *r* |
| $p_{ir}^{A}$ | Price of Armington good *i* in region *r* |
| $p_{r}^{C}$ | Price of aggregate household consumption in region *r* |
| $p_{Cr}^{E}$ | Price of aggregate household energy consumption in region *r* |
| $w_r$ | Wage rate in region *r* |
| $v_r$ | Price of capital services in region *r* |
| $q_{ir}$ | Rent to natural resources in region *r* (i $\in$ FF) |
| $t_r^{CO2}$ | $CO_2$ tax in region *r* |

*Table A.4: Endowments and emissions coefficients*

| | |
|---|---|
| $\overline{L}_r$ | Aggregate labor endowment for region r |
| $\overline{K}_r$ | Aggregate capital endowment for region r |
| $\overline{Q}_{ir}$ | Endowment of natural resource i for region r (i∈FF) |
| $\overline{B}_r$ | Balance of payment deficit or surplus in region r (note: $\sum_r \overline{B}_r = 0$) |
| $\overline{CO_2}_r$ | Endowment of carbon emission rights in region r |
| $a_i^{CO_2}$ | Carbon emissions coefficient for fossil fuel i (i∈FF) |

*Table A.5: Cost shares*

| | |
|---|---|
| $\theta_{ir}^X$ | Share of exports in sector *i* and region *r* |
| $\theta_{jir}$ | Share of intermediate good *j* in sector *i* and region *r* (i∉FF) |
| $\theta_{ir}^{KLE}$ | Share of KLE aggregate in sector *i* and region *r* (i∉FF) |
| $\theta_{ir}^E$ | Share of energy in the KLE aggregate of sector *i* and region *r* (i∉FF) |
| $\alpha_{ir}^T$ | Share of labor (*T*=*L*) or capital (*T*=*K*) in sector *i* and region *r* (i∉FF) |
| $\theta_{ir}^Q$ | Share of natural resources in sector *i* of region *r* (i∈FF) |
| $\theta_{Tir}^{FF}$ | Share of good *i* (*T*=*i*) or labor (*T*=*L*) or capital (*T*=*K*) in sector *i* and region *r* (i∈FF) |
| $\theta_{ir}^{COA}$ | Share of coal in fossil fuel demand by sector *i* in region *r* (i∉FF) |
| $\theta_{ir}^{ELE}$ | Share of electricity in energy demand by sector *i* in region *r* |
| $\beta_{jir}$ | Share of liquid fossil fuel *j* in energy demand by sector *i* in region *r* (i∉FF, j∈LQ) |
| $\theta_{isr}^M$ | Share of imports of good *i* from region *s* to region *r* |
| $\theta_{ir}^A$ | Share of domestic variety in Armington good *i* of region *r* |
| $\theta_{Cr}^E$ | Share of fossil fuel composite in aggregate household consumption in region *r* |
| $\gamma_{ir}$ | Share of non-energy good *i* in non-energy household consumption demand in region *r* |
| $\theta_{iCr}^E$ | Share of fossil fuel *i* in household energy consumption in region *r* |

*Table A.6: Elasticities*

| | | |
|---|---|---|
| $\eta$ | Transformation between production for the domestic market and production for the export | 2 |
| $\sigma_{KLE}$ | Substitution between energy and value-added in production (except fossil fuels) | 0.8 |
| $\sigma_{Q,i}$ | Substitution between natural resources and other inputs in fossil fuel production calibrated consistently to exogenous supply elasticities $\mu_{FF}$ | $\mu_{COA}$=0.5<br>$\mu_{CRU}$=1.0<br>$\mu_{GAS}$ =1.0 |
| $\sigma_{ELE}$ | Substitution between electricity and the fossil fuel aggregate in production | 0.3 |
| $\sigma_{COA}$ | Substitution between coal and the liquid fossil fuel composite in production | 0.5 |
| $\sigma_{A}$ | Substitution between the import aggregate and the domestic input | 4 |
| $\sigma_{M}$ | Substitution between imports from different regions | 8 |
| $\sigma_{EC}$ | Substitution between the fossil fuel composite and the non-fossil fuel consumption aggregate in household consumption | 0.8 |
| $\sigma_{FF,C}$ | Substitution between fossil fuels in household fossil energy consumption | 0.3 |

*Figure A.1: Nesting in non-fossil fuel production*

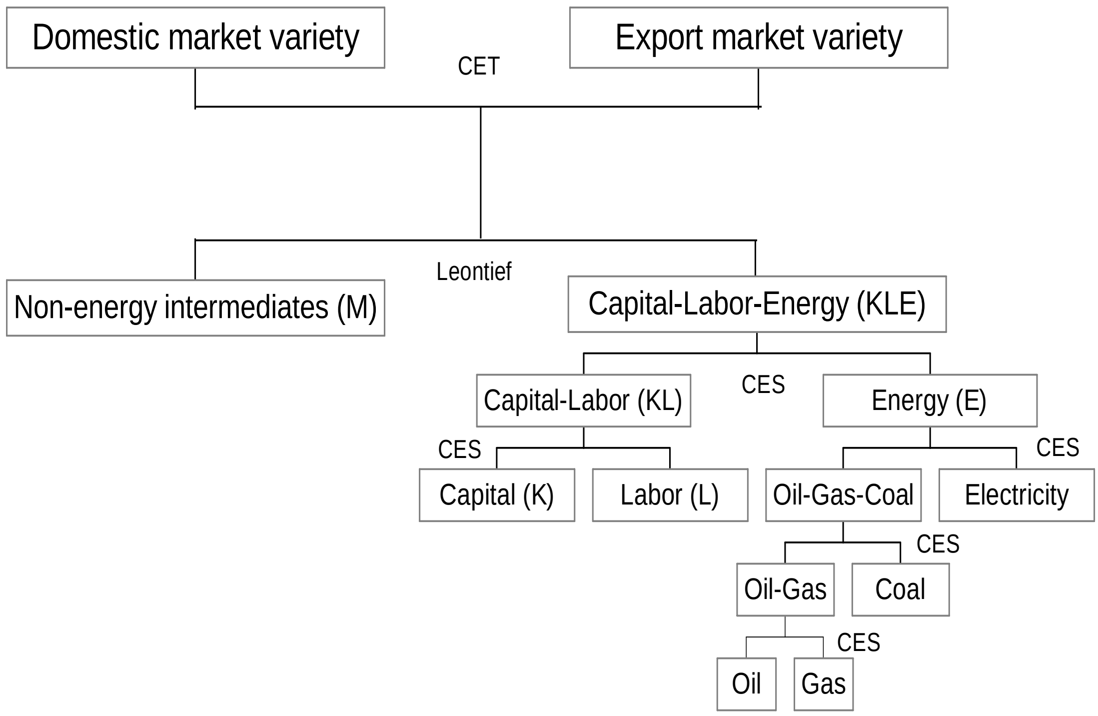

*Figure A.2: Nesting in fossil fuel production*

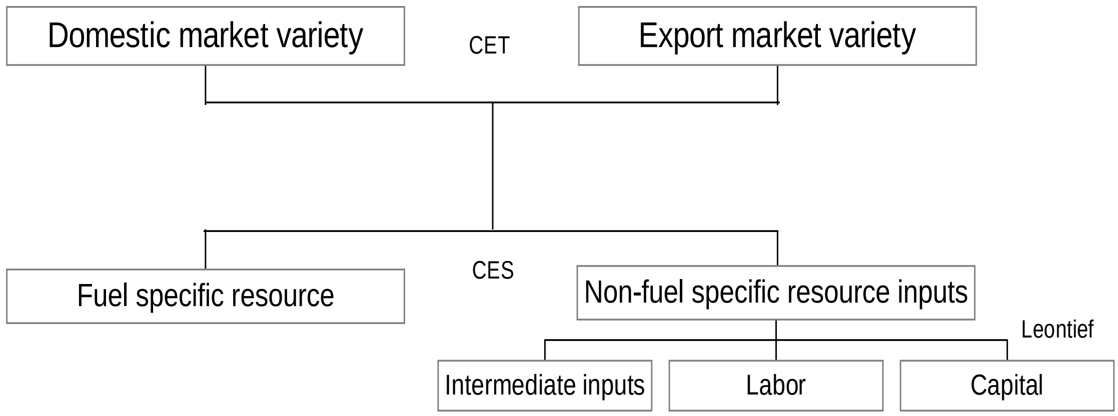


*Figure A.3: Nesting in household consumption*

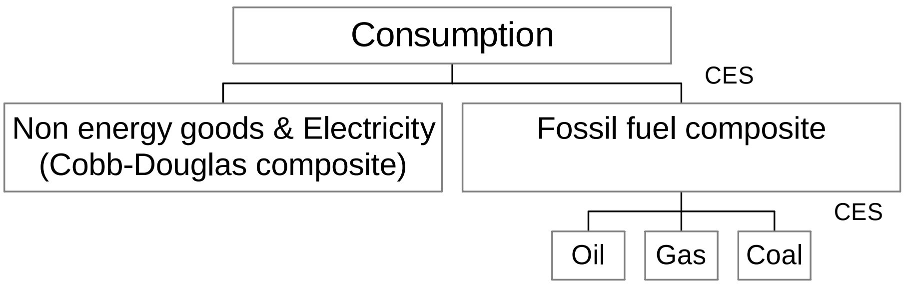


*Figure A.4: Nesting in Armington production*