TranSust.Scan

"WP 1 Task 2: Linking Core and Extended Models"

-Interim Report-

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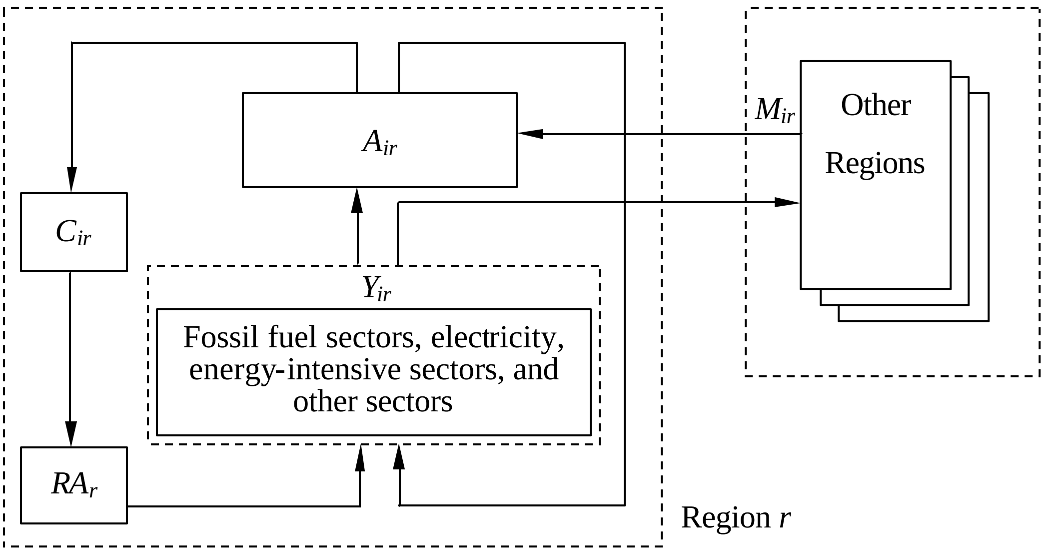
1 Non-technical Summary of the CGE Framework (PACE)

Figure 1 lays out the diagrammatic structure of the multi-sector, multi-region model PACE (*Policy Assessment based on Computable Equilibrium*; see Böhringer and Vogt 2003) for the world economy which may be used 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.

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 1: Model dimensions

Production sectors	Regions and primary factors
Energy	*Regions*
Coal	European Union (EUR)
Crude oil	Non-EU OECD (OEC)
Natural gas (GAS)	Rest of World (ROW)
Refined oil products (OIL)	
Electricity (ELE)	
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 aggregate 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 1 summarizes the resent regional, sectoral, and factor aggregation of the model. However, alternative regional and sectoral aggregation os the model is also possible.

2 Model characteristics and Policy issues

In order to quantify the competitiveness effects of EU ETS at the sectoral and economy-wide level, it is crucial to account for complexities such as detailed production structures and various market interactions. Computable general equilibrium (CGE) models have become the standard tool for applied economy-wide analysis of policy measures. The main virtue of the CGE approach is its comprehensive representation of price-dependent market interactions based on rigorous microeconomic theory.

Since PACE models the energy sector in sufficient detail, it is particularly suitable to analyze sustainable consumption and production issues. It thus enables the modeller to assess the impact of environmental policy scenarios on the consumption of energy carriers as well as on the economy as a whole. The multi-regional structure of the model allows for an analysis of trade flows. Thus, PACE can also be used to analyze consequences of regional policies for their competitiveness.

In accordance with the DoW, the version of PACE used in TranSust.Scan does not dispose of a detailed transport sector nor does it depict household heterogeneity. However, in parallel/future projects, extensions of PACE by these aspects are being implemented.

References

Armington, P. S. (1969): “A Theory of Demand for Producers Distinguished by Place of Production”, IMF Staff Papers 16, 159-178.

Böhringer, C. and C. Vogt (2003): “Economic and Environmental Impacts of the Kyoto Protocol”, Canadian Journal of Economics 36, 475-494.

Dimaranan, B. and R.A. McDougall (2002): “Global Trade, Assistance and Production: The GTAP 5 Data Base, Center for Global Trade Analysis”, Purdue University, West Lafayette, IN.

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 Π^z_{ir} 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:

$$\Pi^Y_{ir} = \left(\theta^X_{ir} p^{X\,1-\eta}_{ir} + (1-\theta^X_{ir})\, p^{1-\eta}_{ir}\right)^{\frac{1}{1-\eta}} - \sum_{j\notin EG} \theta_{jir}\, p^A_{jr} - \theta^{KLE}_{ir}\left[\theta^E_{ir}\, p^{E\;1-\sigma_{KLE}}_{ir} + (1-\theta^E_{ir})\left(w_r^{\alpha^L_{jr}}\, v_r^{\alpha^K_{jr}}\right)^{1-\sigma_{KLE}}\right]^{\frac{1}{1-\sigma_{KLE}}} = 0 \qquad i \notin FF$$

2. Production of fossil fuels:

$$\Pi^Y_{ir} = \left(\theta^X_{ir} p^{X\,1-\eta}_{ir} + (1-\theta^X_{ir})\, p^{1-\eta}_{ir}\right)^{\frac{1}{1-\eta}} - \left[\theta^Q_{ir}\, q_{ir}^{1-\sigma_{Q,i}} + (1-\theta^Q_{ir})\left(\theta^{FF}_{Lir}\, w_r + \theta^{FF}_{Kir}\, v_r + \sum_j \theta^{FF}_{jir}\, p^A_{jr}\right)^{1-\sigma_{Q,i}}\right]^{\frac{1}{1-\sigma_{Q,i}}} = 0 \qquad i \in FF$$

3. Sector-specific energy aggregate:

$$\Pi^E_{ir} = p^E_{ir} - \left\{\theta^{ELE}_{ir}\, p^{A\;1-\sigma_{ELE}}_{\{ELE,r\}} + (1-\theta^{ELE}_{ir})\left[\theta^{COA}_{ir}\, p^{A\;1-\sigma_{COA}}_{\{COA,r\}} + (1-\theta^{COA}_{ir})\left(\prod_{j\in LQ} p^{A\;\beta_{jir}}_{jr}\right)^{1-\sigma_{COA}}\right]^{\frac{1-\sigma_{ELE}}{1-\sigma_{COA}}}\right\}^{\frac{1}{1-\sigma_{ELE}}} = 0$$

4. Armington aggregate:

$$\Pi^A_{ir} = p^A_{ir} - \left[\left(\theta^A_{ir}\, p_{ir}^{1-\sigma_A} + (1-\theta^A_{ir})\, p^{M\;1-\sigma_A}_{ir}\right)^{\frac{1}{1-\sigma_A}} + t^{CO2}_r\, a^{CO2}_i\right] = 0$$

5. Aggregate imports across import regions:

$$\Pi^M_{ir} = p^M_{ir} - \left(\sum_s \theta^M_{isr}\, p^{X\;1-\sigma_M}_{is}\right)^{\frac{1}{1-\sigma_M}} = 0$$

6. Household consumption demand:

$$\prod_r^C = p_r^C - \left(q_{Cr}^E \, p_{Cr}^{E\;1-s_{EC}} + (1-q_{Cr}^E) \left[\prod_{i \notin FF} p_{ir}^{A\,q_{ir}} \right]^{1-s_{EC}} \right)^{\frac{1}{1-s_{EC}}} = 0$$

7. Household energy demand:

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

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$\in$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$\in$FF)

Table A.5: Cost shares

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

Table A.6: Elasticities

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

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

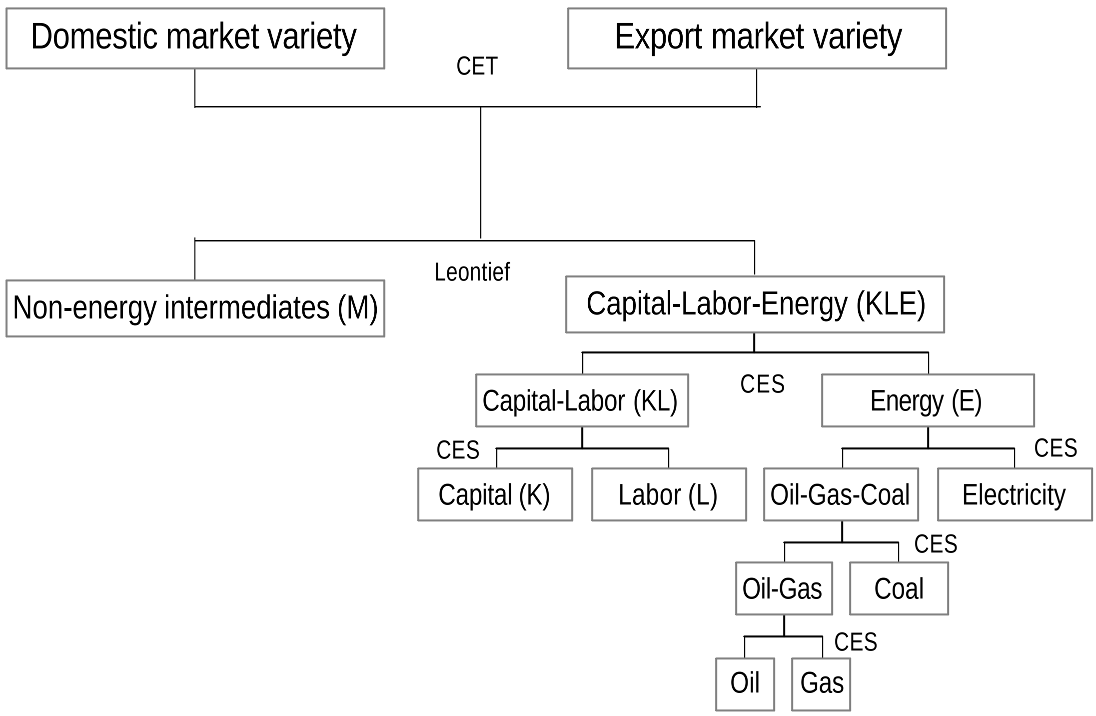


Figure A.2: Nesting in fossil fuel production

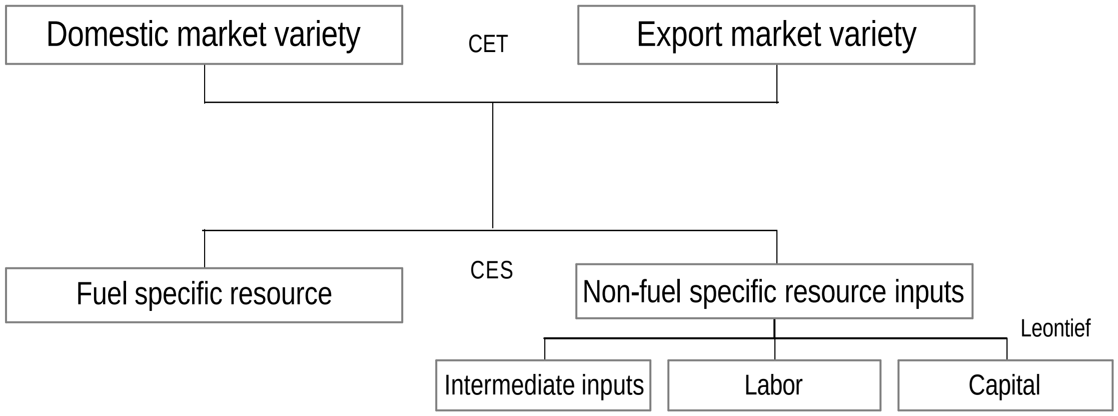


Figure A.3: Nesting in household consumption

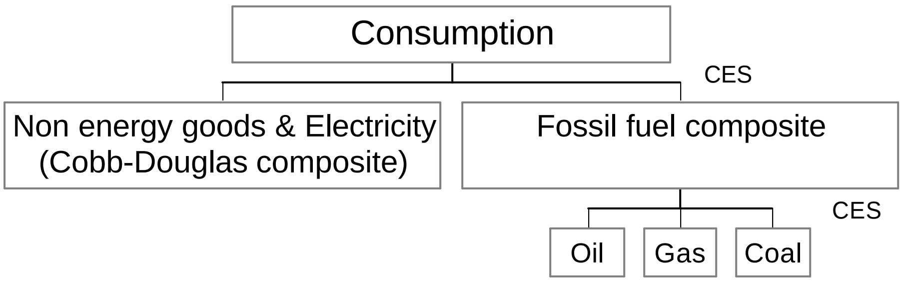


Figure A.4: Nesting in Armington production