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Thinking Ahead on International Trade (TAIT) – 2nd Conference
Climate Change, Trade and Competitiveness: Issues for the WTO

Climate-Linked Tariffs: Practical Issues[1]

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Thinking Ahead on International Trade (TAIT)

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[2] ETH Zurich. This research has been supported by the World Bank. The ideas included in this paper are based in part on current collaboration with Christoph Böhringer, Jared Carbone, Bruno Lanz and Andreas Lange. The views expressed here are my own.

Climate-Linked Tariffs: Practical Issues*

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Abstract

Climate policy measures producing a significant reduction in greenhouse gas emissions will affect competitiveness of energy-intensive industries. Economic analysts are often asked to assess the economic impact of these policies, and there are several alternative frameworks for such assessments. Input-output, partial equilibrium and general equilibrium models have all been used in such assessments.

In this paper the GTAP 7.1 dataset is used to parameterize two models: (i) a multi-regional input-output model which assesses the "carbon footprint" of goods produced throughout the world, and (ii) a static multiregional general equilibrium model based on empirical estimates of import demand functions for goods produced in different regions. Calculations demonstrate that multi-regional input-output models can provide a misleading sense of the potential effectiveness of border measures to deter carbon emissions in unconstrained countries.

We calculate the *carbon yield* for a climate policy regime with border tax adjustments, a value which relates realized abatement to the implicit carbon-footprint associated with bilateral trade flows. In multi-regional trade models with empirically-estimate trade elasticities, carbon yields rarely exceed 60%. For China, the most important contributor to leakage, the carbon yield is on the order of 10%.

Keywords: Climate policy, Green Tariffs, International Environmental Agreements, Carbon leakage.

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1 Introduction

Carbon leakage describes the extent to which emission-intensive production relocates outside of regulatory borders in response to climate policy. Most leakage estimates are based on economic models in which prices play a central role in determination of supply and demand. Most commonly, these are multiregional general equilibrium models (MR-GE), but there are also sector-specific studies which would are multi-regional partial equilibrium (MR-PE). The common idea in thiese models is that trade flows respond to relative prices, and carbon policy in a subset of countries thereby influences carbon emissions throughout the world.

Many empirical inputs are required for multiregoinal economic equilibrium analysis. These models combine data from input-output tables, international trade flows, and assumptions about elasticities of substitution and transformation. Typically, such models are based on an assumption of perfect competition and constant or decreasing returns to scale. Subject to these assumptions, the economic equilibrium framework produces theory-consistent, quantitative descriptions of the world economy. The typical analysis proceeds by simulating the effects of counterfactual climate policies and developing insights about the magnitude and pattern of carbon leakage produced by a given policy.

A separate but related line of inquiry has developed in the literature on life cycle analysis (LCA). In the LCA literature, the multi-regional input-output (MR-IO) model is a commonly employed analytic framework. Practitioners of MR-IO focus on the precise calculation of full (direct plus indirect) environmental consequences of economic activities. In the context of climate change policy, MR-IO studies provide quantitative measures of the carbon intensity (the "carbon footprint") of goods made in different countries. The connection to the economic studies of carbon leakage is sometimes unclear. MR-IO estimates can be misinterpreted as estimates of the amount by which global carbon emissions decline per unit reduction in commodity imports.

Price-responsive MR-GE models involve solution of nonlinear systems of equations, and this can limit model dimensionality. MR-IO studies typically involve a larger number of good describing the existing production techniques used in industries. MR-IO models thus track energy usage with higher resolution than the typical price-equilibrium model. However, the MR-IO

model lacks a behavioral basis for predictions about the pattern of adjustment in the economy in response to climate policies. The implicit assumption underlying MR-IO studies of carbon leakage is that there is no change in the carbon intensity of production or consumption in response to policy.

The present paper first argues that MR-IO provides a false sense of precision regarding our ability to calculate the externalities associated with imports of energy-intensive products. The relevant measure of carbon content should be based on the marginal impact of the green tariff. The fact that an input-output model accounts for bilateral trade flows does not mean that the resulting carbon content measures have any policy relevance. Second, the paper assess the claim typically provided by LCA studies that a large dimensional dataset is required to evaluate carbon intensity and leakage. We compute policy assessments with several datasets of differing dimension and find remarkable robustness of the findings with models ranging from 8 to 59 sectors. There are relatively few highly energy intensive sectors, and provided that a model accounts for trade flows in the key industries (e.g., oil, coal, natural gas, petroleum products, electricity, ferrous and non-ferrous metals, plastics, cement), the numerical results are robust.

Analyses based on both MR-GE and MR-IO approaches are regularly consulted by policymakers in the process of designing climate policies, so it is important to understand the relationship between the two tools to the extent that they lead to different policy prescriptions. This paper illustrates MR-IO and MR-GE methods with a common dataset – the most recently released update of the GTAP 7.1 database which features a 2004 base year and a set of econometrically estimated trade elasticities.

The policy simulations in this paper are not intended to portray a specific policy proposal but rather the range of abatement measures which have been discussed during recent months. We thus contemplate a 20% cut back in carbon emissions by each of the OECD member states, including both those who are included in the G20 and a composite Rest-of-Europe region. We compare this equilibrium with a border tax adjustment (BTA) simulation in which tariffs are applied to inputs from all non-OECD states with border taxes are calculated on the basis of the carbon permit price in the importing country and the MR-IO-based carbon content of goods

produced in the non-OECD states.

The BTA scenario illustrates the environmental ineffectiveness of border measures. Such measures reduce cost of abatement for OECD states but largely at the expense of terms of trade changes which impoverish non-OECD countries.

Equilibrium responses can be used to calculate the *carbon yield* of border tax adjustment. Carbon yield is defined as the ratio between the MR-GE and idealized MR-IO-based change in carbon emissions associated with a given reduction in bilateral trade. In multi-regional trade models with empirically-estimate trade elasticities, carbon yields rarely exceed 60%. For China, the model important contributor to leakage, the carbon yield is on the order of 10%.

2 The GTAP 7 Dataset and Model

The Global Trade Analysis Project (GTAP) is a research program initiated in 1992 to provide the economic research community with a global economic dataset for use in the quantitative analyses of international economic issues. The project's objectives include the provision of a documented, publicly available, global, general equilibrium data base, and to conduct seminars on a regular basis to inform the research community about how to use the data in applied economic analysis. GTAP has lead to the establishment of a global network of researchers who share a common interest of multi-region trade analysis and related issues. The GTAP research program is coordinated by Professor Thomas Hertel, Director of the Center for Global Trade Analysis at Purdue University. As Deputy Director of this Center, Robert McDougall oversees the data base work. Software development within the GTAP project has been assisted greatly by the efforts of Ken Pearson, Mark Horridge and other Australian researchers from Centre of Policy Studies, Monash University. (See Hertel [1997] and McDougall [2005]). A list of applications based on the GTAP framework can be found at the GTAP home page, (HTTP://WWW.GTAP.ORG).

The GTAP version 7.1 database, released in May, 2010, represents global production and trade for 113 country/regions, 57 commodities and 5 primary factors. The data characterize intermediate demand and bilateral trade in 2004, including tax rates on imports and exports

and other indirect taxes. [1]

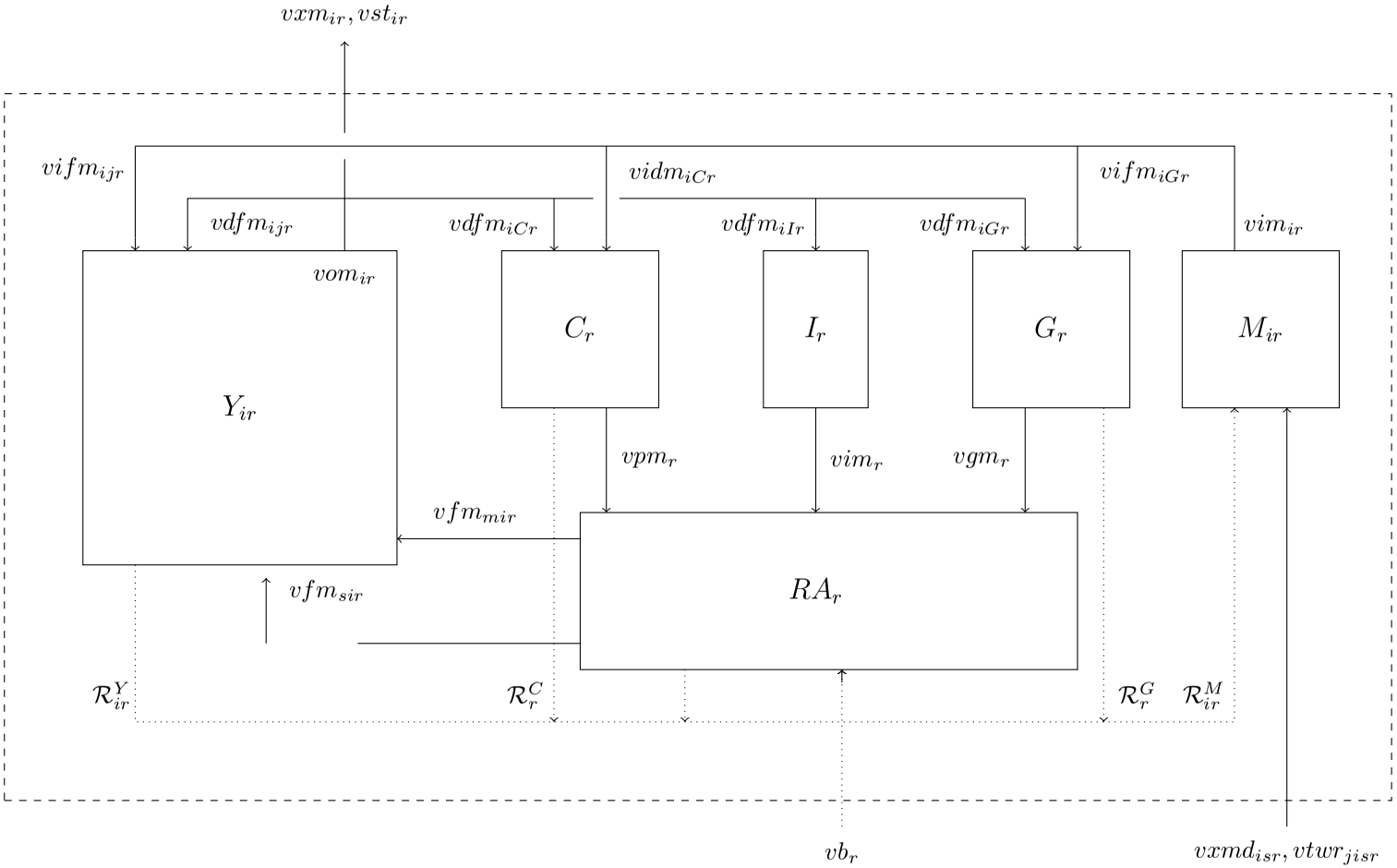
For our purposes, we begin with an aggregation of the underlying database which provides an explicit representation of the G20 countries and two aggregate regions representing non-G20 world. We use the database first as the basis for MR-IO assessment of the direct and indirect carbon content of goods produced in different countries. We then employ the MR-IO-based carbon intensities to evaluate the economic consequences of border measures in a corresponding multi-regional general equilibrium model. [2]

The core GTAP model is a static, multi-regional model which tracks the production and distribution of goods in the global economy. In GTAP the world is divided into regions (typically representing individual countries), and each region's final demand structure is composed of public and private expenditure across goods. The model is based on optimizing behavior. Consumers maximize welfare subject to budget constraint with fixed levels of investment and public output. Producers combine intermediate inputs, and primary factors (skilled and unskilled labor, land, resources and physical capital) at least cost subject for given technology. The dataset includes a full set of bilateral trade flows with associated transport costs, export taxes and tariffs.

[1] A guide to what's new in GTAP7 can be found in [Narayanan and Dimaranan 2008].

[2] *A methodological note:* The principal programming language for GTAP data and modeling work is GEMPACK [Harrison and Pearson 1996]. In the GEMPACK framework the model is solved as a system of nonlinear equations. The present paper describes a version of the GTAP model which has been implemented in GAMS. The GAMS model is essentially implemented as a nonlinear system of equations, although it can be posed either as a CNS or MCP. There are a few substantive differences between the GEMPACK and GAMS version of the model. One of these is the final demand system. Whereas the GEMPACK model is based on a CDE demand system, the GAMS model employs Cobb-Douglas preferences. Second, there are differences in units of account. Values in the GAMS implementation differ from the GEMPACK model by a factor of 1000. The GTAP database measures all transactions in millions of dollars whereas GTAP7inGAMS measures transactions in billions of dollars. Third, the two models differ in their representation of investment demand and global capital markets. The GEMPACK model assumes that a "global bank" allocates international capital flows in response to changes in regional rates of return. The GTAP7inGAMS model makes the simplest possible assumptions regarding investment demand, international capital flows and the time path of adjustment: all of these variables are exogenously fixed at base year levels.

Figure 1: GTAP7 Benchmark Flows



2.1 Benchmark Data and Accounting Identities

The economic structure underlying the GTAP dataset and model is illustrated in Figure 1. Symbols in this flow chart correspond to variables in the economic model. Y_{ir} portrays the production of good i in region r, C_r, I_r and G_r portray private consumption, investment and public demand, respectively. M_{jr} portrays the import of good j into region r. HH_r and $GOVT_r$ stand for representative household and government consumers.

In this figure commodity and factor market flows appear as solid lines. Domestic and imported goods markets are represented by horizontal lines at the top of the figure. Domestic production (vom_{ir}) is distributed to exports ($vxmd_{irs}$), international transportation services (vst_{ir}), intermediate demand ($vdfm_{ijr}$), household consumption ($vdpm_{ir}$), investment ($vdipm_{ir}$)and government consumption ($vdgm_{ir}$). The accounting identity on the output side:

$$\underbrace{vom_{ir}}_{\text{Value of Output}} = \sum_s \underbrace{vxmd_{irs}}_{\text{Bilaterl exports}} + \underbrace{vst_{ir}}_{\text{Transport exports}} + \sum_j \underbrace{vdfm_{ijr}}_{\text{Intermediate Demand}} + \underbrace{vdpm_{ir} + vdim_{ir} + vdgm_{ir}}_{\text{Final Demand (C + I + G)}}$$

The value of output is in turn related to the cost of intermediate inputs, value-added, and tax revenue:

$$\underbrace{vom_{ir}}_{\text{Value of Output}} = \underbrace{\sum_j vifm_{jir} + vdfm_{jir}}_{\text{Intermediate Inputs}} + \underbrace{\sum_f vfm_{fir}}_{\text{Factor Earnings}} + \underbrace{\mathcal{R}^Y_{ir}}_{\text{Tax Revenue}} \tag{1}$$

Imported goods which have an aggregate value of vim_{ir} enter intermediate demand ($vifm_{jir}$), private consumption ($vipm_{ir}$) and public consumption ($vigm_{ir}$). The accounting identity on the output side for these flows is thus:

$$\underbrace{vim_{ir}}_{\text{Value of Imports}} = \underbrace{\sum_j vifm_{ijr}}_{\text{Intermediate Demand}} + \underbrace{vipm_{ir} + vigm_{ir}}_{\text{Final Demand (C+G)}}$$

and the accounting identify relating the value of imports to the cost of associated inputs is:

$$\underbrace{vim_{ir}}_{\text{CIF Value of Imports}} == \underbrace{\sum_{s} vxmd_{isr} + \sum_{j} vtwr_{jisr}}_{\text{FOB Exports + Transport Cost}} + \underbrace{\mathcal{R}^{M}_{ir}}_{\text{Tariffs Net Subsidies}} \tag{2}$$

Part of the cost of imports includes the cost of international transportation services, $vtwr$. These services are provided with inputs from regions throughout the world, and the supply demand balance in the market for transportation service j requires that the sum across all regions of service exports (vst_{ir}, at the top of the figure) equals the sum across all bilateral trade flows of service inputs ($vtwr_{jisr}$ at the bottom of the figure):

$$\underbrace{\sum_{r} vst_{jr}}_{\text{Service } j \text{ Exports}} = \underbrace{\sum_{isr} vtwr_{jisr}}_{\text{Transport Demand for } j} \tag{3}$$

Carbon emissions associated with fossil fuels are represented in the GTAP database through a sattelite data table ($eco2_{igr}$) constructed on the basis of energy balances from the International Energy Agency. These emissions are proportional to fossil fuel use (commodities OIL, GAS, and COL).

Given detailed emissions associated with fossil fuel use, we can calculate direct carbon emissions associated with the production of good g in region r as:

$$\underbrace{co2e_{gr}}_{\text{Aggregate Carbon}} = \underbrace{\sum_{i} eco2_{igr}}_{\text{Sum of Carbon in Fuel Inputs}}$$

where $eco2_{igr}$ is the IEA-based statistics describing carbon emissions associated with the input of fuel i in the production of good g in region r.

2.2 Two Models Based on GTAP 7

This paper employs two fairly "generic" models based on the GTAP7.1 dataset. The first is a multi-regional input-output model which is employed to calculate the aggregate carbon content

of goods produced in different regions of the world. This multi-regional input-output model is processed as a system of linear equations which may either be solved directly or iteratively.

The second model developed for this paper is a multi-regional general equilibrium model in which value shares and most elasticities are based on values from the GTAP database. A few additional assumptions are required to account for the representation of energy-economy interactions. These include *own-price elasticities of supply* for crude oil, coal and natural gas, *price elasticities of demand* for energy, trade elasticities and elasticities of substitution among energy goods (electricity, refined oil, coal, and natural gas).

2.2.1 A Multi-Regional Input-Output Model

Variables characterizing the MR-IO model include:

x^y_{gr} Carbon content of produced goods, C, I and G.

x^m_{ir} Carbon content of imported commodity i (weighted average)

x^t_j Carbon content of international trade services

The multiregional input-output model includes a set of accounting identities conforming to the GTAP dataset identities. For example, the composite carbon embodied in the output of good i in region r follows from equation (1):

$$\underbrace{x^y_{gr} vom_{gr}}_{\text{Total Embodied Carbon}} = \underbrace{co2e_{gr}}_{\text{Direct Carbon}} + \underbrace{\sum_i x^m_{ir} vifm_{igr}}_{\text{Indirect Imported}} + \underbrace{\sum_i x^y_{ir} vdfm_{igr}}_{\text{Indirect Domestic}}$$

The carbon content of imports then follows from equation (2):

$$\underbrace{x^m_{ir} vim_{ir}}_{\text{Carbon Embodied in Imports}} = \underbrace{\sum_s x^y_{is} vxmd_{isr}}_{\text{Carbon in Goods}} + \underbrace{\sum_j x^t_j vtwr_{jisr}}_{\text{Carbon in Transportation}}$$

Finally, the carbon content of transportation follows from the GTAP accounting identity (3):

$$\underbrace{x_j^t vtw_j}_{\text{Carbon Content of Transport}} = \underbrace{\sum_r x_{jr}^y vst_{jr}}_{\text{Carbon in Inputs}}$$

This system of equations can be abstractly represented as a linear system of the form:

$$x = b + Ax$$

and can be formulated and solved directly as a square system of equations in GAMS. Alternatively the system can be solved recursively in GAMS (or Excel), with a diagonalization procedure. The estimate in iteration $k+1$ is a simple refinement of the estimate in iteration k:

$$x_{k+1} = b + Ax_k$$

Iterative solution of the MR-IO model involves the following steps:

Initialize:

$$x_{gr}^y = co2e_{gr}$$

Repeat: i. Refine estimates of the carbon content of international trade services:

$$x_j^t = \frac{\sum_r vst_{jr} x_{jr}^y}{vtw_j}$$

ii. Refine estimates of the carbon content of bilateral imports:

$$x_{ir}^m = \frac{\sum_s \left(vxmd_{isr} x_{is}^y + \sum_j x_j^t vtwr_{jisr} \right)}{vim_{ir}}$$

iii. Update carbon content estimates:

$$x_{gr}^y := \frac{co2_{gr} + \sum_i x_{ir}^m vifm_{igr} + \sum_i x_{ir}^y vdfm_{igr}}{vom_{gr}}$$

Table 1: Set Indices

i, j	Sectors and goods, an aggregation of the 55 sectors in the GTAP 7 database
g	The union of produced goods i, private consumption `"c"`, public demand `"g"` and investment `"i"`
r	Regions, an aggregation of the 113 regions in the GTAP 7 database
f	Factors of production (consisting of *mobile factors*, $f \in m$, skilled labor, unskilled labor and capital, and specific factors corresponding to crude oil, natural gas and coal resources)[3]

Table 2: Activity Levels

Var	Description	GAMS Variable	Bmk value
Y_{ir}	Production	`Y(i,r)`	`vom(i,r)`
C_r	Aggregate consumption D	`Y("c",r)`	`vom("c",r)`
G_r	Aggregate public D	`Y("g",r)`	`vom("g",r)`
I_r	Aggregate investment D	`Y("i",r)`	`vom("i",r)`
M_{ir}	Aggregate imports	`M("i",r)`	`vim(i,r)`
YT_j	Intl. transp. services	`YT(j)`	`vtw(j)`

2.3 The General Equilibrium Model

Variables which define a general equilibrium model based on GTAP 7.1 are summarized in the Tables 1 - 3. Table 1 defines the various dimensions which characterize an instance of the model, including the set of sectors/commodities, the set of regions, the set of factors of production. Set g is combines the production sectors i and private and public consumption demand (indices `"c"` and `"g"`) and investment demand (index `"i"`). Tables 2 and 3 display the concordance between the variables and their GAMS equivalents.

The GTAP database includes a 113 regions and 57 commodities, but dimensionality typically

Table 3: Prices

p_r^C	Consumer price index
p_r^G	Public provision price index
p_{ir}^Y	Supply price, gross of indirect producer taxes
p_{ir}^M	Import price, gross of export taxes and tariffs.
p_j^T	Marginal cost of transport services
p_{fr}^F	Factor prices for labor, land and resources
p_{ir}^S	Price of the sector-specific primary factor for CRU, GAS and COL.

limits the number of regions and goods which can be included in a single model. The regions employed in the present study are displayed in Table 4 and sectors in the model are displayed in Table 5.

Table 2 defines the primal variables (activity levels) which define an equilibrium. The model determines values of all the variables except international capital flows, a parameter which would be determined endogenously in an intertemporal model.

Table 3 defines the relative price variables for goods and factors in the model. As is the case in any Shoven-Whalley model, the equilibrium conditions determine *relative* rather than *nominal* prices. One market equilibrium condition corresponds to each of the equilibrium prices.

Our model departs from the conventional GTAP framework with the explicit representation of energy demand and supply elasticities. Thus, while the basic equilibrium conditions (market clearance, zero-profit and income balance) are more or less identical to the GTAP7inGAMS model [Rutherford 2010], there are several differences in the nesting structure of sectoral production and private consumption where explicit substitution between energy and non-energy composites has been introduced.

The energy goods included in the model include:

Table 4: Regions in the G20 Aggregation

ANZ	Australia and New Zealand
ARG	Argentina
BRA	Brazil
CAN	Canada
CHN	China and Hong Kong
FRA	France
DEU	Germany
IND	India
IDN	Indonesia
ITA	Italy
JPN	Japan
MEX	Mexico
RUS	Russian Federation
XWS	Western Asia
ZAF	South Africa
KOR	South Korea
TUR	Turkey
GBR	United Kingdom
USA	United States
EUR	Rest of European Union
ROW	Rest of World

Table 5: Commodities in the GTAP Dataset

PDR	Paddy rice	LUM	Wood products
WHT	Wheat	PPP	Paper products, publishing
GRO	Cereal grains nec	CRP	Chemical, rubber, plastic products
V_F	Vegetables, fruit, nuts	NMM	Mineral products nec
OSD	Oil seeds	I_S	Ferrous metals
C_B	Sugar cane, sugar beet	NFM	Metals nec
PFB	Plant-based fibers	FMP	Metal products
OCR	Crops nec	MVH	Motor vehicles and parts
CTL	Bovine cattle, sheep and goats, horses	OTN	Transport equipment nec
OAP	Animal products nec	ELE	Electricity
RMK	Raw milk	OME	Machinery and equipment nec
WOL	Wool, silk-worm cocoons	OMF	Manufactures nec
FRS	Forestry	WTR	Water
FSH	Fishing	CNS	Construction
OIL	Oil	TRD	Trade
GAS	Gas	OTP	Transport nec
OMN	Minerals nec	WTP	Water transport
CMT	Bovine meat products	ATP	Air transport
OMT	Meat products nec	CMN	Communication
VOL	Vegetable oils and fats	OFI	Financial services nec
MIL	Dairy products	ISR	Insurance
PCR	Processed rice	OBS	Business services nec
SGR	Sugar	ROS	Recreational and other services
OFD	Food products nec	OSG	Public Administration, Defense, Education, Health
B_T	Beverages and tobacco products	DWE	Dwellings
TEX	Textiles	COL	Coal
WAP	Wearing apparel	CRU	Petroleum, coal products
LEA	Leather products	EEQ	Electronic equipment

CRU	Crude oil
OIL	Refined oil products
COL	Coal
GAS	Gas
ELE	Electricity

Two of these are *secondary* energy goods (refined oil and electricity), both of which are produced subject to constant returns to scale with inputs of capital, labor, energy and materials. Oil products are refined from crude, and electricity is produced with inputs of coal, natural gas and oil. Variations in dispatch of different generating units are approximated through a Cobb-Douglas aggregation of gas, coal and oil inputs.

Primary factors in the model correspond to skilled and unskilled labor, capital and energy resources. Capital and labor are intersectorally mobile whereas crude oil, gas and coal resources are sector-specific. Given specific factors, the primary fossil fuels, crude oil, coal and natural gas, are produced subject to decreasing returns to scale. Given resource rental shares (θ_{ir}) from the database, the elasticity of substitution between resources and other inputs to primary energy production are calibrated to match assumed price elasticities of supply for these three fossil fuels, using. The calibrated substitution elasticities are given by:[4]

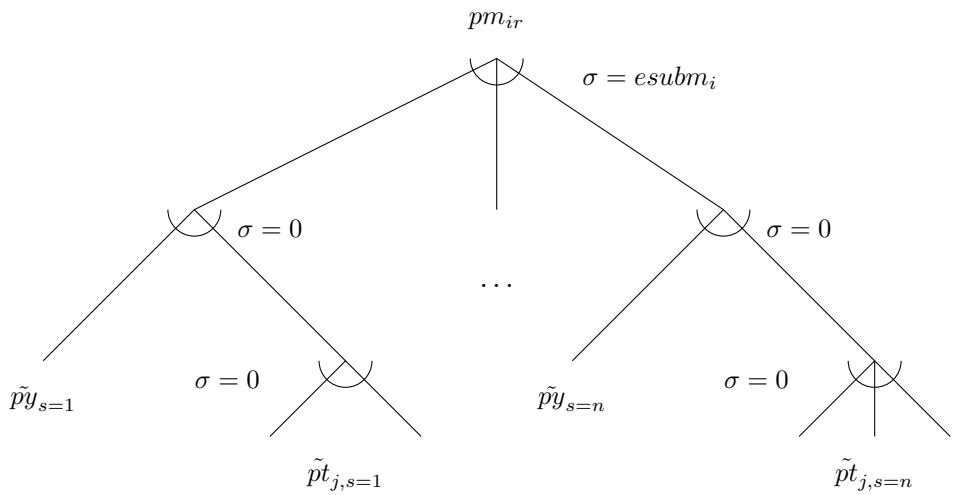
$$\sigma_{ir} = \eta_i \frac{1 - \theta_{ir}}{\theta_i r}$$

Our equilibrium framework is based on the assumption of optimizing atomistic agents, and applies for both producers and consumers. Profit maximization in the constant returns to scale setting is equivalent to cost minimization subject to technical constraints. For sector Y_{ir} we characterize input choices as though they arose from minimization of unit production costs.

Underlying production function are reprented by a nested constant-elasticity-of-substitution (CES) form in which the top-level substitution describes energy demand and a Cobb-Douglas aggregate describes trade-offs between electricity, natural gas, oil and coal. Non-energy intermediates enter as fixed-coefficients (Leontief) nest with capital-labor value-added composite in

[4]The calculations presented here are based on assumed values $\eta_{\text{COL}} = 1$, $\eta_{\text{CRU}} = 0.5$, and $\eta_{\text{GAS}} = 0.25$.

Figure 2: Armington Aggregation : $M_{ir} = A_{ir}(dxmd, dtwr)$



which capital, skilled and unskilled labor are substitutable with elasticity σ_g^{KL}.

Bilateral trade flows are determined by a constant-elasticity aggregate across goods provided by different trading partners. This formulation follows Armington's idea of regionally differentiated products, but it could just as easily be interpreted as a monopolistic competition model in which the number of firms in each region is fixed.

The import aggregation function is described by the nested CES-Leontief function shown in Figure 2. Transportation services enter on a proportional basis with imports from different countries, reflecting differences in unit transportation margins across different goods and trading partners. Substitution at the top level in an Armington composite involves trading off of both imported goods and associated transportation services. Trade flows are subject to export subsidies and import tariffs, with subsidies paid by government in the exporting region, and tariffs collected by government in the importing region.

Private consumption (final demand), like production, introduces substitution between an energy composite and a non-energy composite. At the second level non-energy goods are substitutable according to a Cobb-Douglas substitution function.

Finally, international transportation services are provided as a Cobb-Douglas aggregation of transportation services exported from countries throughout the world, and both public con-

sumption and investment demands are fixed. This formulation introduces substitution at the second level between domestic and imported inputs while holding sectal commodity aggregates constant.

3 Simulation Results

3.1 Carbon Content

Carbon intensities across regions and commodities are quite dispersed. Generally, chemicals, ferrous and non-ferrous metals and transportation services tend to be energy- and carbon-intensive. Most other commodities have substantially lower carbon content.

3.2 General Equilibrium Simulations

REF Reference case: OECD carbon emissions are reduced by 20% from their benchmark levels with regional permit markets which equalize the marginal cost of abatement within but not between OECD countries in the G20. OECD regions in the model include:

ANZ	Australia and New Zealand
CAN	Canada
USA	United States
DEU	Germany
FRA	France
GBR	United Kingdom
ITA	Italy
EUR	Rest of European Union
JPN	Japan

NB: Capital stocks, GDP and all other exogenous parameter remain uncchanged at levels consistent with the 2004 benchmark equilibrium. This calculation involves no "forward calibration" based on assumptions regarding anticipated growth rates throughout the world.

BTA As in REF, carbon emissions in OECD countries are reduced by 20%, together with a border tax adjustments in which tariffs are applied which are proportional to carbon content as calculated in the MR-IO model.

EQV An "equivalent abatement" scenario, in which emission targets in the OECD are chosen such that *global* carbon emissions are equivalent to those realized in scenario BTA.

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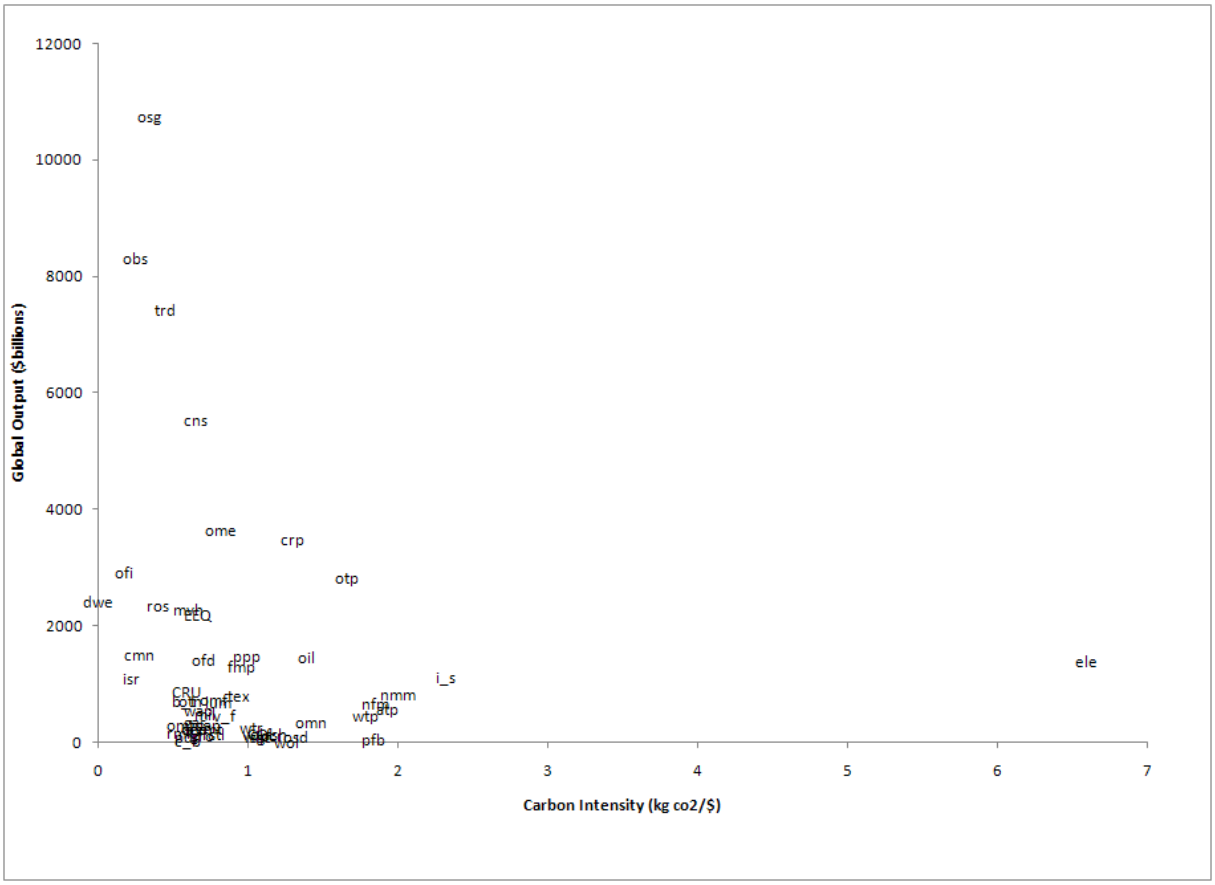
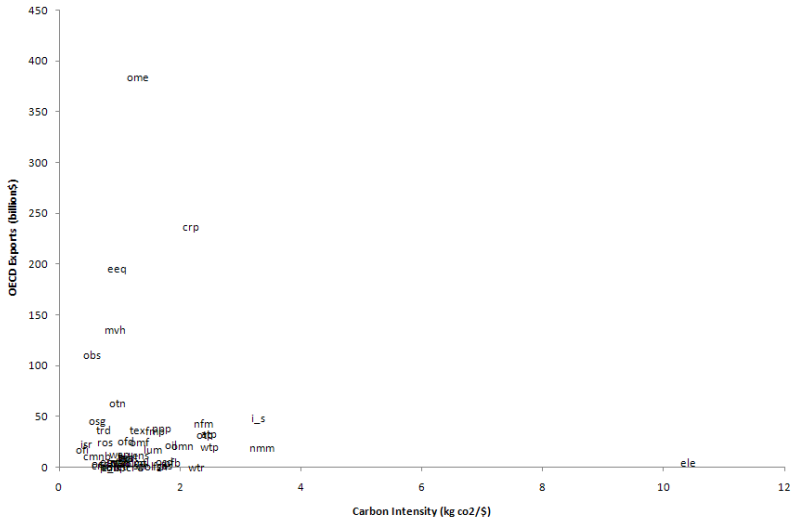
Figure 1: Global Production and Carbon Intensity



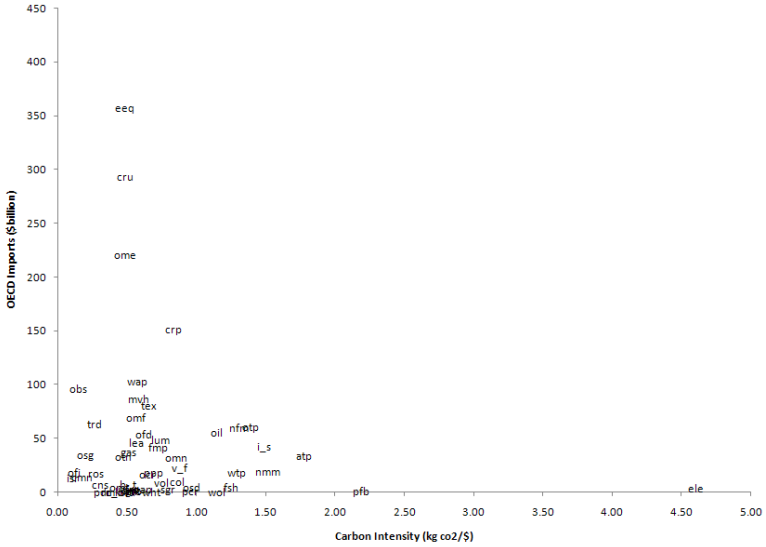
Source: MRIO calculation with the GTAP 7.1 database

Figure 2: OECD Exports and Carbon Intensity



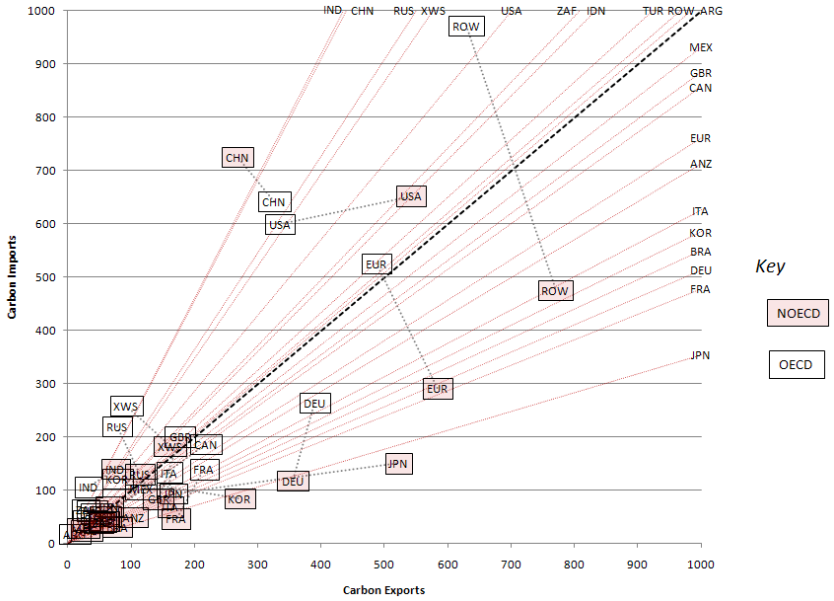
Source: MRIO calculation with the GTAP 7.1 database

Figure 3: OECD Imports and Carbon Intensity



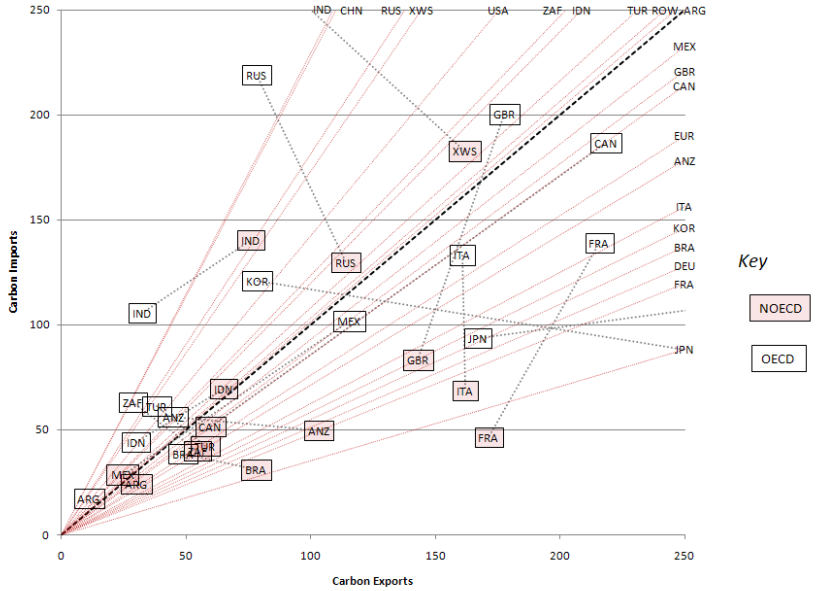
Source: MRIO calculation with the GTAP 7.1 database

Figure 4: Embodied Carbon Trade



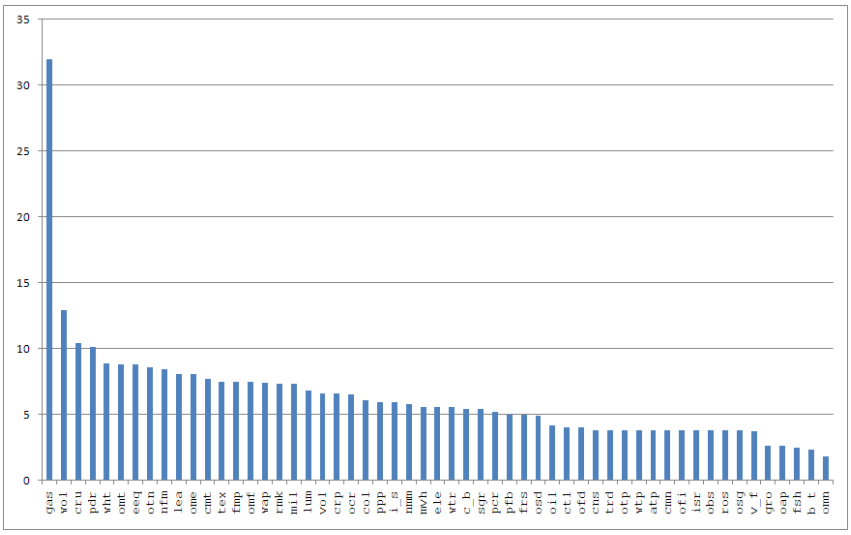
Source: MRIO calculation with GTAP 7.1 database

Figure 5: Embodied Carbon Trade (smaller countries)



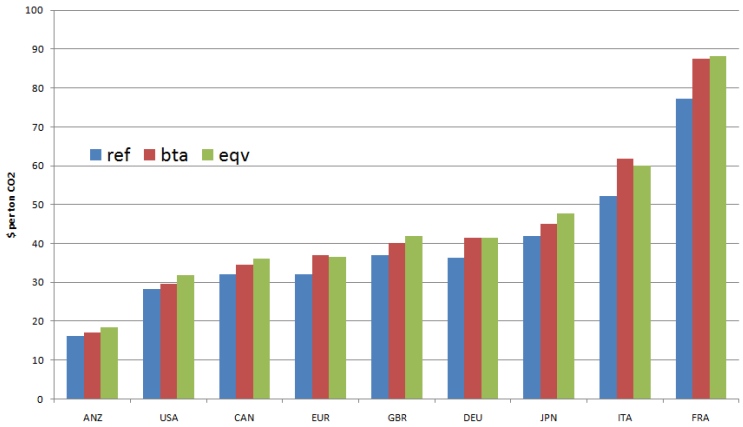
Source: MRIO calculation with the GTAP 7.1 database

Figure 6: Armington Elasticities: σ_{MM}



Source: GTAP 7.1 database

Figure 7: Marginal Cost of Carbon Abatement: 20% Cutback

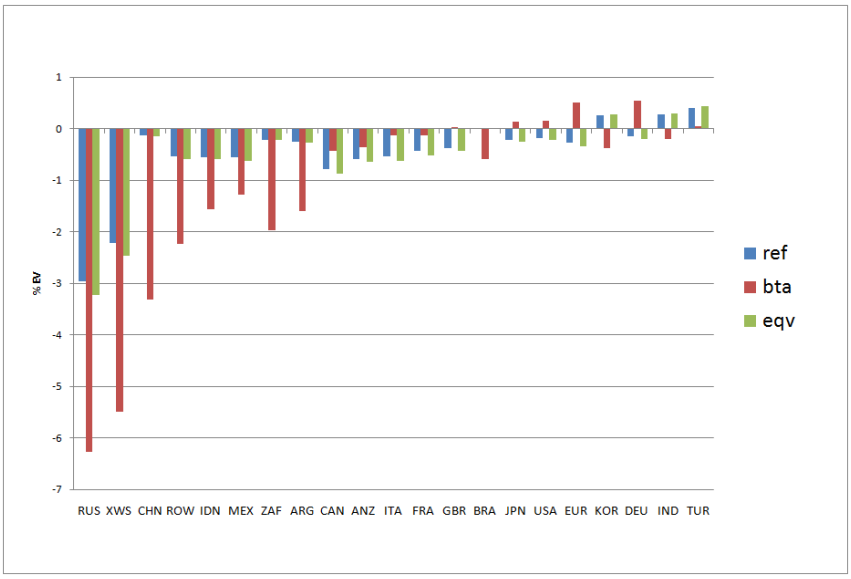


Source: Static MRGE calculation with the GTAP 7.1 database.

Figure 8: Welfare Cost of Mitigation ($)

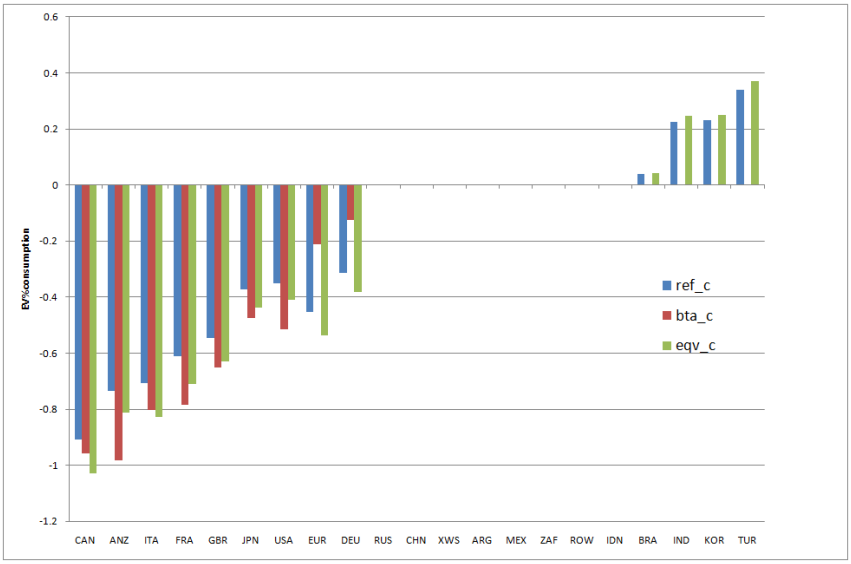
Source: Static MRGE calculation with the GTAP 7.1 database.

Figure 9: Welfare Cost of Mitigation (%)



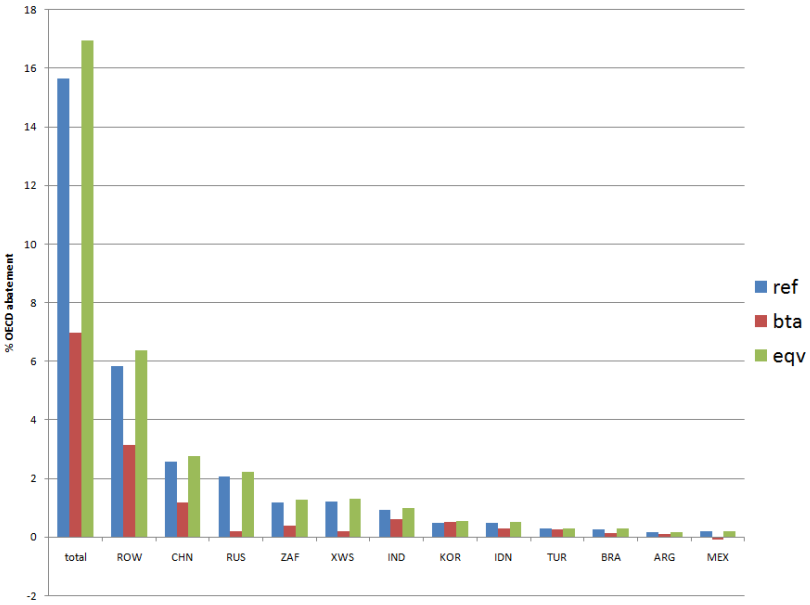
Source: Static MRGE calculation with the GTAP 7.1 database.

Figure 10: Welfare Cost with Endogenous Compensation



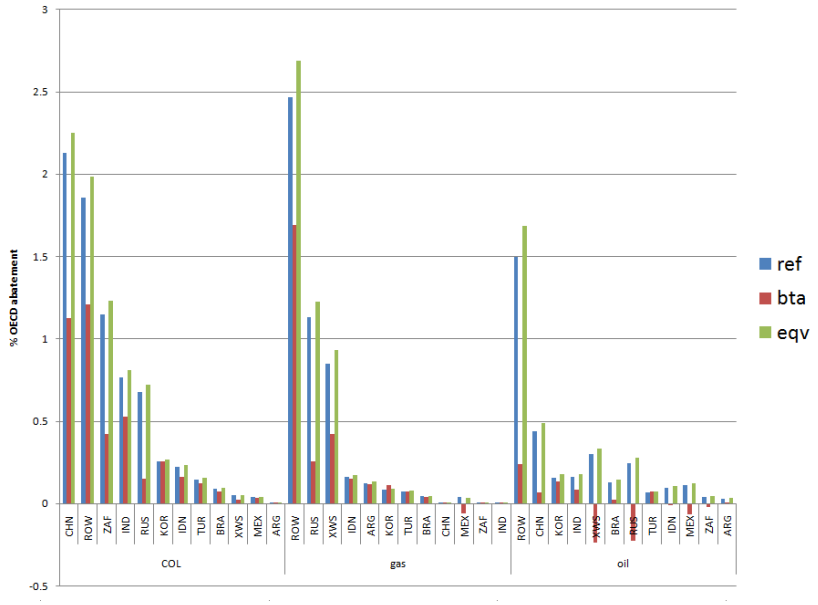
Source: Static MRGE calculation with the GTAP 7.1 database.

Figure 11: Leakage Rates



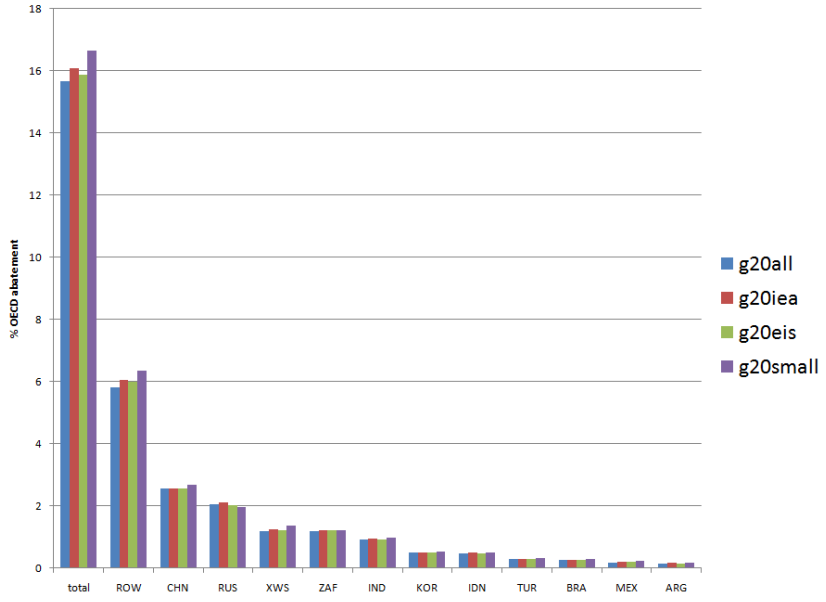
Source: Static MRGE calculation with the GTAP 7.1 database.

Figure 12: Leakage by Fuel and Region



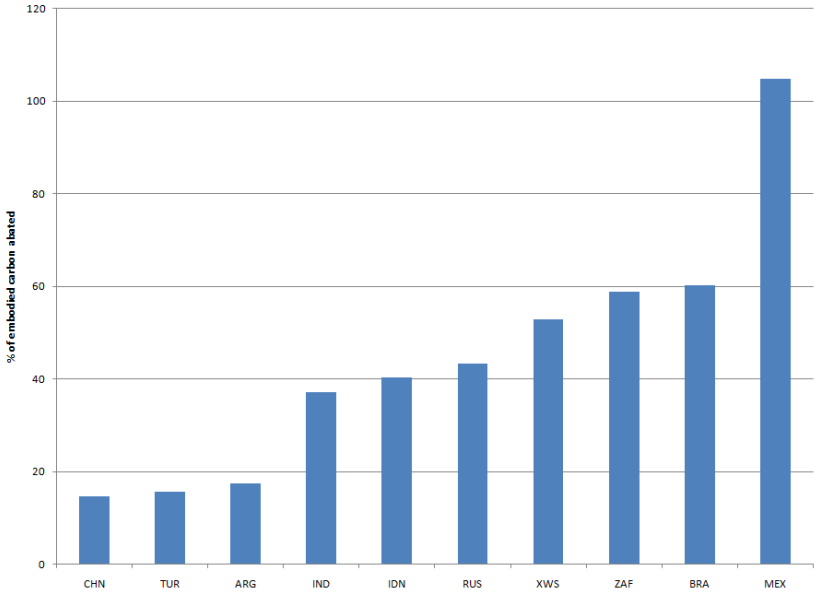
Source: Static GE model based on GTAP 7.1

Figure 13: Leakage Rate in Alternative Aggregations



Source: Static MRGE calculation with the GTAP 7.1 database.

Figure 14: Effective Yield of Border Measures



Source: Static MRGE calculation with the GTAP 7.1 database.