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GTAP-Energy in GAMS:
The Dataset and Static Model

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GTAP-Energy in GAMS: The Dataset and Static Model

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Abstract

The paper documents the energy-economy dataset GTAP-EG which is based on the general Global Trade Analysis Project (GTAP) database and OECD International Energy Agency (IEA) statistics. The GTAP-EG dataset is developed in collaboration with the researchers at Purdue University, who created a GEMPACK version of the energy dataset. In contrast to their work, the GTAP-EG is implemented in the GAMS programming language using a different calibration procedure. An illustrative static model in MPSGE syntax complements the GTAP-EG. Having the dataset in GAMS is helpful for researchers because of its open-architecture approach which permits to modify easily the dataset and the model for their own purposes. The document contains a description and directions for installing and using the GAMS-EG dataset. The paper also helps to quantify the extent to which the calibration method affects the data.

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1 Introduction

The purpose of the paper is to provide an easily accessible set of energy-economic statistics to researchers working on environment-trade related issues. Modellers who conduct quantitative analysis of international trade issues in an economy-wide framework often use the Global Trade Analysis Project (GTAP) database (Hertel [1997]). The GTAP is a research program initiated in 1992 at Purdue University to provide the economic research community with a global economic dataset for use in the quantitative analyses of international economic policy. The GTAP version 4 database represents global production and trade for 45 country/regions, 50 commodities and 5 primary factors. The data characterize intermediate demand and bilateral trade in 1995, including tax rates on imports and exports. The GTAP data alone, however, are unsuitable for assessing issues such as energy use or climate change.

Expanding economic activities can impose potentially irreversable environmental damage at local and global level. A major example is "the greenhouse effect". This term refers to the effect of rising atmospheric concentrations of carbon dioxide and other gases emitted from burning of fossil fuels and other human activity. According to different models (see, for example, Bruce et al [1996] for a review), the greenhouse effect will cause significant global warming by the middle of the next century in the absence of policy intervention.

In 1992 Framework Convention on Climate Change was ratified by 154 countries. According to 1997 Kyoto Protocol, these countries agreed to limit greenhouse emissions. The Protocol calls for industrialized countries[1] to limit their emissions by the first part of the next century. Flexible instruments are allowed to achieve the emission reduction targets, such as the international trading of emission permits.

The economic analysis of limiting carbon emissions is based on models. The starting point for a general equilibrium model is a consistent benchmark equilibrium dataset. However, it has been observed that the GTAP economic data provide a poor representation of energy flows (Babiker and Rutherford [1997]). In particular, the GTAP data is at variance with the energy statistics of the International Energy Agency (IEA). In addition, the GTAP database is expressed in terms of *values*, i.e. price times quantity. The IEA has data on energy quantities, where the energy balances are expressed in a common unit, tonnes of oil equivalent. Information on energy prices and taxes at the level consistent with the GTAP data has been collected by Babiker and Malcolm [1998]. However, since only two out of three variables (price, quantity, value) can be regarded as independent, it is problematic to incorporate both price and quantity data into the GTAP database. Special procedures have been developed in order to incorporate the energy data into the GTAP 4 database[2]. The resulting dataset (called GTAP-E) is a balanced set of economic accounts (expressed in value terms) which is calibrated to energy quantity and price data.

The data integration process has proceeded in parallel at Purdue University and the University of Colorado at Boulder. Reconciling energy and economic data requires heroic adjustments. Two different approaches for calibration have been used. As a result, two energy datasets have been created. The purpose of this document is to document the GAMS-based version of the energy-economic dataset, identify a degree of consistency with GEMPACK-generated data, and give examples of how energy related analysis can be implemented in GAMS-based models. Having the dataset implemented in GAMS is helpful for researchers because of its open-architecture approach which permits the user to easily modify the dataset and the model for their own purposes.

An approach for calibration taken at Purdue University is to use the RAS procedure (United Nations [1973]) to fit energy quantities with "target" quantities, and then use FIT procedure to adjust the single region input-output coefficients. The process of incorporating energy data into GTAP is described in detail by Malcolm and Truong [1999]. We denote the Purdue dataset as GTAP-E-FIT (Energy dataset created with the FIT procedure). As a result, the information from

[1] The countries are listed in the agreement in the Annex B, so they called Annex B or Annex I countries. They include most OECD countries. For a full list of Annex B countries, see Appendix 1.

[2] A current version of GTAP database is GTAP 4. The fifth version is announced to be released in 2000.

all three data sources (GTAP economic data, IEA energy quantities, and price data) has been changed in the process of calibration. The standard programming language for GTAP data and modeling work has been GEMPACK (Harrison and Pearson [1996]).

In contrast to Purdue approach, we apply standard optimization techniques for calibrating the GTAP data to energy statistics. The resulting dataset which is described in this paper called GTAP-EG (GTAP-Energy in GAMS). Accordingly, the dataset and an illustrative model are presented in the GAMS programming language (Brook, Kendrick, Meeraus [1992]). The process of GTAP-EG creation by incorporating energy statistics into GTAP format is described in Rutherford and Paltsev [2000]. The GTAP-EG approach is to modify the GTAP value data as little as required while preserving the IEA energy quantity statistics and most of the prices.

The document is organized as follows. Section 2 describes the GTAP-EG dataset. This section provides information about the data organization and differences between the GTAP-EG and GTAP-E-FIT datasets. Section 3 presents the illustrative static model. This section provides notation and equations describing technology, preferences, and equilibrium conditions along with GAMS code. Section 4 has a practical perspective with step-by-step instructions on how to install the GTAP-EG package. The intent of this material is to provide as short as possible a learning curve for economists who wish to perform calculations using the GTAP-EG dataset.

2 The Energy Dataset

This section provides an overview of the GTAP-EG dataset. The description begins with the dataset organization, including both parameters which are stored and those which are assigned. Users accustomed to working with the GTAP dataset in its original GEMPACK implementation should be forewarned of significant differences between the GTAP dataset as it is stored in GEMPACK and how it is represented in GAMS.

Distribution files for GTAP-EG are located as follows:

- A zip archive (http://debreu.colorado.edu/download/gtap-eg.zip).
- A PDF version of this document (http://debreu.colorado.edu/download/gtap-eg.pdf).

An HTML document which describes the GTAP-EG dataset and provides an access to the distribution files is located at http://debreu.colorado.edu/download/gtap-eg.html.

2.1 Organization

The Energy Dataset GTAP-EG has a similar structure to the GTAPinGAMS package (Rutherford [1998]) with the addition of energy specific parameters. An important feature of the GTAP-EG (and GTAPinGAMS) packages is that datasets may be freely aggregated into fewer regions, sectors, and primary factors. This feature permits a modeller to do preliminary model development using a small dataset to ensure rapid response and a short debug cycle. After having implemented a small model, it is then a simple matter to expand the number of sectors and/or regions in order to obtain a more precise empirical estimate.

All GTAP datasets are defined in terms of three primary sets: r - the set of countries and regions, i - the set of sectors and produced commodities, and f - the set of primary factors. The original GTAP4 dataset has 45 regions, 50 goods[3], and 5 primary factors. The energy statistics collected in OECD by Complainville [1998] are in a more disaggregated form: 135 regions, 32 goods, and 7 energy commodities. The resulting GTAP-EG dataset has 45 regions, 23 goods (5 of which are energy goods), and 5 primary factors.

[3]GTAPinGAMS has 51 goods/production sectors: 50 goods + Investment composite (CGD)

Table 1: Regional Identifiers in the Full GTAP-EG Dataset

```
SET   r   Regions /

AUS    Australia,                          ARG    Argentina,
NZL    New Zealand,                        BRA    Brazil,
JPN    Japan,                              CHL    Chile,
KOR    Republic of Korea,                  URY    Uruguay,
IDN    Indonesia,                          RSM    Rest of South America,
MYS    Malaysia,                           GBR    United Kingdom,
PHL    Philippines,                        DEU    Germany,
SGP    Singapore,                          DNK    Denmark,
THA    Thailand,                           SWE    Sweden,
VNM    Vietnam,                            FIN    Finland,
CHN    China,                              REU    Rest of EU,
HKG    Hong Kong,                          EFT    European Free Trade Area,
TWN    Taiwan,                             CEA    Central European Associates,
IND    India,                              FSU    Former Soviet Union,
LKA    Sri Lanka,                          TUR    Turkey,
RAS    Rest of South Asia,                 RME    Rest of Middle East,
CAN    Canada,                             MAR    Morocco,
USA    United States of America,           RNF    Rest of North Africa,
MEX    Mexico,                             SAF    South Africa,
CAM    Central America and Caribbean,      RSA    Rest of South Africa,
VEN    Venezuela,                          RSS    Rest of Sub-Saharan Africa,
COL    Columbia,                           ROW    Rest of World  /;
RAP    Rest of Andean Pact,
```

Table 1 presents regional identifiers of the full GTAP-EG dataset. An aggregation of 135 IEA-format regions into 45 GTAP regions is shown in Appendix 2. Most of the regional identifiers in the dataset correspond to standard UN three-character country codes[4].

To combine energy and trade data, 32 IEA-format sectors are aggregated into 22 sectors. In order to comply with IEA aggregation, the original 50 industrial sectors of GTAP data are also aggregated into the same 22 sectors. A sector for the investment composite is added to the original GTAP-GEMPACK representation. Table 2 presents the identifiers for the 23 GTAP-EG sectors. The sectoral identifiers for energy are different from the GTAP-E-FIT identifiers[5]. The differences are noted in Table 3.

A concordance between IEA, GTAP 4, and GTAP-EG production sectors is presented in Appendix 3. The process of incorporating IEA statistics into GTAP-EG format is described in detail in Rutherford and Paltsev [2000]. Sectors may be aggregated to produce more compact datasets. The aggregation routine is described in Section 4.

Table 4 presents the three-character identifiers used for primary factors. Note that these differ from the primary factor names employed in the GEMPACK model.

The GTAP data describe economic transactions in 1995. All parameters in GTAP are expressed in terms of values (i.e. price times quantity). Units of account in GTAP in its original GEMPACK representation (and GTAP-E-FIT) are millions of 1995$. The units in GTAP-EG are different by

[4]Users can define their own aggregations of the GTAP data and use any labels to describe regions. For technical reasons, if a GTAP dataset is to be used with MPSGE, then regional identifiers can have at most four characters.

[5]GTAP-E-FIT has the same identifiers as the GTAP4 dataset.

Table 2: Sectoral and Primary Factors Identifiers in the Full GTAP-EG Dataset

```
Set I Sectors and goods /
GAS Natural gas works
ELE Electricity and heat
OIL Refined oil products
COL Coal
CRU Crude oil

I_S Iron and steel industry
CRP Chemical industry
NFM Non-ferrous metals
NMM Non-metallic minerals
TRN Transport equipment
OME Other machinery
OMN Mining
FPR Food products
PPP Paper-pulp-print
LUM Wood and wood-products
CNS Construction
TWL Textiles-wearing apparel-leather
OMF Other manufacturing
AGR Agricultural products
T_T Trade and transport
SER Commercial and public services
DWE Dwellings,
CGD Investment composite /;


Set f Primary Factors /
LND Land
SKL Skilled Labor
LAB Unskilled Labor
CAP Capital
RES Natural Resources /;
```

Table 3: Differences between GTAP-E-FIT and GTAP-EG sectoral identifiers.

Sector	GTAP-E-FIT	GTAP-EG
Electricity and heat	ELY	ELE
Refined oil products	P_C	OIL
Crude oil	OIL	CRU

Table 4: Differences between GTAP-E-FIT and GTAP-EG primary factor identifiers.

Sector	GTAP-E-FIT	GTAP-EG
Land	Land	LND
Skilled labor	SkLab	SKL
Unskilled labor	UnSkLab	LAB
Capital	Capital	CAP
Natural resources	NatRes	RES

a factor of 10,000. GTAP-EG measures transactions in tens of billions of 1995$. Scaling units in this way assures better numerical precision in equilibrium calculations.

GAMS statements which declare all parameters in a GTAP-EG dataset are shown in Table 5. The GTAP-EG dataset has a similar structure to GTAPinGAMS (Rutherford [1998]) with the addition of energy quantities. The parameters beginning with ``v'' are base year (1995) value data, most of which are from the original GEMPACK implementation of GTAP. Not all value data from the original dataset are included here. The principal difference is that the GTAP-EG dataset stores tax *rates* rather than gross and net of tax transaction values as in the GEMPACK implementation. The tax parameters, beginning with ``t'' are not in the original GEMPACK dataset.

The energy parameters, beginning with ``e'' are in neither the original GTAP nor in the GTAPinGAMS dataset. Energy prices can be recovered by division of the respective values by the energy quantities. IEA statistics are expressed in a common unit, tonnes of oil equivalent. In the GTAP-EG units for electricity are converted into trillion kilowatt hour (TKWH) and units for other energy flows are converted into exajoules (EJ)[6].

Figure 1 presents the general GTAP database flows, which are explicitly represented in the dataset. Additional parameters are calculated based on the general flows.

[6]Energy is defined as the capacity to do work. One joule (J) is a unit of energy equal to the work done when a force of 1 newton acts through a distance of 1 meter. One joule is approximately equivalent to the potential energy of one apple one meter above the floor. 1 exajoule (EJ) = $10^{18} J$. For conversion: 1 EJ = 23.88 million tonnes of oil equivalent (MTOE). For electricity: 1kwh = $3.61 \cdot 10^6 J$, or 1EJ = 0.2778 trillion kwh.

Table 5: Parameters Explicitly Represented in a GTAP-EG Dataset

```
alias (i,j), (r,s);

PARAMETER
        ty(i,r)          Output tax
        ti(j,i,r)        Intermediate input tax
        tf(f,i,r)        Factor tax
        tx(i,s,r)        Export tax rate (defined on a net basis)
        tm(i,s,r)        Import tariff rate
        tg(i,r)          Tax rates on government demand
        tp(i,r)          Tax rate on private demand

        vafm(j,i,r)      Aggregate intermediate inputs
        vfm(f,i,r)       Value of factor inputs (net of tax)
        vxmd(i,r,s)      Value of commodity trade (fob - net export tax)
        vtwr(i,r,s)      Transport services
        vst(i,r)         Value of international transport sales
        vdgm(i,r)        Government demand (domestic)
        vigm(i,r)        Government demand (imported)
        vdpm(i,r)        Aggregate private demands (domestic)
        vipm(i,r)        Aggregate private demands (domestic);


        eind(i,i,r)      Industrial energy demand (EJ&TKWH),
        efd(i,r)         Final energy demand (EJ&TKWH),
        eexp(i,r)        Energy exports (EJ&TKWH),
        eimp(i,r)        Energy imports (EJ&TKWH),
```

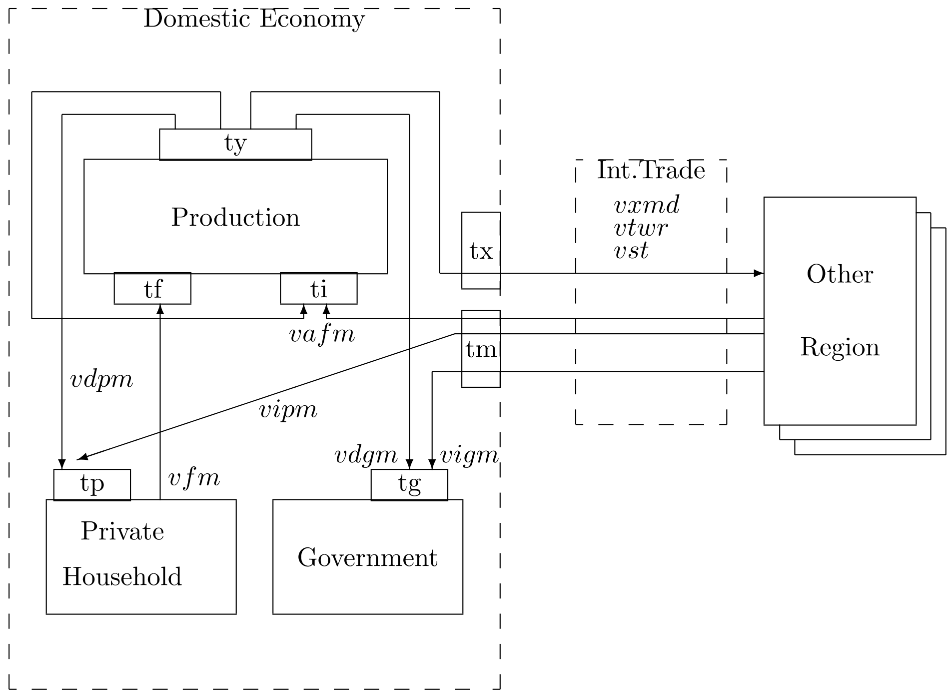

Fig. 1. GTAP flows explicitly represented in the dataset.

Whenever the GTAP-EG dataset is read, additional intermediate parameter values are assigned. Declarations for the computed parameters are presented in Table 6. Table 7 lists the GAMS parameter assignment statements for the computed items. Briefly, this is done as follows: (i) aggregate exports at market prices (`vxm`) are defined from the matrix of bilateral trade flows; (ii) aggregate imports at market prices (`vim`) are defined by bilateral exports, export taxes, transportation margins and tariff rates; (iii) domestic output (`vdm`) is determined as a residual through the zero profit condition; (vi) domestic supply to the intermediate demand (`vdfm`) is defined as a residual given domestic production and other demands for domestic output; (vii) import supply to intermediate demand (`vifm`) is also defined as a residual given aggregate imports, private and public import demand. This sequence of assignments implies that any imbalance in the dataset shows up as either a discrepancy in the demand and supply for intermediate inputs or as an imbalance between demand and supply of transportation services. The parameter `market` is created to generate a report of consistency of the benchmark data. Primary factor markets always balance because endowments are computed residually given benchmark factor demands across sectors. Likewise, regional current account balances are computed from the income-expenditure identity.

Table 8 lists declarations and assignments of reference prices for each of the benchmark transactions which are subject to tax. These parameters are used in the GAMS model as part of the calibration of demand functions. For more discussion about the GAMS implementation of the static model, see Section 3.

2.2 The GTAP-EG Dataset: Basic Statistics

A summary of economic activity by production sectors and regions in the GTAP-EG dataset is presented in Appendix 4. These numbers differ slightly from GTAP-E-FIT dataset[7]. The two energy datasets are different even though they are based on the same initial data, such as the GTAP version 4 (Hertel [1997]) expressed in terms of values (i.e. price times quantity), OECD International Energy Agency statistics (Complainville [1998]) expressed in terms of quantity, and

[7] A summary of economic activities from GTAP-E-FIT dataset can be found at http://debreu.colorado.edu/download/gtap-eg.html

Table 6: Computed Benchmark Parameters

```
parameter
        vim(i,r)        Total value of imports (gross tariff)
        vxm(i,r)        Value of export (gross excise tax)
        vdm(i,r)        Value of domestic output (net excise tax)
        vdfm(i,r)       Aggregate intermediate demand (domestic)
        vifm(i,r)       Aggregate intermediate demand (imported)
        vom(i,r)        Aggregate output value (gross of tax)
        vgm(i,r)        Public expenditures
        vpm(i,r)        Private expenditures
        vg(r)           Total value of public expenditure
        vp(r)           Total value of private expenditure
        vi(r)           Total value of investment
        vt              Value of international trade margins
        vb(*)           Net capital inflows
        market(*,*)     Consistency check for calibrated benchmark
        evoa(f,r)       Value of factor income
        va(d,i,r)       Armington supply
        vd(d,i,r)       Domestic supply
        vm(d,i,r)       Imported supply;
```

energy price and tax data (Babiker and Malcolm [1998]). The reason for this discrepancy is the different calibration procedures that have been used. Since only two out of three variables (price, quantity, value) can be regarded as independent, it is problematic to incorporate both price and quantity data into the GTAP database.

The GTAP-EG approach is to preserve the IEA energy quantity statistics and most of the prices and adjust the GTAP values. In contrast, the GTAP-E-FIT energy dataset is created using the procedure where the information from all three data sources has been changed in the process of calibration (Malcolm and Truong [1999]). The GTAP-EG and GTAP-E-FIT datasets have some differences in the parameter values for several regions. To illustrate the difference, we calculate carbon dioxide emissions and then compare the results with the IEA [1997] publication where the carbon dioxide emissions from fuel combustion are reported. It should be noted that the results from the IEA publication [1997] and the IEA statistics collected by Complainville are different. One source of the difference is International Marine Bunkers which are present in IEA book but not in the datasets. The International Marine Bunkers contains emissions from fuels burned by sea-going ships of all flags that are engaged in international transport. These emissions are excluded from national totals in IEA publication. As a result, the data for countries with big sea fleet differs substantially.

The CO_2 emissions for the full list of GTAP countries are presented in Appendix 4. Table 9 shows the results for the countries where differences in calculated CO_2 emissions are substantial. We report carbon dioxide emissions from the IEA publication. Then we compare them with the calculated emissions based on IEA statistics, GTAP-E-FIT, and GTAP-EG energy datasets. We have also provided the numbers for the GTAP-EG dataset without a fix for agriculture in USA (an ad hoc adjustment) described in Rutherford and Paltsev [2000]. It should be noted that there is a discrepancy between all four sources of the energy data. The calibration procedures employed in both the GTAP-E-FIT and the GTAP-EG do not reconcile precisely the IEA statistics. The carbon dioxide emissions are underestimated in the GTAP-E-FIT while they are overestimated slightly in the GTAP-EG.

Table 7: Assignments for Computed Benchmark Parameters

```
vxm(i,r) = sum(s, vxmd(i,r,s)) + vst(i,r);

vim(i,r) = sum(s,(vxmd(i,s,r)*(1+tx(i,s,r))+vtwr(i,s,r))*(1+tm(i,s,r)));

vdm(i,r) = ( sum(j, vafm(j,i,r)*(1+ti(j,i,r)))
           + sum(f,  vfm(f,i,r)*(1+tf(f,i,r)))) / (1-ty(i,r)) - vxm(i,r);

vdfm(i,r) = vdm(i,r)  - vdgm(i,r) - vdpm(i,r) - vdm(i,r)$cgd(i);

vi(r) = sum(cgd, vdm(cgd,r));

vifm(i,r) = vim(i,r) - vipm(i,r) - vigm(i,r);

vom(i,r) = vdm(i,r) + vxm(i,r);

vgm(i,r) = vigm(i,r)+vdgm(i,r);

vpm(i,r) = vipm(i,r)+vdpm(i,r);

vg(r) = sum(i, vgm(i,r) * (1 + tg(i,r)));

vp(r) = sum(i, vpm(i,r) * (1 + tp(i,r)));

vt = sum((i,r), vst(i,r));

evoa(f,r) = sum(i, vfm(f,i,r));

vb(r) = vp(r) + vg(r) + vdm("cgd",r)
        - sum(f, evoa(f,r))
        - sum(i,     ty(i,r)   * vom(i,r))
        - sum((i,j), ti(j,i,r) * vafm(j,i,r))
        - sum((i,f), tf(f,i,r) * vfm(f,i,r))
        - sum((i,s), tx(i,r,s)  * vxmd(i,r,s))
        - sum((i,s), tm(i,s,r)  * (vxmd(i,s,r)*(1+tx(i,s,r)) + vtwr(i,s,r)) )
        - sum(i,     tg(i,r)*vgm(i,r))
        - sum(i,     tp(i,r)*vpm(i,r));

vm("c",i,r) = vipm(i,r);        vd("c",i,r) = vdpm(i,r);
vm("g",i,r) = vigm(i,r);        vd("g",i,r) = vdgm(i,r);
vm("i",i,r) = vifm(i,r);        vd("i",i,r) = vdfm(i,r);
va(d,i,r) = vm(d,i,r) + vd(d,i,r);
market(r,i) = vdfm(i,r) + vifm(i,r) - sum(j, vafm(i,j,r));
market("world","t") = vt - sum((i,r,s), vtwr(i,r,s));
```

Table 8: Benchmark Prices

```
parameter

        pc0(i,r)        Reference price index for private consumption
        pf0(f,i,r)      Reference price index for factor inputs
        pg0(i,r)        Reference price index for public
        pi0(j,i,r)      Reference price index for intermediate inputs
        pt0(i,s,r)      Reference price index for transport
        px0(i,s,r)      Reference price index for imports;

px0(i,s,r) = (1+tx(i,s,r))*(1+tm(i,s,r));
pt0(i,s,r) = 1+tm(i,s,r);
pc0(i,r)   = 1+tp(i,r);
pg0(i,r)   = 1+tg(i,r);
pi0(j,i,r) = 1+ti(j,i,r);
pf0(f,i,r) = 1+tf(f,i,r);
```

Table 9: Carbon dioxide emissions (selected countries) - billion of tonnes

	IEA book	IEA stat	E-FIT	EG before fix	EG
JPN	1.151	1.208	1.145	1.257	1.257
KOR	0.353	0.449	0.396	0.449	0.449
SGP	0.059	0.085	0.085	0.085	0.085
CHN	3.007	3.098	2.902	3.112	3.112
IND	0.803	0.771	0.765	0.773	0.773
CAN	0.471	0.505	0.472	0.506	0.506
USA	5.228	5.339	5.175	5.340	5.460
MEX	0.328	0.328	0.309	0.328	0.328
BRA	0.287	0.269	0.256	0.289	0.289
GBR	0.565	0.605	0.540	0.607	0.607
DEU	0.884	0.973	0.865	0.973	0.973
REU	1.560	1.734	1.628	1.735	1.735
FSU	2.483	2.542	2.341	2.549	2.549
RME	0.817	0.788	0.755	0.827	0.827
ROW	0.518	0.208	0.183	0.208	0.208
total	22.150	22.482	21.272	22.644	22.764

3 A Static Model

In this section, an illustrative static model based on the GTAP-EG dataset is presented. We start with a description of the flows of goods and factors in the model. Then a general structure of the Arrow-Debreu model in Mathiesen format is discussed. We present basic blocks of the core model and their nesting structure as implemented in GAMS-MPSGE. MPSGE (Mathematical Programming System for General Equilibrium) is a compact and powerful programming language for economic modelling developed by Rutherford [1999][8].

The simplified structure of the regional flows of goods and factors is presented in Figure 2. The world is divided into regions. Each region incorporates markets for electricity, E, and non-electric energy, N. Non-electric energy includes: oil, gas and coal. Crude oil may be produced domestically or imported, and it is then refined prior to delivery as an input to production and final demand. Electricity is not traded, and produced using coal, oil, gas or non-fossil inputs. Final energy products are supplied both as inputs to production and final demand.

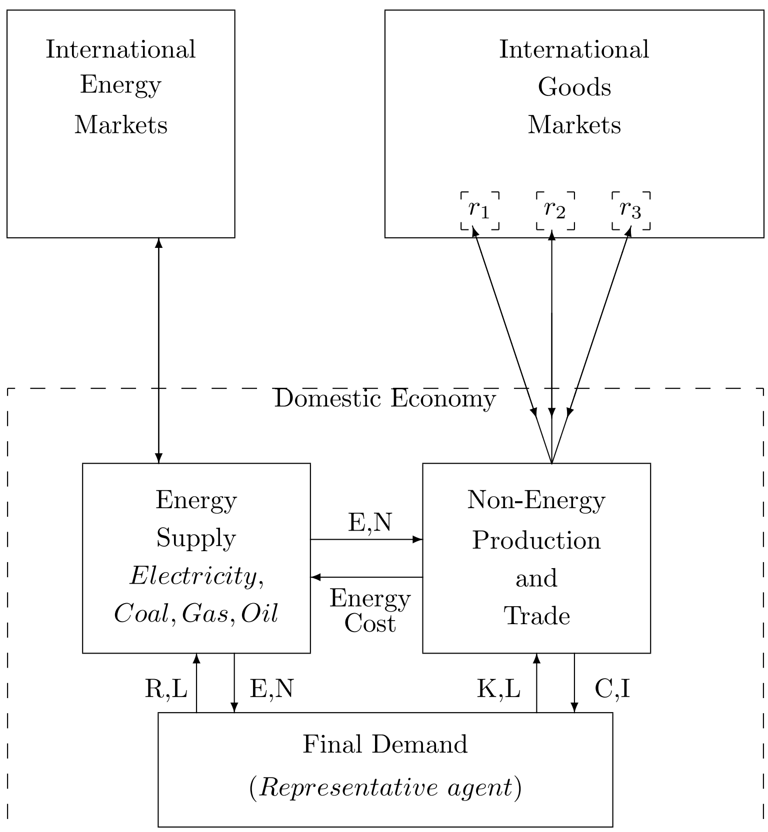

Fig. 2. Regional Flows of Goods and Factors

Consumption in each region is associated with utility maximization by a representative agent subject to a budget constraint. The agent supplies primary factors (capital, K, labor, L, and energy resources, R) to non-energy and energy sectors. Factor income of each representative agent is then allocated to the purchase of energy (E and N), non-energy goods (C), and investment (I). Regions are connected with the global economy through trade in energy and non-energy

[8] MPSGE syntax can be found at http://debreu.colorado.edu/mainpage/mpsge.htm

goods. Energy trade involves primarily crude oil and coal which can be exported or imported in international markets.

The core model described here is a static, multi-regional model which tracks the production and distribution of goods in the global economy. The model is an Arrow-Debreu general economic equilibrium model concerning the interaction of consumers and producers in markets. Lars Mathiesen [1985] proposed a representation of this class of models in which two types of equations define an equilibrium: zero profit and market clearance. The corresponding variables defining an equilibrium are activity levels (for constant-returns-to-scale firms) and commodity prices.[9]

Commodity markets merge primary endowments of households with producer outputs. In equilibrium the aggregate supply of each good must be at least as great as total intermediate and final demand. Initial endowments are exogenous. Producer supplies and demands are defined by producer activity levels and relative prices. Final demands are determined by market prices.

Economists who have worked with conventional textbook equilibrium models can find Mathiesen's framework to be somewhat opaque because many quantity variables are not explicitly specified in the model. Variables such as final demand by consumers, factor demands by producers and commodity supplies by producers, are defined implicitly in Mathiesen's model. For example, given equilibrium prices for primary factors, consumer incomes can be computed, and given income and goods prices, consumers' demands can then be determined. The consumer demand functions are written down in order to define an equilibrium, but quantities demanded need not appear in the model as separate variables. The same is true of inputs or outputs from the production process: relative prices determine conditional demand, and conditional demand times the activity level represents market demand. Omitting decisions variables and suppressing definitional equations corresponding to intermediate and final demand provides significant computational advantages at the cost of a somewhat more complex model statement.

The flows represented in Figure 2 are implemented in the GTAP-EG model in the following way. In the model there are two types of produced commodities, fossil-fuel and non-fossil fuel commodities. The model assumes that goods produced in different regions are qualitatively distinct (Armington [1968]). This implies that trade in goods is represented as flows between pairs of countries rather than from individual countries and an integrated global market. Every bilateral trade flow requires its own transportation services. Primary factors in each region include labor, capital and fossil-fuel resources. Labor is mobile within domestic borders but cannot move between regions. Capital can be global or region-specific. Natural resources are sector-specific.

Now we turn to a formulation of the GTAP-EG model in MPSGE format. The MPSGE framework is based on nested constant elasticity of substitution utility functions and production functions. MPSGE uses a concept of representing these functions as separate "blocks". We describe the basic blocks only. Some exception operators are omitted here to make the code easier to read[10]. Appendix 5 contains listing of the GAMS-MPSGE code.

In the GTAP-EG model an economy in region r consists of three production blocks. The block $y(i,r)$ is related to production, where fossil-fuel production has a different structure from other production sectors. We implicitly introduced a production block for Armington supply which represents an aggregation between domestic and import varieties and across imports from different trading partners. Armington aggregation is described by the block $a(i,r)$. Armington supply is used then for private consumption and as an intermediate input to production. Private consumption is presented by the block $c(r)$. Finally, a production block yt describes the provision of international transport services.

In order to represent consumption, another class of the MPSGE variables is introduced. In

[9] Under a maintained assumption of perfect competition, Mathiesen may characterize technology as CRTS without loss of generality. Decreasing returns are accommodated through introduction of a specific factor, while increasing returns are inconsistent with the assumption of perfect competition. In this environment zero excess profit is consistent with free entry for atomistic firms producing an identical product.

[10] GAMS has a special operator used for exception handling. It is denoted as a dollar sign. The exception operator is very useful, for example, in the cases when we want to represent some sectors of an economy which may not be active in a benchmark. For more information, see GAMS User's Guide.

each region the representative agent (described by a consumption block $ra(r)$) depicts a collective decision process for allocating income to households and to a government. Both $c(r)$ and $ra(r)$ MPSGE blocks are needed because final consumption is taxed and taxes cannot be imposed on a demand block.

Regions may apply domestic carbon taxes. Carbon tax revenue is collected by the representative agent in each region. Within this model, the carbon tax policy is equivalent to an emission permit system where the permit price coincides with the carbon tax. There are also taxes on output ty, intermediate inputs ti, consumption tc, export tx, and import tm. Figure 3 depicts the struture of the GTAP-EG model.

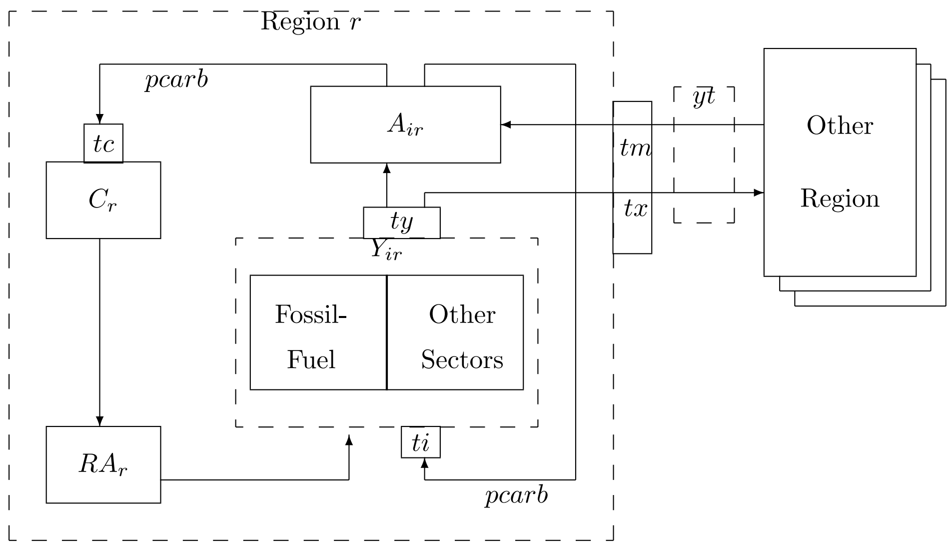

Fig. 3. Structure of the GTAP-EG model.

An MPSGE model is specified by endogenous variable declarations and a sequence of function "blocks", one for each production sector and consumer in the model. A declaration of the GTAP-EG variables is presented below. Key words in the declaration as follows. $\$SECTORS$: describes production activities that convert commodity inputs into commodity outputs. The variable associated with a sector is the activity level. $\$COMMODITIES$ are related to a good or factor. The variable associated with a commodity is its price, not its quantity. $\$CONSUMERS$ denote individuals who demand commodities, supply factors and receive tax and other revenues. The variable associated with a consumer is income from all sources.

```
$sectors:
        c(r)                    ! Private consumption
        y(i,r)                  ! Output
        a(i,r)                  ! Armington aggregation
        yt                      ! Transport

$commodities:
        pc(r)                   ! Final demand
        py(i,r)                 ! Output price
        pa(i,r)                 ! Armington composite price
        pl(r)                   ! Wage rate
        pr(i,r)                 ! Energy resource
        rkr(r)$rsk              ! Return to regional capital
        rkg$gk                  ! Return to global capital
```

```
        pt                      ! Transport services
        pcarb(r)                ! Carbon permits -- non-tradable

$consumers:
        ra(r)                   ! Representative agent
```

According to Figure 3 and the declarations above, the GTAP-EG model includes sectors related to production by commodity and region $y(i,r)$; Armington aggregation between domestic and import varieties and across imports from different trading partners $a(i,r)$; the provision of international transport services yt; and private demand by region $c(r)$.

The production activity for private demand is associated with an output which represent the marginal cost of private consumption $pc(r)$. For each commodity and region there are three different price indices: $py(i,r)$ represents the cost index for a unit of output; $pa(i,r)$ is the cost index of a unit of composite Armington supply; $pr(i,r)$ represents the cost index for energy resource. Labor is mobile within a region and the wage rate is $pl(r)$. Capital may be region-specific $rkr(r)$ or global rkg. The market price of a unit of international transport services is represented by pt. Emission permit price is $pcarb(r)$.

The final class of variables in the MPSGE model are the consumers, and in this model there is one representative consumer for each region. In equilibrium, $ra(r)$ is a variable representing income of the consumer in the region r.

3.1 Production

Fossil fuel production activities includes crude, gas, and coal. Production has the structure shown in Figure 4, where a value to the right of the arc represents an elasticity. Fossil fuel output ($y(xe)$, where xe is one type of exhaustible energy: crude, gas, coal) is produced as an aggregate of a resource input ($pr(xe)$) and a non-resource input composite. The non-resource input for the production is a fixed - coefficient (Leontief) composite of labor (pl) and the Armington aggregation ($pa(i)$) of domestic and imported intermediate input from a production sector i. The elasticity of substitution between pa and pl equals to zero ($id:0$), which characterizes a Leontief composite. The elasticity of substitution ($s:esub_es$) between the resource input and a non-resource input composite depends on the value share of resource inputs in fossil fuel supply.

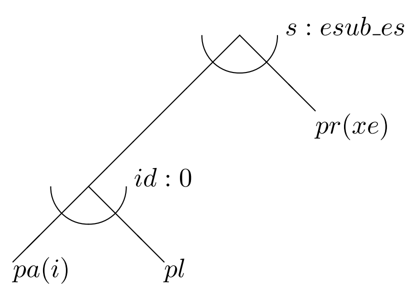

Fig. 4. Fossil fuel production

Production block for the fossil fuel production $y(xe,r)$ (where xe is a set of exhaustible energy) has the following implementation in MPSGE. There are inputs (i : fields) and outputs (o : field) associated with a production block. Each of them has an associated reference quantity (q : field) and reference price (p : field). If a reference price is equal to zero, then the price field can be omitted. The nesting structure consists of two nests with top level elasticity equal to $s : esub\_es$, and the elasticity between intermediate and labor inputs equals 0 ($id : 0$).

Output taxes ty and intermediate input taxes ti are collected by a representative agent in region r. The field a : shows who collects a tax, and the field t : determines a tax rate. For example, taxes are levied on intermediate demand inputs at net rate ti. The market value of intermediate inputs purchased by firms is $vafm(j, xe, r)$, but the total cost to firms equals $vafm(j, xe, r) * (1 + ti(j, xe, r))$, of which $vafm(j, xe, r)$ is paid to sellers of intermediate inputs $vafm(j, xe, r) * ti(j, xe, r)$ is paid as a tax to $ra(r)$.

```
*       Fossil fuel production activity (crude, gas and coal):

$prod:y(xe,r)$vom(xe,r)  s:(esub_es(xe,r))  id:0

o:py(xe,r)      q:vom(xe,r)     a:ra(r) t:ty(xe,r)
i:pa(j,r)       q:vafm(j,xe,r)  p:pai0(j,xe,r)  a:ra(r) t:ti(j,xe,r) id:
i:pl(r)         q:ld0(xe,r)  id:
i:pr(xe,r)      q:rd0(xe,r)
```

Non-fossil fuel production (including electricity and refining) has a different structure. Figure 5 illustrates the nesting and typical elasticities employed in production sectors other than fossil fuels. Output is produced with fixed-coefficient (Leontief) inputs of intermediate non-energy goods and an energy-primary factor composite. The energy-primary factor composite is a constant-elasticity of substitution (CES) function with elasticity = 0.5. Primary factor inputs of labor and capital are aggregated through a Cobb-Douglas production function ($va : 1$). The energy composite is a CES function of electricity versus other energy inputs, coal versus liquid fuels, and oil versus gas.

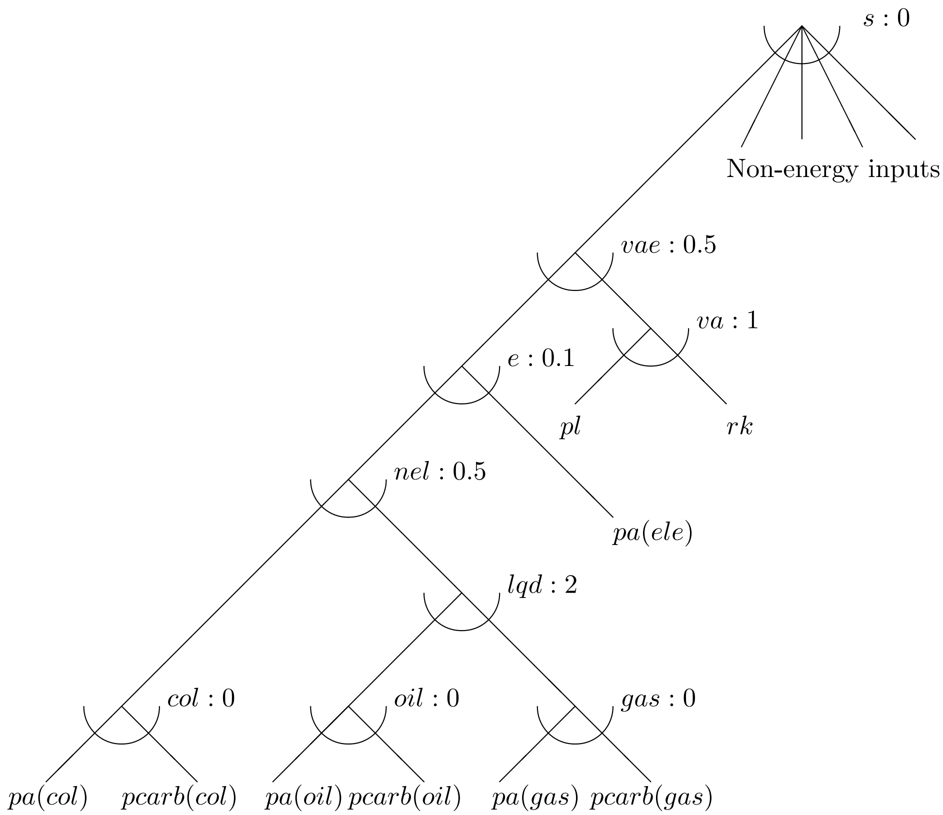

Fig. 5. Non-fossil fuel production

The following MPSGE block describes production of non-energy products ($y(i,r)$). This block is generated only for non-fossil fuel sectors, as noted by the inclusion of the exception operator $\$nr(i,r)$, where $nr(i,r)$ is a set created as `nr(i,r) = yes$(vom(i,r)$(not xe(i)));`. This GAMS line means that a sector i in a region r is included in the set $nr(i,r)$ if an aggregate output value $vom(i,r)$ of sector i is not equal to zero and the sector i is not an exhaustible energy sector xe.

```
*       Non-fossil fuel production (includes electricity and refining):

$prod:y(i,r)$nr(i,r)   s:0  vae(s):0.5  va(vae):1
+                       e(vae):0.1  nel(e):0.5 lqd(nel):2
+                       oil(lqd):0 col(nel):0 gas(lqd):0

o:py(i,r)       q:vom(i,r)  a:ra(r) t:ty(i,r)
i:pa(j,r)$(not fe(j)) q:vafm(j,i,r) p:pai0(j,i,r) e:$ele(j) a:ra(r) t:ti(j,i,r)
i:pl(r)         q:ld0(i,r)                        va:
i:rkr(r)$rsk    q:kd0(i,r)                        va:
i:rkg$gk        q:kd0(i,r)                        va:
i:pcarb(r)#(fe) q:carbcoef(fe,i,r) p:1e-6   fe.tl:
i:pa(fe,r)      q:vafm(fe,i,r)  p:pai0(fe,i,r) fe.tl: a:ra(r) t:ti(fe,i,r)
```

The nesting of the production block is clearly more complicated than for fossil-fuel production. First, note that $i : pa$ appears in two places of the production block. This is because Armington composite enters into production differently for different sectors. The line $i : pa(j,r)\$(not fe(j))$ defines it for non final energy sectors, where fe denotes a set of a final energy (oil, coal, gas). The top level elasticity (s :) equals to zero. It has a subnest $vae(s)$, which in turn has two subnests $va(vae)$ and $e(vae)$. An elasticity e : is only applied for electricity, which is shown by an exception operator $e : ele(j)$. It means that the elasticity for all non final energy sectors except electricity is equal to the top level elasticity ($s : 0$). Capital and labor are in va : nest.

The final energy has a special treatment in the line $i : pa(fe,r)$. The line of elasticities $nel(e) : lqd(nel) : oil(lqd) : col(nel) : gas(lqd)$: shows that the final energy is a subnest of e :. As such, intermediate inputs in the form of each final energy and its associated carbon tax enter as fixed-coefficient composites defined by an elasticity of substitution equal to zero ($fe.tl : 0$). The suffix ($.tl$) represents a GAMS text label for a set element. It is used here to represent the nest generated for a set of final energy fe as shown in Figure 5.

Again, a representative agent in region r collects output taxes ty and intermediate input taxes ti. Carbon tax $pcarb(r)$ is levied if production uses oil, gas, or coal as an intermediate input. The $i : pcarb(r)\#(fe)$ input represents the fact that the tax is applied for each element of the set fe.

3.2 Armington Supply

Armington aggregation activity generates intermediate demand for production and final demand for consumption as a mix of domestic and imported goods as imperfect substitutes. We assume that the domestic-imports elasticity of substitution (d) equals to 4, while the elasticity of substitution among import sources (m) equals to 8. Imports from every region require transportation services (pt) which are implemented as shown in Figure 6 for region S.

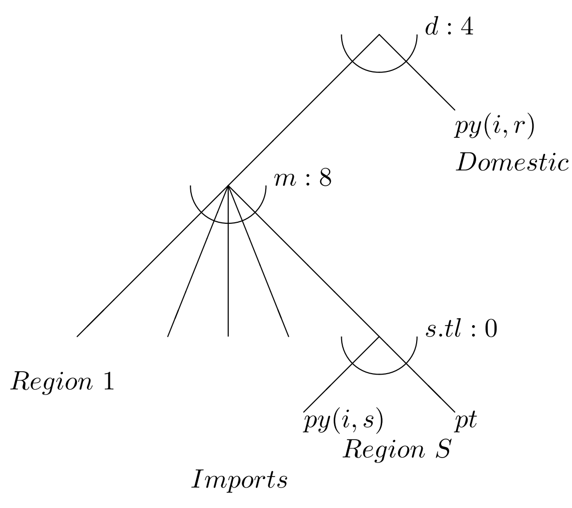

Fig. 6. Armington aggregation

The MPSGE function declaration indicates a top-level substitution elasticity between domestic ($py(i,r)$) and imported ($py(i,s)$) goods equal to four ($s : 4$). Then it defines the aggregation of imports from a trading partner with the second-level substitution elasticity between imported commodities equal to eight ($m : 8$). It applies export taxes (tx) and import tariffs (tm) on all bilateral trades. Note that the $i : py(i,s)$ input also represents fob payments to producers in region s, and as such export taxes on sales from region s to region r are accrued to the representative agent in region s ($a : ra(s)$) while import tariffs are paid to the representative agent in region r ($a : ra(r)$).

The Armington supply block also applies transportation margins which are proportional to quantities traded. The `i:pt#(s)` input represents multiple inputs of transportation services, one for each element of set s. There are multiple inputs of transportation services into each imported good because every bilateral trade flow demands its own transportation services. Using a Leontief aggregate on each bilateral trade flow assures that transport costs and imports remain strictly proportional to the base year level.

```
*       Armington aggregation over domestic versus imports:

$prod:a(i,r)$a0(i,r)  s:4  m:8 s.tl(m):0
        o:pa(i,r)       q:a0(i,r)
        i:py(i,r)       q:d0(i,r)
        i:py(i,s)       q:vxmd(i,s,r)  p:pmx0(i,s,r) s.tl:
+               a:ra(s) t:tx(i,s,r)     a:ra(r) t:(tm(i,s,r)*(1+tx(i,s,r)))
        i:pt#(s)       q:vtwr(i,s,r)  p:pmt0(i,s,r) s.tl: a:ra(r) t:tm(i,s,r)
```

3.3 International Transport

The international transport services are assumed to be a Cobb-Douglas composite of goods provided in the domestic markets in each region, as shown in Figure 7.

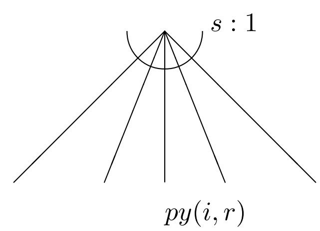

Fig. 7. International transport services

The MPSGE representation shows yt as a Cobb-Douglas ($s:1$) composite of goods provided in the domestic markets of each region.

```
*       International transport services (Cobb-Douglas):

$prod:yt  s:1
        o:pt           q:(sum((i,r), vst(i,r)))
        i:py(i,r)       q:vst(i,r)
```

3.4 Final Demand

Final demand has the structure shown in Figure 8. Utility in each country is a constant elasticity aggregate of non-energy consumption and energy. The non-energy composite is in turn a Cobb-Douglas aggregate of different goods while final energy is a Cobb-Douglas aggregate of electricity, oil, gas, and coal.

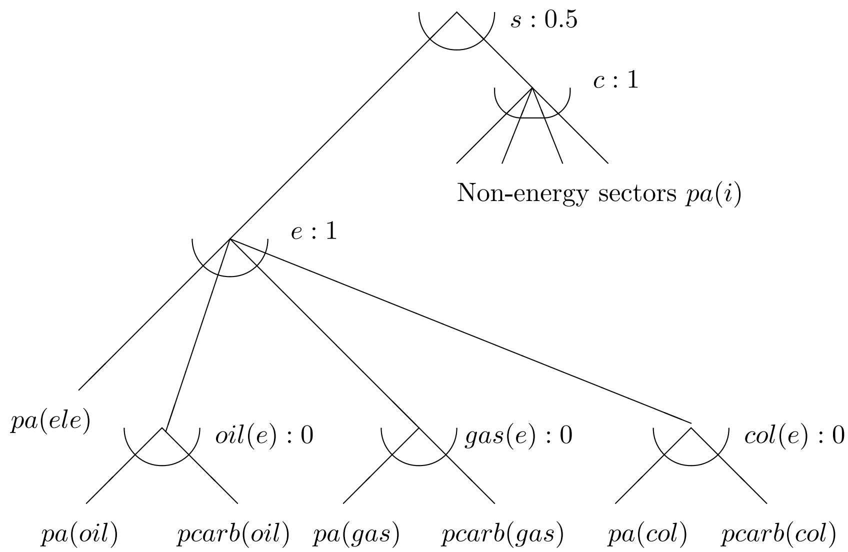

Fig. 8. Final demand

Final consumption in region r is characterized by activity $c(r)$, which is a constant elasticity aggregate ($s : 0.5$) of non-energy consumption and energy. The non-energy composite is in turn a Cobb-Douglas ($c : 1$) aggregate of different goods while final energy is a Cobb-Douglas ($e : 1$) aggregate of electric energy, oil, gas, and coal. Carbon tax $pcarb(r)$ is applied to a final demand.

```
*       Final demand

$prod:c(r)  s:0.5 c:1 e:1  oil(e):0 col(e):0 gas(e):0

o:pc(r)   q:ct0(r)
i:pa(i,r) q:c0(i,r) p:pc0(i,r) i.tl:$fe(i) c:$(not e(i)) e:$ele(i) a:ra(r) t:tc(i,r)
i:pcarb(r)#(fe)     q:carbcoef(fe,"final",r) p:1e-6  fe.tl:
```

The model statement concludes with a specification of endowment and demand for each region's representative agent. Each agent is endowed with primary factors, capital inflows, non-tradable carbon permits and collects tax revenue. The income is allocated to investment and private demand. Representative agents are "endowed" with a fixed negative quantity of the domestic "CGD" commodity representing the exogenously-specified demand for investment. Private demand is determined by utility maximizing behavior.

```
$demand:ra(r)
        d:pc(r)         q:ct0(r)
        e:py("cgd",r)   q:-vom("cgd",r)
        e:rkr(r)$rsk    q:(sum(i, kd0(i,r)))
        e:rkg$gk        q:(sum(i, kd0(i,r)))
        e:pl(r)         q:evoa("lab",r)
        e:pr(xe,r)      q:rd0(xe,r)
        e:pc("usa")     q:vb(r)
        e:pcarb(r)      q:carblim(r)
```

3.5 An Illustrative Calculation: Leakage Rate

In this section we show a calculation of a leakage rate based on the GTAP-EG model. The leakage rate is defined as the ratio of total carbon emissions by non-Annex B countries to total emissions abatement by the Annex B. This means that if the leakage rate is 50%, then a decrease in carbon emissions by the Annex B countries of 100 million tons will lead to the increase in carbon emissions by the non-Annex B countries of 50 million tons.

The formula for the leakage rate is

$$LeakageRate = \sum_n 100 \cdot \frac{CARB_{1,n} - CARB_{0,n}}{\sum_m CARB_{0,m} - CARB_{1,m}} \tag{1}$$

where n denotes the non-Annex B countries, m represents the Annex B, $CARB_0$ is the level carbon emissions in a benchmark, $CARB_1$ denotes carbon emissions in a counterfactual scenario. The calculation of the leakage rate can be implemented in GAMS in the following way.

```
leakage(r)$(not annexb(r)) = 100 * (scncarbon(r) - baucarbon(r)) /
   sum(annexb(rr), baucarbon(rr) - scncarbon(rr));

leakage("total")=sum(r, leakage(r));
```

The results of calculations based on the GTAP-EG model using the two different aggregated versions of the energy-economy datasets are as follows: GTAP-E-FIT - 8.1%, GTAP-EG - 11.5%. Once again, it shows a small difference between the datasets in their representation of the energy flows.

4 Using the Dataset

This section describes a usage of the GTAP-EG dataset. There are two versions of the dataset: the full version (file `aspen.zip`) and an aggregated version (file `aspen_small.zip`). The full version of GTAP-EG has a restricted distribution. In order to use the full energy dataset, a modeller needs to obtain the standard GTAP4 data file `gsddat.har`[11], and then download the GTAP-EG distribution archive with a build routine which prepares the GTAP data for calibration, and combines the GTAP with the energy data. The instructions for using the GTAP-EG dataset are given below[12]. For testing purposes, an aggregated version of the GTAP-EG dataset is provided with the archive. A modeller can test the aggregated energy dataset by running an illustrative model. The modeller can change the model to suit his specific purpose because he has a full access to the code of the build routine and the model.

4.1 System Requirements

You will need to have the following GAMS system components:

- GAMS compiler version 2.50[13]
- PATH complementarity solver
- MINOS5 nonlinear optimizer and nonlinear system solver

[11] The instructions for obtaining the GTAP data can be found at `http://www.agecon.purdue.edu/gtap/`

[12] Short directions are also given in the file `README.TXT` of the `GTAP-EG` archive.

[13] These programs should work with GAMS 2.25.089 or later, but the matrix balancing relies on some significant improvements in robustness which Michael Ferris and his students have achieved with the latest release of PATH. If you are running GAMS with version 2.25 and encounter problems with the rebalancing routine, you could try obtaining the latest version of PATH.

- MPSGE subsystem
- LIBINCLUDE Tools for Writing GAMS-Readable Data Files (optional)[14]
- A Pentium computer running Windows 95 or NT with more than 100 MB of free disk space.

4.2 Download

The GAMS-EG package is distributed in a zip archive (`gtap-eg.zip`) file. You can download it from `http://debreu.colorado.edu/download/gtap-eg.zip`. The archive has the directory structure presented in Table 10.

After downloading the file `gtap-eg.zip` into your computer, unzip the file making sure that the archive's directory structure is preserved[15]. The GTAP-EG dataset has two versions: full (`aspen.zip`) and aggregated (`aspen_small.zip`). In order to get the full version, a user needs to run the build routine `ASPEN.BAT` described below. The aggregated dataset is created for testing purposes. It is located in the `DATA` subdirectory and ready to use. A description of the aggregated dataset is given below.

4.3 The build routine ASPEN.BAT

The GTAP-EG dataset is built on the standard GTAP-4 database, which is not distributed freely. In order to construct the full GTAP-EG dataset, a user needs to contact GTAP at `http://www.agecon.purdue.edu/gtap/` to obtain the GTAP4 dataset (the file `gsddat.har`).

The file `gsddat.har` needs to be placed into the `DATA` subdirectory. To create the full version of GTAP-EG, a user needs to run `aspen.bat` file[16], which is described below.

The file `aspen.bat` is intended to:

- Read `gsddat.har` file.
- Convert `gsddat.har` into `gtap.gms`.
- Relabel and scale the data to create `gtap.zip`.
- Filter and recalibrate the data to `gtap001.zip`.
- Aggregate to a dataset compatible with the IEA data: `iea.zip`.
- Calibrate the GTAP and IEA energy data to create `gtap1000.zip`.
- Relabel the energy commodities, translating `gtap1000.zip` to `aspen.zip`.
- Delete work files.
- Give to a user an option of creating the aggregated GTAP-EG dataset and running an illustrative model.

Users can edit `aspen.bat` to suit their specific applications. In particular, a pause option can be uncommented for every step[17]. The original build routine has a pause in one place only - before the aggregation and running the illustrative model. At this point you'll see a message

[14] The GTAP-EG build routine and the model use the LIBINCLUDE tools located in the INCLIB directory of the GTAP-EG distribution package. In order to be able to use the tools in your own applications, you need to install them into GAMS directory. The latest version of the LIBINCLUDE tools is distributed as a file `inclib.pck`. To install it on your computer download the file from http://nash.colorado.edu/tomruth/inclib/inclib.pck into your GAMS system directory, and run GAMSINST. A description of `inclib.pck` can be found at http://nash.colorado.edu/tomruth/inclib/gams2txt.htm

[15] The files from the ZIP archive can be extracted by using `WinZip.exe` or `unzip.exe`. WinZip can be downloaded from `http://www.winzip.com`

[16] In MS-DOS prompt, type `aspen` and press `Enter`. Run time on Pentium 500 is about 12 minutes.

[17] To uncomment a `pause` command, delete a :(column) sign, i.e. change a line from `:pause` to `pause`.

Table 10: Structure of the archive GTAP-EG.ZIP

Directory	Purpose	File	Purpose
ASPEN	build dataset	aspen.bat	Batch file to build the dataset
		chkeq.gms	Check equilibrium subroutine
		filter.gms	Filter data
		filter.inc	Input file for filter.gms
		gtapaggr.bat	Aggregation
		gtapaggr.gms	Aggregation GAMS file
		gtapsets.gms	Make sets for aggregation
		iea_vail.gms	Calibration
		ieo.dat	IEO Projections Data
		ieodata.gms	IEO Projections
		recalib.gms	Recalibration
		regbal.gms	Regional Balance
		relabel.gms	Relabel to GAMS format
		seehar.exe	Read HAR-file utility
DATA	initial and resulting data	vail.dat	Aggregated Energy Data
		aspen_small.zip	13x8 GTAP-EG dataset
		(gsddat.har)	GTAP Data (not included)
		(aspen.zip)	Created after running ASPEN.BAT
DEFINES	stores .set and .map files	aspen.map	Full GTAP-EG mapping
		aspen.set	Full GTAP-EG sets
		aspen_small.map	13x8 GTAP-EG mapping
		aspen_small.set	13x8 GTAP-EG sets
		gtap.set	GTAP4 sets
		iea.map	IEA-GTAP mapping
		iea.set	IEA-GTAP sets
INCLIB	standard GAMS utilities	aggr.gms	Aggregation
		checkset.gms	Check set
		chktarget.gms	Check target
		gams2har.gms	Move to HAR format
		gams2prm.gms	Move to GAMS parameter
		gams2tbl.gms	Move to table
		gams2txt.gms	Move to text file
		gdpreport.gms	Report GDP
		har2gams.gms	Move from HAR format
		mrtdata.gms	GTAP parameters calculation
		unzip.gms	Call unzip
		zip.gms	Call zip
MODEL	static model	baseyear.gms	Illustrative Static Model
readme.txt	Installation Directions		

```
Aggregate to 13x8, include energy projections and create aspen_small.zip
Will aggregate to aspen_small.zip:
Press any key to continue . . .
```

If you press any key, then in addition to the full dataset an aggregated dataset will be created (a new file `aspen_small.zip` will replace an old one) and an illustrative model will run on an aggregated data. If you press "Ctrl-C", then the following message appears.

```
Terminate batch job (y/n)?
```

If you terminate the batch job at this time (by pressing "y" and then "Enter"), `aspen.bat` will stop and only the full version of the GTAP-EG dataset will be created and placed into `DATA` subdirectory under the name `aspen.zip`.

In the process of building the dataset, several echo files are placed in the `ASPEN` subdirectory:

- `iea.ech` - Report on economic activity by sector and region from GTAP data;
- `energy1000.ech` - Energy statistics;
- `aspen.ech` - Report on economic activity by sector and region from the full GTAP-EG dataset;
- `aspen_small.ech` - Report on economic activity by sector and region from the aggregated GTAP-EG dataset.

4.4 Aggregation

Once you have built the initial GTAP-EG dataset `aspen.zip`, you can begin to think about a particular application and which aggregations of the original GTAP-EG data would be appropriate for studying those issues. Typically it is useful to create two aggregations for any new model, one with a minimal number of regions and commodities and another with a larger number of dimensions. The small aggregation can then be used for model development.

The `gtapaggr.bat` program is used to aggregate a GTAP-EG dataset. A command line argument defines the name of the target aggregation. You only need to provide the batch file with the target because the target's mapping file defines the source. Before running `gtapaggr.bat`, you must create two files, one defining the sets of commodities, regions and primary factors in the target dataset, and another defining the name of the source dataset and a correspondence between elements of the source and target. The aggregation routine produces a brief report of GDP and trade shares in the new dataset. The SET and MAP files for a new dataset are GAMS-readable files located in the `DEFINES` subdirectory. An example of aggregating the full GTAP-EG dataset to `ASPEN_SMALL` is given below.

Step 1. Creating SET and MAP files. Appendix 6 shows a sample set file `aspen_small.set` defining the identifiers of the resulting dataset `ASPEN_SMALL`. The file defines the sets of goods, regions, and primary factors which are in the model. Appendix 7 presents the associated mapping file, `aspen_small.map`. The file provides a definition of the source dataset together with mapping definitions for commodities and factors. When no mapping is defined for the set of regions, the aggregation routine retains the same set as in the source data. In order to run the GTAP-EG model on the aggregated dataset two requirements should be fulfilled: a) commodity `CGD`, the investment-savings composite, must be included in every aggregation; b) primary factors should be aggregated into capital and labor.

Step 2. Placing the files into the proper subdirectories. The files should placed into the proper subdirectories: the files `aspen_small.set` and `aspen_small.map` into the `DEFINES` subdirectory, and the source datafile `aspen.zip` into the `DATA` subdirectory. Make sure that you have the files `gtapaggr.bat`, `gtapaggr.gms`, and `gtapsets.gms` in the `ASPEN` subdirectory.

Step 3. Running the aggregation routine. To run the aggregation routine, go to `ASPEN` subdirectory, type `gtapaggr aspen_small` at MS-DOS prompt, and press "Enter". The target dataset `aspen_small.zip` will be placed in the `DATA` subdirectory [18]. Now you can define your own SET and MAP and create your own aggregated datasets using `gtapaggr.bat`. It should be noted that the aggregation routine also includes the energy projections into the aggregated dataset if the source file is `aspen.zip`.

4.5 An aggregated 13x8 dataset: ASPEN_SMALL.ZIP

The `GTAP-EG.ZIP` archive contains an aggregated version of GTAP-EG. It is located in `DATA` subdirectory and named `ASPEN_SMALL.ZIP`. The archive contains the data file `ASPEN_SMALL.GMS`, and associated `SET` and `MAP` files. The aggregated dataset has 13 regions, 8 goods, and two primary factors. The identifiers for the aggregated dataset are contained in the `SET` file, which is provided in Appendix 6. Basic statistics from the `ASPEN_SMALL` dataset is presented in Table 11.

Table 11. Basic statistics from the aggregated GTAP-EG dataset

CO2 inventories (IEA)-- mton

	total	ind_nele	fd_nele	electric	ind_total	fd_total	kg/$
USA	1489.2	613.2	337.1	539.0	1014.5	474.8	0.2
CAN	138.1	83.9	28.6	25.6	104.1	34.0	0.3
EUR	981.7	515.6	225.7	240.4	705.3	276.4	0.1
JPN	342.8	198.3	54.8	89.7	269.7	73.0	0.1
OOE	86.7	39.9	11.0	35.8	68.0	18.7	0.2
FSU	695.1	324.6	72.3	298.2	576.6	118.5	1.8
CEA	208.1	91.3	25.0	91.8	167.2	40.9	0.8
CHN	912.4	570.5	83.7	258.2	798.2	114.2	1.0
IND	210.9	88.1	26.4	96.4	172.4	38.5	0.8
BRA	78.9	61.5	14.1	3.3	64.2	14.7	0.1
ASI	254.0	158.9	39.0	56.1	205.5	48.5	0.3
MPC	435.8	260.4	77.3	98.1	338.8	97.0	0.5
ROW	374.9	212.2	60.2	102.5	296.6	78.3	0.3
total	6208.5	3218.4	1054.9	1935.1	4781.2	1427.3	

Sectoral CO2 intensities --kg per $output

	Y	EIS	ELE
USA	0.1	0.2	2.0
CAN	0.1	0.2	0.8
EUR		0.1	0.9
JPN		0.1	0.4
OOE	0.1	0.3	2.4
FSU	0.6	1.5	6.6
CEA	0.2	0.6	4.1
CHN	0.2	0.9	5.2
IND	0.2	1.0	3.4
BRA		0.1	0.2

[18] SET and MAP files are provided with the GTAP-EG archive. An aggregation to `aspen_small.zip` is done automatically if you run `aspen.bat`

```
ASI          0.1          0.2          1.6
MPC          0.2          0.4          2.6
ROW          0.1          0.2          1.6
```

4.6 Running the GTAP-EG model

An illustrative static model (file `baseyear.gms`) is included in the GTAP-EG archive. It recreates the benchmark equilibrium and also calculates a leakage rate, which is the ratio of total increased carbon emissions by non-Annex B countries to total emissions abatement by the Annex B.

In the GTAP-EG illustrative model, we restrict carbon emissions by 25% and calculate the leakage rate. You can run the model by typing `gams baseyear` in MS-DOS prompt. The results are placed in the listing file `baseyear.lst`. There is an option of using global (GK) or region-specific (RSK) capital in the model. By default, region-specific capital option is used, which is defined by the following GAMS scalar.

```
SCALAR  RSK     Flag for region-specific capital /1/,
        GK      Flag for global capital          /0/;
```

A switch to the global capital specification may be done by changing the scalars. The GTAP-EG model is set for the calculations based on the aggregated `ASPEN_SMALL` dataset. A user may run the model on a dataset created from his own aggregation. It can be done by changing the name of the dataset in the line `$setglobal dataset aspen_small` in the file `baseyear.gms`.

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Appendix 1. Annex-B countries

Appendix 1 presents Annex B countries as they are identified in the full GTAP-EG dataset.

AUS	Australia
NZL	New Zealand
JPN	Japan
CAN	Canada
CEA	Central European Associates
USA	United States of America
GBR	United Kingdom
DEU	Germany
DNK	Denmark
SWE	Sweden
FIN	Finland
REU	Rest of EU,
EFT	European Free Trade Area
FSU	Former Soviet Union

CEA includes Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia, and Slovenia. REU includes Austria, Belgium, Spain, France, Giblartar, Greece, Ireland, Italy, Luxembourg, Netherlands, and Portugal. EFT includes Switzerland, Iceland, and Norway. FSU includes Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Lithuania, Latvia, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan.

Appendix 2. Aggregation of IEA regions into GTAP format

Country	IEA code	Region	GTAP-EG code
Australia	AUS	Australia	AUS
New Zealand	NZL	New zealand	NZL
Japan	JPN	Japan	JPN
Korea	KOR	Korea	KOR
Indonesia	IDN	Indonesia	IDN
Malaysia	MYS	Malaysia	MYS
Philippines	PHL	Phillipines	PHL
Singapore	SGP	Singapore	SGP
Thailand	THA	Thailand	THA
Vietnam	VNM	Vietnam	VNM
China	CHN	China	CHN
Hong Kong	HKG	Hong Kong	HKG
Taiwan	TWN	Taiwan	TWN
India	IND	India	IND
Sri Lanka	LKA	Sri Lanka	LKA
Bangladesh	RAS_BGD	Rest of South Asia	RAS
Nepal	RAS_NPL	Rest of South Asia	RAS
Pakistan	RAS_PAK	Rest of South Asia	RAS
Canada	CAN	Canada	CAN
USA	USA	USA	USA
Mexico	MEX	Mexico	MEX
Antilles	CAM_ANT	Central America and Carribean	CAM
Costa Rica	CAM_CRI	Central America and Carribean	CAM
Cuba	CAM_CUB	Central America and Carribean	CAM
Dominican Republic	CAM_DOM	Central America and Carribean	CAM
Guatemala	CAM_GTM	Central America and Carribean	CAM
Honduras	CAM_HND	Central America and Carribean	CAM
Haiti	CAM_HTI	Central America and Carribean	CAM
Jamaica	CAM_JAM	Central America and Carribean	CAM
Nicaragua	CAM_NIC	Central America and Carribean	CAM
Panama	CAM_PAN	Central America and Carribean	CAM
El Salavador	CAM_SLV	Central America and Carribean	CAM
Trinidad & Tobago	CAM_TTO	Central America and Carribean	CAM
Venezuela	VEN	Venezuela	VEN
Columbia	COL	Columbia	COL
Bolivia	RAP_BOL	Rest of Andean Pact	RAP
Ecuador	RAP_ECU	Rest of Andean Pact	RAP
Peru	RAP_PER	Rest of Andean Pact	RAP
Argentina	ARG	Argentina	ARG
Brazil	BRA	Brazil	BRA
Chile	CHL	Chile	CHL
Uruguay	URY	Uruguay	URY
Paraguay	RSM_PRY	Rest of South America	RSM
Great Britain	GBR	Great Britain	GBR
Germany	DEU	Germany	DEU
Denmark	DNK	Denmark	DNK
Sweden	SWE	Sweden	SWE
Finland	FIN	Finland	FIN

Austria	REU_AUT	Rest of European Union	REU
Belgium	REU_BEL	Rest of European Union	REU
Spain	REU_ESP	Rest of European Union	REU
France	REU_FRA	Rest of European Union	REU
Giblartar	REU_GIB	Rest of European Union	REU
Greece	REU_GRC	Rest of European Union	REU
Ireland	REU_IRL	Rest of European Union	REU
Italy	REU_ITA	Rest of European Union	REU
Luxembourg	REU_LUX	Rest of European Union	REU
Netherlands	REU_NLD	Rest of European Union	REU
Portugal	REU_PRT	Rest of European Union	REU
Switzerland	EFT_CHE	European Free Trade Area	EFT
Iceland	EFT_ISL	European Free Trade Area	EFT
Norway	EFT_NOR	European Free Trade Area	EFT
Bulgaria	CEA_BGR	Central European Associates	CEA
Czech Republic	CEA_CZE	Central European Associates	CEA
Hungary	CEA_HUN	Central European Associates	CEA
Poland	CEA_POL	Central European Associates	CEA
Romania	CEA_ROM	Central European Associates	CEA
Slovakia	CEA_SVK	Central European Associates	CEA
Slovenia	CEA_SVN	Central European Associates	CEA
Armenia	FSU_ARM	Former Soviet Union	FSU
Azerbaijan	FSU_AZE	Former Soviet Union	FSU
Belarus	FSU_BLR	Former Soviet Union	FSU
Estonia	FSU_EST	Former Soviet Union	FSU
Georgia	FSU_GEO	Former Soviet Union	FSU
Kazakhstan	FSU_KAZ	Former Soviet Union	FSU
Kyrgyzstan	FSU_KGZ	Former Soviet Union	FSU
Lithuania	FSU_LTU	Former Soviet Union	FSU
Latvia	FSU_LVA	Former Soviet Union	FSU
Moldova	FSU_MDA	Former Soviet Union	FSU
Russia	FSU_RUS	Former Soviet Union	FSU
Tajikistan	FSU_TJK	Former Soviet Union	FSU
Turkmenistan	FSU_TKM	Former Soviet Union	FSU
Ukraine	FSU_UKR	Former Soviet Union	FSU
Uzbekistan	FSU_UZB	Former Soviet Union	FSU
Turkey	TUR	Turkey	TUR
United Arab Emirates	RME_ARE	Rest of Middle East	RME
Bahrain	RME_BHR	Rest of Middle East	RME
Iran	RME_IRN	Rest of Middle East	RME
Iraq	RME_IRQ	Rest of Middle East	RME
Israel	RME_ISR	Rest of Middle East	RME
Jordan	RME_JOR	Rest of Middle East	RME
Kuwait	RME_KWT	Rest of Middle East	RME
Lebanon	RME_LBN	Rest of Middle East	RME
Oman	RME_OMN	Rest of Middle East	RME
Qatar	RME_QAT	Rest of Middle East	RME
Saudi Arabia	RME_SAU	Rest of Middle East	RME
Syria	RME_SYR	Rest of Middle East	RME
Yemen	RME_YEM	Rest of Middle East	RME

Morocco	MAR	Morocco	MAR
Algeria	RNF_DZA	Rest of North Africa	RNF
Egypt	RNF_EGY	Rest of North Africa	RNF
Libya	RNF_LBY	Rest of North Africa	RNF
Tunisia	RNF_TUN	Rest of North Africa	RNF
South Africa CU	SAF	South Africa	SAF
Angola	RSA_AGO	Rest of South Africa	RSA
Mozambique	RSA_MOZ	Rest of South Africa	RSA
Tanzania	RSA_TZA	Rest of South Africa	RSA
Zambia	RSA_ZMB	Rest of South Africa	RSA
Zimbabwe	RSA_ZWE	Rest of South Africa	RSA
Benin	RSS_BEN	Rest of South-Saharan Africa	RSS
Cote d'Ivoire	RSS_CIV	Rest of South-Saharan Africa	RSS
Cameroon	RSS_CMR	Rest of South-Saharan Africa	RSS
Congo	RSS_COG	Rest of South-Saharan Africa	RSS
Ethiopia	RSS_ETH	Rest of South-Saharan Africa	RSS
Gabon	RSS_GAB	Rest of South-Saharan Africa	RSS
Ghana	RSS_GHA	Rest of South-Saharan Africa	RSS
Kenya	RSS_KEN	Rest of South-Saharan Africa	RSS
Nigeria	RSS_NGA	Rest of South-Saharan Africa	RSS
Sudan	RSS_SDN	Rest of South-Saharan Africa	RSS
Senegal	RSS_SEN	Rest of South-Saharan Africa	RSS
Zaire	RSS_ZAR	Rest of South-Saharan Africa	RSS
Albania	ROW_ALB	Rest of World	ROW
Bosnia	ROW_BIH	Rest of World	ROW
Brunei	ROW_BRN	Rest of World	ROW
Cyprus	ROW_CYP	Rest of World	ROW
Croatia	ROW_HRV	Rest of World	ROW
Macedonia	ROW_MKD	Rest of World	ROW
Malta	ROW_MLT	Rest of World	ROW
Myanmar	ROW_MMR	Rest of World	ROW
Papua New Guinea	ROW_PNG	Rest of World	ROW
North Korea	ROW_PRK	Rest of World	ROW
Serbia	ROW_SER	Rest of World	ROW
Other Africa	OTHERAFRIC	Rest of World	ROW
Other Asia	OTHERASIA	Rest of World	ROW
Other Latin America	OTHERLATIN	Rest of World	ROW

Appendix 3. An aggregation of production sectors into GTAP-EG format

Appendix 3 describes the mapping of IEA and GTAP 4 production sectors into GTAP-EG format. For more details, see Rutherford and Paltsev [2000] where the process of incorporating of IEA statistics into GTAP-EG is described. The original IEA statistics has 35 sectors. The following table presents a concordance between IEA and GTAP-EG production sectors.

IEA code	Sector	GTAP-EG sector
COL	Coal	COL
AGR	agriculture	AGR
CNS	Construction	CNS
CRP	Chemical and Petrochemical	CRP
DWE	Dwellings	DWE and final consumption (?)
ELY	Electricity	ELE
EXPORTS	Exports	goes to export data
FPR	Food and Tobacco	FRP
GAS	Gas	GAS
HEAT	Heat	Not used
I_S	Iron and steel	I_S
IMPORTS	Imports	goes to import data
INDPROD	Indigenous production	Not used
LUM	Wood products	LUM
NEINTREN	Non energy use in industry	CRP
NEOTHER	Non-energy use in other sectors	AGR
NETRANS	Non-energy use in transport	T_T
NFM	Non ferrous metals	NFM
NMM	Non metallic minerals	NMM
NONROAD	Other (non road) transport	T_T
OIL	Oil	CRU
OME	Machinery	OME
OMF	Other manufacturing	OMF
OMN	Mining	OMN
OWNUSE	Ownuse	Not used
P_C	Petroleum	OIL
PPP	Paper, Pulp, and Print	PPP
RENEW	Renewable	Not used
ROAD	Road	Part to T_T and part to final consumption
SER	Services	SER
TRN	Transport equipment	TRN
TWL	Textile and leather	TWL

An aggregation of GTAP 4 into GTAP-EG is done with the aggregation routine `gtapaggr`, described in Section 4. The following table shows the mapping.

GTAP 4	GTAP-EG	Sector
GDT, GAS	GAS	Natural gas works
ELY	ELE	Electricity and heat
P_C	OIL	Refined oil products
COL	COL	Coal transformation
OIL	CRU	Crude oil
I_S	I_S	Iron and steel industry
CRP	CRP	Chemical industry
NFM	NFM	Non-ferrous metals
NMM	NMM	Non-metallic minerals
MVH, OTN	TRN	Transport equipment
ELE, OME, FMP	OME	Other machinery
OMN	OMN	Mining
OMT, VOL, MIL, PCR, SGR, OFD, B_T, CMT	FPR	Food products
PPP	PPP	Paper-pulp-print
LUM	LUM	Wood and wood-products
CNS	CNS	Construction
TEX, WAP, LEA	TWL	Textiles-wearing apparel-leather
OMF, WTR	OMF	Other manufacturing
PDR, WHT, GRO, V_F, OSD, C_B, PFB, OCR, CTL, OAP, RMK, WOL, FRS, FSH	AGR	Agricultural products
T_T	T_T	Trade and transport
OSP, OSG	SER	Commercial and public services
DWE	DWE	Dwellings
CGD	CGD	Investment composite

Appendix 4. GTAP-EG: Basic statistics

Table A.4.1. Economic activity by sector

	gdp	gdp%	trade	trade%
DWE	104.0	4.1		
ELE	93.8	3.7		
CNS	159.9	6.3	2.2	0.4
COL	12.0	0.5	2.3	0.4
GAS	14.6	0.6	3.2	0.5
NMM	21.0	0.8	7.3	1.2
OIL	18.4	0.7	8.5	1.4
OMN	5.8	0.2	9.1	1.5
LUM	19.1	0.7	11.0	1.8
NFM	5.5	0.2	11.3	1.8
OMF	25.5	1.0	15.3	2.5
PPP	41.6	1.6	16.1	2.6
I_S	20.6	0.8	18.5	3.0
CRU	37.1	1.5	21.3	3.4
AGR	120.3	4.7	25.9	4.2
FPR	76.0	3.0	35.1	5.6
TWL	44.2	1.7	46.4	7.5
SER	892.3	35.0	46.4	7.5
T_T	505.5	19.8	53.3	8.6
TRN	55.0	2.2	58.0	9.3
CRP	84.4	3.3	64.1	10.3
OME	190.9	7.5	165.8	26.7

Table A.4.2. Economic activity by region

	gdp	gdp%	trade	trade%
RSM	0.4	0.0	0.4	0.1
URY	1.4	0.1	0.4	0.1
LKA	1.2	0.0	0.5	0.1
VNM	1.2	0.0	0.7	0.1
MAR	2.6	0.1	1.0	0.2
COL	6.9	0.3	1.5	0.2
RSA	1.6	0.1	1.5	0.2
RAP	7.4	0.3	1.6	0.3
RAS	6.9	0.3	1.7	0.3
CHL	5.5	0.2	2.0	0.3
VEN	6.8	0.3	2.0	0.3
NZL	5.1	0.2	2.2	0.3
PHL	5.9	0.2	2.8	0.4
ARG	24.9	1.0	2.9	0.5
ROW	22.0	0.9	3.3	0.5
SAF	12.7	0.5	3.5	0.6
TUR	15.6	0.6	3.8	0.6
RNF	10.7	0.4	3.9	0.6

RSS	13.6	0.5	4.3	0.7
CAM	7.2	0.3	4.4	0.7
IND	27.7	1.1	4.4	0.7
FIN	11.6	0.5	4.9	0.8
IDN	19.6	0.8	5.7	0.9
BRA	62.9	2.5	6.2	1.0
DNK	15.5	0.6	6.4	1.0
AUS	31.8	1.2	7.2	1.2
THA	14.9	0.6	7.5	1.2
HKG	9.9	0.4	8.2	1.3
MEX	25.2	1.0	8.9	1.4
SWE	19.3	0.8	9.2	1.5
MYS	7.1	0.3	9.3	1.5
FSU	44.8	1.8	11.4	1.8
CEA	27.8	1.1	11.7	1.9
SGP	6.0	0.2	13.3	2.1
TWN	24.6	1.0	15.1	2.4
RME	39.8	1.6	15.8	2.5
KOR	39.7	1.6	16.0	2.6
EFT	40.8	1.6	16.6	2.7
CAN	49.7	2.0	21.1	3.4
CHN	55.5	2.2	23.7	3.8
GBR	101.3	4.0	29.6	4.8
JPN	463.1	18.2	54.3	8.7
DEU	222.1	8.7	58.6	9.4
USA	655.8	25.7	79.5	12.8
REU	372.0	14.6	132.2	21.3

Table A.4.3. Carbon inventories -- mton

	total	ind_nele	fd_nele	electric	ind_total	fd_total	kg/$
AUS	78.0	33.2	9.8	35.0	60.8	17.1	0.2
NZL	8.8	6.8	1.2	0.8	7.4	1.4	0.2
JPN	342.8	198.3	54.8	89.7	269.7	73.0	0.1
KOR	122.4	83.5	18.0	20.9	101.4	21.0	0.3
IDN	64.0	40.3	12.3	11.5	48.8	15.2	0.3
MYS	23.1	12.8	3.7	6.6	18.4	4.6	0.3
PHL	12.2	7.2	1.9	3.1	9.7	2.5	0.2
SGP	23.2	16.8	0.8	5.6	21.6	1.6	0.4
THA	38.4	18.2	8.2	12.0	28.1	10.3	0.3
VNM	5.4	4.0	0.6	0.8	4.6	0.8	0.5
CHN	848.8	534.0	78.5	236.4	745.1	103.7	1.6
HKG	13.8	7.5	0.4	5.8	12.2	1.6	0.1
TWN	49.8	28.9	4.8	16.1	42.1	7.7	0.2
IND	210.9	88.1	26.4	96.4	172.4	38.5	0.8
LKA	2.1	1.7	0.3	0	1.7	0.3	0.2
RAS	27.4	14.8	5.5	7.1	20.3	7.1	0.4
CAN	138.1	83.9	28.6	25.6	104.1	34.0	0.3
USA	1489.2	613.2	337.1	539.0	1014.5	474.8	0.2
MEX	89.6	54.5	16.3	18.8	70.1	19.5	0.4

CAM	27.2	17.5	2.7	7.0	23.5	3.8	0.4
VEN	33.1	22.2	5.8	5.1	26.4	6.7	0.5
COL	17.8	10.8	4.1	2.9	12.9	4.8	0.3
RAP	13.8	9.8	2.5	1.5	11.0	2.7	0.2
ARG	33.4	15.6	12.2	5.6	20.0	13.4	0.1
BRA	78.9	61.5	14.1	3.3	64.2	14.7	0.1
CHL	11.3	6.9	2.6	1.9	8.5	2.8	0.2
URY	1.6	1.2	0.3	0	1.3	0.3	0.1
RSM	0.9	0.4	0.5	0	0.4	0.5	0.2
GBR	165.6	84.9	37.4	43.3	117.9	47.7	0.2
DEU	265.4	118.4	64.4	82.6	184.2	81.2	0.1
DNK	18.6	7.7	2.7	8.2	13.9	4.7	0.1
SWE	17.5	11.1	4.4	2.1	12.6	4.9	0.1
FIN	16.2	8.4	2.4	5.4	12.7	3.5	0.1
REU	473.1	267.7	106.9	98.5	346.6	126.4	0.1
EFT	25.3	17.5	7.4	0.3	17.8	7.5	0.1
CEA	208.1	91.3	25.0	91.8	167.2	40.9	0.8
FSU	695.1	324.6	72.3	298.2	576.6	118.5	1.7
TUR	45.9	27.5	7.1	11.3	37.0	8.9	0.3
RME	225.6	133.4	39.4	52.8	175.2	50.4	0.6
MAR	7.3	3.7	1.0	2.7	5.7	1.6	0.3
RNF	56.5	32.3	9.2	15.1	44.5	12.1	0.5
SAF	96.0	44.1	10.9	41.0	79.8	16.2	0.8
RSA	7.2	4.5	0.6	2.1	6.3	0.9	0.5
RSS	22.7	16.0	4.4	2.3	17.9	4.8	0.2
ROW	56.8	32.0	5.6	19.2	47.2	9.6	0.3
total	6208.5	3218.4	1054.9	1935.1	4784.3	1424.1	

Table A.4.4. Carbon emissions as a percentage of global carbon emissions

ANNEX B

	as % of annex	as % of total
AUS	1.978	1.256
NZL	0.222	0.141
JPN	8.696	5.521
CAN	3.503	2.224
USA	37.782	23.987
GBR	4.202	2.668
DEU	6.732	4.274
DNK	0.471	0.299
SWE	0.445	0.282
FIN	0.411	0.261
REU	12.002	7.620
EFT	0.642	0.407
CEA	5.279	3.352
FSU	17.636	11.197
annex b	100.000	63.488

NON-ANNEX B

	as % of non-annex	as % of total
KOR	5.398	1.971
IDN	2.824	1.031
MYS	1.018	0.372
PHL	0.539	0.197
SGP	1.023	0.374
THA	1.694	0.618
VNM	0.237	0.086
CHN	37.446	13.672
HKG	0.607	0.222
TWN	2.195	0.801
IND	9.303	3.397
LKA	0.091	0.033
RAS	1.207	0.441
MEX	3.951	1.442
CAM	1.202	0.439
VEN	1.460	0.533
COL	0.784	0.286
RAP	0.608	0.222
ARG	1.471	0.537
BRA	3.479	1.270
CHL	0.501	0.183
URY	0.070	0.025
RSM	0.039	0.014
TUR	2.024	0.739
RME	9.954	3.634
MAR	0.322	0.118
RNF	2.495	0.911
SAF	4.235	1.546
RSA	0.316	0.115
RSS	1.003	0.366
ROW	2.504	0.914
non-annex b	100.000	36.512

Table A.4.5. Carbon dioxide emissions - billion of tonnes

	IEA book	IEA stat	GTAP-E-FIT	EG with no fix	GTAP-EG
AUS	0.286	0.286	0.283	0.286	0.286
NZL	0.029	0.032	0.033	0.032	0.032
JPN	1.151	1.208	1.145	1.257	1.257
KOR	0.353	0.449	0.396	0.449	0.449
IDN	0.227	0.235	0.212	0.235	0.235
MYS	0.092	0.085	0.084	0.085	0.085
PHL	0.050	0.045	0.044	0.045	0.045
SGP	0.059	0.085	0.085	0.085	0.085

THA	0.156	0.140	0.140	0.141	0.141
VNM	0.022	0.020	0.021	0.020	0.020
CHN	3.007	3.098	2.902	3.112	3.112
HKG	0.044	0.052	0.052	0.050	0.050
TWN	0.167	0.182	0.179	0.182	0.182
IND	0.803	0.771	0.765	0.773	0.773
LKA	0.006	0.008	0.007	0.008	0.008
RAS	0.211	0.100	0.097	0.100	0.100
CAN	0.471	0.505	0.472	0.506	0.506
USA	5.228	5.339	5.175	5.340	5.460
MEX	0.328	0.328	0.309	0.328	0.328
CAM	0.111	0.097	0.100	0.100	0.100
VEN	0.113	0.114	0.112	0.121	0.121
COL	0.065	0.063	0.062	0.065	0.065
RAP	0.052	0.050	0.047	0.051	0.051
ARG	0.128	0.121	0.115	0.122	0.122
BRA	0.287	0.269	0.256	0.289	0.289
CHL	0.042	0.042	0.039	0.042	0.042
URY	0.005	0.006	0.006	0.006	0.006
RSM	0.003	0.003	0.004	0.003	0.003
GBR	0.565	0.605	0.540	0.607	0.607
DEU	0.884	0.973	0.865	0.973	0.973
DNK	0.060	0.067	0.063	0.068	0.068
SWE	0.056	0.064	0.061	0.064	0.064
FIN	0.054	0.059	0.057	0.059	0.059
REU	1.560	1.734	1.628	1.735	1.735
EFT	0.078	0.093	0.082	0.093	0.093
CEA	0.749	0.762	0.707	0.763	0.763
FSU	2.483	2.542	2.341	2.549	2.549
TUR	0.160	0.168	0.156	0.168	0.168
RME	0.817	0.788	0.755	0.827	0.827
MAR	0.026	0.027	0.026	0.027	0.027
RNF	0.213	0.204	0.201	0.207	0.207
SAF	0.321	0.347	0.337	0.352	0.352
RSA	0.025	0.026	0.026	0.026	0.026
RSS	0.081	0.083	0.103	0.083	0.083
ROW	0.518	0.208	0.183	0.208	0.208
total	22.150	22.482	21.272	22.644	22.764

Appendix 5. MPSGE formulation

Appendix 5 presents the function declarations for GTAP-EG model implemented in MPSGE.

```
*       Final demand
$prod:c(r)  s:0.5 c:1 e:1  oil(e):0 col(e):0 gas(e):0
  o:pc(r)   q:ct0(r)
  i:pa(i,r) q:c0(i,r) p:pc0(i,r) i.tl:$fe(i) c:$(not e(i)) e:$ele(i) a:ra(r) t:tc(i,r)
  i:pcarb(r)#(fe)     q:carbcoef(fe,"final",r) p:1e-6  fe.tl:

*       Non-fossil fuel production (includes electricity and refining):
$prod:y(i,r)$nr(i,r)   s:0  vae(s):0.5  va(vae):1
+                        e(vae):0.1  nel(e):0.5 lqd(nel):2
```

```
+                       oil(lqd):0 col(nel):0 gas(lqd):0

        o:py(i,r)       q:vom(i,r)  a:ra(r) t:ty(i,r)
        i:pa(j,r)$(not fe(j)) q:vafm(j,i,r) p:pai0(j,i,r) e:$ele(j) a:ra(r) t:ti(j,i,r)
        i:pl(r)         q:ld0(i,r)                      va:
        i:rkr(r)$rsk    q:kd0(i,r)                      va:
        i:rkg$gk        q:kd0(i,r)                      va:
        i:pcarb(r)#(fe) q:carbcoef(fe,i,r) p:1e-6   fe.tl:
        i:pa(fe,r)      q:vafm(fe,i,r)  p:pai0(fe,i,r) fe.tl: a:ra(r) t:ti(fe,i,r)

*       Fossil fuel production activity (crude, gas and coal):
$prod:y(xe,r)$vom(xe,r)  s:(esub_es(xe,r))  id:0
        o:py(xe,r)      q:vom(xe,r)     a:ra(r) t:ty(xe,r)
        i:pa(j,r)       q:vafm(j,xe,r)  p:pai0(j,xe,r)  a:ra(r) t:ti(j,xe,r) id:
        i:pl(r)         q:ld0(xe,r)  id:
        i:pr(xe,r)      q:rd0(xe,r)

*       Armington aggregation over domestic versus imports:
$prod:a(i,r)$a0(i,r)  s:4  m:8 s.tl(m):0
        o:pa(i,r)       q:a0(i,r)
        i:py(i,r)       q:d0(i,r)
        i:py(i,s)       q:vxmd(i,s,r)  p:pmx0(i,s,r) s.tl:
+               a:ra(s) t:tx(i,s,r)     a:ra(r) t:(tm(i,s,r)*(1+tx(i,s,r)))
        i:pt#(s)       q:vtwr(i,s,r)  p:pmt0(i,s,r) s.tl: a:ra(r) t:tm(i,s,r)

*       International transport services (Cobb-Douglas):

$prod:yt  s:1
        o:pt           q:(sum((i,r), vst(i,r)))
        i:py(i,r)       q:vst(i,r)

*       Final demand:
$demand:ra(r)
        d:pc(r)         q:ct0(r)
        e:py("cgd",r)   q:-vom("cgd",r)
        e:rkr(r)$rsk    q:(sum(i, kd0(i,r)))
        e:rkg$gk        q:(sum(i, kd0(i,r)))
        e:pl(r)         q:evoa("lab",r)
        e:pr(xe,r)      q:rd0(xe,r)
        e:pc("usa")     q:vb(r)
        e:pcarb(r)      q:carblim(r)
```

Appendix 6. ASPEN_SMALL.SET

```
$TITLE   Set Definitions for 13 regions and 8 goods

SET   I   Sectors/
Y Other manufactures and services
EIS Energy-intensive sectors
COL Coal
```

```
OIL     Petroleum and coal products (refined)
CRU Crude oil
GAS Natural gas
ELE Electricity
CGD Savings good/;

SET R Aggregated Regions /
USA United States
CAN Canada
EUR Europe
JPN Japan
OOE Other OECD
FSU Former Soviet Union
CEA Central European Associates
CHN China (including Hong Kong + Taiwan)
IND India
BRA Brazil
ASI Other Asia
MPC Mexico + OPEC
ROW Rest of world /

Set   F  Aggregated factors /
       LAB      Labor,
       CAP      Capital /;
```

Appendix 7. ASPEN_SMALL.MAP

```
$title Map file

* Aggregating ASPEN dataset (45x23) into ASPEN_SMALL dataset (13x8)

*       ---------------------------------------------------------------
*       The target dataset has fewer sectors, so we need to specify how
*       each sector in the source dataset is mapped to a sector in the
*       target dataset:

$SETGLOBAL source aspen

Set mapi Sectors and goods /

GAS.GAS Natural gas works
ELE.ELE Electricity and heat
OIL.OIL Refined oil products
COL.COL Coal transformation
CRU.CRU Crude oil

I_S.EIS Iron and steel industry (IRONSTL)
CRP.EIS Chemical industry (CHEMICAL)
NFM.EIS Non-ferrous metals (NONFERR)
NMM.EIS Non-metallic minerals (NONMET)
```

```
TRN.EIS Transport equipment (TRANSEQ)
PPP.EIS Paper-pulp-print (PAPERPRO)

T_T.Y   Trade margins
AGR.Y   Agricultural products
OME.Y   Other machinery (MACHINE)
OMN.Y   Mining (MINING)
FPR.Y   Food products (FOODPRO)
LUM.Y   Wood and wood-products (WOODPRO)
CNS.Y   Construction (CONSTRUC)
TWL.Y   Textiles-wearing apparel-leather (TEXTILES)
OMF.Y   Other manufacturing (INONSPEC)
SER.Y   Commercial and public services
DWE.Y   Dwellings,

CGD.CGD Investment composite /;

SET MAPR  mapping GTAP regions /
 AUS.OOE    Australia
 NZL.OOE    New Zealand
 JPN.JPN    Japan
 KOR.ASI    Republic of Korea
 IDN.MPC    Indonesia
 MYS.ASI    Malaysia
 PHL.ASI    Philippines
 SGP.ASI    Singapore
 THA.ASI    Thailand
 VNM.ASI    Vietnam
 CHN.CHN    China
 HKG.CHN    Hong Kong
 TWN.CHN    Taiwan
 IND.IND    India
 LKA.ASI    Sri Lanka
 RAS.ASI    Rest of South Asia
 CAN.CAN    Canada
 USA.USA    United States of America
 MEX.MPC    Mexico
 CAM.ROW    Central America and Caribbean
 VEN.ROW    Venezuela
 COL.ROW    Columbia
 RAP.ROW    Rest of Andean Pact
 ARG.ROW    Argentina
 BRA.BRA    Brazil
 CHL.ROW    Chile
 URY.ROW    Uruguay
 RSM.ROW    Rest of South America
 GBR.EUR    United Kingdom
 DEU.EUR    Germany
 DNK.EUR    Denmark
 SWE.EUR    Sweden
 FIN.EUR    Finland
 REU.EUR    Rest of EU,
```

```
 EFT.EUR    European Free Trade Area
 CEA.CEA    Central European Associates
 FSU.FSU    Former Soviet Union
 TUR.ROW    Turkey
 RME.MPC    Rest of Middle East
 MAR.ROW    Morocco
 RNF.MPC    Rest of North Africa
 SAF.ROW    South Africa
 RSA.ROW    Rest of South Africa
 RSS.ROW    Rest of South-Saharan Africa
 ROW.ROW    Rest of World  /;

*       The following statements illustrate how to aggregate
*       factors of production in the model.  Unlike the aggregation
*       of sectors or regions, you need to declare the set of
*       primary in the source as set FF, then you can specify the
*       mapping from the source to the target sets.


set ff /LND,SKL,LAB,CAP,RES/;
SET MAPF mapping of primary factors /LND.CAP,SKL.LAB,LAB.LAB,CAP.CAP,RES.CAP/;
```