MIRAGRODEP 2.0: Documentation

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Abstract

MIRAGRODEP is a recursive-dynamic, multi-region, multi-sector computable general equilibrium model, devoted to trade and agricultural policy analysis. It is developed for AGRODEP and draws upon the MIRAGE model built by CEPII. It incorporates specific features such as foreign direct investment and runs with a tariff aggregation module that allows the user to capture the exclusion effects at a detailed level and the variance of tariffs. The model also includes a submodule allowing to test different closures for the public sector as well as the inefficiency of the tax collection system. MIRAGRODEP 2.0 includes an improved demand system. Social Accounting Matrix (SAM) and trade data in MIRAGRODEP are based on the GTAP database. Additional sources such as MacMap are used for protection data. This technical note presents an expanded documentation, with instructions on how to run the model and an illustrative application.

1. Introduction

MIRAGRODEP is a Computable General Equilibrium (CGE) model based on MIRAGE (Modelling International Relations Under Applied General Equilibrium). It is a multi-region, multi-sector model, dynamically recursive[1] CGE model. MIRAGE was initially developed at Centre d'Etudes Prospectives et d'Informations Internationales (CEPII), in Paris, and devoted to trade policy analysis. MIRAGRODEP differs from MIRAGE in several points: a specific modelling of government has been introduced; an optimal tariff aggregator has been introduced (see Laborde, Martin and Van der Mensbrugghe, 2017); MIRAGRODEP offers several options of public closure; the programming of MIRAGRODEP is simpler.

As opposed to a single country CGE model, a multi-country CGE model allows a detailed and consistent representation of international relations of each country with the Rest of the World. This way, international economic linkages are captured through the international trade of goods and services, and foreign direct investment (FDI). This is a key element when a research project intends to evaluate the potential economic and trade consequences of a regional or a multilateral trade agreement.

Social Accounting Matrix (SAM) and trade data in MIRAGRODEP are based on GTAP10 (Aguiar et al., 2019). The GTAP10 Data Base is a fully documented, publicly available global data base which contains complete bilateral trade information, transport, and protection linkages among 141 countries/regions for all 65 GTAP commodities/services for four reference years (2004, 2007, 2011, and 2014). For trade policy data, the MAcMAP-HS6 database, designed at CEPII, is used.

For fifteen years, MIRAGRODEP has been used extensively for *ex-ante* evaluations. It includes the evaluation of:

- Multilateral trade agreements like the Doha Development Agenda: Bouët, Mevel and Orden (2007); Bouët and Laborde (2010a; 2010b);

- Regional trade agreements like the African Continental Free Trade Area (Bouët, Laborde, and Traoré, 2022), the Eastern African Community (Bouët, Laborde, and Traoré, 2021a), the South Asian Free Trade Area (Bouët and Corong, 2009), a European Union-Mercosur trade agreement (Bouët, Estrades, and Laborde, 2011);

- Preferential trade agreements like the Andean Trade Preference Act (ATPA - Bouët, Mevel and Thomas, 2008), the EU-ECOWAS Economic Partnership Agreement (Bouët, Laborde and Traoré, 2018), the EU-African, Caribbean and Pacific countries Economic Partnership Agreement (Berisha-Krasniqi, Bouët, and Mevel, 2008), EU-SADC Economic Partnership

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[1] Dynamically recursive models do not include expectation of value of variables in future periods in the model. Plus, value of variable X at the end of period t is the initial value of variable X at the beginning of period t+1.

Agreement (Bouët, Laborde, and Traoré, 2021b), Duty-Free Quota-Free regime for poor countries (Bouët et al., 2012);

- Biofuels support programs: Bouët, Dimaranan and Valin, 2010; Laborde, 2011;
- WTO trade reforms like the search for solutions to the DDA deadlock (Bouët and Laborde, 2010c) or plurilateral agreements (Bouët and Laborde, 2019)
- The economic, trade, and environmental impact of disciplines on agricultural support (Laborde et al., 2020);
- The impact of COVID-19 on global poverty, food security and diets (Laborde, Martin, and Vos. 2020; Osendarp et al., 2021)
- The impact of export taxation: Bouët and Laborde (2012), Bouët, Estrades and Laborde (2013);
- The impact of trade wars: Bouët and Laborde (2018).

Several versions of MIRAGRODEP are available, each of them dedicated to a specific modelling: **MIRAGRODEP-Biofuels** includes a modelling of the production, consumption and trade of biofuels (ethanol and biodiesel); **MIRAGRODEP Dual-Dual** includes a modelling of rural-urban migration in African countries, but also a modelling of the reallocation of unskilled labor between formal and informal sectors in these economies; **MIRAGRODEP-HH** includes the modelling of the consumption-savings decision of several representative households in several countries; the **MIRAGRODEP-POVANA** model conducts a top-down connection of MIRAGRODEP with POVANA, a household dataset and model, which includes data on the full income distribution for over 300,000 representative households globally.

The objective of this Technical Note is three-folds. First, it aims to describe the mathematical structure[2] of and the economic hypothesis behind the MIRAGRODEP model, version 2.0, which includes an improved demand system. Second, this expanded documentation aims at explaining concretely how to use MIRAGRODEP with instructions on how to run the model. Third, it aims at illustrating the use of MIRAGRODEP with a simple case study.

The document is organized as follows. In Section 2, we present the main pillars of the model structure, with a summary of equations and variables mapped to their counterparts in GAMS code. Section 3 presents the dynamic relationships of the model and the various simulations conducted under a research project. Section 4 explains how to run MIRAGRODEP and Section 5 illustrates the use of MIRAGRODEP through a modelling exercise: in a world with ten regions of which Europe and North America are included, and five sectors (Agriculture; Agrifood; Industry-textiles and apparel excluded; Textiles and apparel; Services) a

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[2] For a comprehensive review of the functional forms commonly used in CGE models, please refer to Femenia (2012).

full trade liberalization and a free trade agreement between Europe and North America are is implemented in 5 years. Section 6 concludes.

2. Model Structure

2.1 Dimensions and sets

The MIRAGRODEP model distinguishes multiple sectors (or activities, industries) each of them producing one single commodity (or good, product). Sectors and commodities are referred to using indices *i* or *j*, both representing the exact same elements. The subset *Transport* refers to the transportation commodities and sectors.

MIRAGRODEP is a global dynamic model. Each variable is thus indexed in time (index t) and by region using indices either r, or s, or *rr* and or *ss*, which all correspond to the same elements: when two region indices are used, the first one refers to the origin of the flow, while the second one refers to the origin: for example, $TRADE_{i,s,r,t}$ is the trade flow of good i exported by country s to country r, at time t.

Another dimension is added: simul which refers to the scenario, either the reference ref or the simulation sim. In the GAMS files of MIRAGRODEP, a dynamic set is used: sim. It takes the value "ref" in the baseline and "sim" in the simulation. So, in the GAMS file all variables have a supplementary dimension, sim, which will not be included in this document for the commodity of exposition.

Set *f* refers to the five (5) factors of production: skilled labor (index *SkLab*), unskilled labor (*UnSkLab*), natural resources (*NatlRes*), capital (*Capital*) and land (*Land*). As will be discussed below, it is assumed that unskilled workers are not perfectly mobile across sectors of production. Hence, sectors are grouped according to the area, rural (*L1*) or urban (*L2*), both elements being included in set *Ltype*. The grouping of sectors i as either *L1* or *L2* is conducted in the excel file defining the sectoral and geographic disaggregation.

2.2 Production

The production in each sector and in each region follows the nested structure depicted in 0 below. At the top level, total output $Y_{j,r,t}$ is a Leontief of total value added, $VA_{j,r,t}$, and of total intermediate consumption, $CNTER_{j,r,t}$. In other words, there are no substitution possibilities between the two aggregated inputs, they are used in perfect complementarity, and thus their volume shares in total production in volume are constant. Mathematically:

$$Y_{j,r,t} = a_{j,r}^{VA} \, VA_{j,r,t} \qquad\qquad (1)$$

$$Y_{j,r,t} = a_{j,r}^{CNTER} \, CNTER_{j,r,t} \qquad\qquad (2)$$

with

$a_{j,r}^{VA}$ Value added scale coefficient

$a_{j,r}^{CNTER}$ Total intermediate consumption scale coefficient

Hence, the producer price of output, $PY_{j,r,t}$, is a weighted sum of the price of value added, $PVA_{j,r,t}$, and of that of total intermediate consumption, $PCNTER_{j,r,t}$.

$$PY_{j,r,t} \, Y_{j,r,t} = PVA_{j,r,t} \, VA_{j,r,t} + PCNTER_{j,r,t} \, CNTER_{j,r,t} \qquad (3)$$

Figure 1: Nested production function[3]
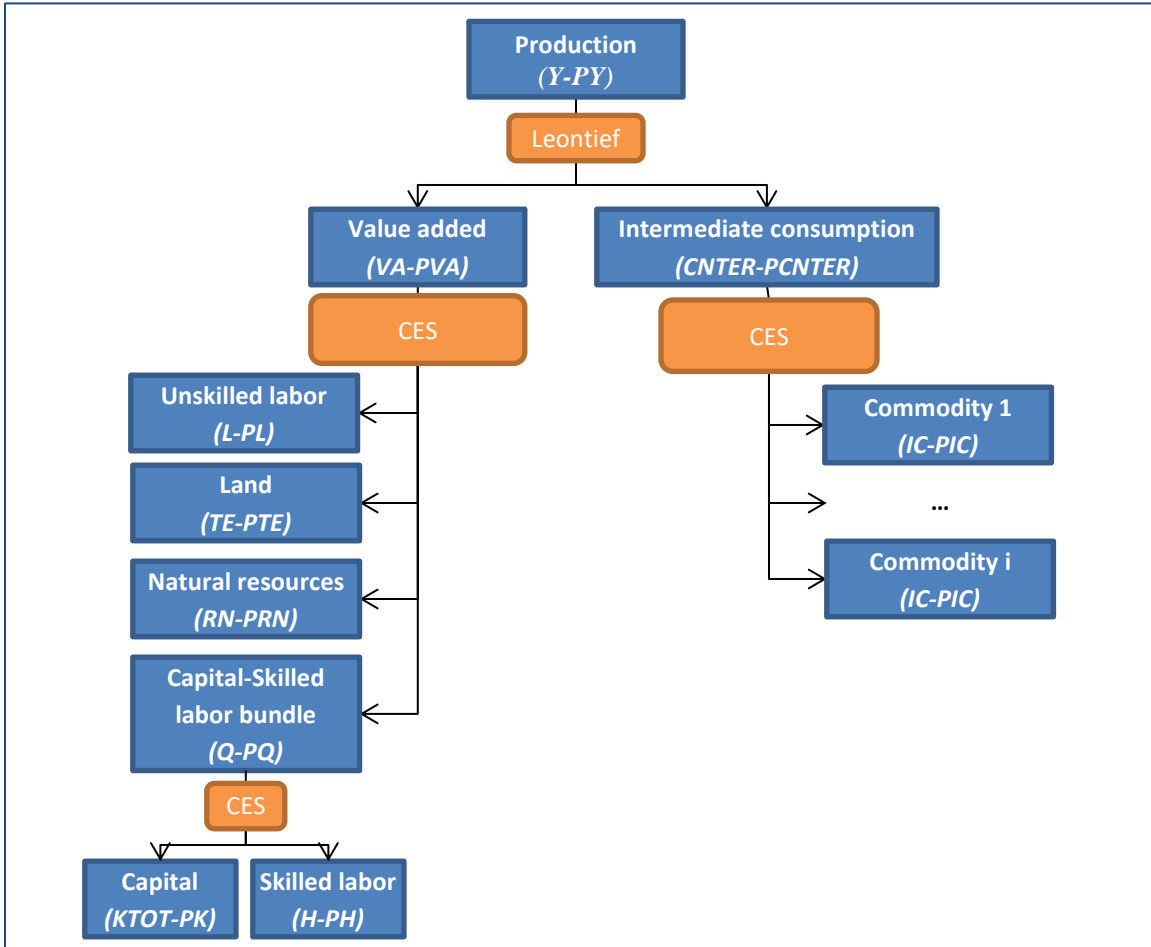
Source: authors

At the second level, on the value added side, total value added is a combination of unskilled labor, $L_{j,r,t}$, land, $TE_{j,r,t}$, natural resources, $RN_{j,r,t}$, and capital-skilled labor bundle, $Q_{j,r,t}$. It is assumed that these inputs are imperfect substitutes for one another, which is represented through a constant elasticity of substitution

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[3] The acronyms for the volume followed by its corresponding price appear in brackets.

(CES) function[4]. The representative firm minimizes its costs subject to the CES aggregator, which yield the following first order conditions:

$$L_{j,r,t} = a_{j,r}^L \, VA_{j,r,t} \, PGFI_{j,r,t}{}^{\sigma_j^{VA}-1} \left(\frac{PVA_{j,r,t}}{PL_{j,r,t}}\right)^{\sigma_j^{VA}} \tag{4}$$

$$TE_{j,r,t} = a_{j,r}^{TE} \, VA_{j,r,t} \, PGFI_{j,r,t}{}^{\sigma_j^{VA}-1} \left(\frac{PVA_{j,r,t}}{PTE_{j,r,t}}\right)^{\sigma_j^{VA}} \tag{5}$$

$$RN_{j,r,t} = a_{j,r}^{RN} \cdot VA_{j,r,t} \cdot PGF_{j,r,t}{}^{\sigma_j^{VA}-1} \left(\frac{PVA_{j,r,t}}{PRN_{j,r,t}}\right)^{\sigma_j^{VA}} \tag{6}$$

$$Q_{j,r,t} = a_{j,r}^{Q} \cdot VA_{j,r,t} \cdot PGFI_{j,r,t}{}^{\sigma_j^{VA}-1} \cdot \left(\frac{PVA_{j,r,t}}{PQ_{j,r,t}}\right)^{\sigma_j^{VA}} \tag{7}$$

with

$a_{j,r}^L$	Unskilled labor coefficient
$a_{j,r}^{TE}$	Land coefficient (country level)
$a_{j,r}^{RN}$	Natural resources coefficient
$a_{j,r}^Q$	Capital-skilled labor aggregate coefficient
σ_j^{VA}	Value added elasticity
$PVA_{j,r,t}$	Composite price of value-added
$PGFI_{j,r,t}$	Total factor productivity
$PL_{j,r,t}$	Aggregate price of labor (including taxes)
$PTE_{j,r,t}$	Aggregate price of land (including taxes)
$PRN_{j,r,t}$	Aggregate price of natural resources (including taxes)
$PQ_{j,r,t}$	Aggregate price of the composite factor (capital-skilled labor bundle)

It is worth noting that total factor productivity is differentiated by country and sector. However, in most cases, there is no information on how total factor productivity differs across sectors such that $\forall j \neq j'$, $PGFI_{j,r,t} = PGFI_{j',r,t}$. However, when a reliable estimate of sectoral total factor productivity is available, $PGFI_{j,r,t} \neq PGFI_{j',r,t}$. Then, this supplementary equation matters:

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[4] It might be worth noting that some parameters are solely indexed in j. It is the case, for example, for the elasticity used in the value-added functions (σ^{VA}_j). This specification implies that the same parameter is used for all regions, but that it differs from one sector to the other.

$$PGFI_{j,r,t} - 1 = (PGF_{r,t} - 1).FactorPGFI_{j,r,t} \tag{8}$$

In all cases, as will be explained in the section dedicated to dynamics, $PGF_{r,t}$ is determined endogenously in the baseline to make Gross Domestic Products in each country equal to the World Bank's predictions. If a reliable estimate of sectoral total factor productivity exists, these estimates feed the parameter $FactorPGFI_{j,r,t}$ which may differ from 1. If not, equation (8) is neutralized since $\forall j, \forall r, FactorPGFI_{j,r,t} = 1$ and $\forall j, PGFI_{j,r,t} = PGF_{r,t}$.

It follows that the price of value added ($PVA_{j,r,t}$) is a weighted sum of the price of unskilled labor, $PL_{j,r,t}$ the price of land, $PTE_{j,r,t}$ the price of natural resources, $PRN_{j,r,t}$, and the aggregated price of capital and skilled workers, $PQ_{j,r,t}$.

$$PVA_{j,r,t} \, VA_{j,r,t} = PL_{j,r,t} \, L_{j,r,t} + PTE_{j,r,t} \, TE_{j,r,t} + PRN_{j,r,t} \, RN_{j,r,t} + PQ_{j,r,t} \, Q_{j,r,t} \tag{9}$$

The price paid by the producer for each factor differs from the one received by the households by the amount of taxes, which can be negative in the cases where factors are subsidized. The model also distinguishes ad valorem taxes ($taxf^{VAL}_{UnSkLab,j,r,t}$ in the case of unskilled labor) from taxes that are applied on volume ($taxf^{VOL}_{UnSkLab,j,r,t}$ still in the case of unskilled labor). Concerning taxes applied on volume, they are supposed to be augmented each period to follow the consumer price index such that they do not decrease in real terms. Hence:

$$PL_{j,r,t} = WLt_{Ltype,r,t} \left(1 + taxf^{VAL}_{UnSkLab,j,r,t}\right) + PIndC_{r,t} \, taxf^{VOL}_{UnSkLab,j,r,t} \tag{10}$$

$$PTE_{j,r,t} \cdot TE_{j,r,t} = WTE_{j,r,t} \left(1 + taxf^{VAL}_{Land,j,r,t}\right) + PIndC_{r,t} \, taxf^{VOL}_{Land,j,r,t} \tag{11}$$

$$PRN_{j,r,t} = WRN_{j,r,t} \left(1 + taxf^{VAL}_{NatlRes,j,r,t}\right) + PIndC_{r,t} \, taxf^{VOL}_{NatlRes,j,r,t} \tag{12}$$

with

$WLt_{Ltype,r,t}$	Rate of return to unskilled labor (net of taxes)
$WTE_{j,r,t}$	Rate of return to land (net of taxes)
$WRN_{j,r,t}$	Rate of natural resources (net of taxes)
$PIndC_{r,t}$	Consumer price index
$taxf^{VAL}_{f,j,r,t}$	Rate of factor-based taxes (ad valorem)
$taxf^{VOL}_{f,j,r,t}$	Rate of factor-based taxes (on volume)

With this notation, the rate of return to rural unskilled labor ($WLt_{"L1",r,t}$) differs from the rate of return to urban unskilled labor ($WLt_{"L2",r,t}$).

At the bottom level (see 0), on the value added side, capital, $KTOT_{j,r,t}$ and skilled labor, $H_{j,r,t}$, are combined through a CES function, once again to represent the imperfect substitutability between the two factors of production. The five primary factors of production are not at the same level of the nested production function. This allows different degrees of substitutability between factors. In MIRAGRODEP, the idea is to be able to simulate the possibility of replacing unskilled labor with a combination of capital and skilled labor. This combination is substitutable for unskilled labor, while capital is rather complementary (or hardly substitutable for) skilled labor.

Minimization of production costs subject to the CES aggregator gives the following demand functions:

$$H_{j,r,t} = a_{j,r}^H \, Q_{j,r,t} \left(\frac{PQ_{j,r,t}}{PH_{j,r,t}} \right)^{\sigma_j^{CAP}} \tag{13}$$

$$KTOT_{j,r,t} = a_{j,r}^K \, Q_{j,r,t} \left(\frac{PQ_{j,r,t}}{PK_{j,r,t}} \right)^{\sigma_j^{CAP}} \tag{14}$$

with

$\quad a_{j,r}^H \qquad$ Skilled labor coefficient

$\quad a_{j,r}^K \qquad$ Capital coefficient

$\quad \sigma_j^{CAP} \qquad$ Capital-skilled labor elasticity

The price of the capital-skilled labor bundle $PQ_{j,r,t}$ is thus a weighted sum of the rental rate of capital, $PK_{j,r,t}$, and of the price of skilled labor, $PH_{j,r,t}$.

$$PQ_{j,r,t} \, Q_{j,r,t} = PK_{j,r,t} \, KTOT_{j,r,t} + PH_{j,r,t} \, H_{j,r,t} \tag{15}$$

Again, the prices paid for the factors of production differ from the ones received by households as there are taxes levied on each of them. Again, the model distinguishes ad valorem taxes from taxes that are applied on volume.

$$PH_{j,r,t} = WH_{r,t} \left(1 + taxf_{SkLab,j,r,t}^{VAL} \right) + PIndC_{r,t} \, taxf_{SkLab,j,r,t}^{VOL} \tag{16}$$

$$PK_{j,r,t} = WK_{j,r,t} \left(1 + taxf_{Capital,j,r,t}^{VAL} \right) + PIndC_{r,t} \, taxf_{Capital,j,r,t}^{VOL} \tag{17}$$

with

$\quad WH_{r,t} \qquad$ Rate of return to skilled labor (net of taxes)

$\quad WK_{j,r,t} \qquad$ Rate of return to capital (net of taxes)

On the intermediate consumption side, the commodities (index i) used in the production process of sector j are assumed to be imperfect substitutes. Once again, a CES function is used to represent this imperfect substitutability, and cost minimization yields the demand for each input i by sector j, $IC_{i,j,r,t}$:

$$IC_{i,j,r,t} = a_{i,j,r}^{IC} \, CNTER_{j,r,t} \left(\frac{PCNTER_{j,r,t}}{PIC_{i,j,r,t}} \right)^{\sigma^{IC}} \tag{18}$$

with

$a_{i,j,r}^{IC}$	Intermediate consumption scale coefficient
σ^{IC}	Intermediate consumption elasticity
$PCNTER_{j,r,t}$	Price of total intermediate consumption in sector j
$PIC_{i,j,r,t}$	Price of intermediate consumption of good i in sector j

The price of total intermediate consumption is a weighted sum of the price paid for each commodity, $PIC_{i,j,r,t}$:

$$PCNTER_{j,r,t} \, CNTER_{j,r,t} = \sum_i PIC_{i,j,r,t} \, IC_{i,j,r,t} \tag{19}$$

The price of each input is subject to taxes, *taxicc$_{i,j,r,t}$*, and thus differ from the price received by producers of intermediate good i, *PDEMTOT$_{i,r,t}$*.

$$PIC_{i,j,r,t} = PDEMTOT_{i,r,t} \left(1 + taxicc_{i,j,r,t} \right) \tag{20}$$

2.3 Income and savings

2.3.1 Households

Households are assumed to be homogenous and they own all factors of production. They, hence, receive all the payments made to factors of production. Households' income, $REVH_{r,t}$, consists in the sum of all these payments, plus transfers from the government, $TRH_{r,t}$ denoting the transfer per capita. This transfer is indexed on the evolution of the consumer price index.

$$REVH_{r,t} = \sum_j \{ WRN_{j,r,t} \, RN_{j,r,t} + WTE_{j,r,t} \cdot TE_{j,r,t} + WH_{r,t} \, H_{j,r,t} +$$

$$\sum_{Ltype} WLt_{Ltype,r,t} \, L_{j,r,t} + \sum_s WK_{j,s,t} \, K_{j,r,s,t} \} + Pop_{totpop,r,t} TRH_{r,t} \, PIndC_{r,t} \tag{21}$$

With:

$Pop_{totpop,r,t}$	Total population of country r.

As far as equation (21), two remarks are worth mentioning:

- $K_{j,r,s,t}$ is the supply of capital by country r's agents to sector j in country s, such that $\sum_s WK_{j,s,t} \, K_{j,r,s,t}$ is the total payments to capital received by households in country r: they receive payments for the capital invested in sectors of their own country ($WK_{j,r,t} \, K_{j,r,r,t}$) and for capital invested abroad ($\sum_{s \neq r} WK_{j,s,t} \, K_{j,r,s,t}$). Let us remind that in equations (14) and (15), $KTOT_{j,r,t}$ is the *demand* for capital by sector j in country r.

- When the public closure requires the implementation of a lump-sum tax on households, another term $Pop_{totpop,r,t} lumpsum_{r,t}$ is subtracted from the right-hand side of equation (21), with $lumpsum_{r,t}$ the lump-sum tax.

Households' savings, $SAVH_{r,t}$, are a fixed proportion $epa_{r,t}$ of their income net of indirect taxes, $RECDIR_{r,t}$, and the rest of their income is dedicated to consumption budget, $BUDH_{r,t}$.

$$SAVH_{r,t} = epa_{r,t} (REVH_{r,t} - RECDIR_{r,t}) \qquad (22)$$

$$BUDH_{r,t} = REVH_{r,t} - SAVH_{r,t} - RECDIR_{r,t} \qquad (23)$$

It is easy to suppose either that the saving rate is constant over time $epa_{r,t} = epa_r , \forall t$ or varies over time according to a specific function.

2.3.2 Government

The income of the government, $REVG_{r,t}$, consists of taxes collected on production, $RECPROD_{i,r,t}$, on factors of production, $RECFAC_{i,r,t}$, on exports, $RECEXP_{i,r,t}$, on imports, $RECDD_{i,r,t}$, on consumption, $RECCONS_{i,r,t}$, and households' income, $RECDIR_{r,t}$. Let us note that $RECPROD_{i,r,t}$, $RECFAC_{i,r,t}$, $RECEXP_{i,r,t}$, $RECDD_{i,r,t}$, and $RECCONS_{i,r,t}$ are indexed on sectors i. Thus, the income of the government, $REVG_{r,t}$ is given by:

$$REVG_{r,t} = \sum_i \{RECPROD_{i,r,t} + RECFAC_{i,r,t} + RECEXP_{i,r,t} + RECDD_{i,r,t} +$$

$$RECCONS_{i,r,t}\} + RECDIR_{r,t} \qquad (24)$$

In case of a public closure that involves the implementation of a lump-sum tax, the term $Pop_{totpop,r,t} lumpsum_{r,t}$ is added on the right-side of equation (24).

Taxes on production are collected on the value of output of each activity. It is important to note that tax rates should be considered as *net* rates, that is taxes net of subsidy. Hence, all tax rates can be either positive or negative.

$$RECPROD_{i,r,t} = taxP_{i,r,t} \, PY_{i,r,t} \, Y_{i,r,t} \qquad (25)$$

With:

$taxP_{i,r,t}$ 　　　Production tax rate

Receipt from taxes on factors of production is the sum of volume and value taxes on each factor.

$$RECFAC_{j,r,t} = PIndC_{r,t} \left(taxf^{VOL}_{Land,j,r,t} \, TE_{j,r,t} + taxf^{VOL}_{NatlRes,j,r,t} \, RN_{j,r,t} + \right.$$

$$taxf^{VOL}_{SkLab,j,r,t} \, H_{j,r,t} + taxf^{VOL}_{UnSkLab,j,r,t} \, L_{j,r,t} + taxf^{VOL}_{Capital,j,r,t} \, KTOT_{j,r,t} \left. \right) +$$

$$taxf^{VAL}_{Land,j,r,t} \, WTE_{j,r,t} \, TE_{j,r,t} + taxf^{VAL}_{NatlRes,j,r,t} \, WRN_{j,r,t} \, RN_{j,r,t} + taxf^{VAL}_{SkLab,j,r,t} \, WH_{r,t} \, H_{j,r,t} +$$

$$taxf^{VAL}_{UnSkLab,j,r,t} \, \sum_{Ltype} WLt_{Ltype,r,t} \, L_{j,r,t} + taxf^{VAL}_{Capital,j,r,t} \, WK_{j,r,t} \, KTOT_{j,r,t} \qquad (26)$$

Exports may be subject to three taxes: taxes on production, $taxP_{i,r,t}$, regular taxes on exports, $taxEXP_{i,r,s,t}$, and export tax equivalent of multi-fiber arrangement quota premium, $taxAMF_{i,r,s,t}$.

$$RECEXP_{i,r,t} = PY_{i,r,t}\left(1 + taxP_{i,r,t}\right)\sum_s\left(taxEXP_{i,r,s,t} + taxAMF_{i,r,s,t}\right)TRADE_{i,r,s,t} \qquad (27)$$

With:

$TRADE_{i,r,s,t}$ Exports of commodity i from country r to country s

Import duties, $DD_{i,s,r,t}$, are defined as *ad valorem* and collected on imports by country s of product i coming from country r; these imports are evaluated at the Cost-Insurance-Freight (CIF) price, $PCIF_{i,s,r,t}$.

$$RECDD_{i,r,t} = \sum_s DD_{i,s,r,t}\, PCIF_{i,s,r,t}\, TRADE_{i,s,r,t} \qquad (28)$$

Taxes are levied on households' consumption, $CH_{i,r,t}$, on government's expenditures on goods and services, $CG_{i,r,t}$, on commodities sold for investment purposes, $KG_{i,r,t}$, and on intermediate consumption, $IC_{i,j,r,t}$. Each buyer faces a specific tax rate, respectively, $taxcc_{i,r,t}$, $taxgc_{i,r,t}$, $taxkgc_{i,r,t}$, and $taxicc_{i,j,r,t}$.

$$RECCONS_{i,r,t} = PDEMTOT_{i,r,t}\left\{taxcc_{i,r,t}\, CH_{i,r,t} + taxgc_{i,r,t}\, CG_{i,r,t} + taxkgc_{i,r,t}\, KG_{i,r,t} + \right.$$

$$\left.\sum_j taxicc_{i,j,r,t}\, IC_{i,j,r,t}\right\} \qquad (29)$$

If the public closure requires the imposition of a supplementary consumption tax, each of these four taxes on consumption is increased by $addtaxcc_{r,t}$.

Finally, the government collects another receipt $RECDIR_{r,t}$ from direct taxes on households' income through a taxation rate $taxdir_{r,t}$:

$$RECDIR_{r,t} = taxdir_{r,t}\, REVH_{r,t} \qquad (30)$$

If the public closure requires the imposition of a supplementary income tax on households, this tax is increased by $addtaxdir_{r,t}$.

Public sold $SAVG_{r,t}$ is defined as public revenues $REVG_{r,t}$ minus public expenditures which consist in public current expenditures on goods and services $BUDG_{r,t}$ and public transfers to households.

$$SAVG_{r,t} = REVG_{r,t} - BUDG_{r,t} - Pop_{totpop,r,t}\, TRH_{r,t}\, PIndC_{r,t} \qquad (31)$$

There are several options of public closure. In this basic version of MIRAGRODEP we suppose that public sold $SAVG_{r,t}$ is a fixed proportion, $PUBSOLD_r$, of GDP at market prices, $GDPMP_{r,t}$. This hypothesis can easily be changed.

$$SAVG_{r,t} = PUBSOLD_r\, GDPMP_{r,t} \qquad (32)$$

Six options of public closure are available. Either each government's budgetary expenses are endogenous and adjust to a variation of government's revenues such that equation (32) is respected (option 1), or

budgetary expenses are constant in nominal terms and public saving is constant in proportion of GDP at market prices (equation 32): a new tax is levied, either a lumpsum tax (option 2), or an additional consumption tax (option 3), or an additional income tax on households (option 4). Or budgetary expenses are constant per capita and in real terms, and public saving is constant in proportion of GDP thanks to a lumpsum tax (option 5). Or budgetary expenses are constant in proportion of GDP at market prices, and public saving is constant in proportion of GDP thanks to a lumpsum tax (option 6).

2.4 Demand

Domestic absorption of each commodity, $DEMTOT_{i,r,t}$, is the sum of households' final demand, $CH_{i,r,t}$, of demand from public administrations, $CG_{i,r,t}$, of intermediate demand, $IC_{i,j,r,t}$ and of demand for investment purposes, $KG_{i,r,t}$.

$$DEMTOT_{i,r,t} = CH_{i,r,t} + CG_{i,r,t} + \sum_j IC_{i,j,r,t} + KG_{i,r,t} \tag{32}$$

2.4.1 Private demand

Households' demand is characterized by a LES-CES (Linear Expenditure System - Constant Elasticity of Substitution) specification. This utility function allows a modification of the demand structure of each region to be accounted for as its income level changes: income-elasticity of final consumption is not unitary. So, households' utility, $AUX_{r,t}$, is a LES-CES of three broad categories of goods: food products, industrial goods and services (see 0). Additionally, the elasticity of substitution is constant only among the sectoral consumptions over and above a minimum level. The minimal level of consumption can vary across region (e.g. developing versus developed country).

Figure 2: Nested Final Consumption function[5]
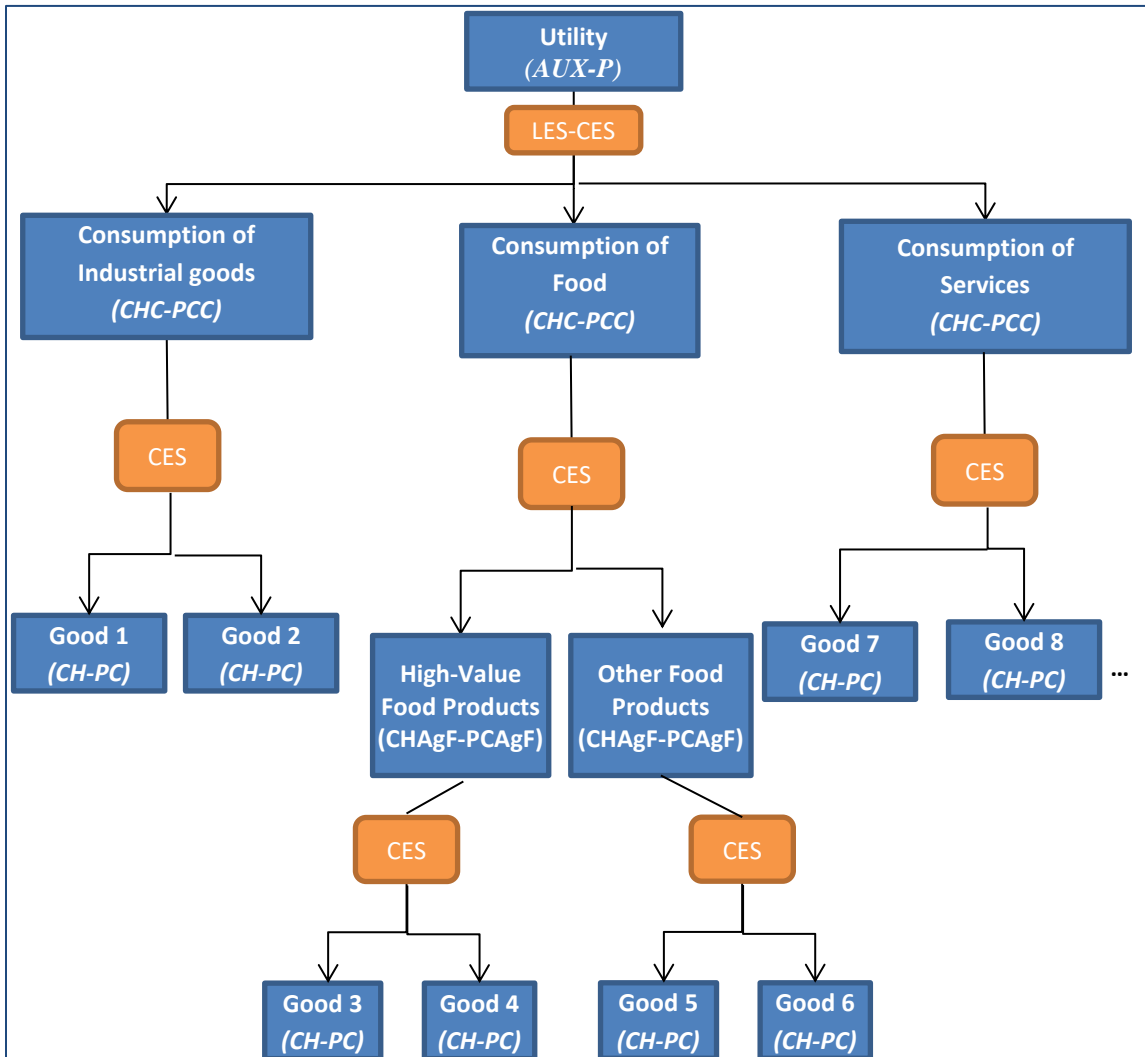
Source: authors

The final consumption of each "broad" category, AGI, of goods, $CHC_{AGI,r,t}$, is a CES of the final consumption of each good, $CH_{i,r,t}$, of which price is $PC_{i,r,t}$. This allows the introduction of different levels of elasticity of substitution within each "broad" category of goods. Concerning food, there is another level of nesting, as total consumption of food is a CES of the consumption of two sets of food products, high-value food products and other food products. This modelling choice allows the introduction of different levels of elasticity of substitution within these two sets of goods.

So, the first level of the final consumption nesting is as follows:

[5] The acronyms for the volume followed by its corresponding price appear in brackets.

$$CHC_{AGI,r,t} = Pop_{totpop,r,t} \left(cmin_{AGI,r} + a_{AGI,r}^{CC} \, AUX_{r,t} \left(\frac{P_{r,t}}{PCC_{AGI,r,t}} \right)^{\sigma_r^{CC}} \right) \qquad (33)$$

With:

AGI	a set of "broad" categories of goods
$cmin_{AGI,r}$	Minimal consumption of commodity AGI (per capita)
$a_{AGI,r}^{CC}$	Household consumption share parameter (over minimal consumption)
$AUX_{r,t}$	Utility
$P_{r,t}$	Shadow price of utility
$PCC_{AGI,r,t}$	Price of final private consumption
σ_r^{CC}	Households' consumption elasticity of substitution.

The price of utility is such that:

$$P_{r,t} \, AUX_{r,t} = \sum_{AGI} PCC_{AGI,r,t} \left(\frac{CHC_{AGI,r,t}}{Pop_{totpop,r,t}} - cmin_{AGI,r} \right) \qquad (34)$$

Concerning the consumption of food products ("broad" category 'Food'), the second level of the final consumption nesting is as follows:

$$CHAgF_{AgF,r,t} = a_{AgF,r}^{CAgF} \, CHC_{'Food',t} \left(\frac{PCC_{'Food'',r,t}}{PCAgF_{AgF,r,t}} \right)^{\sigma_{r,'Food'}^{C}} \qquad (35)$$

With:

AgF:	the set consisting of 'high-value food products' and 'other food products'
$CHAgF_{AgF,r,t}$:	the composite final consumption of goods from the set AgF
$a_{AgF,r}^{CAgF}$:	a share parameter
$PCAgF_{AgF,r,t}$:	the composite price of final consumption of goods from the set AgF
$\sigma_{r,'Food'}^{C}$:	the substitution elasticity of consumption between high-value food products and other food products.

The third level of the final consumption nesting concerning food products is as follows:

$$\forall i \in AgF, \quad CH_{i,r,t} = a_{i,r}^{C} \, CHAgF_{AgF,r,t} \left(\frac{PCAgF_{AgF,r,t}}{PC_{i,r,t}} \right)^{\sigma_{r,AgF}^{CAgF}} \qquad (36)$$

$$PCAgF_{AgF,r,t} \, CHAgF_{AgF,r,t} = \sum_{i \in AgF} PC_{i,r,t} CH_{i,r,t} \qquad (37)$$

With:

$a_{i,r}^C$:   a share parameter

$\sigma_{r,AgF}^{CAgF}$:   the substitution elasticity of consumption between goods from the set AgF.

Concerning the consumption of industrial products and services, the second level of the final consumption nesting is as follows:

$$\forall i \in AGI, \quad CH_{i,r,t} = a_{i,r}^C \, CHC_{AGI,r,t} \left(\frac{PCC_{AGI,r,t}}{PC_{i,r,t}}\right)^{\sigma_{r,AGI}^C} \tag{38}$$

$$PCC_{AGI,r,t} \, CHC_{AGI,r,t} = \sum_{i\in AGI} PC_{i,r,t} CH_{i,r,t} \tag{39}$$

Households maximize their utility subject to their consumption budget, $BUDH_{r,t}$, from which one can derive the shadow price of utility, $P_{r,t}$.

$$BUDH_{r,t} = \sum_i PC_{i,r,t} \, CH_{i,r,t} \tag{40}$$

The price paid by household for each commodity, $PC_{i,r,t}$, differs from the one received by the suppliers, $PDEMTOT_{i,r,t}$, by the amount of taxes collected, $taxcc_{i,r,t}$.

$$PC_{i,r,t} = PDEMTOT_{i,r,t} \, (1 + taxcc_{i,r,t}) \tag{41}$$

In case of a public closure where an additional consumption tax is levied, the term $(1 + taxcc_{i,r,t})$ in equation (42) becomes $(1 + taxcc_{i,r,t} + addtaxcc_{r,t})$. Finally, the consumer price index, $PIndC_{r,t}$, is a Fisher index.

$$PindC_{r,t} = \sqrt{\left[\frac{\sum_i PC_{i,r,t} \, CH_{i,r}^O}{\sum_i PC_{i,r}^O \, CH_{i,r}^O}\right]\left[\frac{\sum_i PC_{i,r,t} \, CH_{i,r,t}}{\sum_i PC_{i,r}^O \, CH_{i,r,t}}\right]} \tag{42}$$

with

$CH_{i,r}^O$ Benchmark value of households' consumption

$PC_{i,r}^O$ Benchmark value of final private consumption

2.4.2 Public demand

Government spending on each commodity is a fixed share, $\alpha_{i,r}^G$, of total public expenditure in goods and services, $BUDG_{r,t}$, and government purchases are subject to taxes, $taxgc_{i,r,t}$: it may be interpreted as a utility-maximizing government where the utility functional form is a Cobb-Douglas; put differently, the share of each commodity in government spending is constant in value (equation 44).

$$PCG_{i,r,t} \, CG_{i,r,t} = \alpha_{i,r}^G \, BUDG_{r,t} \tag{43}$$

$$PCG_{i,r,t} = PDEMTOT_{i,r,t} \left(1 + taxgc_{i,r,t}\right) \qquad (44)$$

With:

$PCG_{i,r,t}$ Price of final public consumption

In case of a public closure where an additional consumption tax is levied, the term $(1 + taxgc_{i,r,t})$ in equation (42) becomes $(1 + taxgc_{i,r,t} + addtaxcc_{r,t})$.

2.4.3 Demand for investment purposes

Finally, there is demand for capital goods. At the national level, total investment is $INVTOT_{r,t}$. This total investment is a demand for capital goods to each sector, *i.e.* demand for investment purposes, $KG_{i,r,t}$. The relation between total investment $INVTOT_{r,t}$ and demand for capital goods addressed to a specific sector $KG_{i,r,t}$ is characterized by a CES function: at the national level, there is a substitutability between demand for capital goods addressed to two sectors and the associated price-elasticity of substitution is constant. This relation is as follows:

$$KG_{i,r,t} = a_{i,r}^{KG} \, INVTOT_{r,t} \left(\frac{PINVTOT_{r,t}}{PKG_{i,r,t}}\right)^{\sigma^{KG}} \qquad (45)$$

With:

$a_{i,r}^{KG}$ Capital good scale coefficient

$PINVTOT_{r,t}$ Price of investment

$PKG_{i,r,t}$ Price of capital good consumption

σ^{KG} Capital good elasticity

The aggregated price of capital, $PINVTOT_{r,t}$, is thus a weighted sum of the price paid for each commodity, $PKG_{i,r,t}$.

$$PINVTOT_{r,t} \, INVTOT_{r,t} = \sum_i PKG_{i,r,t} \, KG_{i,r,t} \qquad (46)$$

Again, the price paid by the purchaser differs from the one received by the seller, as consumption taxes apply.

$$PKG_{i,r,t} = PDEMTOT_{i,r,t} \left(1 + taxkgc_{i,r,t}\right) \qquad (47)$$

In the case of a public closure where an additional consumption tax is levied, the term $(1 + taxkc_{i,r,t})$ in equation (42) becomes $(1 + taxkc_{i,r,t} + addtaxcc_{r,t})$.

2.4.4 Demand by geographic origin

MIRAGRODEP is a trade model explaining bilateral trade flows. It is based on the Armington assumption: commodities are assumed to be distinguished by place of origin, and thus, they are imperfect substitutes for

one another (Armington, 1969). Nested CES functions are used to reflect preferences among varieties originating from different countries. Therefore, countries can export and import the same product at the same time due to consumer preferences for different varieties. It results in an imperfect price transmission between domestic and international market and the intensity of this price transmission is highly dependent on the choice of the CES trade elasticities and the initial share of trade. The nested demand by geographic origin is represented on 0.

Figure 3: Demand by geographic origin[6]
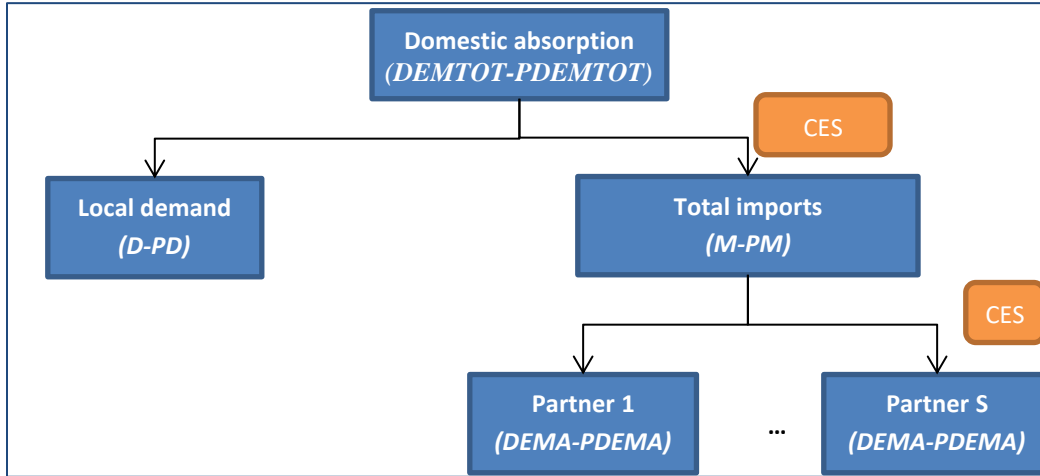
Source: authors

At the top level, total demand, $DEMTOT_{i,r,t}$, combines aggregated imports, $M_{i,r,t}$, and local production, $D_{i,r,t}$, through a CES function. From cost minimization subject to the CES aggregator, the following demand functions can be derived:

$$D_{i,r,t} = a_{i,r}^D \ DEMTOT_{i,r,t} \left(\frac{PDEMTOT_{i,r,t}}{PD_{i,r,t}} \right)^{\sigma_i^{ARM}} \tag{48}$$

$$M_{i,r,t} = a_{i,r}^M \ DEMTOT_{i,r,t} \left(\frac{PDEMTOT_{i,r,t}}{PM_{i,r,t}} \right)^{\sigma_i^{ARM}} \tag{49}$$

With:

$a_{i,r}^D$	Local demand scale coefficient
$a_{i,r}^M$	Total import demand scale coefficient
σ_i^{ARM}	Armington elasticity
$PD_{i,r,t}$	Price of demand for domestic commodity

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[6] The acronyms for the volume followed by its corresponding price appear in brackets.

$$PM_{i,r,t} \qquad \text{Aggregated price of imports}$$

Consequently, the price of the aggregated commodity, $PDEMTOT_{i,r,t}$, is a weighted sum of aggregated imports, $PM_{i,r,t}$, and of the price of the domestically produced commodity, $PD_{i,r,t}$, which differs from the amount received by the producer, $PY_{i,r,t}$, since production taxes, $taxP_{i,r,t}$, apply.

$$PDEMTOT_{i,r,t} \, DEMTOT_{i,r,t} = PD_{i,r,t} \, D_{i,r,t} + PM_{i,r,t} \, M_{i,r,t} \tag{50}$$

$$PD_{i,r,t} = PY_{i,r,t} \, (1 + taxP_{i,r,t}) \tag{51}$$

At the second level, total imports, $M_{i,r,t}$, are a CES combination of imports from the different trading partners, $DEMA_{i,s,r,t}$. Cost minimization under the CES aggregation constraint leads to the following demand function:

$$DEMA_{i,s,r,t} = a_{i,s,r}^{IMP} \, M_{i,r,t} \left(\frac{PM_{i,r,t}}{PDEMA_{i,s,r,t}} \right)^{\sigma_i^{IMP}} \tag{52}$$

With:

$$a_{i,s,r}^{IMP} \qquad \text{Import demand scale coefficient}$$

$$\sigma_i^{IMP} \qquad \text{Import elasticity}$$

$$PDEMA_{i,s,r,t} \quad \text{Price of bilateral trade}$$

This specification implies that the price of aggregated imports is a weighted sum of the price paid to the different partners. The price paid by the purchaser differs from the CIF price as import duties, $DD_{i,s,r,t}^{A}$, apply.

$$PM_{i,r,t} \, M_{i,r,t} = \sum_s PDEMA_{i,s,r,t} \, DEMA_{i,s,r,t} \tag{53}$$

$$PDEMA_{i,s,r,t} = PCIF_{i,s,r,t} \left(1 + DD_{i,s,r,t}^{A} \right) \tag{54}$$

And the CIF price is determined by the production costs, on which taxes apply, plus the transportation costs.

$$PCIF_{i,s,r,t} = PY_{i,s,t} \left(1 + taxEXP_{i,s,r,t} + taxAMF_{i,s,r,t} \right) \left(1 + taxP_{i,s,t} \right) + MUO_{i,s,r} \, PTr_{i,s,r,t} \tag{55}$$

with

$$PTr_{i,s,r,t} \qquad \text{Price of transportation per commodity exported}$$

$$MUO_{i,s,r} \qquad \text{Transport coefficient}$$

Following the consistent aggregator methodology as defined in Laborde, Martin, and van der Mensbrugghe (2011), aggregation of volumes differs whether they are estimated at world prices or at domestic prices (see below). Hence, the shadow price of bilateral trade, $PDEM_{i,s,r,t}$, is evaluated as follows:

$$PDEM_{i,s,r,t} = PCIF_{i,s,r,t}(1 + DD_{i,s,r,t}) \tag{56}$$

which leads to the definition of the aggregator $TRADE_{i,s,r,t}$:

$$DEMA_{i,s,r,t}\ PDEMA_{i,s,r,t} = PDEM_{i,s,r,t}\ TRADE_{i,s,r,t} \tag{57}$$

2.4.5 Demand for transportation services

The volume of transportation $Tr_{i,s,r,t}$ required to move commodity i imported by region r from region s is a fixed proportion $MUO_{i,s,r}$ of total imports $TRADE_{i,s,r,t}$.

$$Tr_{i,s,r,t} = MUO_{i,s,r}\ TRADE_{i,s,r,t} \tag{58}$$

Transportation demand per mode, $TrMode_{Transport,i,s,r,t}$, is then determined as being a fixed share $a^{Tr}_{Transport,i,s,r}$ of total transportation demand. Implicitly, thus, total demand for transportation is a Cobb-Douglas type of function. Hence, the exact price formulation for the aggregated price of transportation, $PTr_{i,s,r,t}$, is the dual form of a Cobb-Douglas.

$$PTrMode_{Transport,t}\ TrMode_{Transport,i,s,r,t} = a^{Tr}_{Transport,i,s,r}\ Tr_{i,s,r,t}\ PTr_{i,s,r,t} \tag{59}$$

$$PTr_{i,s,r,t} = \prod_{Transport} PTrMode_{Transport,t}^{a^{Tr}_{Transport,i,s,r}} \tag{60}$$

with

$PTrMode_{Transport}$: Price of transport per mode

$PTr_{i,r,s,t}$: Price of transportation by commodity and partners

2.5 Supply and market clearing

2.5.1 Transportation market

The world supply of transportation services per mode, $WorldTr_{Transport,t}$, follows a Cobb-Douglas specification (equation 62). It follows that the supply from each region, $TrSupply_{Transport,r,t}$, is a constant share of the world value of transportation (equation 63).

$$WorldTr_{Transport,t} = c^{T}_{Transport} \prod_{r} TrSupply_{Transport,r,t}^{a^{TrSupply}_{Transport,r}} \tag{61}$$

$$PY_{Transport,r,t}(1 + taxP_{Transport,r,t})\ TrSupply_{Transport,r,t} =$$
$$a^{TrSupply}_{Transport,r}\ PTrMode_{Transport,t}\ WorldTr_{Transport,t} \tag{62}$$

with

$c^{T}_{Transport}$: Scale coefficient

$a^{TrSupply}_{Transport,r}$: Share of each region in the world transport production

Market for transportation clears since demand of transportation is equal to supply (equation 64). Equilibrium on the transportation market determines the world prices of transportation per mode, $PTrMode_{Transport,t}$.

$$WorldTr_{Transport,t} = \sum_{i,r,s} TrMode_{Transport,i,r,s,t} \tag{63}$$

2.5.2 Commodity market

In each region, supply of each commodity is equal to demand. Market clearing determines the price of each commodity, $PY_{i,r,t}$.

$$Y_{i,r,t} = D_{i,r,t} + \sum_s TRADE_{i,r,s,t} \tag{64}$$

If sector i is the transportation sector, then $TrSupply_{i,r,t}$ is added on the right side of equation (65).

2.5.3 Factors of production market

2.5.3.1 Labor market

Total supply of skilled workers, $\bar{H}_{r,t}$, is fixed and grows exogenously. Skilled workers are assumed to be perfectly mobile across all sectors, and there is no unemployment. Hence, the equilibrium between supply and demand determines the wage rate.

$$\bar{H}_{r,t} = \sum_j H_{j,r,t} \tag{65}$$

Regarding unskilled workers ($\bar{L}_{r,t}$), total supply is exogenous and grows at an exogenous rate.

Unskilled workers are not perfectly mobile between rural and urban areas. A constant elasticity of transformation (CET) is used to characterize the allocation of unskilled workers between rural and urban activities. Unskilled workers maximize their income subject to the CET aggregator, which leads to the following supply function:

$$Lt_{Ltype,r,t} = b^{Lt}_{Ltype,r} \bar{L}_{r,t} \left(\frac{WLt_{Ltype,r,t}}{\overline{WL}_{r,t}}\right)^{\sigma^L} \tag{66}$$

With

$Lt_{Ltype,r,t}$:　　Labor supply on the Ltype market, either urban or rural activities.

$b^{Lt}_{Ltype,r}$:　　Labor scale coefficient

$\overline{WL}_{r,t}$:　　Aggregated wage for unskilled workers

σ^L:　　Labor elasticity

It follows that the aggregated wage for unskilled workers $\overline{WL}_{r,t}$ is a weighted sum of the wages received on each market:

$$\overline{WL}_{r,t} \, \bar{L}_{r,t} = \sum_{Ltype} WLt_{Ltype,r,t} \, Lt_{Ltype,r,t} \tag{67}$$

which is determined by the equilibrium between supply and demand.

$$Lt_{Ltype,r,t} = \sum_j L_{j,r,t} \tag{68}$$

2.5.3.2 Land market

Land mobility across sectors is assumed to be imperfect. Land supply, $\overline{TE}_{r,t}$ behaves as an isoelastic function of the real return to land (Lee and Mensbrugghe, 2001). This implies that the greater the real overall return to land, the greater will be the overall supply of land.

$$\overline{TE}_{r,t} = \overline{TE}_r^O \left(\frac{\overline{WTE}_{r,t}}{P_{r,t}} \right)^{\sigma_r^{TE}} \tag{69}$$

with

$\overline{TE}_r^O$:   Benchmark value of total land supply in region z

$\overline{WTE}_{r,t}$:   Aggregated price for land in region z

σ_r^{TE}:   Total land supply elasticity

To represent the imperfect mobility of land, supply to each activity, $TE_{j,r,t}$, is determined following a CET aggregation. Landowners maximize their income subject to the CET aggregator, which leads to the following first order condition:

$$TE_{j,r,t} = b_{j,r}^{TE} \, \overline{TE}_{r,t} \left(\frac{WTE_{j,r,t}}{\overline{WTE}_{r,t}} \right)^{\sigma^{TE}} \tag{70}$$

with

$b_{j,r}^{TE}$:   Land scale coefficient

σ^{TE}:   Land elasticity

It follows that the aggregated price of land is a weighted sum of the price received in each activity.

$$\overline{WTE}_{r,t} \, \overline{TE}_{r,t} = \sum_j WTE_{j,r,t} \, TE_{j,r,t} \tag{71}$$

2.5.3.3 Capital market

At each period, the capital stock invested by region s in activity j in region r, $K_{j,s,r,t}$, is given by the depreciated stock of capital inherited from the preceding period plus new investment $INV_{j,s,r,t}$

$$K_{j,s,r,t} = K_{j,s,r,t-1}(1 - \delta_r) + INV_{j,s,r,t} \tag{72}$$

with

δ_r: Depreciation rate

The investment per activity and region of destination $INV_{j,s,r,t}$ depends on the rate of return to capital $WK_{j,r,t}$, the aggregated price of new capital $PINVTOT_{r,t}$ and capital stock $KTOT_{j,r,t}$. [7]

$$INV_{j,s,r,t} = B_{s,t}\, a_{j,s,r}\, KTOT_{j,r,t}\, e^{\alpha \left(\frac{WK_{j,r,t}}{PINVTOT_{r,t}}\right)} \qquad (73)$$

with

$B_{s,t}$:	Scale coefficient for investment
$a_{j,s,r}$:	Investment scale coefficient
α:	Elasticity of investment to return on capital

Total investment made in region r, $INVTOT_{r,t}$, is simply the sum of investment made in each sector of each region:

$$INVTOT_{r,t} = \sum_{j,s} INV_{j,s,r,t} \qquad (74)$$

In each sector, total supply of capital equals demand, which determines the rate of return to capital specific to this sector ($WK_{j,r,t}$).

$$KTOT_{i,r,t} = \sum_s K_{i,s,r,t} \qquad (75)$$

The remunerations of unskilled labor ($\overline{WL}_{r,t}$), skilled labor ($WH_{r,t}$), land ($WTE_{j,r,t}$) and natural resources ($WRN_{j,r,t}$) in each country r are endogenous variables. To get a complete view on how remunerations of productive factors are modified by a reform, a rate of remuneration of capital, $WKbar_{r,t}$, is calculated:

$$WKbar_{r,t} \sum_j KTOT_{j,r,t} = \sum_j WK_{j,r,t} KTOT_{j,r,t} \qquad (76)$$

2.6 Macroeconomic relations

In each region, total investment must be equal to total savings:

$$SAVH_{r,t} + SAVG_{r,t} - CAB_{r,t} = \sum_{i,s} PINVTOT_{s,t}\, INV_{i,r,s,t} \qquad (77)$$

Where $CAB_{r,t}$ represents the current account balance, which is a constant share $SOLD_{r,t}$ of GDP at market prices, $GDPMP_{r,t}$.

$$CAB_{r,t} = GDPMP_{r,t}\, SOLD_{r,t} \qquad (78)$$

The sum of all current account balances is equal to zero:

$$\sum_r CAB_{r,t} = 0 \qquad (79)$$

World GDP is the simply the sum of regional GDPs, $GDPMP_{r,t}$:

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[7] For a complete discussion on the investment behaviour, see Decreux and Valin (2007).

$$PIBMVAL_t = \sum_r GDPMP_{r,t} \tag{80}$$

Consistent with the system of national accounting, each region's GDP at market prices is given by the sum of payments to factors of production and of indirect taxes.

$$GDPMP_{r,t} = \sum_j PVA_{j,r,t} VA_{j,r,t} + \sum_i \{RECPROD_{i,r,t} + RECEXP_{i,r,t} + RECDD_{i,r,t} +$$

$$RECCONS_{i,r,t}\} \tag{81}$$

Real GDP, $GDPVOL_{r,t}$, is computed by dividing GDP at market prices by a consumer price index $PIndC_{r,t}$:

$$GDPVOL_{r,t} = \frac{GDPMP_{r,t}}{PIndC_{r,t}} \tag{82}$$

Lastly, the consumer price index is a Fisher index of consumer prices:

$$PIndC_{r,t} = \sqrt{\frac{\sum_i PC_{i,r,t} CHO_{i,r} \sum_i PC_{i,r,t} CH_{i,r,t}}{\sum_i PCO_{i,r} CHO_{i,r} \sum_i PCO_{i,r} CH_{i,r,t}}} \tag{83}$$

With

$CHO_{i,r}$ Initial households' consumption

$PCO_{i,r}$ Initial consumption prices.

2.7 Economic Closures

In MIRAGRODEP, each agent achieves a balance between expenses and revenues: concerning households, revenue from the ownership of productive factors and from received transfers equals consumption expenditures, plus savings, plus transfers paid; firms' spending (including payment to capital) equals firms' revenue. At the country level, a gap between private and public savings and investment can occur due to a current account surplus or deficit, which leads to real exchange rate adjustments (determining relative international prices among economies). Furthermore, supply equals demand for all commodities and factors in the economy.

More specifically, the following assumptions are made regarding the savings-investment balance, the public closure and the current account balance.

For this research, the so-called Neo-Classical closure is adopted: the marginal propensity to save is constant such that variations in income lead to variations in savings, which lead to variations in investment. Thus, investment is "savings-driven."

Regarding the public closure, when implementing a scenario which systematically affects public revenues, the user has the choice between six options:

- Public expenses per head vary and adjust to variation in public revenues such that the ratio public deficit / GDP is constant.

- No variation in real public expenses per head and a lumpsum tax is levied such that the ratio public deficit / GDP is constant.

- No variation in real public expenses per head and an additional consumption tax is levied such that the ratio public deficit / GDP is constant.

- No variation in real public expenses per head and an additional income tax is levied such that the ratio public deficit / GDP is constant.

- No variation in public expenses in proportion of GDP at market prices and a lumpsum tax is levied such that the ratio public deficit / GDP is constant.

- No variation in budgetary expenses in nominal terms and public saving is constant in proportion of GDP at market prices

The choice of either option is not neutral and particularly important when it comes to welfare analysis. In order not to bias the welfare analysis results, a closure with no variation in real public expenses per head and a tax (either a lumpsum tax, or an additional consumption tax or and additional income tax) levied to maintain the ratio public deficit / GDP constant should be preferred. A lumpsum tax is not distortive so from an economic point of view, it should be considered. An additional consumption or income tax is sometimes preferred, as this policy option is considered as more realistic.

Finally, we assume in MIRAGRODEP that the current account balance is fixed (in the model, this is expressed as a percent of global GDP). The fixed level of the current account balance is maintained through an adjustment of the real exchange rate. With this specification, there is no "free lunch;" if a country needs to increase its imports, it will have to increase its exports as well through a depreciation of its real exchange rate. In doing so we avoid biased welfare analysis, where the country's consumption, and welfare, is "subsidized" through transfers from the rest of the world (capital inflows).

3. Dynamics, baseline and scenario

MIRAGRODEP is a dynamic CGE model of the recursive type. There is no expectation of future values by any agent. At each period t, each variable takes initially the value which it had at the end of the previous period. For illustration, the first variable that we presented above is total output of good j in country/region r at time t: $Y_{j,r,t}$. At each period, this variable is initialized by $Y.l_{j,r,t} = Y.l_{j,r,t-1}$. In GAMS, the suffix ".l" is the current value of a variable; so, $Y.l_{j,r,t} = Y.l_{j,r,t-1}$ means that in t, the current value of $Y_{j,r,t}$ is the value taken at t-1.

3.1 Dynamic relations

Dynamic relations in MIRAGRODEP concern the accumulation of productive factors and technical progress, or total factor productivity.

Concerning the accumulation of productive factors, skilled and unskilled labor supplies are exogenously increased by a growth rate of the economically active population (source: United Nations) and unskilled labor supply is allocated to rural or urban activities following equation (67), which is a Constant Elasticity of Transformation function. Other factors augment endogenously, as explained by equation (70) concerning land, and by equations (73) and (74) concerning capital. The supply of Natural Resources is constant.

Technical progress is incorporated in MIRAGRODEP through a Total Factor Productivity variable $PGF_{r,t}$ which is endogenous and adjusts such that the growth of GDP in each country or region is equal to the World Bank's predictions. If information about differential rate of growth of Total Factor Productivity is available, equation (8) is effective and a differential evolution of technical progress by sector and country is included in the model.

3.2 Baseline and scenario

In the modelling of an impact of a reform or a shock on the world economy, the dynamic version of MIRAGRODEP first builds a baseline, i.e. a simulation of the world economy over a specific number of years without any reform or any shock; the baseline is sometimes called the "Business As Usual" simulation. Then one or more scenarios are run; these are simulations of the world economy over the same number of years, with the reform(s) studied under the research project.

Results are evaluated by comparison of the scenario and the baseline. So, for example, if the research project concludes that the reform will lead to a x% increase of country A's GDP in 2030 and that the simulation started in 2020, it does not mean that country A's GDP is expected to increase by x% between 2020 and 2030, but that in 2030, the comparison of the scenario to the baseline gives an x% increase of country A's GDP: this is really the impact of the reform that leads to this augmentation.

Let us make two remarks at this stage. First, this way of modeling baseline and scenarios adds a dimension to every variable. For example, total output of good j in country/region r at time t is not $Y_{j,r,t}$, but $Y_{j,r,t,sim}$. The dimension "sim" is added and consists in a set with the baseline (called "Ref" in MIRAGRODEP) and each scenario. The impact of the "Scen1" scenario on country A's GDP in percentage is therefore: $100 * (\frac{Y_{j,r,t,'SCEN1'}}{Y_{j,r,t,'Ref'}} - 1)$.

Second, the modeler can decide to include in the baseline a reform that is already adopted and expected to be implemented after the initial year of the modelling: it means that this reform will be included in the baseline and in the scenario. For example, consider the case where the modeling includes three countries A, B, and C, and the rest of the world, and the modeling exercise simulates the world economy from t_0 to t_1. If the research evaluates the impact of a trade agreement between A and B, and if a trade agreement between A and C is already adopted in t_0, but its implementation starts between t_0 and t_1, it is better to

include the agreement between A and C in both the baseline and the scenario. The representation of the world economy is improved.

4. Running MIRAGRODEP

Using MIRAGRODEP for policy analysis requires a number of steps which the user needs to follow strictly so that the model can run properly. It is important to follow the indicated sequence, otherwise a bug will occur. Also, note all the files must be modified by the user. Handling an efficient and clean management of files is a key issue when using MIRAGRODEP. There are six files that need to work on, one Excel file and five Gams files[8]:

- Aggregation.xlsx
- options.gms
- MSD.gms
- Ref.gms
- Simul.gms
- Results.gms

First of all, the aggregation levels for products and regions have to be defined in the Aggregation.xlsx file. In the Excel file, the user is requested to decide 1) a sector disaggregation (see **Error! Reference source not found.**); 2) a geographic disaggregation (see **Error! Reference source not found.**). Let us remind that data comes from the GTAP database.

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[8] It supposes that the modeler does not operate a specific treatment of tariffs data.

Figure 4: Selection of sector disaggregation in MIRAGRODEP

GTAP Code	Label	Aggregation Code
pdr	Paddy rice	Agriculture
wht	Wheat	Agriculture
gro	Cereal grains nec	Agriculture
v_f	Vegetables. fruit. nuts	Agriculture
osd	Oil seeds	Agriculture
c_b	Sugar cane. sugar beet	Agriculture
pfb	Plant-based fibers	Agriculture
ocr	Crops nec	Agriculture
ctl	Cattle.sheep.goats.horses	Agriculture
oap	Animal products nec	Agriculture
rmk	Raw milk	Agriculture
wol	Wool. silk-worm cocoons	Agriculture
frs	Forestry	Industry
fsh	Fishing	Industry
coa	Coal	Industry
oil	Oil	Industry
gas	Gas	Industry
omn	Minerals nec	Industry
cmt	Meat: cattle.sheep.goats.horse	Agrifood
omt	Meat products nec	Agrifood
vol	Vegetable oils and fats	Agrifood
mil	Dairy products	Agrifood
pcr	Processed rice	Agrifood
sgr	Sugar	Agrifood
ofd	Food products nec	Agrifood
b_t	Beverages and tobacco products	Agrifood
tex	Textiles	TextApparel
wap	Wearing apparel	TextApparel
lea	Leather products	TextApparel
lum	Wood products	Industry
ppp	Paper products. publishing	Industry
p_c	Petroleum. coal products	Industry
crp	Chemical.rubber.plastic prods	Industry
nmm	Mineral products nec	Industry
i_s	Ferrous metals	Industry
nfm	Metals nec	Industry
fmp	Metal products	Industry
mvh	Motor vehicles and parts	Industry
otn	Transport equipment nec	Industry
ele	Electronic equipment	Industry
ome	Machinery and equipment nec	Industry
omf	Manufactures nec	Industry
ely	Electricity	Services
gdt	Gas manufacture. distribution	Services
wtr	Water	Services
cns	Construction	Services
trd	Trade	Services
otp	Transport nec	Services
wtp	Sea transport	Services
atp	Air transport	Services
cmn	Communication	Services
ofi	Financial services nec	Services
isr	Insurance	Services
obs	Business services nec	Services
ros	Recreation and other services	Services
osg	PubAdmin/Defence/Health/Educat	Services
dwe	Dwellings	Services

Sectors Nb: 5

Aggregation Code	GTAP tariffs	Labor type 1	Total agri	Agri	Informal Sector	Dem_Food	Dem_Ind	Dem_Services	LandCET_lvl1
Agriculture	Y	Y	Y	Y		Y			Y
Industry	Y						Y		
Agrifood	Y		Y			Y			
TextApparel	Y						Y		
Services	Y							Y	

Source: authors

Concerning the sector disaggregation, the user needs to fill the third column (C) in yellow and type the same aggregation code for all the GTAP sectors that will be aggregated together in the same MIRAGRODEP sector. In this sheet (**Error! Reference source not found.**), extracted from the Agregation.xlsx which is used for the simulation in the next section, GTAP sectors are listed in the first two columns (A and B), while the MIRAGRODEP sectors are listed in the third one (C): here the GTAP sectors Textiles (tex), Wearing apparel (wap), and Leather products (lea) are aggregated in the same MIRAGRODEP sector titled TextApparel. As column C is filled, the fifth column (E) in light grey is automatically filled with the number and name of the MIRAGRODEP sectors: here 5 sectors.

Concerning the geographic disaggregation (see **Error! Reference source not found.**), the user needs to fill the third column (C) in yellow and type the same aggregation code for all the GTAP countries or regions that will be aggregated together in the same MIRAGRODEP country/region.

Figure 5: Selection of geographic disaggregation in MIRAGRODEP

Mapping table

GTAP Code	Label	Aggregation Code
AUS	Australia	RichAsiaOceania
NZL	New Zealand	RichAsiaOceania
XOC	Rest of Oceania	PoorAsiaOceania
CHN	China	EmerggAsiaOceania
HKG	Hong Kong	EmerggAsiaOceania
JPN	Japan	RichAsiaOceania
KOR	Korea	RichAsiaOceania
TWN	Taiwan	RichAsiaOceania
XEA	Rest of East Asia	PoorAsiaOceania
KHM	Cambodia	PoorAsiaOceania
IDN	Indonesia	EmerggAsiaOceania
LAO	Laos	PoorAsiaOceania
MYS	Malaysia	EmerggAsiaOceania
PHL	Philippines	EmerggAsiaOceania
SGP	Singapore	RichAsiaOceania
THA	Thailand	EmerggAsiaOceania
VNM	Viet Nam	PoorAsiaOceania
XSE	Rest of Southeast Asia	PoorAsiaOceania
BGD	Bangladesh	EmerggAsiaOceania
IND	India	EmerggAsiaOceania
PAK	Pakistan	EmerggAsiaOceania
LKA	Sri Lanka	PoorAsiaOceania
NPL	Nepal	PoorAsiaOceania
XSA	Rest of South Asia	PoorAsiaOceania
CAN	Canada	NorthAmerica
USA	United States of America	NorthAmerica
MEX	Mexico	EmggLatinAm
XNA	Rest of North America	LatinAmerica
ARG	Argentina	EmggLatinAm
BOL	Bolivia	LatinAmerica
BRA	Brazil	EmggLatinAm
CHL	Chile	EmggLatinAm
COL	Colombia	EmggLatinAm
ECU	Ecuador	LatinAmerica
PRY	Paraguay	LatinAmerica
PER	Peru	EmggLatinAm
URY	Uruguay	LatinAmerica
VEN	Venezuela	LatinAmerica
XSM	Rest of South America	LatinAmerica
CRI	Costa Rica	LatinAmerica
GTM	Guatemala	LatinAmerica
NIC	Nicaragua	LatinAmerica
PAN	Panama	LatinAmerica
SLV	El Salvador	LatinAmerica
HND	Honduras	LatinAmerica
XCA	Rest of Central America	LatinAmerica
DOM	Dominican Republic	LatinAmerica
JAM	Jamaica	LatinAmerica

Regions Nb: **10**

Aggregation Code	North	Scarce land	Dual labor market
RichAsiaOceania	Y	Y	
PoorAsiaOceania			
EmerggAsiaOceania		Y	
NorthAmerica	Y		
EmggLatinAm			
LatinAmerica			
Europe	Y	Y	
ROW			
OtherEmgg			
Africa			

Source: authors

In this sheet (**Error! Reference source not found.**), extracted from the Agregation.xlsx which is used for the simulation in the next section, GTAP countries/regions are listed in the first two columns (A and B), while the MIRAGRODEP countries/regions are listed in the third one (C): here the GTAP regions Canada (CAN), and United States of America (USA) are aggregated in the same MIRAGRODEP region titled NorthAmerica. As column C is filled by the modeler, the fifth column (E) in light grey is filled with the number and name of the MIRAGRODEP regions: here 10 regions.

Once this is done, the AggregationGTAP.gms file must be run to execute the selected aggregation.

After the aggregation done, the user needs to define in options.gms file:

- the first (TIni) and last year (Tend) of the simulation.

- The choice for the public closure: the scalar "pubclosure" must be either equal to 0, or, 1, or 2, or 3, or 4, or 5.

- The parameter of imperfect mobility that must be put at 1 if this modelling option is selected by the user.

- The value of the scalar BL figuring the endogenous total factor productivity. It is very seldom that this parameter is changed. Almost all dynamic simulations start with BL=1, meaning that as the baseline is run first, the total factor productivity is endogenous such that the GDP of each region is equal to exogenous GDP (see subsection of baseline).

Once all the options are selected, running a simulation involves the execution of four (4) files in the following order[9]:

- MSD.gms: the core model file; it must be solved for the first year and it includes the calibration file (Calib.gms): see **Error! Reference source not found.**.

- Ref.gms: the file for the reference (baseline) scenario

- Simul.gms: the simulation file

- Results.gms: the results file

The execution sequence is managed by GAMS *save* and *restart* functions that reduce considerably the amount of work when working with large models. So, the MSD.gms[10] file is first run and saved, then the Ref.gms file is run starting with the results of the MSD.gms file. and is saved in turn. The Simul.gms file is then run starting from the Ref.gms results and is saved to be the starting point of the Results.gms file. Using this configuration, if one needs to just change the reporting of some results, there is no need to run the whole model. The only thing to do is to modify the results file and run it, saving potentially a huge amount of time[11]. Alternatively, one can run all the four files using master_file.gms with the following commands[12]:

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[9] All the other files must remain unchanged.

[10] One may also run the Calib.gms file alone to check some features of the model and the aggregation/calibration process.

[11] Depending on the degree of disaggregation, the type of simulation and the period (number of years), each scenario may take more than 30 mns.

[12] The results at each stage are stored in a gdx file.

Figure 6: How MIRAGRODEP operates
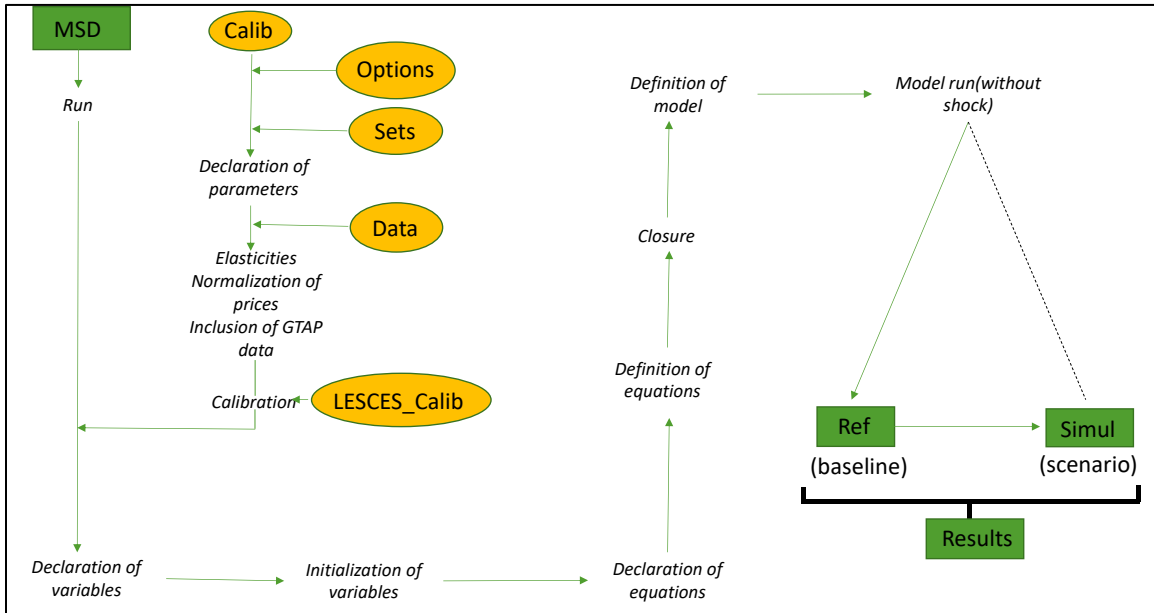
Source: authors

EXECUTE 'gams MSD.gms   s=restart/msd gdx=gdx/msd'

EXECUTE 'gams Ref.gms   r=restart/msd s=restart/ref gdx=/gdx/ref'

EXECUTE 'gams Simul.gms   r=restart/ref s=restart/simul gdx=/gdx/simul'

EXECUTE 'gams Results.gms   r=restart/simul gdx=/gdx/results'

It is of course necessary before running the master file, that the aggregation is done as well as the selection of the options of the model.

5. An illustration

Let us now present an illustration of a (simple) research project conducted with MIRAGRODEP. We objective of the project is to evaluate the potential impacts of a free trade area between Europe and North America, consisting of Canada and the US.

5.1 Disaggregation

We adopt a simple sector and geographic disaggregation to get an easy execution of the program and interpretation of results. We adopt a geographic disaggregation (0) with a region composed of the USA and Canada, called "North America" and a region called Europe consisting in the European Economic Area, i.e. the European Union (with 28 countries as United Kingdom is included – it is before Brexit) and the European Free Trade Association (Iceland, Liechtenstein, and Norway). These are the two regions that are supposed to join in a free trade agreement.

Table 1: Geographic disaggregation - Illustration

#	Code name	Label	GTAP regions
1	Africa	Africa	BEN, BFA, BWA, CIV, CMR, EGY, ETH, GHA, GIN, KEN, MDG, MOZ, MUS, MWI, NAM, NGA, RWA, SEN, TGO, TUN, TZA, UGA, ZMB, ZWE, XNF, XWF, XCF, XAC, XEC, XSC
2	EmerggAsiaOceania	Emerging Asia and Oceania	BGD, CHN, HKG, IDN, IND, MYS, PAK, PHL, THA
3	EmggLatinAm	Emerging Latin America	ARG, BRA, CHL, COL, MEX, PER
4	Europe	Europe	ALB, AUT, BEL, BGR, CHE, CYP, CZE, DEU, DNK, ESP, EST, FIN, FRA, GBR, GRC, HRV, HUN, IRL, ITA, LTU, LUX, LVA, MLT, NLD, NOR, POL, PRT, ROU, SVK, SVN, SWE, XEF
5	LatinAmerica	Latin America	BOL, CRI, DOM, ECU, GTM, HND, JAM, NIC, PAN, PRI, PRY, SLV, TTO, URY, VEN, XNA, XSM, XCA, XCB
6	NorthAmerica	North America	CAN, USA
7	OtherEmgg	Other Emerging Countries	ISR, MAR, RUS, TUR, UKR, ZAF
8	PoorAsiaOceania	Poor Asia and Oceania	ARM, AZE, GEO, IRN, KAZ, KGZ, KHM, LAO, LKA, MNG, NPL, TJK, VNM, XOC, XEA, XSE, XSA, XSU, XWS
9	RichAsiaOceania	Rich Asia and Oceania	AUS, JPN, KOR, NZL, SGP, TWN
10	ROW	Rest of the World	ARE, BHR, BLR, JOR, KWT, OMN, QAT, SAU, XEE, XER, XTW

Source: authors

The other regions are selected based on a geographic and/or an income criterion. **Error! Reference source not found.** indicates sectoral disaggregation with five sectors: agriculture, agrifood which consists of food processing, industry (textiles, apparel and leather excluded), services and a sector called "TextApparel" which includes textiles, apparel and leather. The region Africa does not include emerging countries like Morocco, South Africa, which are in the "Other Emerging countries".

Table 2: Sectoral disaggregation - Illustration

#	Code	Labels	GTAP sectors
1	Agriculture	Agriculture	pdr, wht, gro, v_f, osd, c_b, pfb, ocr, ctl, oap, rmk, wol
2	Agrifood	Agrifood	cmt, omt, vol, mil, pcr, sgr, ofd, b_t
3	Industry	Industry	omn, frs, fsh, coa, oil, gas, lum, ppp, p_c, crp, nmm, i_s, nfm, fmp, mvh, otn, ele, ome, omf
4	Services	Services	isr, ely, gdt, wtr, cns, trd, otp, wtp, atp, cmn, ofi, obs, ros, osg, dwe
5	TextApparel	Textile and Apparel	tex, wap, lea

Source: authors

Let us explain the closures of the model.

- Concerning the labor market, we assume that employment in each country or region is constant. The impact of the agreement on the labor market will be appreciated through a variation of labor remuneration.

- Concerning the public closure, we assume that there is no variation in real public expenses per head, and that the ratio public deficit / GDP is constant: an additional consumption tax is levied to make sure that these constraints are respected.

- Concerning the external closure, we assume that the current account is constant in proportion of GDP. The real exchange rate of each region adjusts to fill this constraint.

5.2 Baseline

Conducting a baseline allows the user to visualize how each economy performs without the studied trade agreement. For instance, **Error! Reference source not found.** shows the evolution of regional GDPs between 2020 and 2030.

Figure 7: Evolution of regional GDPs in volume – 2020/2030
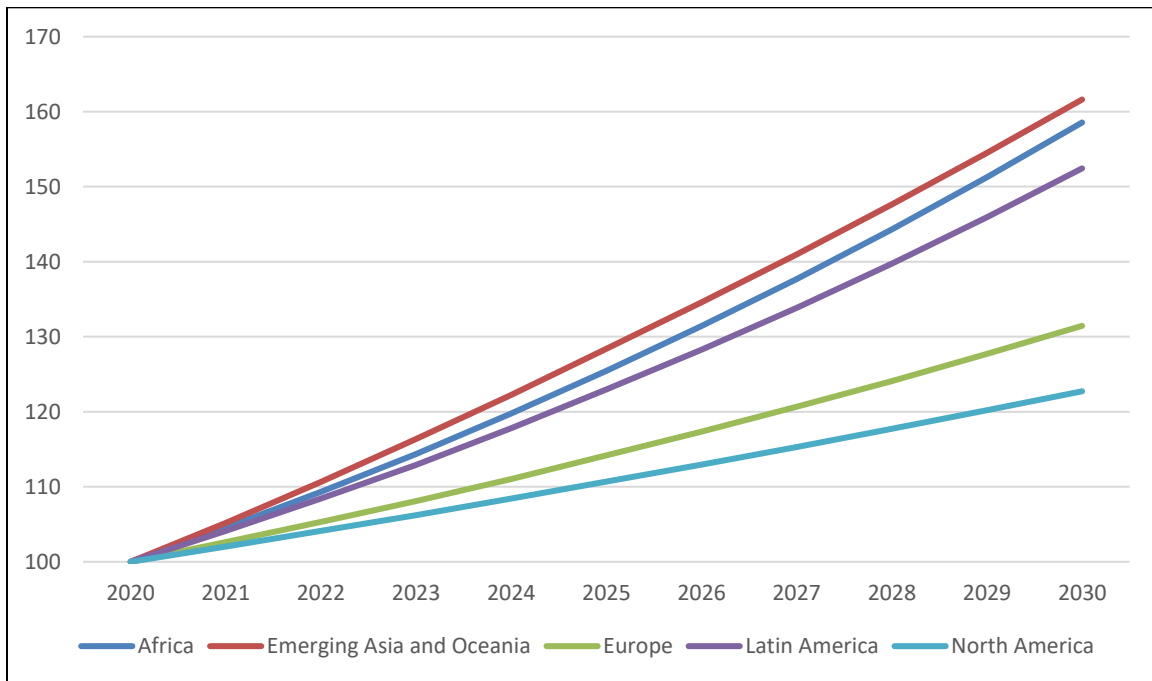
Source: MIRAGRODEP and authors' calculation
Note: to make the figure readable, only five regions are represented

Another illustration of the use of the baseline is given in 0. It indicates the evolution of export shares of the region in row to the region in column, from 2014 to 2030. For example, 38.5% of Africa's exports are towards Europe in 2014 and without any reform, this share decreases to 36.2% in 2030. North America

represents 23.4% of Europe's exports of goods and services; without any reform, this share is reduced by 1.5 percentage points (20.9%) in 2030.

Table 3: Trade matrix: share of region in column in total exports of region in row – 2014 and 2030 – Goods and services

2014	Africa	Emerging Asia and Oceania	Emerging Latin America	Europe	Latin America	North America	Other Emerging	Poor Asia and Oceania	Rich Asia and Oceania	Rest of the World
Africa	6,1%	21,6%	2,7%	38,5%	0,6%	11,0%	7,4%	1,4%	5,7%	4,8%
Emerging Asia and Oceania	3,7%	17,5%	5,6%	19,3%	1,3%	19,0%	4,5%	6,7%	18,8%	3,7%
Emerging Latin America	1,7%	13,7%	9,2%	13,3%	6,3%	44,2%	1,9%	1,4%	6,4%	1,8%
Europe	6,6%	21,9%	6,7%	0,0%	1,9%	23,4%	14,6%	4,3%	12,5%	8,2%
Latin America	1,8%	10,7%	11,1%	20,1%	9,8%	35,4%	3,0%	1,4%	5,3%	1,4%
North America	2,0%	12,8%	14,1%	21,9%	3,5%	25,6%	3,0%	1,6%	12,1%	3,4%
Other Emerging	5,7%	10,7%	1,5%	44,3%	0,7%	7,3%	8,2%	7,0%	8,4%	6,1%
Poor Asia and Oceania	1,2%	30,4%	1,6%	25,0%	0,5%	14,0%	6,4%	3,0%	15,2%	2,7%
Rich Asia and Oceania	1,5%	42,1%	3,4%	11,5%	0,9%	13,5%	2,4%	4,8%	17,0%	3,1%
Rest of the World	2,6%	24,2%	1,1%	15,0%	0,3%	14,5%	5,1%	2,2%	28,5%	6,6%
2030	Africa	Emerging Asia and Oceania	Emerging Latin America	Europe	Latin America	North America	Other Emerging	Poor Asia and Oceania	Rich Asia and Oceania	Rest of the World
Africa	7,3%	26,4%	2,6%	36,2%	0,7%	9,7%	6,0%	1,8%	5,0%	4,2%
Emerging Asia and Oceania	4,5%	21,7%	5,6%	17,8%	1,6%	16,8%	3,8%	8,0%	16,9%	3,4%
Emerging Latin America	2,0%	20,1%	8,9%	12,4%	7,0%	38,7%	1,5%	1,9%	5,9%	1,6%
Europe	7,6%	27,3%	6,7%	0,0%	2,2%	20,9%	11,7%	5,1%	11,6%	6,9%
Latin America	2,2%	14,5%	11,1%	18,2%	11,6%	32,3%	2,4%	1,7%	4,8%	1,2%
North America	2,3%	18,0%	13,9%	20,9%	3,8%	22,4%	2,4%	2,0%	11,4%	2,8%
Other Emerging	6,4%	13,7%	1,6%	43,4%	0,8%	6,6%	6,6%	8,3%	7,8%	4,9%
Poor Asia and Oceania	1,3%	37,4%	1,5%	22,8%	0,6%	11,9%	5,2%	3,4%	13,5%	2,3%
Rich Asia and Oceania	1,6%	48,5%	3,2%	10,5%	0,9%	11,4%	1,8%	5,0%	14,7%	2,4%
Rest of the World	2,8%	29,2%	1,1%	14,7%	0,4%	13,2%	4,1%	2,5%	26,5%	5,5%

Source: MIRAGRODEP and authors' calculation

5.3 Scenarios

We now present results concerning the impact of the free trade agreement between regions "Europe" (the European Economic Area) and "NorthAmerica" (Canada and the US). We call this agreement EUNA.

A benchmark is always interesting, as it gives a point of reference for the evaluation of the studied reform. Therefore, we present results of a full trade liberalization (FTL) scenario: all tariffs on trade in goods are completely removed with a linear cut in 5 years starting on 2020. The other scenario is a free trade agreement between Europe and North America where all tariffs on goods traded between both regions are removed with the same linear cut in 5 years.

To illustrate the richness of a Computable General Equilibrium model like MIRAGRODEP, we present results concerning macroeconomic variables (country dimension), then bilateral trade (country*country dimension), then sectoral production (country*sector dimension), and remuneration of productive factors in each region (country*productive factor dimension). There are many other variables that can be used to understand the economic impacts of each reform.

- Macroeconomic impacts

0 shows the macroeconomic impacts of a full trade liberalization in 2030 while 0 presents the same indicators concerning the Europe-North America trade agreement. The three macroeconomic indicators, presented in both tables, are the rate of variation of welfare of each region's representative consumer, the variation of GDP in volume and the variation of total exports in volume, all expressed in percent. Welfare is measured by equivalent variation, that is to say the minimal amount of money that must be transferred to the representative agent to be indifferent, at initial prices, with the new situation.

Table 4: FTL - Macroeconomic impacts – 2030 - %

	Variation Welfare	Variation GDP (volume)	Variation Exports (volume)
Rich Asia and Oceania	1.40	1.1	12.6
Poor Asia and Oceania	-0.79	-0.1	20.8
Emerging Asia and Oceania	0.32	0.2	17.0
North America	0.21	0.1	6.5
Emerging Latin America	-0.08	0.2	10.7
Latin America	-0.14	0.2	17.3
Europe	0.44	0.1	16.8
Rest of the World	0.51	0.2	8.4
Other Emerging Countries	0.46	0.4	13.4
Africa	-0.61	0.3	26.6
World	**0.32**	**0.2**	**14.6**

Source: MIRAGRODEP and authors' calculation

Of course, the macroeconomic impact of the full trade liberalization is significantly greater than the Europe-North America free trade agreement. The increase of world GDP is 0.2% in the case of the former reform, close to zero in the latter case. In terms of GDP in volume, the impact of the full trade liberalization is positive in each region except for "Poor Asia and Oceania" which is slightly negatively affected. Concerning the Europe-North America free trade agreement, the impact on GDP is positive for Europe and North America, but negative for all other regions.

Table 5: EUNA - Macroeconomic impacts – 2030 - %

	Variation Welfare	Variation GDP (volume)	Variation Exports (Volume)
Rich Asia and Oceania	-0.01	-0.01	-0.08
Poor Asia and Oceania	-0.02	-0.01	-0.1
Emerging Asia and Oceania	-0.02	-0.01	-0.09
North America	0.02	0	1.65
Emerging Latin America	-0.03	-0.01	-0.18
Latin America	-0.04	-0.02	-0.18
Europe	0.02	0.01	1.83
Rest of the World	-0.03	-0.01	-0.07
Other Emerging Countries	-0.02	-0.01	-0.11
Africa	-0.02	-0.02	-0.11
World	**0**	**-0.01**	**0.43**

Source: MIRAGRODEP and authors' calculation

Let us now present the impact on bilateral trade in value between each pair of regions, for the full trade liberalization scenario (**Error! Reference source not found.**), and for the Europe-North America trade agreement (0).

Table 6: FTL - Impact on bilateral trade in value – 2030 - %

	Africa	Emerging Asia and Oceania	Emerging Latin America	Europe	Rest of Latin America	North America	Other Emerging Countries	Poor Asia and Oceania	Rich Asia and Oceania	Rest of the World	World
Africa	-5.7	21.3	10.3	29.8	16.8	27,0	9.7	0.2	27.8	32,0	22.3
Emerging Asia and Oceania	68,0	6.7	28.8	21.2	42.8	8.7	23.6	30.6	5.4	17.2	16.9
Emerging Latin America	-5.2	12.7	-9.2	27.3	-13.5	7,0	58.5	5.1	20.4	26.8	9.4
Europe	-11.1	52.3	16.2	0,0	11.6	0.1	5.4	7.2	6.8	8.4	17.2
Rest of Latin America	6.8	30.5	-1.2	25.4	-6.8	11.2	91.2	4.4	14.6	21.1	15.1
North America	22.8	27.9	-12.5	12.6	9,0	-5.8	18.6	-6.5	2.2	11.3	6.4
Other Emerging Countries	-24.1	7.4	13.9	7.2	-5.1	2.8	-3.1	25.9	110.8	-4.2	13.3
Poor Asia and Oceania	14.1	6.7	86.6	23.6	57.7	44.5	-4,0	18,0	18.7	14.5	18.3
Rich Asia and Oceania	30.7	11.7	13.9	16.6	35.6	-1.6	76.2	11.7	10.4	24.6	12.6
Rest of the World	-32.4	8.9	-5.4	10.2	-19,0	-0.9	-18.9	-23.9	31.7	-25.4	8.6
World	19.7	18.5	8.9	18.2	12.7	5,0	14.1	19.1	13.2	11,0	14.2

Source: MIRAGRODEP and authors' calculation
Note: exporting region in row; importing region in column

Table 7: EUNA - Impact on bilateral trade in value – 2030 - %

	Africa	Emerging Asia and Oceania	Emerging Latin America	Europe	Latin America	North America	Other Emerging	Poor Asia and Oceania	Rich Asia and Oceania	Rest of the World	World
Africa	0,1	0,1	0,2	-0,4	0,1	-0,6	0,2	0,0	0,1	0,2	-0,1
Emerging Asia and Oceania	0,1	0,1	0,2	-0,1	0,1	-1,0	0,2	0,0	0,1	0,2	-0,1
Emerging Latin America	0,1	0,1	0,2	-0,7	0,2	-0,5	0,1	0,1	0,2	0,2	-0,2
Europe	-0,5	-0,4	-0,3		-0,4	10,3	-0,4	-0,5	-0,3	-0,4	1,8
Latin America	0,2	0,2	0,2	-0,4	0,2	-0,8	0,2	0,2	0,2	0,3	-0,2
North America	-1,0	-1,0	-0,8	12,3	-1,1	-1,3	-1,0	-0,9	-0,8	-1,0	1,7
Other Emerging	0,1	0,0	0,1	-0,3	0,1	-0,5	0,1	0,0	0,1	0,1	-0,1
Poor Asia and Oceania	0,1	0,0	0,1	-0,1	0,1	-1,2	0,2	0,0	0,1	0,2	-0,1
Rich Asia and Oceania	0,0	0,0	0,1	-0,2	0,0	-0,6	0,1	-0,1	0,0	0,1	-0,1
Rest of the World	0,1	0,0	0,1	-0,3	0,1	-0,6	0,1	0,0	0,0	0,1	-0,1
World	-0,2	-0,1	-0,2	1,8	-0,2	1,2	-0,1	-0,1	-0,1	-0,1	0,4

Source: MIRAGRODEP and authors' calculation
Note: exporting region in row; importing region in column

Full trade liberalization leads to an increase of world total exports of each region (last column of **Error! Reference source not found.**) while in the case of the Europe-North America trade agreement, world exports augment for Europe and North America, but decrease for all other regions. For Europe and North America, this free trade agreement leads to trade creation between these two regions, but trade diversion on all other destinations.

We now present the impact on production in volume, in the case of the FTL scenario (0) and the EUNA one (**Error! Reference source not found.**). The impact of the former scenario on production in volume is significantly greater than in the latter scenario. Production decreases when in the baseline, the sector is protected from foreign competition by relatively high tariffs: this is the case of the textile and apparel sector in Europe, Latin America and North America, but also for Africa in all sectors except industry (textile and apparel excluded). The highest increase in production in volume is the textile and apparel sector in Poor Asia and Oceania which benefits from the removal of high protection in Europe, Latin America, and North America: it expands by 78.5% in real terms. Other beneficiaries are the agricultural sector in Latin America and Other Emerging countries: it includes Russia, Ukraine, and South Africa.

Table 8: FTL – Impact on production by sector in volume – 2030 - %

	Agriculture	Agrifood	Industry	Services	TextApparel
Africa	-0,7	-3,1	1,3	-0,2	-7,7
Emerging Asia and Oceania	-0,8	0,7	-0,3	-0,4	13,6
Emerging Latin America	3,1	4,0	-0,1	-0,2	-10,5
Europe	0,6	-0,4	1,3	-0,3	-9,6
Rest of Latin America	2,5	1,0	-0,1	-0,1	-11,7
North America	1,6	3,0	0,2	0,0	-8,3
Other Emerging	13,4	-3,8	-1,0	-0,2	0,0
Poor Asia and Oceania	-1,5	-2,0	-2,0	-1,3	78,5
Rich Asia and Oceania	-14,8	18,8	1,1	-0,6	6,1
Rest of the World	43,8	-17,9	-1,0	0,1	-10,1

Source: MIRAGRODEP and authors' calculation

Table 9: EUNA – Impact on production by sector in volume – 2030 - %

	Agriculture	Agrifood	Industry	Services	TextApparel
Africa	0,0	-0,1	0,0	0,0	-0,1
Emerging Asia and Oceania	0,0	0,0	0,0	0,0	-0,2
Emerging Latin America	0,0	-0,1	0,0	0,0	-0,2
Europe	0,0	0,1	0,0	0,0	2,4
Rest of Latin America	0,0	-0,1	0,0	0,0	-0,8
North America	0,1	0,6	0,1	0,0	0,3
Other Emerging	0,0	-0,1	0,0	0,0	0,0
Poor Asia and Oceania	0,0	-0,1	0,0	0,0	-0,8
Rich Asia and Oceania	0,0	-0,1	0,0	0,0	-0,2
Rest of the World	0,0	-0,1	0,0	0,0	-0,1

Source: MIRAGRODEP and authors' calculation

The impact of the free trade agreement between Europe and North America on sectoral production in volume is relatively limited. Only production in these two regions is positively affected and the rate of variation is relatively small except for the European textile and apparel sector, for which production increases by 2.4% in volume.

Let us present the impact on the real remuneration of productive factors of both FTL (0) and EUNA (0) scenarios. When activity is increasing in a sector, it needs more productive factors. The impact on the real

remuneration of productive factors is related to the variation of production in volume and the intensity of each factor in each sector. For example, the real remunerations of rural unskilled labor and of land in Latin America (both Emerging and Rest of) are positively affected by full trade liberalization because production in these sectors in those regions are positively affected (see 0). This is related to the expansion of Latin American agricultural and agrifood exports: see last column of **Error! Reference source not found.**.

Table 10: FTL – Impact on real remuneration of productive factors – 2030 - %

Region	Skilled labor	Capital	Rural unskilled labor	Urban unskilled labor	Natural resources	Land
Africa	-1,1	0,4	-1,7	-0,7	2,4	-1,8
Emerging Asia and Oceania	0,3	0,4	-1,2	0,6	-0,7	-1,9
Emerging Latin America	-0,5	0,0	3,7	-0,3	0,6	5,2
Europe	0,4	0,3	1,3	0,5	-0,5	1,7
Rest of Latin America	-0,5	-0,2	3,5	-0,4	1,0	4,9
North America	0,2	0,0	1,8	0,2	0,0	2,5
Other Emerging	-0,4	-0,3	21,9	0,1	-0,5	30,5
Poor Asia and Oceania	-0,6	0,4	-2,7	0,3	0,1	-3,5
Rest of the World	-0,3	-0,4	71,6	0,6	-0,5	107,9
Rich Asia and Oceania	1,4	1,6	-20,0	1,8	-0,4	-27,9

Source: MIRAGRODEP and authors' calculation

Table 11: EUNA – Impact on real remuneration of productive factors – 2030 - %

Region	Skilled labor	Capital	Rural unskilled labor	Urban unskilled labor	Natural resources	Land
Africa	0,0	0,0	0,0	0,0	0,2	0,0
Emerging Asia and Oceania	0,0	0,0	0,0	0,0	0,2	0,0
Emerging Latin America	0,0	0,0	0,0	0,0	0,2	0,0
Europe	0,0	0,0	0,0	0,0	0,1	0,1
Latin America	0,0	0,0	-0,1	0,0	0,2	-0,1
North America	0,0	0,0	0,1	0,0	0,0	0,1
Other Emerging	0,0	0,0	-0,1	0,0	0,2	-0,1
Poor Asia and Oceania	0,0	0,0	0,0	0,0	0,2	0,0
Rest of the World	0,0	0,0	-0,1	0,0	0,1	-0,1
Rich Asia and Oceania	0,0	0,0	0,0	0,0	0,1	0,0

Source: MIRAGRODEP and authors' calculation

6. Conclusion

The objective of this technical note was to present the MIRAGRODEP model of the world economy. This is a multi-sector multi-region computable general equilibrium model which allows for the simulation of the economic impacts of reforms or shocks on world markets. This type of model is important because it can be used to quantify the impact of reforms and identify the main channels of transmission of a reform on economic variables in each region or country of the world economy. They are important for policymakers because they are not parsimonious and provide numerous and detailed information. They can also be used to design the accompanying policies that must be implemented to correct the negative implications of a reform on a specific sector or on specific agents.

The MIRAGRODEP model has been used in the evaluation of the impact of trade reforms, either multilateral, or regional, or of trade preferences, the evaluation of biofuels support program, the impact of WTO trade reform, and in many other types of studies.

MIRAGRODEP can still be improved in many directions. To give a few examples, the modelling of non-tariff measures is still a vast domain of research. The impact of bound import duties is another illustration. The introduction of environmental issues may be the most important domain of research for CGE modelers.

Annex - Model Structure

Table A1: Equations of MIRAGRODEP

	Production	
	First level: Leontief	GAMS
1.	$Y_{j,r,t} = a_{j,r}^{VA} \, VA_{j,r,t}$	EQ_VA
2.	$Y_{j,r,t} = a_{j,r}^{CNTER} \, CNTER_{j,r,t}$	EQ_CNTER
3.	$PY_{j,r,t} \, Y_{j,r,t} = PVA_{j,r,t} \, VA_{j,r,t} + PCNTER_{j,r,t} \, CNTER_{j,r,t}$	EQ_Y
	Second level – Value added: CES	GAMS
4.	$L_{j,r,t} = a_{j,r}^{L} \, VA_{j,r,t} \, PGFI_{r,t}^{\sigma_j^{VA}-1} \left(\dfrac{PVA_{j,r,t}}{PL_{j,r,t}} \right)^{\sigma_j^{VA}}$	EQ_L
5.	$TE_{j,r,t} = a_{j,r}^{TE} \cdot VA_{j,r,t} \cdot PGFI_{r,t}^{\sigma_j^{VA}-1} \cdot \left(\dfrac{PVA_{j,r,t}}{PTE_{j,r,t}} \right)^{\sigma_j^{VA}}$	EQ_TE
6.	$RN_{j,r,t} = a_{j,r}^{RN} \cdot VA_{j,r,t} \cdot PGFI_{r,t}^{\sigma_j^{VA}-1} \left(\dfrac{PVA_{j,r,t}}{PRN_{j,r,t}} \right)^{\sigma_j^{VA}}$	EQ_WRN
7.	$Q_{j,r,t} = a_{j,r}^{Q} \cdot VA_{j,r,t} \cdot PGFI_{r,t}^{\sigma_j^{VA}-1} \cdot \left(\dfrac{PVA_{j,r,t}}{PQ_{j,r,t}} \right)^{\sigma_j^{VA}}$	EQ_Q
8.	$PVA_{j,r,t} \, VA_{j,r,t}$ $= PL_{j,r,t} \, L_{j,r,t} + PTE_{j,r,t} \, TE_{j,r,t}$ $+ PRN_{j,r,t} \, RN_{j,r,t} + PQ_{j,r,t} \, Q_{j,r,t}$	EQ_PVA
9.	$PL_{j,r,t} = WLt_{Ltype,r,t} \left(1 + taxf_{UnSkLab,j,r,t}^{VAL} \right)$ $+ PIndC_{r,t} \, taxf_{UnSkLab,j,r,t}^{VOL}$	EQ_PL
10.	$PTE_{j,r,t} = WTE_{j,r,t} \left(1 + taxf_{Land,j,r,t}^{VAL} \right)$ $+ PIndC_{r,t} \, taxf_{Land,j,r,t}^{VOL}$	EQ_PTE

11.	$PRN_{j,r,t} = WRN_{j,r,t} \left(1 + taxf^{VAL}_{NatlRes,j,r,t}\right)$ $+ PIndC_{r,t} \, taxf^{VOL}_{NatlRes,j,r,t}$	EQ_PRN
	Third level – Capital-Skilled labor bundle: CES	GAMS
12.	$H_{j,r,t} = a^H_{j,r} \, Q_{j,r,t} \left(\dfrac{PQ_{j,r,t}}{PH_{j,r,t}}\right)^{\sigma^{CAP}_j}$	EQ_H
13.	$KTOT_{j,r,t} = a^K_{j,r} \, Q_{j,r,t} \left(\dfrac{PQ_{j,r,t}}{PK_{j,r,t}}\right)^{\sigma^{CAP}_j}$	EQ_KTOT
14.	$PQ_{j,r,t} \, Q_{j,r,t} = PK_{j,r,t} \, KTOT_{j,r,t} + PH_{j,r,t} \, H_{j,r,t}$	EQ_PQ
15.	$PH_{j,r,t} = WH_{r,t} \left(1 + taxf^{VAL}_{SkLab,j,r,t}\right)$ $+ PIndC_{r,t} \, taxf^{VOL}_{SkLab,j,r,t}$	EQ_PH
16.	$PK_{j,r,t} = WK_{j,r,t} \left(1 + taxf^{VAL}_{Capital,j,r,t}\right)$ $+ PIndC_{r,t} \, taxf^{VOL}_{Capital,j,r,t}$	EQ_PK
	Second level-Intermediate consumption: Leontief	GAMS
17.	$CNTER_{j,r,t} = a^{L\_IC}_{i,j,r} \cdot IC_{i,j,r,t}$	EQ_IC
18.	$PCNTER_{j,r,t} \, CNTER_{j,r,t} = \sum_i PIC_{i,j,r,t} \, IC_{i,j,r,t}$	EQ_PCNTER
19.	$PIC_{i,j,r,t} = PDEMTOT_{i,r,t} \left(1 + taxicc_{i,j,r,t}\right)$	EQ_PIC
Income and Savings		
Households		GAMS

20.	$REVH_{r,t} = \sum_j \left\{ WRN_{j,r,t} \, RN_{j,r,t} + \sum_z WTE_{j,r,t} \cdot TE_{j,r,t} \right._{j,r,t}$ $+ WH_{r,t} \, H_{j,r,t}$ $+ \sum_{Ltype} WLt_{Ltype,r,t} \, L_{j,r,t} + \sum_s WK_{j,s,t} \, K_{j,r,s,t} \left. \right\}$ $+ Pop^{ag}_{totpop,r,t} TRH_{r,t} \, PIndC_{r,t}$	EQ_REVH
21.	$SAVH_{r,t} = epa_r \, (REVH_{r,t} - RECDIR_{r,t})$	EQ_SAVH
22.	$BUDH_{r,t} = REVH_{r,t} - SAVH_{r,t} - RECDIR_{r,t}$	EQ_BUDH
Government		GAMS
23.	$REVG_{r,t} = \sum_i \left\{ RECPROD_{i,r,t} + RECFAC_{i,r,t} + RECEXP_{i,r,t} \right.$ $+ RECDD_{i,r,t} + RECCONS_{i,r,t} \left. \right\} + RECDIR_{r,t}$	EQ_REVG
24.	$RECPROD_{i,r,t} = taxP_{i,r,t} \, PY_{i,r,t} \, Y_{i,r,t}$	EQ_RECPROD
25.	$RECFAC_{j,r,t} = PIndC_{r,t} \left(taxf^{VOL}_{Land,j,r,t} \, TE_{j,r,t} \right.$ $+ taxf^{VOL}_{NatlRes,j,r,t} \, RN_{j,r,t} + taxf^{VOL}_{SkLab,j,r,t} \, H_{j,r,t}$ $+ taxf^{VOL}_{UnSkLab,j,r,t} \, L_{j,r,t}$ $+ taxf^{VOL}_{Capital,j,r,t} \, KTOT_{j,r,t} \left. \right)$ $+ \sum_z taxf^{VAL}_{Land,j,r,t} \, WTE_{j,r,t} \, TE_{j,r,t}$ $+ taxf^{VAL}_{NatlRes,j,r,t} \, WRN_{j,r,t} \, RN_{j,r,t}$ $+ taxf^{VAL}_{SkLab,j,r,t} \, WH_{r,t} \, H_{j,r,t}$ $+ taxf^{VAL}_{UnSkLab,j,r,t} \sum_{Ltype} WLt_{Ltype,r,t} \, L_{j,r,t}$ $+ taxf^{VAL}_{Capital,j,r,t} \, WK_{j,r,t} \, KTOT_{j,r,t}$	EQ_RECFAC

26.	$RECEXP_{i,r,t} = PY_{i,r,t}\left(1 + taxP_{i,r,t}\right)\sum_{s}\left(taxEXP_{i,r,s,t} + taxAMF_{i,r,s,t}\right)TRADE_{i,r,s,t}$	EQ_RECEXP
27.	$RECDD_{i,r,t} = \sum_{s} DD_{i,s,r,t}\, PCIF_{i,s,r,t}\, TRADE_{i,s,r,t}$	EQ_RECDD
28.	$RECCONS_{i,r,t} = PDEMTOT_{i,r,t}\left\{taxcc_{i,r,t}\, CH_{i,r,t} + taxgc_{i,r,t}\, CG_{i,r,t} + taxkgc_{i,r,t}\, KG_{i,r,t} + \sum_{j} taxicc_{i,j,r,t}\, IC_{i,j,r,t}\right\}$	EQ_RECCONS
29.	$RECDIR_{r,t} = taxdir_{r,t}\, REVH_{r,t}$	EQ_RECDIR
30.	$SAVG_{r,t} = PUBSOLD_{r}\, GDPMP_{r,t}$	EQ_SAVG
31.	$BUDG_{r,t} = REVG_{r,t} - SAVG_{r,t} - Pop^{ag}_{totpop,r,t}\, TRH_{r,t}\, PIndC_{r,t}$	EQ_BUDG
Demand		
32.	$DEMTOT_{i,r,t} = CH_{i,r,t} + CG_{i,r,t} + \sum_{j} IC_{i,j,r,t} + KG_{i,r,t}$	EQ_DEMTOT
Private demand		GAMS
33.	$CHC_{AGI,r,t} = Pop_{totpop,r,t}\left(cmin_{AGI,r} + a^{CC}_{AGI,r}\, AUX_{r,t}\left(\dfrac{P_{r,t}}{PCC_{AGI,r,t}}\right)^{\sigma^{CC}_{r}}\right)$	EQ_CHC
34.	$P_{r,t}\, AUX_{r,t} = \sum_{AGI} PCC_{AGI,r,t}\left(\dfrac{CHC_{AGI,r,t}}{Pop_{totpop,r,t}} - cmin_{AGI,r}\right)$	EQ_P

35.	$$CH_{i,r,t} = a_{i,r}^C \, CHC_{AGI,r,t} \left(\frac{PCC_{AGI,r,t}}{PC_{i,r,t}} \right)^{\sigma_{r,AgF}^{CAgF}}$$	`EQ_CH`
36.	$$PCC_{AGI,r,t} \, CHC_{AGI,r,t} = \sum_{i \in AGI} PC_{i,r,t} CH_{i,r,t}$$	`EQ_PCC`
37.	$$CHAgF_{AgF,r,t} = a_{AgF,r}^{CAgF} \, CHC_{'Food',t} \left(\frac{PCC_{'Food'',r,t}}{PCAgF_{AgF,r,t}} \right)^{\sigma_{r,'Food'}^{C}}$$	`EQ_CHAgF`
38.	$$CH_{i,r,t} = a_{i,r}^C \, CHAgF_{AgF,r,t} \left(\frac{PCAgF_{AgF,r,t}}{PC_{i,r,t}} \right)^{\sigma_{r,AGF}^{C}}$$	`EQ_CF`
39.	$$PCAgF_{AgF,r,t} \, CHAgF_{AgF,r,t} = \sum_{i \in AgF} PC_{i,r,t} CH_{i,r,t}$$	`EQ_PCAgF`
40.	$$BUDH_{r,t} = \sum_{i} PC_{i,r,t} \, CH_{i,r,t}$$	`EQ_AUX`
41.	$$PC_{i,r,t} = PDEMTOT_{i,r,t} \, (1 + taxcc_{i,r,t})$$	`EQ_PC`
42.	$$PindC_{r,t} = \sqrt{ \left[\frac{\sum_i PC_{i,r,t} \, CH_{i,r}^O}{\sum_i PC_{i,r}^O \, CH_{i,r}^O} \right] \left[\frac{\sum_i PC_{i,r,t} \, CH_{i,r,t}}{\sum_i PC_{i,r}^O \, CH_{i,r,t}} \right] }$$	`EQ_PIndC`
Public demand		GAMS
43.	$$PCG_{i,r,t} \, CG_{i,r,t} = \alpha_{i,r}^G \, BUDG_{r,t}$$	`EQ_CG`
44.	$$PCG_{i,r,t} = PDEMTOT_{i,r,t} \, \left(1 + taxgc_{i,r,t} \right)$$	`EQ_PCG`
Demand for investment purposes		GAMS
45.	$$KG_{i,r,t} = a_{i,r}^{KG} \, INVTOT_{r,t} \left(\frac{PINVTOT_{r,t}}{PKG_{i,r,t}} \right)^{\sigma^{KG}}$$	`EQ_KG`
46.	$$PINVTOT_{r,t} \, INVTOT_{r,t} = \sum_{i} PKG_{i,r,t} \, KG_{i,r,t}$$	`EQ_PINVTOT`
47.	$$PKG_{i,r,t} = PDEMTOT_{i,r,t} \, (1 + taxkgc_{i,r,t})$$	`EQ_PKG`

	Demand by geographic origin	GAMS
48.	$D_{i,r,t} = a_{i,r}^D \, DEMTOT_{i,r,t} \left(\dfrac{PDEMTOT_{i,r,t}}{PD_{i,r,t}} \right)^{\sigma_i^{ARM}}$	EQ_D
49.	$M_{i,r,t} = a_{i,r}^M \, DEMTOT_{i,r,t} \left(\dfrac{PDEMTOT_{i,r,t}}{PM_{i,r,t}} \right)^{\sigma_i^{ARM}}$	EQ_M
50.	$PDEMTOT_{i,r,t} \, DEMTOT_{i,r,t} = PD_{i,r,t} \, D_{i,r,t} + PM_{i,r,t} \, M_{i,r,t}$	EQ_PDEMTOT
51.	$PD_{i,r,t} = PY_{i,r,t} \, (1 + taxP_{i,r,t})$	EQ_PD
52.	$DEMA_{i,s,r,t} = a_{i,s,r}^{IMP} \, M_{i,r,t} \left(\dfrac{PM_{i,r,t}}{PDEMA_{i,s,r,t}} \right)^{\sigma_i^{IMP}}$	EQ_DEMA
53.	$PM_{i,r,t} \, M_{i,r,t} = \displaystyle\sum_s PDEMA_{i,s,r,t} \, DEMA_{i,s,r,t}$	EQ_PM
54.	$PDEMA_{i,s,r,t} = PCIF_{i,s,r,t} \left(1 + DD_{i,s,r,t}^A \right)$	EQ_PDEMA
55.	$PCIF_{i,s,r,t} = PY_{i,s,t} \left(1 + taxEXP_{i,s,r,t} + taxAMF_{i,s,r,t} \right) \left(1 + taxP_{i,s,t} \right) + MUO_{i,s,r} \, PTr_{i,s,r,t}$	EQ_PCIF
56.	$PDEM_{i,s,r,t} = PCIF_{i,s,r,t} \left(1 + DD_{i,s,r,t} \right)$	EQ_PDEM
57.	$DEMA_{i,s,r,t} \, PDEMA_{i,s,r,t} = PDEM_{i,s,r,t} \, TRADE_{i,s,r,t}$	EQ_TRADE
	Demand for transportation services	GAMS
58.	$Tr_{i,s,r,t} = MUO_{i,s,r} \, TRADE_{i,s,r,t}$	EQ_Tr
59.	$PTrMode_{Transport,t} \, TrMode_{Transport,i,s,r,t} = a_{Transport,i,s,r,t}^{Tr} \, Tr_{i,s,r,t} \, PTr_{i,s,r,t}$	EQ_TrMode
60.	$PTr_{i,s,r,t} = \displaystyle\prod_{Transport} PTrMode_{Transport,t}^{a_{Transport,i,s,r}^{Tr}}$	EQ_PTr
	Supply and market clearing	
	Transportation market	GAMS

61.	$WorldTr_{Transport,t} = c^T_{Transport} \prod_r TrSupply_{Transport,r,t}^{a^{TrSupply}_{Transport,r}}$	EQ_WorldTr
62.	$PY_{Transport,r,t} \left(1 + taxP_{Transport,r,t}\right) TrSupply_{Transport,r,t}$ $= a^{TrSupply}_{Transport,r} PTrMode_{Transport,t} WorldTr_{Transport,t}$	EQ_TrSupply
63.	$WorldTr_{Transport,t} = \sum_{i,r,s} TrMode_{Transport,i,r,s,t}$	EQ_PTrMode
	Commodity market	GAMS
64.	$Y_{i,r,t} = D_{i,r,t} + \sum_s TRADE_{i,r,s,t} + TrSupply_{i,r,t}$	EQ_PY
	Factors of production market	
	Labor market	GAMS
65.	$\bar{H}_{r,t} = \sum_j H_{j,r,t}$	EQ_WH
66.	$Lt_{Ltype,r,t} = b^{Lt}_{Ltype,r} \bar{L}_{r,t} \left(\dfrac{WLt_{Ltype,r,t}}{\overline{WL}_{r,t}}\right)^{\sigma^L}$	EQ_CET_Lt
67.	$\overline{WL}_{r,t} \bar{L}_{r,t} = \sum_{Ltype} WLt_{Ltype,r,t} Lt_{Ltype,r,t}$	EQ_CET_WLbar
68.	$Lt_{Ltype,r,t} = \sum_j L_{j,r,t}$	EQ_WLt
	Land market	GAMS
69.	$\overline{TE}_{r,t} = \overline{TE}^O_r \left(\dfrac{\overline{WTE}_{r,t}}{P_{r,t}}\right)^{\sigma^{\overline{TE}}_r}$	EQ_TEbar
70.	$TE_{j,r,t} = b^{TE}_{j,r} \overline{TE}_{r,t} \left(\dfrac{WTE_{j,r,t}}{\overline{WTE}_{r,t}}\right)^{\sigma^{TE}}$	EQ_CET_WTE
71.	$\overline{WTE}_{r,t} \overline{TE}_{r,t} = \sum_j WTE_{j,r,t} TE_{j,r,t}$	EQ_CET_WTEbar

Capital market	GAMS
72. $K_{j,s,r,t} = K_{j,s,r,t-1}(1 - \delta_r) + INV_{j,s,r,t}$	EQ_K
73. $INV_{j,s,r,t} = B_{s,t} \, a_{j,s,r} \, KTOT_{j,r,t} \, e^{\alpha\left(\frac{WK_{j,r,t}}{PINVTOT_{r,t}}\right)}$	EQ_INV
74. $INVTOT_{r,t} = \sum_{j,s} INV_{j,s,r,t}$	EQ_INVTOT
75. $KTOT_{i,r,t} = \sum_{s} K_{i,s,r,t}$	EQ_WK
76. $WKbar_{r,t} \sum_{j} KTOT_{j,r,t} = \sum_{j} WK_{j,r,t} KTOT_{j,r,t}$	EQ_WKbar
Macroeconomic constraints	
77. $SAVH_{r,t} + SAVG_{r,t} - CAB_{r,t} = \sum_{i,s} PINVTOT_{s,t} \, INV_{i,r,s,t}$	EQ_B
78. $CAB_{r,t} = PIBMVAL_t \, SOLD_{r,t}$	EQ_CAB
79. $\sum_{r} CAB_{r,t} = 0$	Eq_CABbal
80. $PIBMVAL_t = \sum_{r} GDPMP_{r,t}$	EQ_PIBMVAL
81. $GDPMP_{r,t} = \sum_{j} PVA_{j,r,t} \, VA_{j,r,t}$ $\quad + \sum_{i} \{ RECPROD_{i,r,t} + RECEXP_{i,r,t}$ $\quad + RECDD_{i,r,t} + RECCONS_{i,r,t} \}$	EQ_GDP
82. $GDPVOL_{r,t} = \dfrac{GDPMP_{r,t}}{PIndC_{r,t}}$	EQ_PGF

Table A2: Variables of MIRAGRODEP

Variable	Definition	GAMS
$AUX_{r,t}$	Utility	`AUX(r,Temps,simul)`
$B_{r,t}$	Investment scale coefficient	`B(r,Temps,simul)`
$BUDG_{r,t}$	Budget allocated to public cons'n	`BUDG(r,Temps,simul)`
$BUDH_{r,t}$	Budget allocated to private cons'n	`BUDH(r,Temps,simul)`
$CAB_{r,t}$	Current account balance	`CAB(r,temps,simul)`
$CGi_{r,t}$	Public consumption of commodity i	`CG(i,r,Temps,simul)`
$CH_{i,r,t}$	Cons'n of commodity i by households	`CH(i,r,Temps,simul)`
$CNTER_{j,r,t}$	Aggreg. Interm. cons'n by sector j	`CNTER(j,r,Temps,simul)`
$D_{i,r,t}$	Demand for domestic commodity i	`D(i,r,Temps,simul)`
$DEMA_{i,r,s,t}$	Bilateral trade from r to s (volume)	`DEMA(i,r,s,Temps,simul)`
$DEMTOT_{i,r,t}$	Total demand for composite commodity i	`DEMTOT(i,r,Temps,simul)`
$GDPMP_{r,t}$	Gross domestic product at market prices (nominal)	`GDPMP(r,Temps,simul)`
$GDPVOL_{r,t}$	Gross domestic product at market prices (real)	`GDPVOL(r,Temps,simul)`
$H_{j,r,t}$	Demand for skilled labor by sector	`H(j,r,Temps,simul)`
$\bar{H}_{r,t}$	Total skilled labor supply	`Hbar(r,Temps,simul)`
$IC_{i,j,r,t}$	Intermed. cons'n of good i by sector j	`IC(i,j,r,Temps,simul)`
$INV_{j,s,r,t}$	Inv. made by s in sector j of region r	`INV(j,s,r,Temps,simul)`
$INVTOT_{r,t}$	Total investment in region r	`INVTOT(r,Temps,simul)`
$K_{j,s,r,t}$	Capital stock invested by s in r	`K(j,s,r,Temps,simul)`
$KG_{i,r,t}$	Demand of good i for inv. purposes	`KG(i,r,Temps,simul)`
$KTOT_{j,r,t}$	Capital stock available in sector j	`KTOT(j,r,Temps,simul)`
$L_{j,r,t}$	Demand for unskilled labor by sector j	`L(j,r,Temps,simul)`
$\bar{L}_{r,t}$	Total supply of unskilled labor	`Lbar(r,Temps,simul)`
$Lt_{Ltype,r,t}$	Supply of unskilled labor per type	`Lt(Ltype,r,Temps,simul)`
$M_{i,r,t}$	Aggregate imports by region r	`M(i,r,Temps,simul)`
$P_{r,t}$	Price of utility	`P(r,Temps,simul)`
$PC_{i,r,t}$	Price of final private consumption	`PC(i,r,Temps,simul)`
$PCG_{i,r,t}$	Price of final public consumption	`PCG(i,r,Temps,simul)`
$PCIF_{i,r,s,t}$	CIF price	`PCIF(i,r,s,Temps,simul)`

$PCNTER_{j,r,t}$	Price of aggregate intermediate cons'n by sector j	`PCNTER(j,r,Temps,simul)`
$PD_{i,r,t}$	Price of for domestic good i (including taxes)	`PD(i,r,Temps,simul)`
$PDEM_{i,r,s,t}$	Price of bilateral trade from r to s	`PDEM(i,r,s,Temps,simul)`
$PDEMA_{i,r,s,t}$	Price of bilateral trade from r to s	`PDEMA(i,r,s,Temps,simul)`
$PDEMTOT_{i,r,t}$	Price of composite commodity i	`PDEMTOT(i,r,Temps,simul)`
$PGF_{r,t}$	Total factor productivity	`PGF(r,Temps,simul)`
$PH_{j,r,t}$	Price of skilled labor (including taxes)	`PH(j,r,Temps,simul)`
$PIBMVAL_t$	World gross domestic product (value)	`PIBMVAL(Temps,simul)`
$PIC_{i,j,r,t}$	Price of intermediate consumption good i for sector j (including taxes)	`PIC(i,j,r,Temps,simul)`
$PIndC_{r,t}$	Consumer price index	`PIndC(r,Temps,simul)`
$PINVTOT_{r,t}$	Aggregate price of investment in region r	`PINVTOT(r,Temps,simul)`
$PK_{j,r,t}$	Price of capital (including taxes)	`PK(j,r,Temps,simul)`
$PKG_{i,r,t}$	Price of capital good consumption of good i (including taxes)	`PKG(i,r,Temps,simul)`
$PL_{j,r,t}$	Price of unskilled labor (including taxes)	`PL(j,r,Temps,simul)`
$PM_{i,r,t}$	Price of aggregate imports	`PM(i,r,Temps,simul)`
$PQ_{j,r,t}$	Price of capital - skilled labor aggregate	`PQ(j,r,Temps,simul)`
$PRN_{j,r,t}$	Price of natural resources (including taxes)	`PRN(j,r,Temps,simul)`
$PTE_{j,r,t}$	Average Price of land (including taxes)	`PTE(j,r,Temps,simul)`
$PTr_{i,r,s,t}$	Price of aggregate transport by export	`PTr(i,r,s,Temps,simul)`
$PTrMode_{j,t}$	World price of transport per mode	`PTrMode(j,Temps,simul)`
$PVA_{j,r,t}$	Price of value added	`PVA(j,r,Temps,simul)`
$PY_{j,r,t}$	Output price	`PY(j,r,Temps,simul)`
$Q_{j,r,t}$	Capital - skilled labor aggregate	`Q(j,r,Temps,simul)`
$RECCONS_{i,r,t}$	Consumption tax receipts	`RECCONS(i,r,Temps,simul)`
$RECDD_{i,r,t}$	Tariff revenues	`RECDD(i,r,Temps,simul)`
$RECDIR_{r,t}$	Tax receipts from direct taxation	`RECDIR(r,Temps,simul)`
$RECEXP_{i,r,t}$	Export tax receipts	`RECEXP(i,r,Temps,simul)`
$RECFAC_{j,r,t}$	Receipts from taxes on factors of production	`RECFAC(j,r,Temps,simul)`
$RECPROD_{i,r,t}$	Production tax receipts	`RECPROD(i,r,Temps,simul)`
$REVG_{r,t}$	Government total income	`REVG(r,Temps,simul)`
$REVH_{r,t}$	Households income	`REVH(r,Temps,simul)`

$RN_{j,r,t}$	Demand for natural resources by sector	`RN(j,r,Temps,simul)`
$SAVG_{r,t}$	Government savings	`SAVG(r,Temps,simul)`
$SAVH_{r,t}$	Households savings	`SAVH(r,Temps,simul)`
$SOLD_{r,t}$	Initial share of current account balance in world GDP	`SOLD(r,Temps,simul)`
$TE_{j,r,t}$	Land used in sector j	`TE(j,r,Temps,simul)`
$\overline{TEZ}_{r,z,t}$	Total land supply	`TEbarZ(r,z,Temps,simul)`
$Tr_{i,r,s,t}$	Transport demand by export	`Tr(i,r,s,Temps,simul)`
$TRADE_{i,r,s,t}$	Bilateral trade from r to s (volume)	`TRADE(i,r,s,Temps,simul)`
$TRH_{r,t}$	Public transfers to households	`TRH(r,Temps,simul)`
$TrMode_{j,i,r,s,t}$	Transport demand by export, per mode	`TrMode(j,i,r,s,Temps,simul)`
$TrSupply_{j,r,t}$	Supply of international transportation by region r	`TrSupply(j,r,Temps,simul)`
$VA_{j,r,t}$	Value added	`VA(j,r,Temps,simul)`
$WH_{r,t}$	Rate of return to skilled labor	`WH(r,Temps,simul)`
$WK_{i,r,t}$	Rate of return to capital	`WK(i,r,Temps,simul)`
$\overline{WL}_{r,t}$	Price of aggregate unskilled labor	`WLbar(r,Temps,simul)`
$WLt_{Ltype,r,t}$	Rate of return to unskilled labor	`WLt(Ltype,r,Temps,simul)`
$WorldTr_{j,t}$	World supply of international transportation	`WorldTr(j,Temps,simul)`
$WRN_{j,r,t}$	Rate of return to natural resources	`WRN(j,r,Temps,simul)`
$WTE_{j,r,t}$	Rate of return to land	`WTE(j,r,Temps,simul)`
$\overline{WTE}_{r,t}$	Aggregate price of land	`WTEbar(r,Temps,simul)`
$Y_{j,r,t}$	Total output of sector j	`Y(j,r,Temps,simul)`
$WHr_{r,t}$	Remuneration of Skilled labor in rural sectors in country r (a country with dual-dual modelling)	`WHr(r,Temps, simul)`

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