

# **GTAP-InVEST User Guide**

**A coupled economy-ecosystem model**

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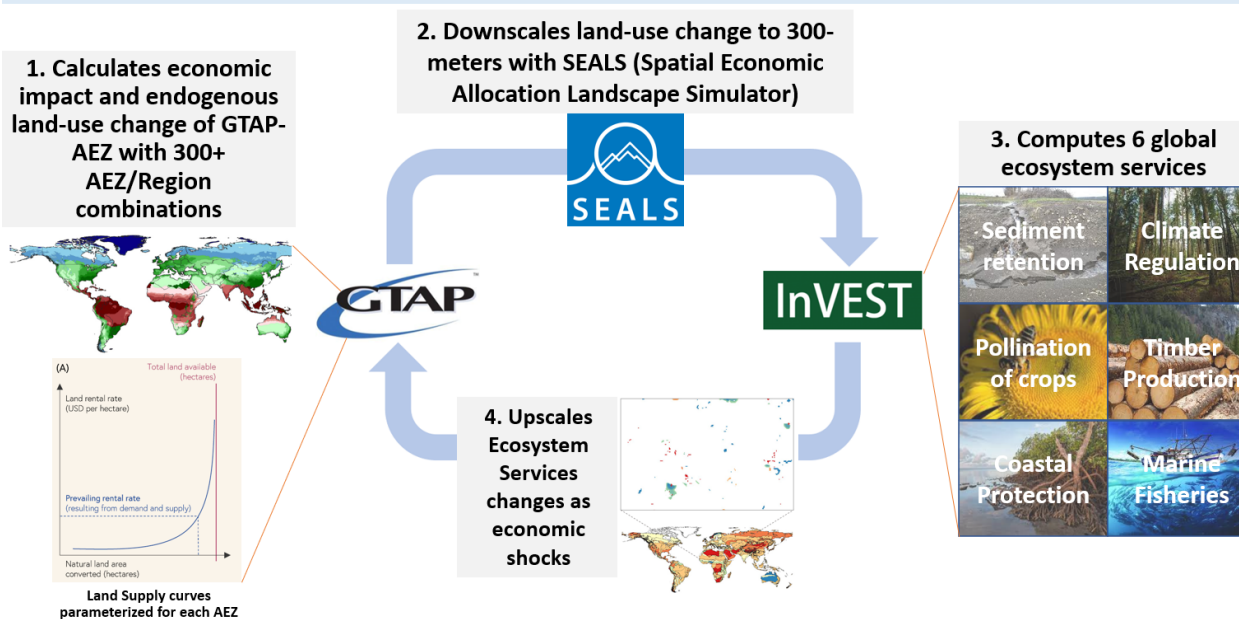
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# 1 GTAP-InVEST User Guide

## 1.1 1. Introduction

This is the User Guide for GTAP-InVEST, a new earth-economy model introduced in “[Investing in nature can improve equity and economic returns](#)” (Johnson et al. 2023, PNAS). The content here originally derived from the supplemental information document included with PNAS article. However, development on the model is progressing rapidly, so please refer to this document, which will remain up-to-date. For additional details, please see the GTAP-InVEST Github repository ([github.com/jandrewjohnson/gtap\\_invest](https://github.com/jandrewjohnson/gtap_invest)). All code and results of the model are available and licensed under a permissive open-source license. Full results may be downloaded at [justinandrewjohnson.com/gtap\\_invest/results](https://justinandrewjohnson.com/gtap_invest/results).

### Overview of GTAP-InVEST: Four key parts



## 1.2 2. Contents

### 1.2.1 Narrative chapters

- [Model summary](#) — overview of how GTAP, SEALS, and InVEST are coupled.
- [Scenarios](#) — scenario design and shock construction.
- [GTAP details](#) — economic model formulation and database choices.

- [InVEST details](#) — ecosystem service models used downstream of SEALS.
- [Ecosystem service impacts](#) — how ES feedbacks enter the second GTAP run.

### 1.2.2 GTAP Database reference

The current GTAP-Invest pipeline uses the **GTAP 12 Data Base** (released 2025), aggregated for analysis. Older v11 references are kept for archival comparison.

- [GTAP v12 regions \(163\)](#) — current
- [GTAP v12 sectors \(65\)](#) — current
- [GTAP v12 model variables](#) — sets, parameters, value flows, prices, shocks, welfare
- [GTAP v11 regions \(160\)](#) — legacy
- [GTAP v11 sectors \(65\)](#) — legacy
- [GTAP v11 model variables](#) — legacy

### 1.2.3 GTAP-Invest aggregation (v12\_s26\_r50)

The GTAP-Invest pipeline runs on an aggregated form of the full database — 50 regions and 26 sectors — so simulations are tractable and aligned with the resolution at which SEALS land-use change and InVEST ecosystem services can be coupled to the economic model.

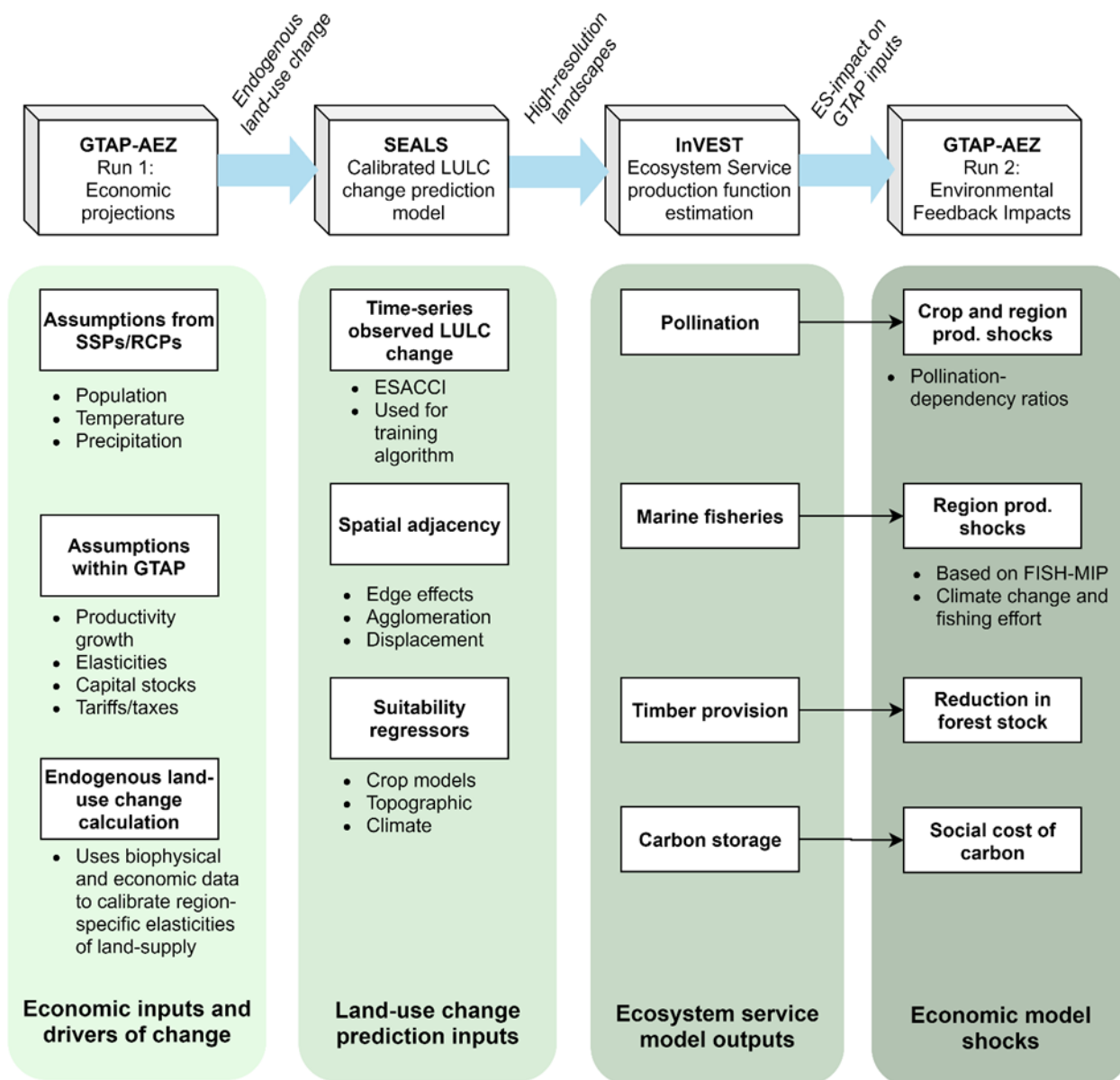
- [s26\\_r50: regions \(50\)](#) — how 163 v12 regions roll up into 50 r50 regions
- [s26\\_r50: sectors \(26\)](#) — how 65 v12 sectors roll up into 26 s26 sectors

## 2 2. GTAP-InVEST Model Summary

In this section, we describe how we link together the models that underlie GTAP-InVEST and discuss the new elements added to each model to make this possible. This section assumes the reader is familiar with the underlying GTAP and InVEST models. If this is not the case, see Sections 4 and 5, which document these two models in more depth.

### 2.0.1 2.1. Overall model structure

GTAP-InVEST is based on several existing models, though a number of new advances were necessary to make the model linkage. These necessary advances fall into two categories: 1. modifications of the underlying models so that they compute what is needed by the other models; and 2., creation of “linkage” code that expresses the outputs of one model as inputs to another model. Figure S.2.1 summarizes the overall structure of the model.



**Figure S.2.1: Overall model linkages within GTAP-InVEST**

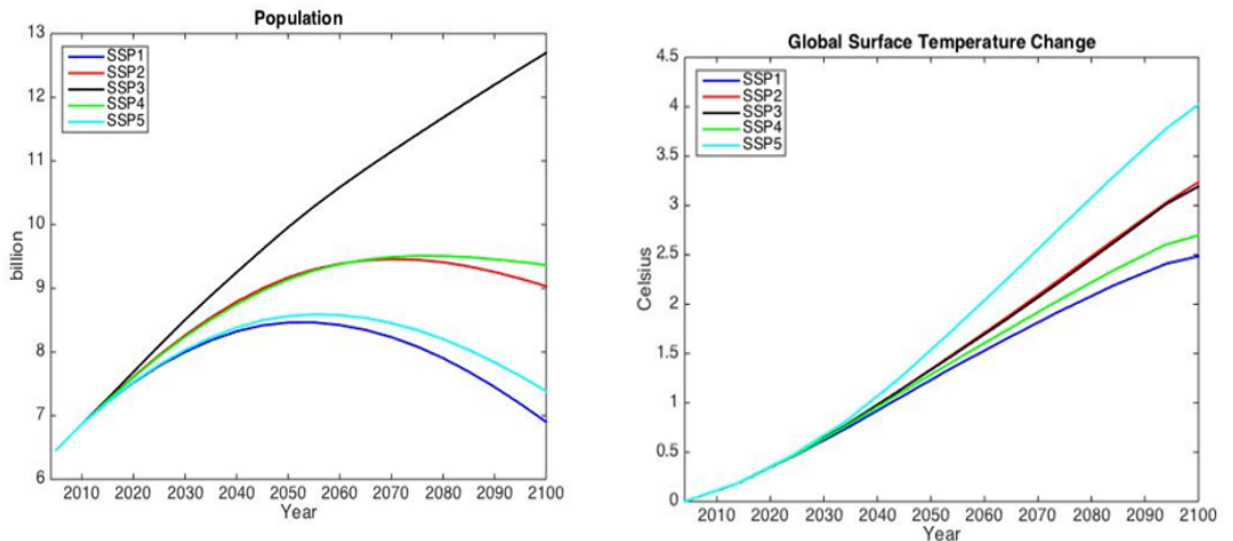
The first step in the model is to project how the economy will evolve between the base year and the terminal year while ignoring impacts from ecosystem services. We refer to this as GTAP Run 1 or the “economic projections run.” It is summarized in Column 1 of Figure S.2.1 (see SI Section 3 for details on the exact input assumptions). The economic projections run calculates a business-as-usual scenario to 2030 that does not yet account for ecosystem services (we label these results as BAU-noES throughout). Because many of the policies rely on detailed consideration of how changing market forces will endogenously drive land-use change and conversion of natural land into economically-utilized land, the GTAP model has expanded representation of heterogeneous land and can endogenously calculate land-use change at the GTAP-AEZ scale. See Section 2.2.3 for a description of how we created this new version of GTAP-AEZ. The results of GTAP Run 1 provide projections of regional land-use change for cropland, pastureland, managed forests and natural land. The next step in GTAP-InVEST is to downscale these regional results (Column 2) using the Spatial

Economic Allocation Landscape Simulator (SEALS) from 341 regions to 8.4 billion grid-cells (10 arc-second resolution, or roughly 300 meters at the equator). This is necessary because the models of biodiversity and ecosystem services we used, specifically the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model, require very high-resolution data to capture local dynamics (Column 3). Finally, the outputs of InVEST are fed back into a second run of the economic model (Column 4), referred to as the GTAP Run 2, or the “ecosystem services impact run.” Run 2 assesses how changes in ecosystem services will have feedback effects on the 2030 economy. In our results, outputs from this second run are labeled with “allES” (or “aES” for short-name variables) to denote that the impacts on the economy from changed ecosystem services are now included. The difference between GTAP Run 1 and Run 2 identifies how much ecosystem services matter (see Figure 1 in the manuscript). The outputs of GTAP Run 2 provide detailed macroeconomic results described in figures 1-3 of the manuscript and in section 7 of this supplemental information.

## 2.0.2 2.2. Input Assumptions

The primary source of inputs for assumptions on exogenous drivers come from the Shared Socioeconomic Pathway (SSP) framework from Riahi et al. (2017) and the associated Representative Concentration Pathways (RCPs), such as for population and global surface temperature change (Figure S.2.2). We take population change, technology change (represented as total-factor productivity projections) and other exogenous factors from the literature, following the approach documented in a special issue of the Journal of Global Economic Analysis (Dellink et al., 2020).

Specifically, these economic drivers include future growth rates for key economic factors, namely Real GDP, Capital Stock, Population, Unskilled Labor and Skilled Labor from Econmap (v2.4) (Fouré et al., 2013) based on the SSP2 scenario. Sector specific productivity growth for Crops, Ruminants and Non-Ruminants are based on per annum growth rates from Ludena et al (2007) over 2001-2040. Because Ludena et al (2007) does not estimate the growth of the managed forestry sector, we infer growth in this sector based on global agricultural productivity growth as defined in Ludena et al (2007). We impose a 2% productivity growth rate for the Manufactures sector to reflect the productivity gap between the Manufactures and Service sectors (Chateau et al., 2020).

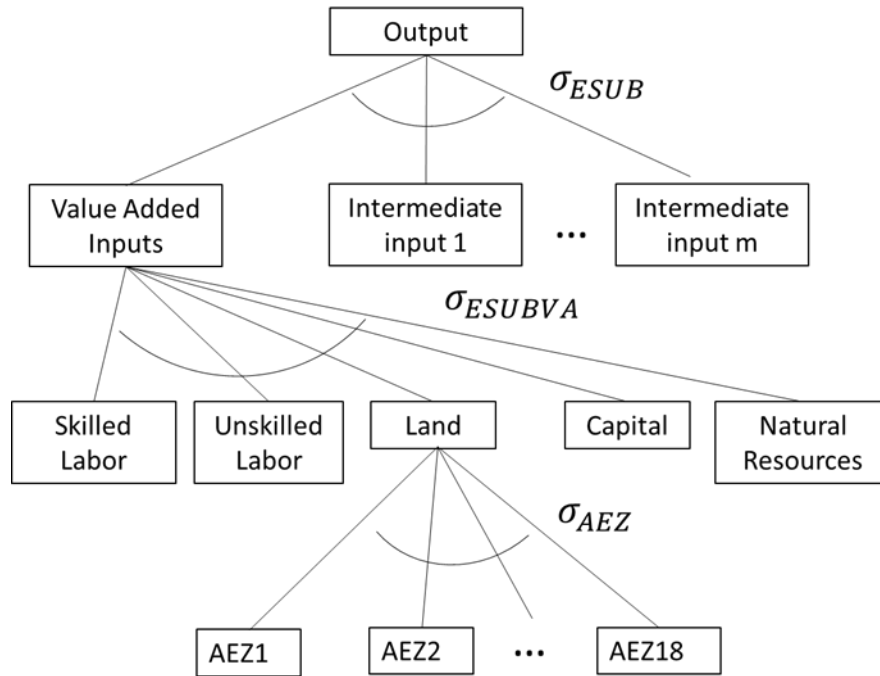


**Figure S.2.2: Input Assumptions from the Shared Socioeconomic Pathways. Source: IIASA (2015). SSP Database 2012-2015. Preliminary scenarios.** Note: Available from <https://tntcat.iiasa.ac.at/SspDb>

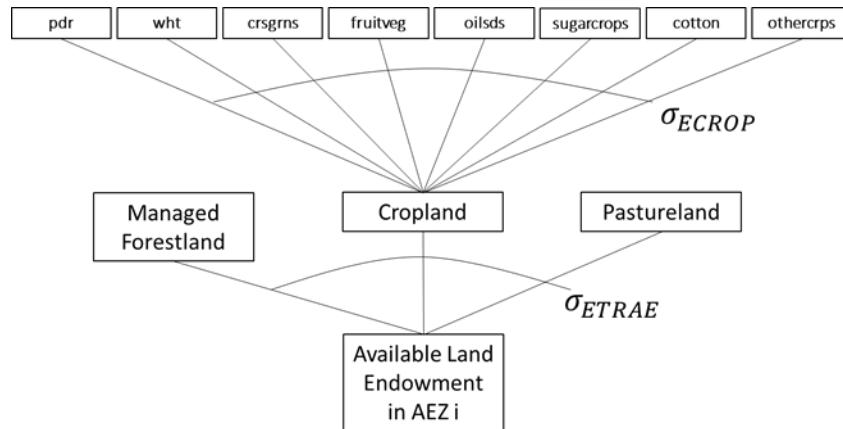
### **2.0.3 2.3. GTAP-AEZ economic methods**

The variant of the GTAP model that we use as the starting point for our model extensions is GTAP-AEZ, which builds on the standard model and database by introducing competition for land resources across crops, pasture, and forestry, as well as heterogeneous land use and land endowments within each region and within each Agro-Ecological Zone (AEZ) suitable for a sector's use. The AEZs are defined in terms of 60 day-long length-of-growing periods, of which there are six, each differentiated by climatic zone (tropical, temperate and boreal). We derive AEZ-level crop production information from Monfreda et al. (2008), while managed forest sector production is based on Sohngen et al. (2009). We draw on multiple sources for land cover information. We use cropland and pasture cover data from Ramankutty et al (2008), urban land cover data from Schneider et al (2009, 2010) and potential vegetation information from Ramankutty (1999). The GTAP-AEZ database is updated to the latest version of the standard GTAP database using national level data from FAOSTAT following the methods described in Baldos (2017). One purpose for defining AEZs is that it lets us specific region-specific endowments of land, which are used by producers as an input to production.

Figure S.2.3.1 shows the modified production structure in the GTAP AEZ. Note that these changes are limited to managed forestry, ruminant livestock and crops sectors - sectors that use land endowments. Following the standard GTAP model, we estimate sectoral output using a constant elasticities of scale (CES) production structure which minimizes cost of production by combining intermediate and value-added inputs. The former are raw commodity inputs used in the production process while the latter includes factors such as land, labor, capital and natural resources. Our model combines skilled and unskilled labor, land, capital and natural resources under the value-added input CES sub-nest, with land endowments in across AEZs pooled under the land input CES sub-nest. Supply of land across each crop sectors and across land cover types are illustrated in Figure S.2.3.2.



**Figure S.2.3.1. Production structure in GTAP-AEZ**



**Figure S.2.3.2. Land supply in GTAP-AEZ**

In the model, the regional household owns land endowments and maximizes total returns to land by allocating their endowment across different uses. Starting at the bottom of the constant elasticity of transformation (CET) function land supply nest (Figure S.2.3.2), the regional household allocates the land endowment within its AEZ to managed forestland, cropland and pastureland based on maximizing returns to land. Managed forestland represents land endowments for the forestry sector, while the ruminant livestock sector uses pastureland. Within the crops sector, the household can allocate available cropland for use in the production of each 8 GTAP crop aggregates, depending on changes in land rents for each use. The model computes returns to land endowments based on the cost shares in the database.

### 2.3.1. Modifications of GTAP-AEZ

In the original GTAP-AEZ model, we assume the supply of land in each AEZ is fixed, though different sectors are able to compete over how land will be used. This means that additional land demanded by one sector needs to come from other sectors. Although this method represented a great advance in the literature on making computable general equilibrium (CGE) models accurately represent land conversion, it is limited in its ability to assess new land being brought into economic use, converted from natural land cover. Our primary modification of GTAP-AEZ in this paper was to add land supply curves, uniquely identified and parameterized for each AEZ-Region, in order to endogenize land supply in the GTAP-AEZ model. Following the approach of Eickhout et al (2009), which the MAGNET model also uses (Woltjer and Kuiper, 2014), land supply in each AEZ is defined as a function of real land rental rates as well as an asymptote which captures maximum available land for use:

$$\textit{Land Supply} = \textit{Maximum Land Available} - \alpha / \textit{LandRents}^\beta$$

The alpha and beta parameters are taken directly from Woltjer and Kuiper (2014) and the maximum land available is calculated as described below. Using this specification, land supply increases when there are positive increases in land rents. Likewise, if land rents fall, then the supply of land also declines, and we assume that any land not being used is allocated back to natural cover. With this specification, it is possible to set aside land for natural use by reducing the maximum area of available land, as long as these reductions are relatively small (see Dixon et al. 2012).

The determination of maximum arable land is very important in this structure. Many existing approaches exist in the literature for defining arable land (e.g., from the Food and Agriculture Organization, but also from the authors of the MAGNET model (Woltjer et al. 2014)). In this paper, we updated the land-supply curves using more recent and higher resolution data on available land. We calculated this using 300 meter resolution data with global availability. In this approach, we also improved the consistency in land-use availability between the competing uses of cropland, pastureland and managed forest land.

Specifically, GTAP-InVEST calculates the land-supply curve for each region using the following approach. We combined data on soil suitability and soil-based growth constraints (Fisher et al., 2008), existing crop caloric yield on nearby areas (Johnson et al. 2016), topographic roughness (authors' calculations, based on data from Hijmans et al. 2008), and existing LULC (based on the European Space Agency's Climate Change Initiative data, henceforth the ESACCI). For the soils data, which are based on the Harmonized World Soils Database, the method excluded any land that had constraints worse than class 4 (where 1 is unconstrained and 7 is completely constrained). After eliminating land based on soil constraints, the methodology then further excluded the following areas: land that had less than 20 billion kilocalories produced within the 5 km of the target cell, land that had a topographic roughness index greater than 20, and land with an overall crop suitability lower than 30 percent. Finally, the methodology excluded urban, water, barren, ice and rocky land-use types. See the GTAP-InVEST GitHub repository for more details. This process resulted in AEZ-Region specific values as presented in the supplemental file `land_supply_parameters.csv`.

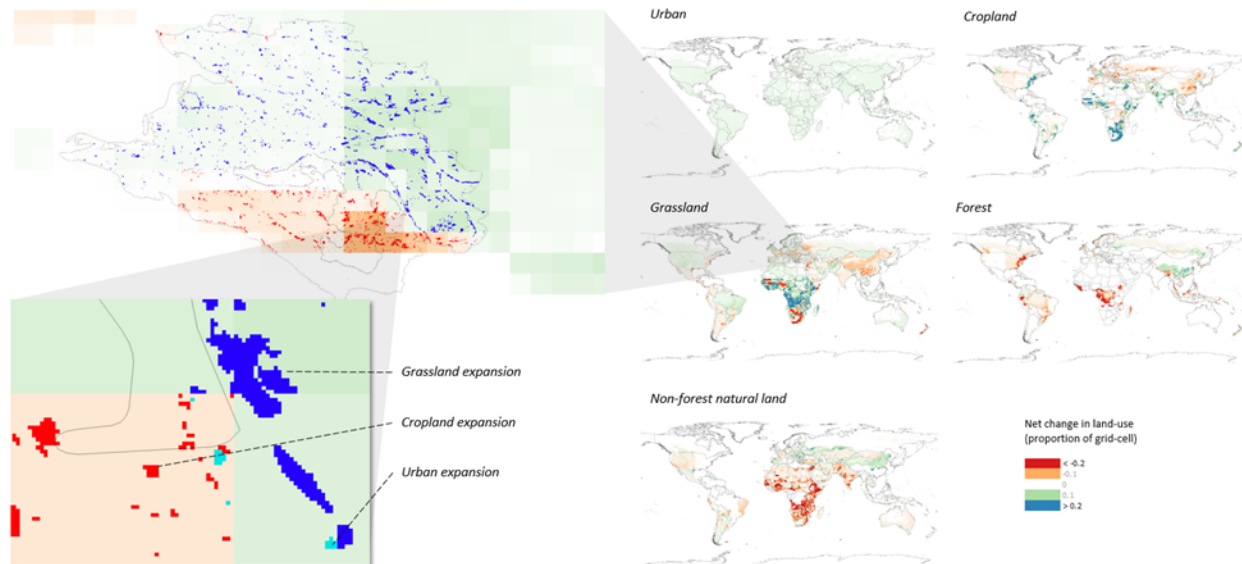
To download the original PNAS-era region definitions — 18 AEZs, 37 aggregated GTAP regions, and corresponding ISO3 codes as a vector file (.gpkg) — see [GTAP37\\_AEZ18\\_ISO3](#). The current pipeline uses the [50-region GTAP-Invest aggregation](#) on top of the [v12 Data Base](#); the corresponding sector aggregation is documented [here](#).

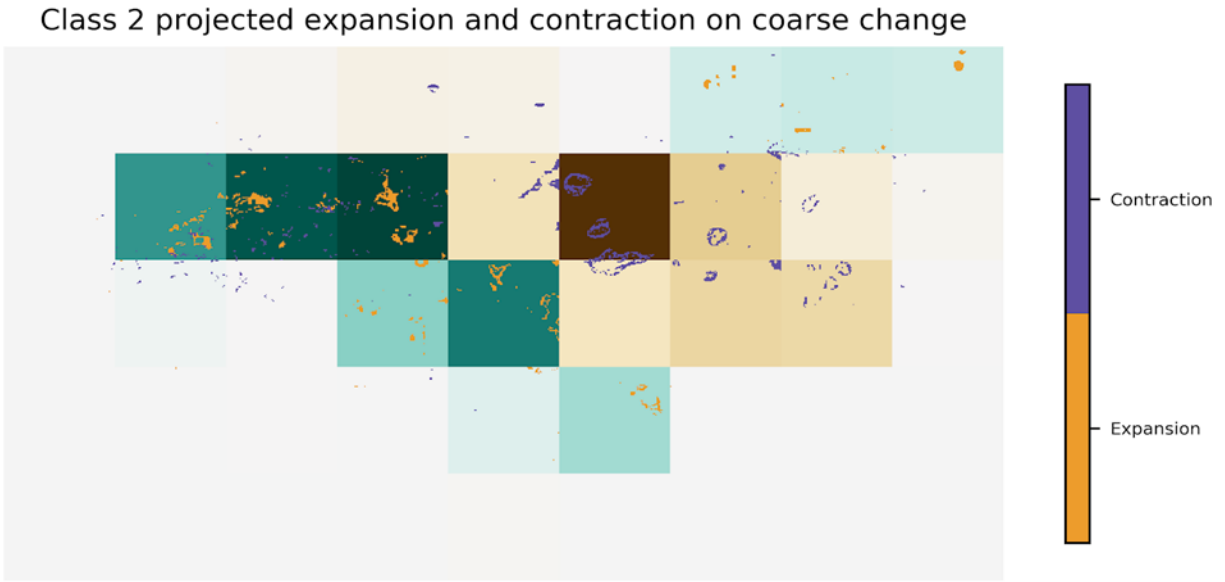
## 2.0.4 2.4. SEALS downscaling methods

In order to analyze ecosystem services, we need to know where within the country the specific changes happen with sufficiently high-resolution data. To enable this, we downscale the regional projections of change produced by the GTAP Run 1 model to a fine (10 arc-second, ~300m) resolution using the Spatial Econometric Allocation Landscape Simulator (SEALS, published in Suh et al. 2020 and extended in Johnson et al. 2020, 2021).

To generate useful results, we also ensured that our downscaled results were consistent with medium-resolution land-use change products currently being used by the global sustainability community. Specifically, we used results reported by the Land-Use Harmonization 2 (LUH2), which provides yearly measures of land-use change for 13 classes under each of 5 different Shared Socioeconomic Pathway (SSP) scenarios used by IPBES, reported at a medium (30km) resolution. We combined the LUH2 data with the AEZ-Region results from GTAP Run 1 by scaling the medium resolution LUH2 data up/down in each AEZ-Region so that (1) the total exactly matched that projected by GTAP Run 1 and (2) within the AEZ-Region, the spatial distribution at the medium resolution matched that of the LUH2 data. See Johnson et al. (2023) for more details along with the code documenting this calculation in the GTAP-InVEST repository.

These results that combine the GTAP-AEZ projections with the LUH2 data, however, are still not at a fine enough resolution to be used in the InVEST ecosystem service tools. Thus, we used SEALS to downscale from the combined 30km LULC data described above to the necessary 300m resolution. Figure S.2.4.1 illustrates how SEALS downscales the medium resolution data to the finer scale. Specifically, the top panel of the figure shows the spatial distribution of five LUC transitions in the LUH2 data, focusing on grassland conversion, and then zooms in to show which 300m grid-cells change in the downscaled data. The bottom panel shows the projections for agricultural land-use change but illustrates both the contraction (brown) and expansion (green) that happens on the landscape. Note that while initially SEALS modeled the expansion of single land-use types, such as maize expansion (Suh et al. 2020), we expanded from the algorithm defined in Suh et al. so that the SEALS model can consider all land-use changes simultaneously.





**Figure 2.4.1: Downscaling using the SEALS model**

#### 2.0.4.1 2.4.1. Allocation Algorithm

We report a simplified explanation of the SEALS algorithm for convenience, drawn from previous publications. See the specific publications for more details (e.g., Suh et al. 2020, Johnson et al. 2020, 2021). SEALS uses a simplified LULC classification scheme that is a hierarchically-defined subset of the ESACCI classes (ESA, 2017). The simplification was used because many relationships were not statistically different among similar class specifications (e.g., between deciduous broadleaf and deciduous needle-leaf forests).

| SEALS LULC Types      | id  | Combined ESA LULC Types                                         |
|-----------------------|-----|-----------------------------------------------------------------|
| Urban                 | 1   | 190                                                             |
| Cropland              | 2   | 10, 11, 12, 20, 30                                              |
| Pasture/Grassland     | 3   | 130                                                             |
| Forest                | 4   | 40, 50, 60, 61, 62, 70, 71, 72, 80, 81, 82, 90, 100             |
| Non-forest vegetation | 5   | 110, 120, 121, 122, 140                                         |
| Water                 | 6   | 210                                                             |
| Barren or Other       | 7   | 150, 151, 152, 153, 160, 170, 180, 190, 200, 201, 202, 210, 220 |
| No-data               | 255 |                                                                 |

**Table S.2.4.1: ESA LULC simplification scheme**

SEALS allocates land-use change by identifying the net change of each LULC class required in each coarse region, then identifying a net change vector , where each entry represents the net change for

the  $i$ -th land-use type in the coarse cell. The allocation algorithm then takes an  $n$  by  $i$  matrix of coefficients for how each  $n$ -th spatial input affects the probability of  $i$ -th expansion in each grid-cell. We provide an example of the table and specification of the functional forms in Table A-4.2. The coefficients actually used are obtained by iteratively solving the allocation algorithm to search for the parameters that minimize the difference between observed change and projected change.

### SEALS Allocation Algorithm

1. For each LULC class  $i$  that might expand and for each  $c$ -th coarse-resolution projection zone, we have a net hectareage change of  $n_c$ .
2. Define the starting condition of the landscape based on the current 300m resolution LULC map  $L_{x,t}$ .
3. Define the spatial allocation algorithm  $S(n_c, L_{x,t}, p_{xi}, a_{xij}, e) = L_{x,t+1}$  that takes the net hectareage change and an existing LULC map ( $L_{x,t}$ ) and produces a LULC map for a future time based on three factors:
  1.  $p_{xi}$  The physical suitability of cell  $x$  to be converted into class  $i$ .
  2.  $a_{xij}$  The effect on suitability of being converted to class  $i$  in cell  $x$  based on the relative adjacency impact of class  $j$ .
  3.  $e$  A 0-1 map that defines which grid-cells are eligible (e.g., prevent expansion into cities).
4. Combine 3.1 - 3.3 with  $n_c$  to define the change-weighted suitability map  $C$ .
5. Rank all values in  $C$  (note, this is where much of the computation time happens) into a map of conversion order  $R$  (lower values denote earlier conversion).
6. Starting with the first conversion in  $R$ , convert to the target LULC class and reduce the remaining amount of conversion necessary in  $n_c$  by the amount converted. Continue until  $n_c = 0$  in all coarse-region projections.

#### 2.0.4.2 2.4.2 Coefficients used

Table S.2.4.2. defines the specific coefficients used. These were established using the calibration algorithm described in the next section, averaging calibrated coefficients from 10 different sampled regions.

| spatial_regres-<br>sor_name | type           | class_1 | class_2 | class_3 | class_4 | class_5 |
|-----------------------------|----------------|---------|---------|---------|---------|---------|
| class_1_con-<br>straint     | multiplicative | 0       | 0       | 0       | 0       | 0       |
| class_2_con-<br>straint     | multiplicative | 1       | 0       | 1       | 1       | 1       |
| class_3_con-<br>straint     | multiplicative | 1       | 1       | 0       | 1       | 1       |
| class_4_con-<br>straint     | multiplicative | 1       | 1       | 1       | 0       | 1       |

|                    |                       |                                                         |                                                         |                                   |             |                                   |
|--------------------|-----------------------|---------------------------------------------------------|---------------------------------------------------------|-----------------------------------|-------------|-----------------------------------|
| class_5_constraint | multiplicative        | 1                                                       | 1                                                       | 1                                 | 1           | 0                                 |
| class_6_constraint | multiplicative        | 0                                                       | 0                                                       | 0                                 | 0           | 0                                 |
| class_7_constraint | multiplicative        | 1                                                       | 1                                                       | 1                                 | 1           | 1                                 |
| class_1_binary     | additive              | 0                                                       | -                                                       | 0.013888889-                      | -           | -                                 |
|                    |                       |                                                         | 0.032222222                                             | 0.0138888890.016666667            |             |                                   |
| class_2_binary     | additive              | -                                                       | 0                                                       | 0.0166666670.0111111110.004333333 |             |                                   |
|                    |                       |                                                         | 0.027777778                                             |                                   |             |                                   |
| class_3_binary     | additive              | 0.0055555560.0188888890                                 |                                                         | 0.041666667-                      |             |                                   |
|                    |                       |                                                         |                                                         |                                   | 0.026111111 |                                   |
| class_4_binary     | additive              | -                                                       | -                                                       | -                                 | 0           | 0.033444444                       |
|                    |                       |                                                         |                                                         |                                   |             | 0.0194444440.0166666670.002666667 |
| class_5_binary     | additive              | 0.01                                                    | 0.1444444440.0601111110.02                              |                                   | 0           |                                   |
| class_6_binary     | additive              | 0                                                       | 0                                                       | 0                                 | 0           | 0                                 |
| class_7_binary     | additive              | -                                                       | 0.0016666670.1266666670.061111111-                      |                                   |             |                                   |
|                    |                       |                                                         | 1.119444444                                             |                                   |             | 0.023333333                       |
| class_1_gaussian_1 | gaussian_parametric_1 | 1.713888889-                                            | -                                                       | 0.041666667-                      |             |                                   |
|                    |                       |                                                         | 1122.23344411.13055556                                  |                                   | 1122.241667 |                                   |
| class_2_gaussian_1 | gaussian_parametric_1 | 0.1055555560.3334444440.022222220                       |                                                         |                                   | -           |                                   |
|                    |                       |                                                         |                                                         |                                   | 11.24444444 |                                   |
| class_3_gaussian_1 | gaussian_parametric_1 | 0.0544444440.0054444440.38                              |                                                         | 0.0182222220.085555556            |             |                                   |
| class_4_gaussian_1 | gaussian_parametric_1 | -                                                       | 1111.065556-0.011                                       | 0.276666667-                      |             |                                   |
|                    |                       |                                                         | 0.122222222                                             |                                   | 0.022233333 |                                   |
| class_5_gaussian_1 | gaussian_parametric_1 | 0.0108888890                                            |                                                         | 0.019444444-                      | 0.466666667 |                                   |
|                    |                       |                                                         |                                                         | 0.122222222                       |             |                                   |
| class_6_gaussian_1 | gaussian_parametric_1 | 0.036555556-                                            | -112.24                                                 | -                                 | -           |                                   |
|                    |                       |                                                         | 112.2027778                                             | 1.1055555561133.322333            |             |                                   |
| class_7_gaussian_1 | gaussian_parametric_1 | -                                                       | -                                                       | -                                 | -           | 0.005555556                       |
|                    |                       |                                                         | 0.127777778112.2555556112.1444441111.133333             |                                   |             |                                   |
| class_1_gaussian_5 | gaussian_parametric_1 | -                                                       | -                                                       | -                                 | -           | -                                 |
|                    |                       |                                                         | 0.07222222211.52222222111.26388890.0933333330.087777778 |                                   |             |                                   |
| class_2_gaussian_5 | gaussian_parametric_1 | 0.0688888890.162333333-                                 |                                                         | 0.1222222220.065555556            |             |                                   |
|                    |                       |                                                         |                                                         | 0.016666667                       |             |                                   |
| class_3_gaussian_5 | gaussian_parametric_1 | 0.100222222-0.025                                       | 0.431111111-                                            | -                                 | -           |                                   |
|                    |                       |                                                         |                                                         | 0.0266777780.041666667            |             |                                   |
| class_4_gaussian_5 | gaussian_parametric_1 | 0.1332222220.3677777780.0763333330.2817777780.113333333 |                                                         |                                   |             |                                   |
| class_5_gaussian_5 | gaussian_parametric_1 | 0                                                       | -                                                       | 0.024444444-                      | 0.152777778 |                                   |
|                    |                       |                                                         | 0.073111111                                             | 0.005555556                       |             |                                   |
| class_6_gaussian_5 | gaussian_parametric_1 | 0.0916666670.005                                        | -                                                       | -                                 | -           |                                   |
|                    |                       |                                                         | 1111.1054441.0927777780.002222222                       |                                   |             |                                   |
| class_7_gaussian_5 | gaussian_parametric_1 | 0.0455555560.15                                         | -                                                       | -                                 | -110.89     |                                   |
|                    |                       |                                                         | 1111.0777780.008333333                                  |                                   |             |                                   |

|                             |                       |             |             |             |              |
|-----------------------------|-----------------------|-------------|-------------|-------------|--------------|
| class_1_gaussian_30         | gaussian_parametric_1 | -           | -           | 0.077777778 | 0            |
| class_2_gaussian_30         | gaussian_parametric_1 | 0.06666667  | 0.07333333  | 0.02611111  |              |
| class_3_gaussian_30         | gaussian_parametric_1 | 0.01111111  | 0.03488889  | -           | -            |
| class_4_gaussian_30         | gaussian_parametric_1 | -           | -0.006      | 0.08166667  | 0.01666667   |
| class_5_gaussian_30         | gaussian_parametric_1 | 0.01722222  |             | 0.03777778  | 0.02433333   |
| class_6_gaussian_30         | gaussian_parametric_1 | -           | 0.15555556  | 0.10888889  | 0.05677778   |
| class_7_gaussian_30         | gaussian_parametric_1 | 0.01611111  |             | 0.15344444  |              |
| soil_organic_content_1m_30s | additive              | 0.00555556  | -           | 0.13722222  | 0.14344444   |
| bio_12                      | additive              | 0.02111111  |             | 0.10555556  |              |
| alt                         | additive              | -           | 0.03655556  | 0.15244444  | 0.05555556   |
| bio_1                       | additive              | 0.02111111  |             |             |              |
| minutes_to_market_30s       | additive              | 0.025       | 1109.978889 | 0.20444444  | -            |
| pop_30s                     | additive              | 0.02777778  | 0.15        | 110.977778  | 111.14       |
| bulk_density_1m_30s         | additive              | 11.11944444 | -           | 1.14        | -1.075       |
| CEC_1m_30s                  | additive              | 0.99444444  |             |             | 11.00444444  |
| clay_percent_1m_30s         | additive              | -           | 0.085       | -           | 0.01         |
| ph_1m_30s                   | additive              | 0.10444444  |             | 0.02488889  | 0.03778889   |
| sand_percent_1m_30s         | additive              | -           | 0.04444444  | -0.01       | -            |
| silt_percent_1m_30s         | additive              | 0.02211111  |             | 0.01111111  | 0.00111111   |
|                             | additive              | 0.01612222  | 0.21        | 0.00555556  | 111.077778   |
|                             | additive              | 0           | 0           | 0           | 0            |
|                             | additive              | 1.15        | 1.12222222  | -           | 22.18444444  |
|                             | additive              | 0           | -           | 0           | 111.07222220 |
|                             | additive              | -           | 0.02        | -           | 1.08433333   |
|                             | additive              | 0.05111111  |             | 0.18611111  | 0.04622222   |
|                             | additive              | 0           | 0.1         | 0           | 0            |
|                             | additive              | 0.03444444  | 0.01833333  | -           | -            |
|                             | additive              | -           | -0.165      | 0           | -            |
|                             | additive              | 0.01277778  |             | 0.05901111  | 0.14611111   |

**Table S.2.4.2. Coefficients used in the SEALS algorithm**

### 2.0.4.3 2.4.3. Calibration

A key component in SEALS is that it downscales according to observed relationships present in time-series input data. SEALS uses a spatial allocation approach that has been calibrated on the ESACCI 1992-2015 time series using an iterative Gaussian L1-loss function minimization approach. The approach is documented in Figure S.2.4.3.1. as per the following algorithm:

1. Define a baseline condition (Panel A, using the year 2000 for this example).
2. Define a projection year in the set of observed years after the baseline year (2010), shown in Panel B, and calculate the net-change between the two years for each coarse resolution (30km) grid-cell. This defines the amount of change in each LULC class that our allocation algorithm will predict.
3. Allocate the net change of each LULC class using only the baseline map and a spatial allocation algorithm,  $S(p1)$ , where  $p1$  is the parameter set used in the allocation and is initially set to an arbitrary value.
4. Calculate how accurate the projected LULC map for 2010 (Panel C) compares to the observed 2010 LULC map. Specifically, calculate the difference score, which is the summation of 5 L1-difference functions, one for each LULC transition, that calculates how different (in terms of Gaussian-blurred distance) each class is in the projected map compared to the observed map. This generates a score for the quality of fit for the current set of parameters (Panel D).
5. Iteratively for each parameter in  $p1\_i$ , increase the parameter by X percent (initially 10), rerun step 4 with the new parameter, observe the new similarity score, then decrease it by 10 percent and rerun.
6. After calculating the change in fit from each parameter increase and decrease in Step 5, identify which change had the greatest improvement in the similarity score. Update the parameter set to include the single best change, and then repeat Steps 3-6 until no additional improvements can be made.

Figure 2.4.3.2. shows more detail on the calibration process, highlighting where specific transitions are projected versus where they actually happen, along with the difference score implied.

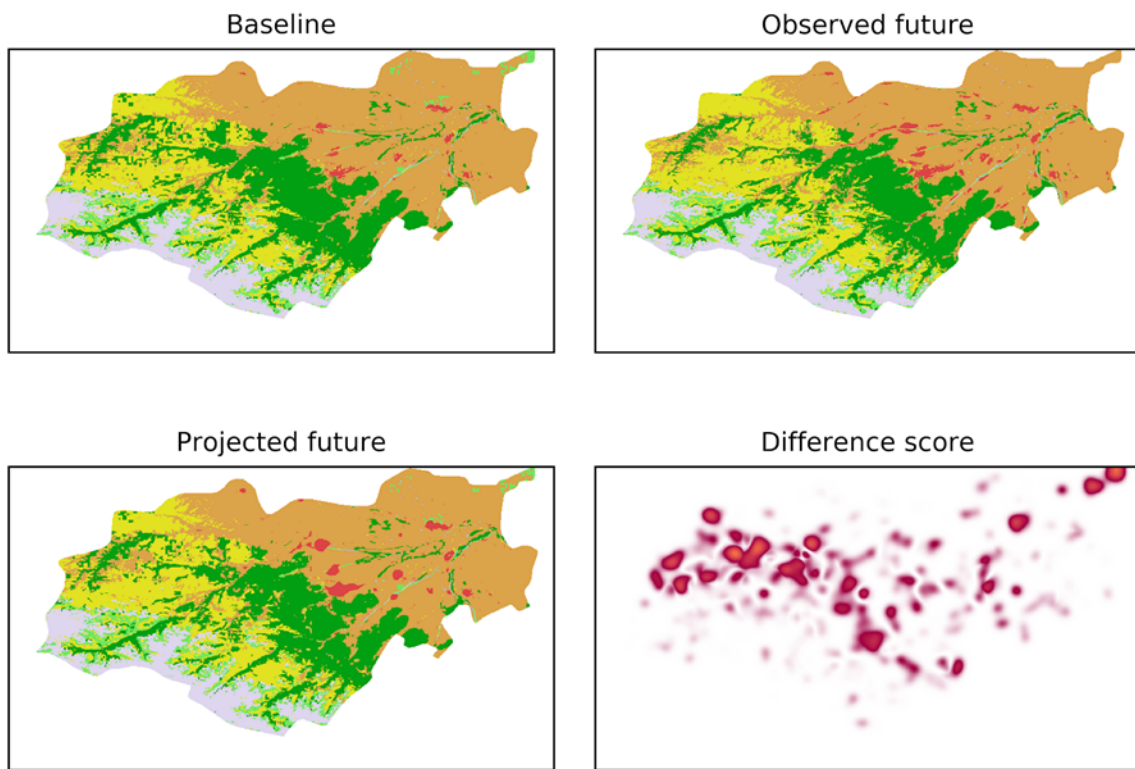
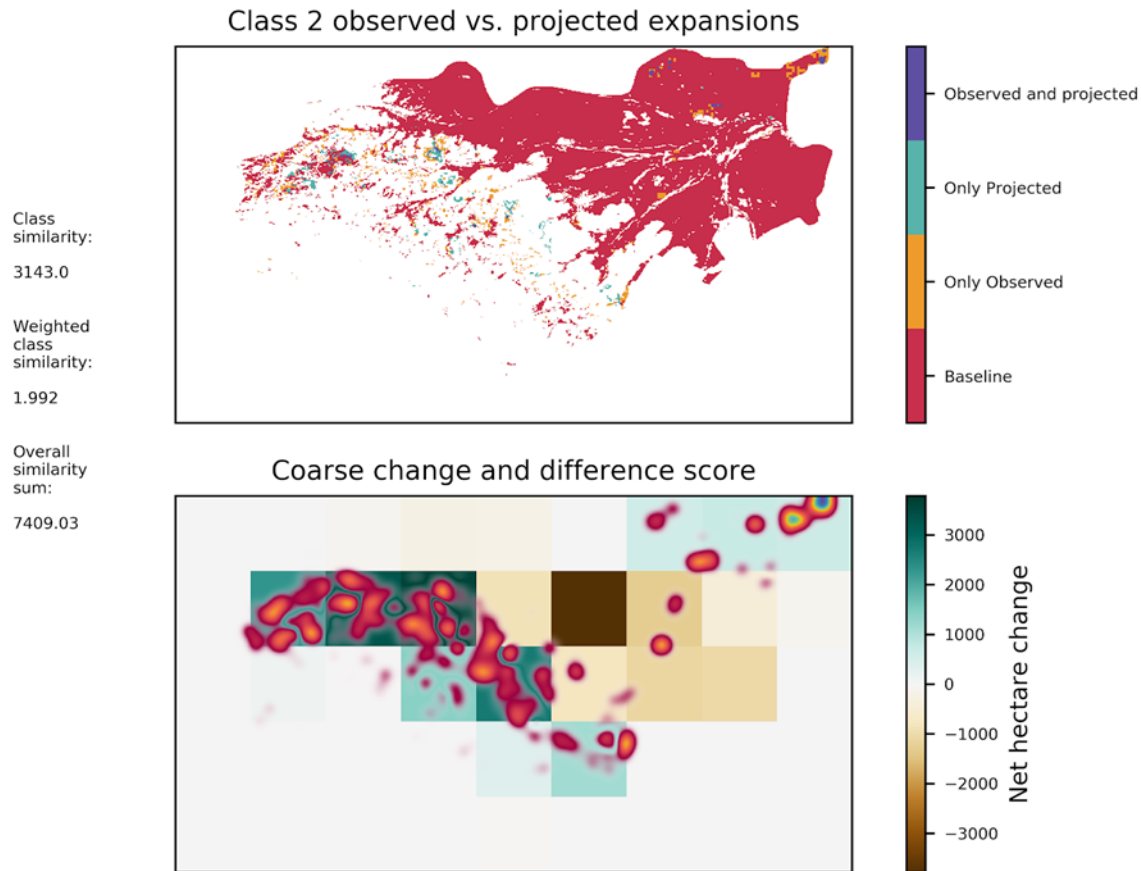


Figure 2.4.3.1. SEALS calibration process



**Figure 2.4.3.2. Assessment of prediction quality-of-fit for 1 LULC class**

#### 2.0.4.4 2.4.4. Current Limitations within SEALS

Due to the computationally heavy nature of calibration, the calibration was only done on a subset of the input data. Subsequent work can improve this by running on more (or potentially all) regions and applying unique values for each region downscaled, instead of averaging the coefficients.

Additionally, in our downscaling approach, we chose to match exactly the results from the LUH2 project. This had some downsides, such as locating massive agricultural expansion in the northern Sahara. In locations where the change projected by LUH2 is well outside any observed changes, the calibration is not effective, and visible artifacting is present. In these locations, no allocation method based on the sparse observed data is likely to produce realistic outputs unless the underlying input LUH2 data is modified. We chose not to modify the input LUH2 data in these locations in order to stay consistent with existing approaches, though other applications of this data may benefit from versions that modify the input data. Future research directions should include dynamic updating between the coarse and fine resolutions to resolve the underlying problem.

It is also important to note that the modelling outputs (including LULC change maps, InVEST outputs, and GTAP outputs) are not meant to be accurate predictions of future change. Instead, they are illustrations of possible future outcomes given the assumptions used. Furthermore, the modelling approaches used in this project are a first step in exploring how the integration of

ecosystem service models (InVEST) and economic models (GTAP) can be connected to help explore the implications of large-scale implementation of global conservation goals, and these methods will be further refined over time.

### 3 3. Scenarios and Policy specification

To understand different aspects of the earth-economy linkage, we compare multiple scenarios on different policies, economic assumptions, and conceptions of “business as usual” (BAU). In this section, we report how we used the created model with multiple scenarios to assess various aspects of the earth-economy linkage.

Before running policy-relevant scenarios, our first step was to update the baseline economy from 2014 to 2021 to be closer to the present year. To do this, we ran a “Base Year Calibration” scenario that projects the global economy from Y2014 – the latest reference year of the GTAP v.10 database – to Y2021, which is the base year used in this paper. We then apply all policies and other shocks to this 2021 snapshot of the economy. To generate the 2021 economy, we specified how the exogenous factors in our model would evolve from 2014 to 2021 and then applied them as a shock to the 2014 equilibrium. We use a similar approach for scenarios that proceed to 2030 (represented in Figure S.3.1 as the “Economic Drivers” arrow on the right-hand side).

With the 2021 baseline economy defined, we then define two sets of future scenarios that project from Y2021 to Y2030. Below, we discuss these two sets of scenarios, namely the BAU scenarios (right-hand side of Figure S.3.1) and the Policy Scenarios (left-hand side).

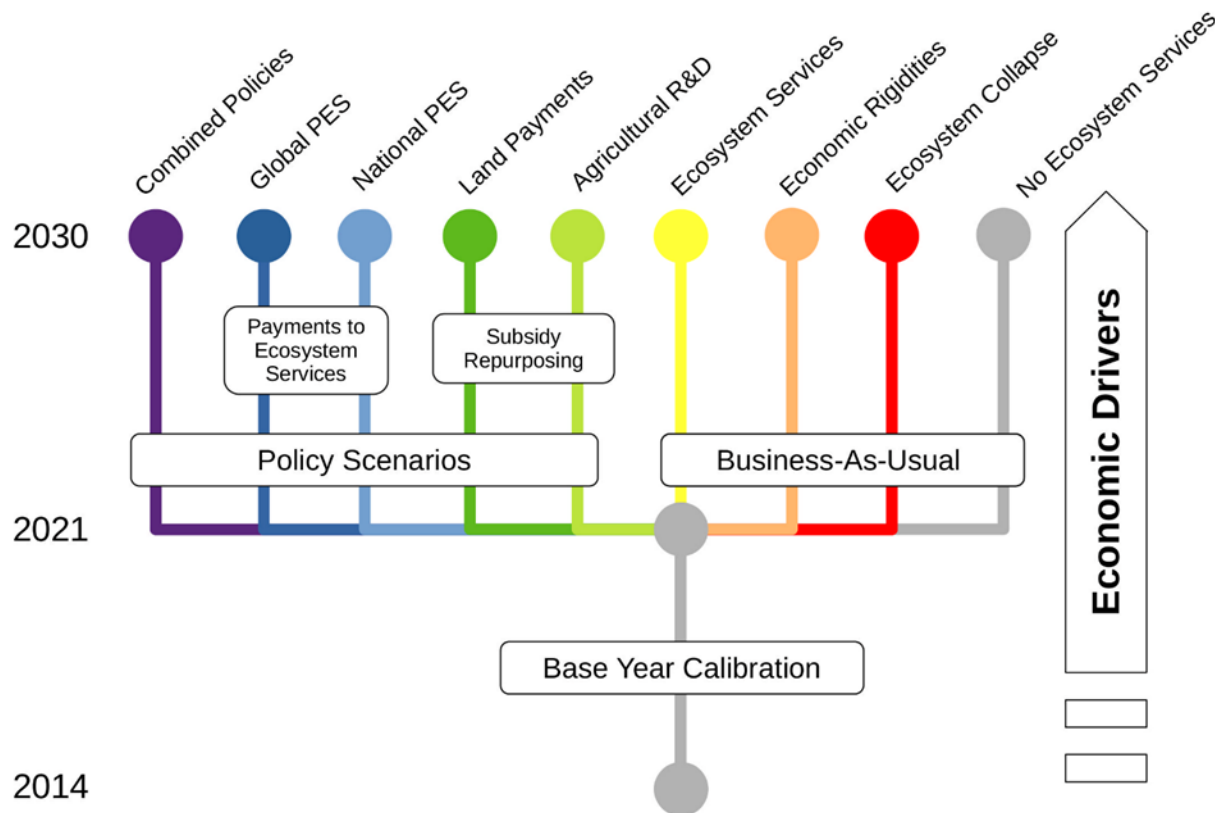


Figure S.3.1: Summary of scenarios and policies analyzed

### 3.0.1 3.1. BAU scenarios

Our BAU scenarios include “no Ecosystem Services”, “Ecosystem Services”, “Economic Rigidities” and “Ecosystem Collapse” scenarios. To create Figure 1 in the main text, we calculated the difference between the “no Ecosystem Services” scenario, which projects basic economic activity to 2030 but ignores all changes in ecosystem services, and the “Ecosystems Services” scenario, which incorporates shocks to the economy from changes in pollination services, timber carbon stock and fisheries stock. The difference between these scenarios identifies a subset of estimates on “how much nature matters” and gives us a sense of how wrong our calculations can be if we ignore earth-economy linkages.

#### 3.1.1. Economic Rigidity

Our BAU scenarios also consider two important sensitivity analyses. First, in the “Economic Rigidities” scenario, we assess what happens to the economy if it exhibits more rigidity and less substitutability. Specifically, this scenario builds on the “Ecosystem Services” scenario and uses smaller elasticity values for key economic parameters in GTAP-AEZ model. These include: (a) Elasticity of transformation between land cover types, (b) Elasticity of cropland transformation among crops, (c) Constant elasticity of substitution (CES) between primary factors in production, (d) Armington CES for regional allocation of imports and (e) Armington CES for domestic/imported allocation. We obtain lower bound of the 95% confidence intervals for the Armington CES for regional allocation of imports and Armington CES for domestic/imported allocation based on

adjusted estimates from Hertel et al (2007) and Hertel et al (2006) respectively. For the other parameters, standard values are deflated by 50%.

### 3.1.2. Ecosystem Collapse

We also analyzed what happens to the economy under an “Ecosystem Collapse” scenario, which analyzes very large changes in ecosystems services rather than just small shocks from currently projected land-use change, as analyzed in the main manuscript. These ecosystem collapse shocks are a highly simplified representation of what might happen when key relationships in the ecosystem pass ecological tipping-points. We draw from the tipping-point scenarios defined in the Dasgupta Review of the Economics of Biodiversity (2021, pp. 375, Box 14.3), which used an earlier version of the GTAP-InVEST model. The three specific elements shocked in the collapse scenario are widespread dieback of tropical forests, collapse of wild pollinator populations, and severe losses in marine fishery populations.

A large body of literature suggests that regime changes may happen because large parts of the biosphere are close to tipping points (Rockström et al. 2009; Steffen et al. 2015). According to these studies, it is possible that when some (probably unknown) ecological thresholds are passed, it might trigger large, non-linear, systemic change in the health of entire ecosystems. It is extremely challenging to predict when tipping points might be crossed. Instead, these results are not predicted to happen at some specific point in time, but are presented to explore scenarios and economic implications of large-scale ecological change. We suggest that our readers interpret these results with some caution because the exact thresholds are unknown and what happens beyond the threshold remains poorly understood, especially at large spatial scales (Lenton 2013).

Conceptually, it is important to consider such non-linear changes and estimate how they might have further, possibly non-linear, effects in the economy. Traditional CGE models ameliorate many negative impacts to some degree by substitution away from affected sectors. However, it might be the case that such substitution is limited in overall quantity and that very large changes could cause decreased flexibility within the economy, amplifying negative effects. We discussed this possibility above in our section on economic rigidity.

To determine which tipping points we wanted to assess, we reviewed the “Regime Changes” database produced by the Stockholm Resilience Center[1]. We identified three scenarios that we were able to evaluate in GTAP-InVEST. These include assessing wide-spread collapse of tropical forests that results in forests converting into grasslands and shrubs, global pollinator collapse, and climate-related reductions in fisheries output.

We define the specific shocks that we impose on the GTAP-InVEST model in Table S.3.1, reproduced with permission from Johnson et al. (2021).

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#### **Sce-    Method to calculate shock nario**

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|                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|----------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Wild pol-<br/>lina-<br/>tion col-<br/>lapse</b>                                                             | The BAU and policy scenario considers how pollination services would change when different levels of pollinator habitat are present near pollinator-dependent crops. It does not consider what happens if broad-scale reductions in pollinator colony health result in additional changes unrelated to LULC configuration. To model this extended pollinator collapse scenario, we modified the pollination scenario to also contain a 90 percent reduction in pollination sufficiency. The 90 percent reduction is less severe than other attempts to model pollinator collapse, e.g., Bauer and Wang (2016) evaluate a scenario where most, but not all, species of wild pollinators cease to provide service. Note that this shock means crops only partially dependent on pollination services will not see yield reductions as large as the pollinator collapse. Assessing the extent to which markets shift, consumers substitute to non-pollinator crops, and producers substitute to non-pollinator intermediate goods will test the global market’s ability to absorb such a large shock. |
| <b>Ma-<br/>rine fish-<br/>eries col-<br/>lapse</b>                                                             | <p>The model relies on the Fisheries and Marine Ecosystem Model Intercomparison Project data (Lotze et al. 2019). To simulate the regime shift, the model assumes a severe climate change scenario (8.5 instead of RCP4.5) and further takes the worst-case outcome in terms of climate change impact reported in the uncertainty bounds and sensitivity analysis. The model simulates severe disruptions of fish migration that lead to a reduced total catch biomass, which in turn impacts the economic model.</p> <p>This type of collapse would reflect when, for example, fish populations are blocked from migrating north or south to keep a constant habitat. The reduced fisheries impact the model by lowering Total Catch Biomass in the projections, which registers as a technology-neutral productivity change in the fisheries sector.</p>                                                                                                                                                                                                                                         |
| <b>Widespread<br/>con-<br/>ver-<br/>sion of<br/>trop-<br/>ical<br/>forests<br/>to<br/>sa-<br/>van-<br/>nah</b> | <p>To create this regime-change shock, we used the SEALS model to project a landscape where 88% of the forests in tropical regions (specifically AEZs 5 and 6) were converted to grassland or shrubland. The landscape generated by this calculation had much less forest cover, so when it was used as an input to InVEST, the relative sizes of ecosystem service impacts were much larger.</p> <p>As with all of these tipping-point scenarios, the precise magnitude of forest dieback is unknown, and instead we aimed to provide illustrative values that can then be processed through the rest of the GTAP-InVEST model. 1</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                             |

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**Table S.3.1: Shocks applied to the GTAP-InVEST model**

Note that the definition of this ecosystem-collapse scenario is subtly different than in Johnson et al. (2021). In the previous study, the shocks to update the global economy from 2021 to 2030 (see Figure S.3.1) were imposed along with the ecosystem-collapse shocks. With this approach, the contractionary impacts of ecosystem-collapse interacted with economic growth, thereby resulting in higher losses (\$2.7 trillion in the previous study versus \$2.0 trillion here). In this article, we applied the ecosystem-collapse shock *after* the economy grew to the 2030 level. We did this to isolate the impacts of ecosystem-collapse on direct economic activity rather than in combination with growth effects, which makes attribution to ecosystem services more challenging. Ecosystem-service and economic growth interactions remain important, however, so future research is needed to further identify this interrelation.

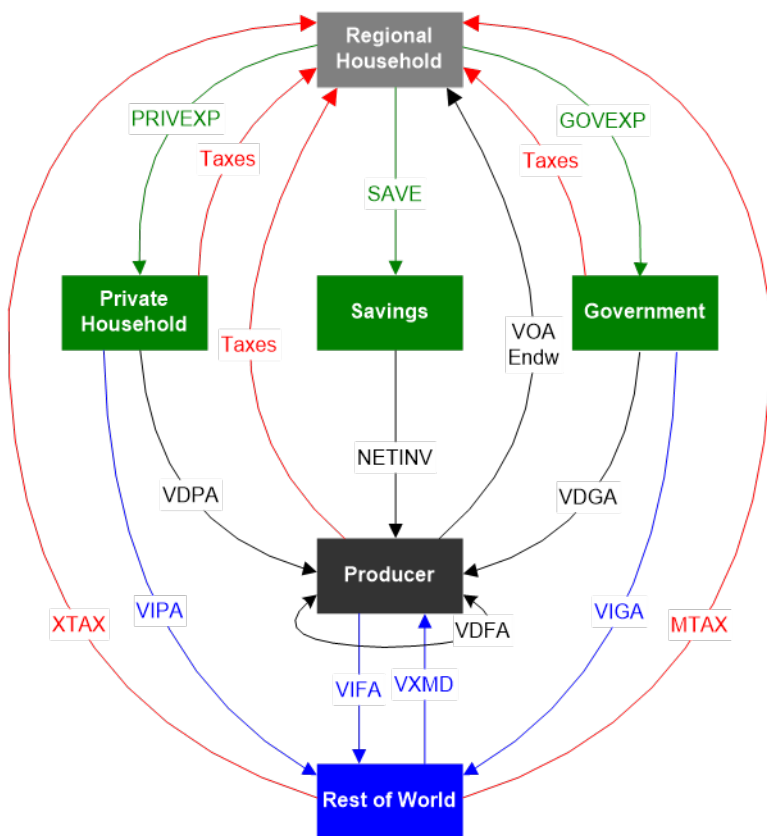
### 3.2. Policy Scenarios

The second set of scenarios are policy scenarios that define several nature-smart policies to see how they impact the outcomes of the GTAP-InVEST model. Our approach draws on four different policies: (i) removing agricultural subsidies, (ii) domestic carbon forest payments, (iii) global carbon forest payments, and (iv) agricultural research and development (R&D). Removing agricultural subsidies, sometimes referred to as “decoupling support to farmers”, requires that certain agricultural subsidies are replaced with a direct payment to landowners using the “savings” obtained from not paying the subsidy. Carbon forest payments can be either domestically or globally managed. In the domestic case, governments compensate landowners to preserve land instead of converting it for agriculture or other purposes. For globally managed forest payments, wealthier countries contribute to a global pool based on their historical emissions. The pool is allocated to developing countries, compensating them to limit land use in a manner equivalent to the payment received. Research and development investments focus on increasing the efficiency of land already converted for agricultural purposes, meaning that supply can rise without expansions in land use.

Referring back to Figure S.3.1, the “Policies” scenarios include subsidy repurposing and payments to ecosystem services. Input and output subsidies paid to the agricultural sector are reallocated as land input subsidies (“Land Payments”) or are reinvested into public agricultural R&D (“Agricultural R&D”). Calculations under “Agricultural R&D” scenario relies heavily on the framework from Baldos et al. (2019), which estimates the public R&D spending increase required to offset agricultural productivity losses from climate change. The payment schemes to ecosystem services include “Local PES” and “Global PES”. Under the “Global PES” scenario, high-income countries fund a global budget via income transfers. The budget compensates income losses in countries that set aside land for natural use. In the “Local PES” scheme, the budget is based on the amount of input and output subsidies in agriculture for each region. Finally, the “Combined Policies” scenario incorporates the methods from the “Agricultural R&D” and “Global PES” scenarios

## 4 4. GTAP model details

The GTAP (Global Trade Analysis Project) model is a multi-commodity, multiregional computable general equilibrium (CGE) model that tracks bilateral trade flows between all countries in the world and explicitly models the consumption and production for all commodities of each national economy (Corong et al., 2017; Hertel, 1997). The standard version of the model is a comparative static CGE model that shows differences between possible states of the global economy for a given year – with and without policy or with respect to base year and future year. At the core of the GTAP model is an input-output accounting framework that accounts for all sources and uses of each market good and economic endowment. Figure S.4.1 is a stylized framework of the GTAP model and summarizes the key flows across economic agents in the model.



**Figure S.4.1: A stylized framework of the GTAP model.** Source: the figure is adapted from Corong et al. 2017

*Consumption framework.* The model has a single representative household for each region (the Regional household). The red line in Figure S.4.1 represents income flows to the household. The household receives all gross factor payments net of the capital depreciation allowance (VOA - Payments of Factors of Production), plus the receipts from all indirect taxes (including Export and

Import Taxes – XTAX, MTAX). Regional income is distributed across three broad categories—Private Household, Government Expenditures, and Savings— by maximizing a top-level Cobb-Douglas utility function. Saving is a unitary good, while Private Household and Government Expenditures utilize sub-level utility functions to determine consumption of each domestic product (Value of Domestic purchases of Private Household and Government - VDPA, VDGA - black lines in Figure S.4.1) and imported commodities (Value of Imported purchases of Private Household and Government - VIPA, VIGA - blue lines in Figure B.1). The sub-level utility function for the Private Household is based on a constant differences of elasticities (CDE) function (Hanoch, 1975). This function is less demanding to solve than the flexible functional forms and permits calibration of income elasticities and own-price elasticities independently, and importantly, it is non-homothetic. The sub-utility function for public expenditure is based on a constant elasticity (CES) utility function (Arrow et al., 1961).

*Production framework.* GTAP uses nested CES functions to model producer behavior for each region. At the top level of the production framework, producers combine aggregate value-added and intermediate inputs, according to a single CES function. Sub-level CES functions produce aggregated value-added from each primary factor commodities and aggregated intermediate input from each purchased inputs. Factors of production, or endowments, are of three types: perfectly mobile (e.g., labor and capital), partially mobile or sluggish (e.g., land) and sector-specific factors (natural resources). Each purchased input can be sourced either domestically or internationally, and this is modelled using another sub-level CES function (Value of Domestic and Imports of Firms – VDFA and VIFA in Figure S.4.1.).

*International trade.* The most notable restriction on trade in the GTAP model is that commodity sourcing is at the border: for each product, all domestic agents (i.e., Private Household, Government, Producers) in an economy use the same mix of imports from different countries, though each agent chooses their own combination of import and domestic product. There is also a two-level system of substitution between products from different sources - an import-domestic top-level CES function above an import-import sub-level CES function. Trade flows generate supply and demand for international transport services, and this is accounted for in the model. There is also no international trade in primary factors in the standard version of GTAP.

The original PNAS results (Johnson et al. 2023) were produced with the GTAP Database Version 10 for year 2014 (Aguiar et al., 2019) — 140 regions and 57 commodities aggregated into 37 regions and 17 commodity groups. The current GTAP-Invest pipeline has since been migrated to the GTAP 12 Data Base (Aguiar et al. 2025), which provides 7 reference years, [163 regions](#) and [65 sectors](#). For tractable simulations these are aggregated to the [v12\\_s26\\_r50](#) configuration — [50 regions](#) and [26 sectors](#). The model variables themselves (sets, value flows, prices, technical change, policy shocks, welfare) come from the GTAP v7 model formulation and are documented [here](#). The GTAP Data Base is composed of Input Output Tables statistics, which are mainly contributed by members of the GTAP Network. The v12 Database includes separate IO tables for individual countries representing the vast majority of global gross domestic product and population, with the remainder grouped into “Rest of ...” regional aggregates. Key value flows in the database include both input-output flows within each region, bilateral international trade flows, capital stock and savings information, international transports costs, domestic input and output subsidies, export subsidies and import tariffs, as well as revenue flows from taxes and tariffs. Most flows are measured at both tax-free and tax-paid prices (i.e., taxes are implicitly accounted for). Key behavioral parameters provided with the GTAP Data Base include the source-substitution or Armington elasticities (used to differentiate goods by country or origin), the factor substitution elasticities, the factor transformation elasticities

affecting the sluggish factors, the investment parameters, and the parameters governing the consumer demand elasticities. The first three sets of parameters are taken from external sources, while the rest are calibrated from the database.

The standard GTAP model is implemented using the GEMPACK (General Equilibrium Modelling PACKage) suite of economic modeling software (Harrison & Pearson, 1996). GEMPACK is distributed by The Centre of Policy Studies Knowledgebase at Victoria University, Melbourne, Australia (<https://www.copsmodels.com/gempack.htm>). Following the standard for the GEMPACK program, all equations of the GTAP model are recorded not in levels (e.g., million USD), but in percentage change form. Due to non-linearities in formulae and update equations— which result in changes in the underlying shares and price elasticities— the solution requires non-linear methods. The GTAP model can be run via command line as well as the Windows-based RunGTAP tool. RunGTAP is a visual interface to various GEMPACK programs and allows the user to run simulations interactively in a Windows environment using the GTAP general equilibrium model. No previous knowledge of the GEMPACK language or programming skills is necessary to use the program. Results and complementary information for further analysis are also provided in a Windows environment and can be accessed interactively. RunGTAP also has several add-on tools that can be helpful to users. The welfare decomposition tool permits the user to break down the regional equivalent variation metric into its component parts, including changes due to allocative efficiency, terms of trade, improved technology, and endowments. The systematic sensitivity analysis tool allows uncertainty analysis in the model shocks and parameters, thereby generating both mean and standard deviations of model output. Finally, the subtotals tool utilizes numerical integration techniques in order to exactly decompose changes in the model outputs as sums of the contributions made by the change in each exogenous variable (Harrison, Horridge & Pearson, 2000). The subtotals are particularly useful in understanding the key drivers of model outcomes. All the input files are binary header array (HAR) files, to keep the size of the files small. The HAR files are designed to work with the GEMPACK program. There is also a GAMS version of the standard GTAP model and software exist for readily converting these HAR files to the General Algebraic Modeling System (GAMS) data exchange file (GDX) format, as well as to CSV files.

Capital, skilled labor, and unskilled labor are perfectly mobile in the GTAP model. This report assumes perfect labor mobility, which means that labor can move across sectors but not across skill types. In general, perfect mobility implies that returns to each factor will be equated across all sectors. Therefore, there is a single economy-wide price for each mobile factor (capital, skilled and unskilled labor), with market equilibrium determined by setting aggregate demand equal to (exogenous) supply. Land is partially mobile (or sluggish in GTAP terminology). The supply of aggregate land to individual activities is less than perfectly elastic, as there is a transformation frontier (Constant Elasticity of Transformation) that moderates the movement of the land across activities. This results in sector-differentiated land prices for each land using sector. The economy-wide price of each land type is then calculated as the CET aggregate price of each land factor.

#### **4.0.1 4.1. Productivity growth from agricultural R&D**

Increasing public agricultural R&D investments is one of the key levers policy makers can use to alter the trajectory of agricultural productivity. Following Baldos et al. (2020), GTAP models implements R&D policy by modelling the linkages between the flow of R&D spending, the stock of accumulated knowledge capital, and subsequent total factor (TFP) productivity growth (Alston et al., 2011; Griliches, 1979; P. Heisey et al., 2011; Huffman, 2009). TFP captures the rise in

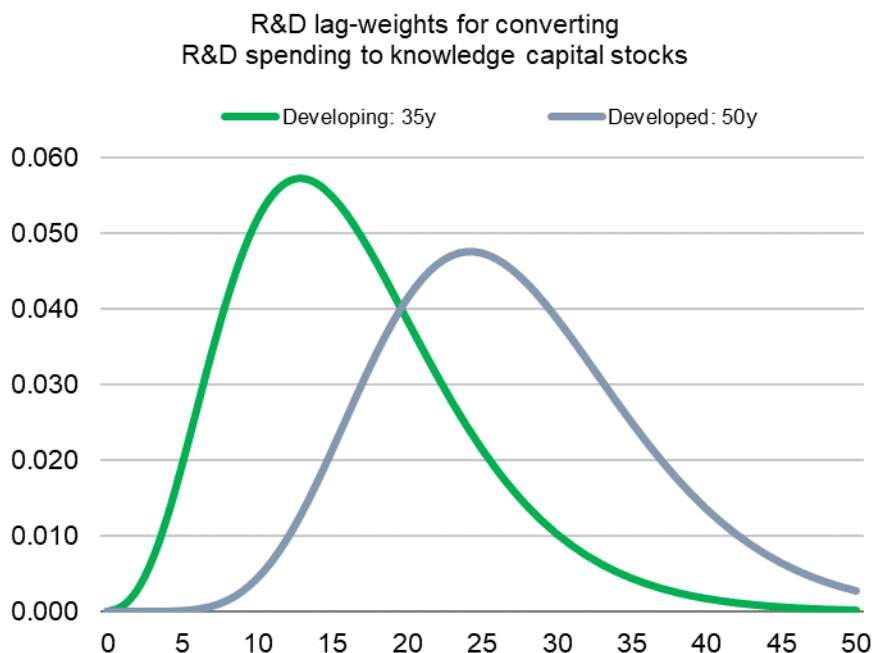
total output given all inputs used in agricultural production, unlike crop yields, which ignores the role of other farm inputs (i.e., total output per area of land input used). The historical national R&D spending data are based on Fuglie (2018), who compiled data on public agricultural R&D expenditures from the literature[2] starting from the 1960s worldwide and from the 1930s for some developed countries, measured in 2005 Purchasing Power Parity (PPP) dollars. Equations 1 to 3 summarize the key linkages under this framework.

$$RD_{t+1} = \sum_{i=0}^L \beta_{RD,i} XD_t \quad (1)$$

$$\beta_{RD,i} = \frac{(i+1)^{\frac{\delta}{1-\delta}} \lambda^i}{\sum_{i=0}^L (i+1)^{\frac{\delta}{1-\delta}} \lambda^i} : \sum_{i=0}^L \beta_{RD,i} = 1: \quad (2)$$

$$\Delta \text{ percent} TFP = \alpha \cdot \Delta \text{ percent} RD \quad (3)$$

Starting with Eq.1, R&D expenditure at time  $t$  ( $XD_t$ ) contributes to R&D stock in years  $t+1$  ( $RD_{t+1}$ ) through  $t + L$ , where  $\beta_{RD,i}$  is the R&D lag weight at period  $i$  and total lag length  $L$  is the number of years R&D contributes to productivity until it fully depreciates (Appendix Figure S.4.1). Following the structure of the R&D lag weights, initially R&D spending at time contributes little to knowledge capital stock, but its effect builds over time as technology arising from that research is developed and is disseminated to farmers. Eventually, the effects peak when technology is fully disseminated, but then wanes due to technology obsolescence. Following Alston et al. (2011), this process is modeled by imposing a gamma distribution for the R&D lag weights (Equation 2). We utilize separate R&D lag distributions for developing and developed regions, calibrated according to lag structures suggested in the literature (Alston et al. 2010). Specifically, we impose a lag length that spans 50 years for developed countries, which are assumed to be on the productivity frontier. Peak impacts of R&D spending on knowledge stocks (and productivity) occur after 26 years ( $\sigma, \lambda = (0.90, 0.70)$ ). For developing countries, we impose a total lag length of 35 years, with peak effects at year 10 ( $\sigma, \lambda = (0.80, 0.75)$ ).



**Figure S.4.1: R&D Lag Weights used to convert R&D spending to R&D knowledge stocks across different years** Note: figure shows the R&D lag weights used to convert R&D spending to R&D knowledge stocks across different years. The value of the weights is zero at Year 0 (investment year), increases as time progress, and eventually goes to zero. The shorter lag length for developing countries reflects their ability to focus more on adaptive R&D, borrowing from global knowledge capital to close existing yield gaps. The longer lag structure for developed countries reflects a greater focus on discovery R&D to push out the global science and technology frontier. We define the total lag length as 50 years following Alston et al (2010).

The growth in knowledge capital stocks is linked to growth in agricultural total factor productivity (TFP) via elasticities that describe the percent rise in TFP given a 1 percent rise in knowledge capital stock (see Equation 3). Using the empirical estimates in the literature as a guide (Fuglie 2018), we assign the R&D stock-to-TFP elasticities for each world region (Appendix Table 1). The values of these parameters reflect generally lower capacity of R&D systems in developing regions (where the value of the R&D elasticity ranges from 0.18 to 0.23) compared to developed countries (where ranges from 0.23 to 0.30). Lower elasticity values imply larger increases in R&D stocks – achieved via greater R&D spending growth – are required in order to raise TFP sufficiently to offset the adverse effects of climate change. It is consistent with the lower research intensities (less R&D spending relative to the value of agricultural output) in developing countries (Pardey et al. 2016). It is important to note that we only consider climate adaptation driven by public R&D investments. We exclude private and international R&D spending for which the contribution to global spending pool has grown steadily in recent years (Beintema et al., 2012). We also abstract from the potential for additional technological spillovers across regions in the context of climate adaptation.

**Table S.4.1: Annual growth rates of key economic variables over 2014-2030.** Note: Compounded annual growth rates are calculated from total changes over 2014-30 in Capital Stock, Real GDP, Population, Unskilled Labor and Skilled Labor from Econmap (v2.4) (Fouré et al 2013) based on SSP2 scenario. Regional productivity growth is used to target changes in regional Real GDP. Sector specific productivity growth for Crops, Ruminants and Non-Ruminants are based on

per annum growth rates from Ludena et al (2007) over 2001-40. Due to lack of estimates, global agricultural productivity growth from Ludena et al (2007) is imposed on the managed forestry sector. A 2% productivity growth is imposed on Manufactures sector to reflect the productivity gap between Manufactures and Service sectors.

| Regions        | Annual growth rates of key economic drivers over 2014-2030 (in %) |            |                  |               |                           |       |          |               |
|----------------|-------------------------------------------------------------------|------------|------------------|---------------|---------------------------|-------|----------|---------------|
| Capital Stock  | Real GDP                                                          | Population | Un-skilled Labor | Skilled Labor | Total Factor Productivity | Crops | Ruminant | Non-ruminants |
| Argentina      | 3.38                                                              | 2.79       | 0.61             | 0.94          | 1.41                      | 0.35  | 0.84     | 2.53          |
| Bangladesh     | 3.66                                                              | 3.91       | 0.80             | 1.27          | 0.94                      | 0.54  | 0.83     | 1.94          |
| Brazil         | 3.26                                                              | 2.62       | 0.57             | 0.81          | 1.94                      | 0.35  | 0.84     | 2.53          |
| Central Amer   | 3.94                                                              | 3.53       | 0.86             | 1.47          | 1.21                      | 0.35  | 0.84     | 2.53          |
| Canada         | 2.62                                                              | 2.82       | 0.96             | 0.72          | 0.92                      | 0.64  | 0.15     | 0.35          |
| China          | 6.82                                                              | 6.07       | -0.07            | -0.30         | 1.62                      | 0.81  | 1.68     | 3.66          |
| Colombia       | 2.61                                                              | 1.96       | 0.97             | 1.39          | 2.16                      | 0.35  | 0.84     | 2.53          |
| Rest of E Asia | 6.69                                                              | 5.70       | 1.04             | 1.02          | 0.29                      | -0.37 | -0.70    | 2.05          |
| Egypt          | 5.58                                                              | 5.21       | 1.42             | 2.13          | 1.76                      | 0.25  | -0.17    | -0.16         |
| Ethiopia       | 4.34                                                              | 3.73       | 1.60             | 2.40          | -0.04                     | 0.51  | 0.32     | -0.03         |
| EU             | 1.96                                                              | 1.81       | 0.25             | -0.12         | 1.17                      | 0.64  | 0.15     | 0.35          |
| Indonesia      | 3.45                                                              | 3.05       | 0.57             | 1.51          | 4.53                      | -0.37 | -0.70    | 2.05          |
| India          | 5.08                                                              | 5.43       | 1.08             | 1.69          | 1.64                      | 0.54  | 0.83     | 1.94          |

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|                       |      |      |       |       |       |       |       |       |
|-----------------------|------|------|-------|-------|-------|-------|-------|-------|
| Japan                 | 1.54 | 1.41 | -0.32 | -0.28 | 0.84  | -0.37 | -0.70 | 2.05  |
| Korea                 | 4.24 | 3.58 | 0.02  | 0.17  | 0.85  | -0.37 | -0.70 | 2.05  |
| Mor-<br>roco          | 3.13 | 3.31 | 0.41  | 0.89  | 2.35  | 0.25  | -0.17 | -0.16 |
| Mada-<br>gascar       | 0.59 | 2.50 | 2.18  | 3.03  | -2.39 | 0.54  | 0.83  | 1.94  |
| M East<br>N<br>Africa | 3.47 | 2.30 | 1.35  | 1.47  | 1.54  | 0.25  | -0.17 | -0.16 |
| Mexico                | 3.52 | 2.82 | 0.64  | 0.98  | 0.60  | 0.35  | 0.84  | 2.53  |
| Malaysia              | 4.68 | 3.73 | 1.28  | 1.49  | 1.23  | -0.37 | -0.70 | 2.05  |
| Nigeria               | 7.00 | 6.47 | 2.20  | 3.02  | 4.68  | 0.51  | 0.32  | -0.03 |
| Oceania               | 3.01 | 3.14 | 1.36  | 1.47  | -0.46 | 0.64  | 0.15  | 0.35  |
| C Asia                | 4.14 | 4.63 | 0.07  | 0.02  | 0.64  | 0.78  | 0.30  | 1.17  |
| Other<br>Europe       | 2.62 | 1.90 | 0.62  | 0.22  | 1.22  | 0.78  | 0.30  | 1.17  |
| Pak-<br>istan         | 4.70 | 3.59 | 1.56  | 2.01  | 1.24  | 0.54  | 0.83  | 1.94  |
| Philip-<br>pines      | 5.11 | 4.94 | 1.42  | 2.22  | 0.86  | -0.37 | -0.70 | 2.05  |
| Poland                | 4.04 | 3.89 | -0.06 | -0.44 | 1.29  | 0.78  | 0.30  | 1.17  |
| Rest of<br>S Asia     | 4.11 | 3.80 | 2.10  | 2.59  | 0.28  | 0.54  | 0.83  | 1.94  |
| Rest of<br>SE Asia    | 4.56 | 3.45 | 0.61  | 0.78  | 2.38  | -0.37 | -0.70 | 2.05  |
| Russia                | 3.40 | 3.42 | -0.12 | -0.67 | -1.21 | 0.78  | 0.30  | 1.17  |
| S<br>America          | 3.54 | 2.65 | 0.78  | 1.34  | 1.13  | 0.35  | 0.84  | 2.53  |

|                 |      |      |      |      |       |       |       |       |
|-----------------|------|------|------|------|-------|-------|-------|-------|
| SS<br>Africa    | 4.38 | 4.77 | 2.08 | 2.83 | 1.98  | 0.51  | 0.32  | -0.03 |
| Turkey          | 4.76 | 4.41 | 0.88 | 1.26 | 1.31  | 0.25  | -0.17 | -0.16 |
| USA             | 2.12 | 1.77 | 0.71 | 0.40 | -0.53 | 0.64  | 0.15  | 0.35  |
| Viet-<br>nam    | 5.37 | 4.59 | 0.61 | 0.54 | 2.77  | -0.37 | -0.70 | 2.05  |
| An-<br>gola+DRC | 6.89 | 5.93 | 2.60 | 3.46 | 3.05  | 0.51  | 0.32  | -0.03 |
| South<br>Africa | 3.67 | 3.37 | 0.62 | 1.26 | 1.57  | 0.64  | 0.15  | 0.35  |

**Table S.4.2: Historical and Projected Average Annual Growth Rate in R&D Spending.**  
Note: Subsidy Repurposing includes R&D spending under Baseline 2021-2030 in addition to savings from subsidy removal.

| Region          | Average annual growth rate      |                                |                                |                                |              |              |              |              |
|-----------------|---------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------|--------------|--------------|--------------|
| Historical Data | Future Projections              |                                |                                |                                |              |              |              |              |
| Baseline        | Subsidy Repurposing 100 percent | Subsidy Repurposing 50 percent | Subsidy Repurposing 20 percent | Subsidy Repurposing 10 percent |              |              |              |              |
| 1991-2000       | 2001-2010                       | 2011-2020                      | 2021-2030                      | 2021-2030                      | 2021-2030    | 2021-2030    | 2021-2030    |              |
| Central America | -3.7 percent                    | 4.0 percent                    | 3.2 percent                    | 3.6 percent                    | 62.1 percent | 22.1 percent | 15.3 percent | 12.4 percent |
| South America   | -0.3 percent                    | 2.7 percent                    | 3.5 percent                    | 3.6 percent                    | 7.8 percent  | 5.5 percent  | 4.4 percent  | 4.1 percent  |

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|                    |              |              |             |             |               |              |              |              |
|--------------------|--------------|--------------|-------------|-------------|---------------|--------------|--------------|--------------|
| South Asia         | 6.9 percent  | 5.4 percent  | 4.0 percent | 3.6 percent | 20.3 percent  | 9.8 percent  | 5.9 percent  | 4.3 percent  |
| South East Asia    | 3.4 percent  | 1.6 percent  | 3.4 percent | 3.6 percent | 35.6 percent  | 17.3 percent | 13.3 percent | 11.7 percent |
| North East Asia    | 6.9 percent  | 11.5 percent | 4.7 percent | 3.6 percent | 27.2 percent  | 13.0 percent | 8.5 percent  | 6.7 percent  |
| West Asia          | 3.9 percent  | 2.6 percent  | 3.7 percent | 3.6 percent | 17.0 percent  | 11.3 percent | 9.4 percent  | 8.7 percent  |
| North Africa       | 2.5 percent  | 3.0 percent  | 4.7 percent | 3.6 percent | 17.0 percent  | 11.3 percent | 9.4 percent  | 8.7 percent  |
| Sub-Saharan Africa | 0.7 percent  | 2.8 percent  | 3.4 percent | 3.6 percent | 23.5 percent  | 14.9 percent | 12.6 percent | 11.8 percent |
| South Africa       | 1.4 percent  | -1.4 percent | 1.1 percent | 1.5 percent | 4.4 percent   | 2.8 percent  | 2.0 percent  | 1.7 percent  |
| Oceania            | 1.2 percent  | -1.6 percent | 1.2 percent | 1.5 percent | 4.6 percent   | 3.1 percent  | 2.3 percent  | 2.0 percent  |
| Canada/USA         | 4.4 percent  | -0.2 percent | 0.6 percent | 1.5 percent | 10.0 percent  | 5.2 percent  | 2.9 percent  | 2.0 percent  |
| Japan/Korea        | 2.2 percent  | 1.3 percent  | 1.3 percent | 1.5 percent | 10.5 percent  | 5.7 percent  | 3.4 percent  | 2.5 percent  |
| Western Europe     | 0.6 percent  | 1.3 percent  | 1.4 percent | 1.5 percent | 16.4 percent  | 7.8 percent  | 4.2 percent  | 2.8 percent  |
| Transition Regions | 10.9 percent | 5.8 percent  | 3.6 percent | 3.6 percent | 381.6 percent | 12.6 percent | 7.9 percent  | 5.9 percent  |
| WORLD              | 1.9 percent  | 2.8 percent  | 2.7 percent | 2.8 percent | 32.3 percent  | 10.0 percent | 6.7 percent  | 5.4 percent  |

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## 4.0.2 4.2. Extending GTAP to include a physical representation of land via GTAP-AEZ

The base GTAP CGE excludes several components necessary to link to environmental models. As discussed above, we chose to augment the base model with specific agro-ecological zones (AEZs) in order to specify biophysical production parameters, make explicit the use of environmental resources (e.g., water), and endogenize use-differentiated land resources (for forestry, agriculture and other land-intensive sectors). Inclusion of these extra factors exposes the key variables in the economy to which our fully spatialized GTAP-InVEST model can connect. The underlying GTAP-AEZ model is based on the formulation in Lee (2005), updated by Tahierpour et al. (2013) and Baldos (2016). For the PNAS paper, we updated the model to GTAP Database Version 10 with greater country-level and AEZ-level disaggregation; subsequent work has migrated the pipeline to the [v12 Data Base](#). The underlying equations in GTAP and GTAP-AEZ are well documented throughout the literature, so we do not present them in full.

## 4.0.3 4.3. Example GTAP configuration file

The configuration below is for the BAU Ecosystem Service adjustment run. See the code repository at [github.com/jandrewjohnson/gtap\\_invest](https://github.com/jandrewjohnson/gtap_invest) for all configuration files. These configuration files are called iteratively by the python code using a batch file that replaces the <cmf> tag with the name of the scenario being run.

```
start with mmnz = 200000000; ! Assign largest starting memory allocation (max is
2100000000)

MA48 increase_MMNZ = veryfast; ! If largest memory is not enough, allow

CPU = yes;

NDS = yes;

Extrapolation accuracy file = NO;

aux files = "GTAPAEZ";

! Input files

file GTAPSETS = ..\gtp1414\sets.har;

file GTAPDATA = ..\work\2021_30_BAU_noES.upd;

file GTAPPARM = ..\gtp1414\default.prm;

file GTAPSUPP = ..\gtp1414\<cmf>_SUPP.har;

! Output files

file GTAPSUM          = ..\work\<cmf>_sum.har;

Updated file GTAPDATA = ..\work\<cmf>.upd;

Solution file         = ..\work\<cmf>.sl4;

Verbal Description =<cmf> ;

log file = ..\work\<cmf>.log;
```

```

Method = Euler;
Steps = 2 4 6;
automatic accuracy = yes;
accuracy figures = 4;
accuracy percent = 90;
minimum subinterval length = 0.0001;
minimum subinterval fails = stop;
accuracy criterion = Both;
subintervals =5;
exogenous
pop
psaveslack pfactwld
profitslack incomeslack endwslack
cgdslack tradslack
ams atm atf ats atd
aosec aoreg
avasec avareg
afcom afsec afreg afecom afesec afereg
aoall afall afeall aoall2 aoall3 aoall4
au dppriv dpgov dpsave
to_1 to_2 !to
!EC change for revenue neutral scenario
tfijr
tfreg
!End: EC change for revenue neutral scenario
tp tm tms tx txs
qo("UnSkLab",REG)
qo("SkLab",REG)
qo("Capital",REG)
qo("NatRes",REG)
tfm tfd;
Exogenous p_slacklandr;

```

Exogenous p\_ECONLAND = zero value on file ..\gtp1414\basedata.har header  
"MAXL" ;

Exogenous p\_slackland = nonzero value on file ..\gtp1414\basedata.har header  
"MAXL" ;

Exogenous p\_LANDCOVER\_L(AEZ\_COMM,"UNMNGLAND",REG);

Exogenous c\_MAX\_LAND;

Rest Endogenous ;

!=====

! Shocks

!=====

! Ecosystem services shocks

! (1) Fishery and Forestry shocks

Shock aoall2("fishery",REG) = file ..\shocks\ALLSHOCKS.har header "BAES" slice  
"fishery";

Shock aoall2("forestsec",REG) = file ..\shocks\ALLSHOCKS.har header "BAES" slice  
"forestsec";

! (2) Pollination shocks from InVEST : Pollination Collapse

Shock aoall3("cotton",REG) = file ..\shocks\ALLSHOCKS.har header "BAES" slice  
"cotton";

Shock aoall3("crsgrns",REG) = file ..\shocks\ALLSHOCKS.har header "BAES" slice  
"crsgrns";

Shock aoall3("fruitveg",REG) = file ..\shocks\ALLSHOCKS.har header "BAES" slice  
"fruitveg";

Shock aoall3("oilsds",REG) = file ..\shocks\ALLSHOCKS.har header "BAES" slice  
"oilsds";

Shock aoall3("othercrps",REG) = file ..\shocks\ALLSHOCKS.har header "BAES" slice  
"othercrps";

!=====

! Subtotal

!=====

Subtotal aoall2("fishery",REG) = fish;

Subtotal aoall2("forestsec",REG)= forest;

Subtotal aoall3("crsgrns",REG) aoall3("fruitveg",REG) aoall3("oilsds",REG) aoall3("cotton",REG)  
aoall3("othercrps",REG) = polli;

## 5 5. InVEST model details

The InVEST model suite is thoroughly documented in its user guide (Sharp et al. 2020). This source identifies how each of the 24 ecosystem service models are calculated, including how to obtain input data. However, the models officially included in InVEST do not always work at the global scale. Thus, we use modified versions of them that have been rewritten to run in parallel at the global scale. These modified versions of the models were first documented in Kim et al. (2018) and more fully in Chaplin-Kramer et al. (2019). In this section, we summarize the modifications made to enable global coverage.

For the pollination model, the global version assumed pollinators are fully abundant on any natural land covers (specifically classes 50 to 180 in our underlying ESACCI LULC database) and that all pollinators had the same relative efficacy and distance decay parameters for their pollination activity. Region-specific applications of InVEST often calibrate the model based on which species of pollinators are present and what their pollination efficiency is (which we did not do). We then calculated the proportional area of natural land covers around every plot of agricultural land (classes 10-20). In brief, the model estimates pollinator sufficiency based on the abundance of pollinator species given the two limiting resources on the landscape: pollinator nesting habitat and pollinator nectar sources (provided here by pollination-dependent crops). We calculated this globally following Chaplin-Kramer et al. (2019), which provided a global map of pollination sufficiency. This was an input to the algorithm described in SI Section 6 that connects InVEST biophysical outputs to GTAP inputs.

We perform the carbon storage calculations by applying a custom version of the InVEST carbon storage model. This version uses a globally-extended lookup table for IPCC Tier-1 (Ruesch and Gibbs 2008) values of carbon content defined for regions breaking out each continent, ecofloristic region and frontier forest status. The default InVEST model takes as an input a biophysical table with *one* of these regions.

## 6 6. Connecting InVEST outputs to GTAP inputs

In the previous section, we described how we calculated the biophysical outputs of the InVEST model. These results on their own provide potentially useful results on the provision of ecosystem services. However, these biophysical changes alone are not enough to identify the impact on the economy. This section walks through the calculations for converting the raw InVEST biophysical outputs to Region-AEZ specific, factor-neutral productivity shocks.

### 6.0.1 6.1. How Region-AEZ aggregated shocks are inputted into GTAP

In GTAP-InVEST, there are three primary ways in which changing environmental conditions enter the CGE model. These include shifting the land supply curve directly to reflect a change in production, implementing a land-augmenting or land-reducing technological changes, or shifting the production function via a factor-neutral productivity shock.

In this section, we describe the third type of shock, which was used for the pollination linkage. We implement this as a factor-neutral (also referred to as Hicks'-neutral) productivity shock, which changes the efficiency coefficient in each impacted production function, scaled uniquely for each region and production activity in the following production function:

$$Q_{ar} = F_{ar} \left( \sum_{i=1}^I \alpha_i X_i^{\rho_{ari}} \right)^{\frac{1}{\rho_{ari}}}$$

where

- $Q$  is the quantity produced for production activity  $a$  in sector  $r$
- input factors are indexed as  $i \in 1 \dots I$ ,
- $\alpha_i$  is the share parameter of input  $i$
- $X_i$  is the quantity of input  $i$
- $\rho_{ari}$  is the substitution parameter for input  $i$  to production activity  $a$  in sector  $r$

In this expression,  $\rho$  can be expressed as an elasticity of substitution  $\varepsilon_{ari} = \frac{1}{1-\rho_{ari}}$

We solve the system of equations in the GTAP model (documented extensively in the GTAP user resources) for equilibrium values of prices and quantities where supply equals demand in all markets and all other regions and sectors can be affected by the change. This interconnection of markets shows one of the important advances captured by using a general equilibrium approach: changes in one component of the model will change equilibrium production and input usage, leading to

different overall levels of change in the economy depending on exactly which sector in which region is affected.

For the pollination shock, the key parameter then is  $\alpha$ . To identify this parameter, we applied the following algorithm to process outputs from the InVEST Pollinator Sufficiency model

1. Calculate the total value in 2014 USD of crop production on each 10 arcsecond grid-cell.
  1. For each grid-cell and for each agricultural production activity, multiply the production tonnage (Monfreda et al. 2008) by the price per ton of that crop, specific to the country the in which the grid-cell is located. These prices are produced from the FAOSTAT database, on which we applied the following missing-data procedure:
    1. If a price was not available for a crop in a given country for the year 2000, use the 10-year moving average.
    2. If 1.b.i cannot be calculated because of missing data, use the continental average price (or its moving average if needed).
    3. If 1.b.ii cannot be calculated due to missing data, use the global average price.
  2. Resample each activity-specific crop value map from 5 arcminutes to 10 arcseconds (to match the LULC map) using bilinear interpolation.
  3. Aggregate all crop-specific production values from 1.b to get the total value of crop production in each 10 arcsecond grid-cell.
  4. Calculate the maximum loss of value for each crop in each grid-cell that would occur if zero pollination habitat existed. To get this, we multiplied the production value from 1.b by 1 minus the pollinator dependence of each crop, as identified in Klein et al. 2013.
  5. Aggregate all crop-specific maximum production loss figures from 3 to get the total maximum loss of crop production value.
  6. Calculate the proportion of maximum value lost for a specific scenario by using the pollination sufficiency map outputted by the InVEST Pollination model for that scenario (see Sharp et al. 2020), categorizing all values greater than 0.3 as having sufficient pollination (threshold chosen based on the approach used in Chaplin-Kramer et al, 2019). In these grid-cells, assign them the value 1, indicating no loss from degraded pollination habitat. For all grid-cells in which pollination dependence is below 0.3, assign them the value  $1 - (1/3) * \text{pollination\_sufficiency}$ , which scales the pollination dependence variable so that it is 1.0 right at the threshold but falls linearly to 0 when pollination sufficiency approaches zero.
  7. Calculate the crop production value lost for each scenario by multiplying the aggregate maximum cropland value lost (4) with the proportion of max value lost specific to that scenario (5).
  8. For each AEZ-Region (n=341), calculate the percent change in cropland value lost in the scenario minus the baseline value lost in 2014. Note that this means that we are only considering newly-lost crop production value and how it compares to the loss of value from pollinators already included in the baseline.
  9. Scale the value in 7 so that it can be aggregated from the AEZ-Region to the Region (n=36) level. Assign this scaled value to the five pollination-dependent production activities (variables gro, ocr, osd, pfb, v\_f). This identifies the factor-neutral productivity shock for each activity and region.
10. Rerun the full GTAP-model but with the values for  $\alpha$  as defined above.

This approach improves upon existing economic models that incorporate pollination. Specifically, past models quantified the contribution of pollination by multiplying the pollination yield-dependency ratio by the value of output for each crop (Gallai, Salles, Settele, & Vaissière, 2009; Lautenbach, Seppelt, Liebscher, & Dormann, 2012). This would provide a proxy estimate of value lost in a static case, but it does not incorporate how changes in production methods or factor usage would lead to different production choices. Other approaches employ CGE methods, such as in Bauer and Wing (2016), but these consider only the complete loss of pollination (and thereby do not consider any degree of spatial dependence between pollinators and pollination-dependent crops). Our approach improves on the literature by incorporating spatially explicit information on which land areas will experience loss in pollinator habitat and calculates the losses from changes in crop pollination, specifying how these losses arise from relevant scenarios of economic growth.

One important difference with our model from the CGE analyses of pollination impact discussed above is that our model goes beyond just calculating some arbitrarily large shock on pollination services, but instead calculates how a specific land-use change, calculated by GTAP-AEZ and represented with a high-resolution LULC map, leads to production effects. Calculating the spatially heterogeneous impacts of a changed landscape generate informative results. Figure S.6.1.1 presents one example of this, showing how the precise configuration of *where* the land-use change happens can have a large effect on the productivity shock.

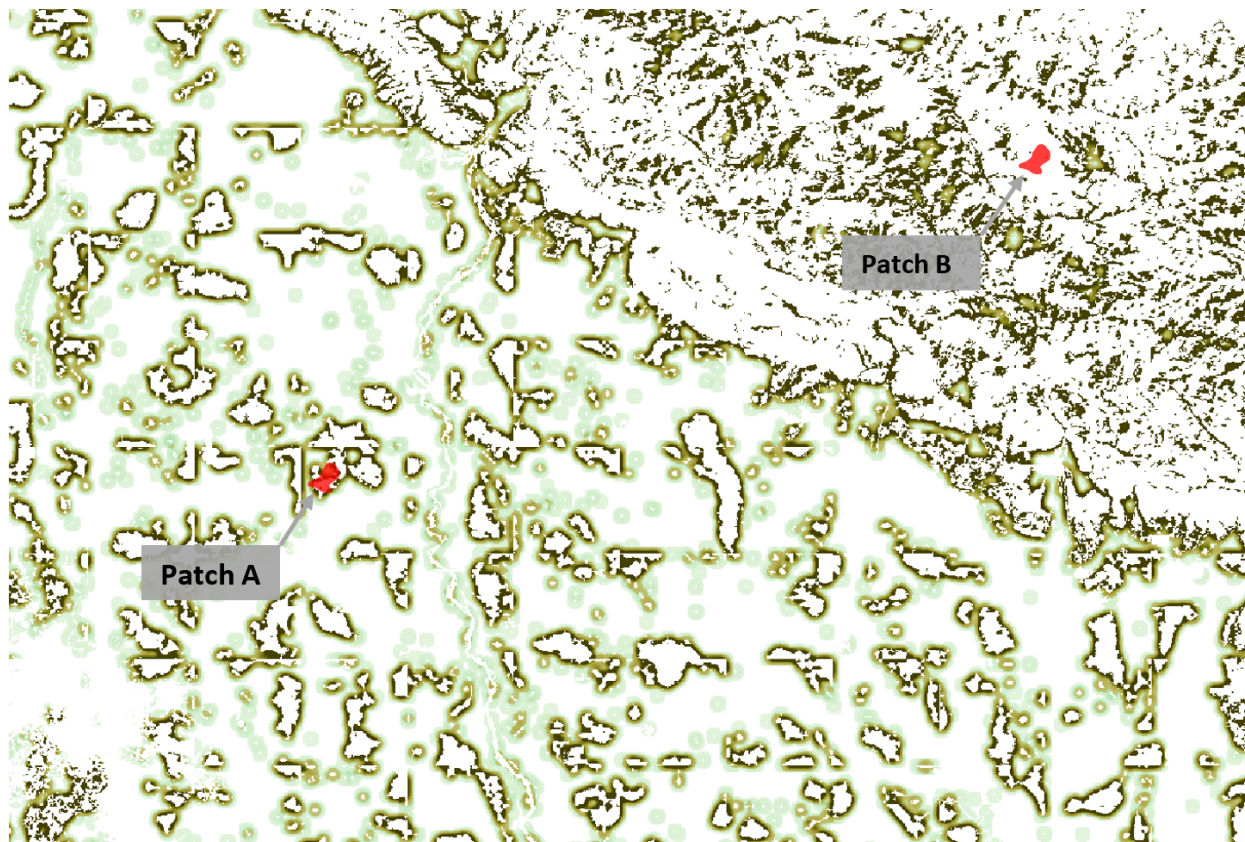


Figure S.6.1: Complexity of landscape affects the degree of pollination service:

### 6.0.2 6.2. Carbon Storage and Timber provision

We used the InVEST carbon storage model for both estimating carbon sequestration (this was subsequently valued using the social cost of carbon) and to estimate changes in productivity in the forestry sector. The InVEST carbon storage and sequestration model works by specifying carbon storage levels present in each of four carbon pools (above-ground, below-ground, soil, and dead matter) specific to each LULC class (see the land-use change downscaling section in this SI for specific LULC classes used, along with their parameters). We use parameters for the carbon storage model taken directly from the IPCC Tier 1 method (Ruesch and Gibbs 2008). The base InVEST model is intended to run for a single ecofloristic region, using carbon pool parameters specific to that region (Sharp et al. 2020). To run this globally, we developed separate carbon-pool tables for each of the approximately 125 carbon zones, where each carbon zone is defined as the unique combination of ecofloristic region, continent, and whether the forest is a frontier forest as specified by the IPCC (as in Ruesch and Gibbs 2008). To develop these tables, we built on work from Suh et al. (in submission), which recategorized ESA LULC data into seven functional types. We extended the classes considered to include carbon storage values for agriculture.

For the forestry sector, we used the outputs of the carbon storage model to calculate the productivity impacts in each region. Specifically, we calculated the percentage change in carbon storage on land identified by the GTAP-AEZ model as used for forestry. We averaged these estimates for each AEZ-Region to find the average change of biomass on potentially-harvestable land. We implemented this as a factor-neutral productivity shock for the forestry sector of each region according to the average percentage change for in that region. Using carbon storage as a proxy for biomass means that we are including more detail than approaches that are based strictly on forest area (e.g., Baldos et al. 2020), accounting for variation in ecofloristic region, frontier forest status, and other factors, based on field-estimates of aboveground biomass as summarized in Ruesch and Gibbs (2008). However, this proxy approach is very simple compared to detailed modeling of forest harvest. We were not able to compute such forestry models at the global scale, but forthcoming work from several research teams may make this possible for future applications.

### 6.0.3 6.3. Marine Fisheries

The InVEST marine fisheries model has been deprecated, and moreover, it would not have been able to produce global estimates. To model the ecosystem changes in marine fisheries, we use outputs from the FISH-MIP program within Intersector Impact Model Intercomparison Project (ISIMIP, [isimip.org](http://isimip.org)). We use results from the EcoOcean and BOATS models, based on the GFDL-ESM2M and IPSL climate reanalysis (following the methods documented in Tittensor et al. 2018). The models we used are global food-web models that incorporate both climate change and human pressures on a global, 0.5-degree grid and outputs results for many (51 in the EcoOcean model) trophic and taxonomic groups with the age structure of the populations included. This model run assumed no ocean acidification and excluded diazotrophic fish species (per the FISH-MIP guidelines). These results are reported in figure S.6.3, reproduced with permission from Johnson et al. 2020, showing the biomass density of commercial species under the baseline 2011 condition and under the 2050 BAU.

We chose to pair three of the FISH-MIP scenarios with our report scenarios as follows: first, our BAU scenario uses the FISH-MIP RCP8.5 and SSP5 scenario with BAU levels of fishing. To calculate the specific shocks given to GTAP, we extracted the total catch biomass (TCB) variable

from the FISH-MIP database (hosted under the ISI-MIP data portal at [www.isimip.org](http://www.isimip.org)), which provide monthly and yearly observations of gridded total biomass of catchable, commercially valued species. For the BAU and SP scenarios, we defined the shock as the percentage change in TCB in each of the GTAP zones (augmented to include their 200-mile nautical claims). These shocks, defined in the supplemental data for this article, were applied as a factor-neutral productivity shock, scaling the TFP term up or down each regions' marine fisheries production function. Note that results for marine fisheries were calculated by joining Marine Exclusive Economic regions with their associated country. We chose to report these results aggregated onto land regions for visual clarity, though the results themselves are calculated on the marine zones.

[1] <https://www.regimeshifts.org/about>

[2] R&D spending data from high-income countries is taken from Heisey and Fuglie (2018). For developing countries, we rely on data from two sources. Data after 1981 is available from the Agricultural Science and Technology Indicators database (<https://www.asti.cgiar.org/>), and we obtain data before 1981 from Pardey and Roseboom (1989) and Pardey, Roseboom, and Anderson (1991). Our R&D spending data for Eastern Europe and the Soviet Union come from Judd, Boyce, and Evenson (1991).

## 7 Release Notes

### 7.1 0.7.0

- Unzipped gtapv7-aez-rd\_26Mar24.zip to <user\_dir>/Files/base\_data/gtappy/cge\_releases/gtapv7-aez-rd\_26Mar24
- Considering changing hyphens to underscores in the file names
  - REJECTED to follow the gtap model naming convention, so we are staying with gtapv7-aez-rd but everything else is underscore
- REQUIRES manually adding a new dir “out” in the “gtapv7\_aez\_rd” dir
- The first run did not find results.map, so I copied this manually from the last release into /mod dir
- Added a \_\_just\_\_mapping.bat file to run the mapping only but this required configuring the directory to not include cd ..
- There are now two time-modes for running:
  - RD and Singleshot
  - One can’t simply run the singleshot because then it will get the 2049-2050 percentage change for GDP POP etc.
  - So, we prepared an additional set of projections that are not recursive. These are prepended with D.  
  

```
set DGDPPC=DGP2
set DPOP=DP02
set DLAB=DLB2

set GDPPC=OGP2
set POP=POP2
set LAB=LAB2
```
  - To switch from the default RD mode to SS, just replace GDPPC with DGDPPC, POP with DPOP, and LAB with DLAB in the .bat file
  - NOTE: GDP is exogenous in BAU to match projections, but then we swap it in any policy shock to endogenously determine GDP.

#### 7.1.1 Added method to modify a specific variable for a specific country

- CMF files cannot change any values at run time, so instead we are going to create a new harfile with the new values
  - To do this in ViewHAR with the example of MAXL, right click on MAXL and select “Clone”.

- \* It's hard to edit in viewhar, so copy to clipboard, then excel, then edit the values, then paste back in for the modified har.
- \* In the CMF file, then call

**Part I**

**GTAP database reference**

# A GTAP Database reference

This section documents the **native classifications of the GTAP Data Base** — the full region and sector lists at the resolution Purdue ships, plus the set/variable/parameter definitions of the GTAP v7 model that operates on them. Use it when you need to know what a code like `xea` or `gro` actually covers, or which set a variable is indexed over.

This is the *unaggregated* reference. For the smaller aggregation actually used in GTAP-Invest simulations (50 regions  $\times$  26 sectors), see [GTAP-Invest aggregation \(s26\\_r50\)](#).

## A.1 Current release — v12 Data Base

The v12 Data Base (released 2024) is the default for new GTAP-Invest runs.

- [v12 regions \(163\)](#) — region codes, names, and the countries that compose each “Rest of” aggregate. Three new African countries split out from `xac/xec` relative to v11.
- [v12 sectors \(65\)](#) — the 65 GTAP sectors with descriptions. Codes are unchanged from v11.
- [v12 model variables](#) — sets, subsets, exogenous/endogenous variables, and parameters of the GTAP v7 model. These are properties of the *model*, not the database, and are identical between v11 and v12 — only the dimensions they’re indexed over change.

## A.2 Legacy — v11 Data Base

Kept for reproducibility of older GTAP-Invest results. Prefer v12 for new work.

- [v11 regions \(160, legacy\)](#)
- [v11 sectors \(65, legacy\)](#)
- [v11 model variables \(legacy\)](#)

## B Regions in v12:

Aggregate string: v12\_r163\_labels

Source: [GTAP 12 Data Base Regions](#)

Changes from v11: 160 → 163 regions. Newly broken out as separate regions: Mauritania (mrt), Angola (ago), São Tomé and Príncipe (stp), Burundi (bdi). Some “Rest of” aggregates have been adjusted accordingly. See [v11 regions](#) for the previous classification.

See also: [v12 sectors \(65\)](#) · [v12 model variables](#) · [GTAP-Invest r50 aggregation](#) (how these 163 regions roll up to 50).

| gtapv7_r163_id | gtapv7_r163_label | gtapv7_r163_name  | gtapv7_r163_description                                                                                                                                                                                                                                                                                      |
|----------------|-------------------|-------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1              | aus               | Australia         | Australia, Christmas Island, Cocos (Keeling) Islands, Heard Island and McDonald Islands, Norfolk Island                                                                                                                                                                                                      |
| 2              | nzl               | New Zealand       | New Zealand                                                                                                                                                                                                                                                                                                  |
| 3              | xoc               | Rest of Oceania   | American Samoa, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Micronesia, Nauru, New Caledonia, Niue, Northern Mariana Islands, Palau, Papua New Guinea, Pitcairn, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, U.S. Minor Outlying Islands, Vanuatu, Wallis and Futuna Islands |
| 4              | chn               | China             | China                                                                                                                                                                                                                                                                                                        |
| 5              | hkg               | Hong Kong         | Hong Kong, Special Administrative Region of China                                                                                                                                                                                                                                                            |
| 6              | jpn               | Japan             | Japan                                                                                                                                                                                                                                                                                                        |
| 7              | kor               | Republic of Korea | Republic of Korea                                                                                                                                                                                                                                                                                            |
| 8              | mng               | Mongolia          | Mongolia                                                                                                                                                                                                                                                                                                     |
| 9              | tw                | Chinese Taipei    | Chinese Taipei                                                                                                                                                                                                                                                                                               |

|    |     |                                       |                                                                                                                       |
|----|-----|---------------------------------------|-----------------------------------------------------------------------------------------------------------------------|
| 10 | xea | Rest of East Asia                     | Macao Special<br>Administrative Region,<br>Democratic People's<br>Republic of Korea                                   |
| 11 | brn | Brunei Darussalam                     | Brunei Darussalam                                                                                                     |
| 12 | khm | Cambodia                              | Cambodia                                                                                                              |
| 13 | idn | Indonesia                             | Indonesia                                                                                                             |
| 14 | lao | Lao People's Democratic<br>Republic   | Lao People's Democratic<br>Republic                                                                                   |
| 15 | mys | Malaysia                              | Malaysia                                                                                                              |
| 16 | phl | Philippines                           | Philippines                                                                                                           |
| 17 | sgp | Singapore                             | Singapore                                                                                                             |
| 18 | tha | Thailand                              | Thailand                                                                                                              |
| 19 | vnm | Viet Nam                              | Viet Nam                                                                                                              |
| 20 | xse | Rest of Southeast Asia                | Myanmar, Timor-Leste                                                                                                  |
| 21 | afg | Afghanistan                           | Afghanistan                                                                                                           |
| 22 | bgd | Bangladesh                            | Bangladesh                                                                                                            |
| 23 | ind | India                                 | India                                                                                                                 |
| 24 | npl | Nepal                                 | Nepal                                                                                                                 |
| 25 | pak | Pakistan                              | Pakistan                                                                                                              |
| 26 | lka | Sri Lanka                             | Sri Lanka                                                                                                             |
| 27 | xsa | Rest of South Asia                    | Bhutan, Maldives                                                                                                      |
| 28 | can | Canada                                | Canada                                                                                                                |
| 29 | usa | United States of America              | United States of America                                                                                              |
| 30 | mex | Mexico                                | Mexico                                                                                                                |
| 31 | xna | Rest of North America                 | Bermuda, Greenland,<br>Saint Pierre and<br>Miquelon                                                                   |
| 32 | arg | Argentina                             | Argentina                                                                                                             |
| 33 | bol | Bolivia (Plurinational<br>State of)   | Bolivia (Plurinational<br>State of)                                                                                   |
| 34 | bra | Brazil                                | Brazil                                                                                                                |
| 35 | chl | Chile                                 | Chile                                                                                                                 |
| 36 | col | Colombia                              | Colombia                                                                                                              |
| 37 | ecu | Ecuador                               | Ecuador                                                                                                               |
| 38 | pry | Paraguay                              | Paraguay                                                                                                              |
| 39 | per | Peru                                  | Peru                                                                                                                  |
| 40 | ury | Uruguay                               | Uruguay                                                                                                               |
| 41 | ven | Venezuela (Bolivarian<br>Republic of) | Venezuela (Bolivarian<br>Republic of)                                                                                 |
| 42 | xsm | Rest of South America                 | Falkland Islands<br>(Malvinas), French<br>Guiana, Guyana, South<br>Georgia and South<br>Sandwich Islands,<br>Suriname |
| 43 | cri | Costa Rica                            | Costa Rica                                                                                                            |

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|    |     |                         |                                                                                                                                                                                                                                                                                                                                                            |
|----|-----|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 44 | gtm | Guatemala               | Guatemala                                                                                                                                                                                                                                                                                                                                                  |
| 45 | hnd | Honduras                | Honduras                                                                                                                                                                                                                                                                                                                                                   |
| 46 | nic | Nicaragua               | Nicaragua                                                                                                                                                                                                                                                                                                                                                  |
| 47 | pan | Panama                  | Panama                                                                                                                                                                                                                                                                                                                                                     |
| 48 | slv | El Salvador             | El Salvador                                                                                                                                                                                                                                                                                                                                                |
| 49 | xca | Rest of Central America | Belize                                                                                                                                                                                                                                                                                                                                                     |
| 50 | dom | Dominican Republic      | Dominican Republic                                                                                                                                                                                                                                                                                                                                         |
| 51 | hti | Haiti                   | Haiti                                                                                                                                                                                                                                                                                                                                                      |
| 52 | jam | Jamaica                 | Jamaica                                                                                                                                                                                                                                                                                                                                                    |
| 53 | pri | Puerto Rico             | Puerto Rico                                                                                                                                                                                                                                                                                                                                                |
| 54 | tto | Trinidad and Tobago     | Trinidad and Tobago                                                                                                                                                                                                                                                                                                                                        |
| 55 | xcb | Rest of Caribbean       | Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Bonaire/Sint Eustatius/Saba, British Virgin Islands, Cayman Islands, Cuba, Curaçao, Dominica, Grenada, Montserrat, Saint Barthélemy, Saint Kitts and Nevis, Saint Lucia, Saint Martin (French), Saint Vincent and Grenadines, Sint Maarten (Dutch), Turks and Caicos Islands, U.S. Virgin Islands |
| 56 | aut | Austria                 | Austria                                                                                                                                                                                                                                                                                                                                                    |
| 57 | bel | Belgium                 | Belgium                                                                                                                                                                                                                                                                                                                                                    |
| 58 | bgr | Bulgaria                | Bulgaria                                                                                                                                                                                                                                                                                                                                                   |
| 59 | hrv | Croatia                 | Croatia                                                                                                                                                                                                                                                                                                                                                    |
| 60 | cyp | Cyprus                  | Cyprus                                                                                                                                                                                                                                                                                                                                                     |
| 61 | cze | Czechia                 | Czech Republic                                                                                                                                                                                                                                                                                                                                             |
| 62 | dnk | Denmark                 | Denmark                                                                                                                                                                                                                                                                                                                                                    |
| 63 | est | Estonia                 | Estonia                                                                                                                                                                                                                                                                                                                                                    |
| 64 | fin | Finland                 | Finland, Åland Islands                                                                                                                                                                                                                                                                                                                                     |
| 65 | fra | France                  | France, Guadeloupe, Martinique, Réunion                                                                                                                                                                                                                                                                                                                    |
| 66 | deu | Germany                 | Germany                                                                                                                                                                                                                                                                                                                                                    |
| 67 | grc | Greece                  | Greece                                                                                                                                                                                                                                                                                                                                                     |
| 68 | hun | Hungary                 | Hungary                                                                                                                                                                                                                                                                                                                                                    |
| 69 | irl | Ireland                 | Ireland                                                                                                                                                                                                                                                                                                                                                    |
| 70 | ita | Italy                   | Italy                                                                                                                                                                                                                                                                                                                                                      |
| 71 | lva | Latvia                  | Latvia                                                                                                                                                                                                                                                                                                                                                     |
| 72 | ltu | Lithuania               | Lithuania                                                                                                                                                                                                                                                                                                                                                  |
| 73 | lux | Luxembourg              | Luxembourg                                                                                                                                                                                                                                                                                                                                                 |

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|     |     |                                                            |                                                                                                                                                                                        |
|-----|-----|------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 74  | mlt | Malta                                                      | Malta                                                                                                                                                                                  |
| 75  | nld | Netherlands                                                | Netherlands                                                                                                                                                                            |
| 76  | pol | Poland                                                     | Poland                                                                                                                                                                                 |
| 77  | prt | Portugal                                                   | Portugal                                                                                                                                                                               |
| 78  | rou | Romania                                                    | Romania                                                                                                                                                                                |
| 79  | svk | Slovakia                                                   | Slovakia                                                                                                                                                                               |
| 80  | svn | Slovenia                                                   | Slovenia                                                                                                                                                                               |
| 81  | esp | Spain                                                      | Spain                                                                                                                                                                                  |
| 82  | swe | Sweden                                                     | Sweden                                                                                                                                                                                 |
| 83  | gbr | United Kingdom of Great<br>Britain and Northern<br>Ireland | United Kingdom of Great<br>Britain and Northern<br>Ireland                                                                                                                             |
| 84  | che | Switzerland                                                | Switzerland                                                                                                                                                                            |
| 85  | nor | Norway                                                     | Norway, Svalbard and<br>Jan Mayen Islands                                                                                                                                              |
| 86  | xef | Rest of EFTA                                               | Iceland, Liechtenstein                                                                                                                                                                 |
| 87  | alb | Albania                                                    | Albania                                                                                                                                                                                |
| 88  | srb | Serbia                                                     | Serbia                                                                                                                                                                                 |
| 89  | blr | Belarus                                                    | Belarus                                                                                                                                                                                |
| 90  | rus | Russian Federation                                         | Russian Federation                                                                                                                                                                     |
| 91  | ukr | Ukraine                                                    | Ukraine                                                                                                                                                                                |
| 92  | xee | Rest of Eastern Europe                                     | Republic of Moldova                                                                                                                                                                    |
| 93  | xer | Rest of Europe                                             | Andorra, Bosnia and<br>Herzegovina, Faroe<br>Islands, Gibraltar,<br>Guernsey, Holy See, Isle<br>of Man, Jersey, Kosovo,<br>Monaco, Montenegro,<br>North Macedonia, San<br>Marino, Sark |
| 94  | kaz | Kazakhstan                                                 | Kazakhstan                                                                                                                                                                             |
| 95  | kgz | Kyrgyzstan                                                 | Kyrgyzstan                                                                                                                                                                             |
| 96  | tjk | Tajikistan                                                 | Tajikistan                                                                                                                                                                             |
| 97  | uzb | Uzbekistan                                                 | Uzbekistan                                                                                                                                                                             |
| 98  | xsu | Rest of Former Soviet<br>Union                             | Turkmenistan                                                                                                                                                                           |
| 99  | arm | Armenia                                                    | Armenia                                                                                                                                                                                |
| 100 | aze | Azerbaijan                                                 | Azerbaijan                                                                                                                                                                             |
| 101 | geo | Georgia                                                    | Georgia                                                                                                                                                                                |
| 102 | bhr | Bahrain                                                    | Bahrain                                                                                                                                                                                |
| 103 | irn | Iran (Islamic Republic<br>of)                              | Iran (Islamic Republic<br>of)                                                                                                                                                          |
| 104 | irq | Iraq                                                       | Iraq                                                                                                                                                                                   |
| 105 | isr | Israel                                                     | Israel                                                                                                                                                                                 |
| 106 | jor | Jordan                                                     | Jordan                                                                                                                                                                                 |
| 107 | kwt | Kuwait                                                     | Kuwait                                                                                                                                                                                 |
| 108 | lbn | Lebanon                                                    | Lebanon                                                                                                                                                                                |

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|     |     |                                     |                                                                                 |
|-----|-----|-------------------------------------|---------------------------------------------------------------------------------|
| 109 | omn | Oman                                | Oman                                                                            |
| 110 | pse | Palestine                           | Palestinian Territory,<br>Occupied                                              |
| 111 | qat | Qatar                               | Qatar                                                                           |
| 112 | sau | Saudi Arabia                        | Saudi Arabia                                                                    |
| 113 | syr | Syrian Arab Republic                | Syrian Arab Republic                                                            |
| 114 | tur | Turkey                              | Türkiye                                                                         |
| 115 | are | United Arab Emirates                | United Arab Emirates                                                            |
| 116 | xws | Rest of Western Asia                | Yemen                                                                           |
| 117 | dza | Algeria                             | Algeria                                                                         |
| 118 | egy | Egypt                               | Egypt                                                                           |
| 119 | mar | Morocco                             | Morocco                                                                         |
| 120 | tun | Tunisia                             | Tunisia                                                                         |
| 121 | xnf | Rest of North Africa                | Libya, Western Sahara                                                           |
| 122 | ben | Benin                               | Benin                                                                           |
| 123 | bfa | Burkina Faso                        | Burkina Faso                                                                    |
| 124 | cmr | Cameroon                            | Cameroon                                                                        |
| 125 | civ | Cote d'Ivoire                       | Côte d'Ivoire                                                                   |
| 126 | gha | Ghana                               | Ghana                                                                           |
| 127 | gin | Guinea                              | Guinea                                                                          |
| 128 | mli | Mali                                | Mali                                                                            |
| 129 | mrt | Mauritania                          | Mauritania                                                                      |
| 130 | ner | Niger                               | Niger                                                                           |
| 131 | nga | Nigeria                             | Nigeria                                                                         |
| 132 | sen | Senegal                             | Senegal                                                                         |
| 133 | tgo | Togo                                | Togo                                                                            |
| 134 | xwf | Rest of Western Africa              | Cabo Verde, Gambia,<br>Guinea-Bissau, Liberia,<br>Saint Helena, Sierra<br>Leone |
| 135 | ago | Angola                              | Angola                                                                          |
| 136 | caf | Central African Republic            | Central African Republic                                                        |
| 137 | tcd | Chad                                | Chad                                                                            |
| 138 | cog | Congo                               | Congo                                                                           |
| 139 | cod | Democratic Republic of<br>the Congo | Democratic Republic of<br>the Congo                                             |
| 140 | gnq | Equatorial Guinea                   | Equatorial Guinea                                                               |
| 141 | gab | Gabon                               | Gabon                                                                           |
| 142 | stp | Sao Tome and Principe               | Sao Tome and Principe                                                           |
| 143 | bdi | Burundi                             | Burundi                                                                         |
| 144 | com | Comoros                             | Comoros                                                                         |
| 145 | eth | Ethiopia                            | Ethiopia                                                                        |
| 146 | ken | Kenya                               | Kenya                                                                           |
| 147 | mdg | Madagascar                          | Madagascar                                                                      |
| 148 | mwi | Malawi                              | Malawi                                                                          |
| 149 | mus | Mauritius                           | Mauritius                                                                       |
| 150 | moz | Mozambique                          | Mozambique                                                                      |

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|     |     |                                           |                                                                                                 |
|-----|-----|-------------------------------------------|-------------------------------------------------------------------------------------------------|
| 151 | rwa | Rwanda                                    | Rwanda                                                                                          |
| 152 | sdn | Sudan                                     | Sudan                                                                                           |
| 153 | tza | United Republic of<br>Tanzania            | United Republic of<br>Tanzania                                                                  |
| 154 | uga | Uganda                                    | Uganda                                                                                          |
| 155 | zmb | Zambia                                    | Zambia                                                                                          |
| 156 | zwe | Zimbabwe                                  | Zimbabwe                                                                                        |
| 157 | xec | Rest of Eastern Africa                    | Djibouti, Eritrea,<br>Mayotte, Seychelles,<br>Somalia, South Sudan                              |
| 158 | bwa | Botswana                                  | Botswana                                                                                        |
| 159 | swz | Eswatini                                  | Eswatini                                                                                        |
| 160 | nam | Namibia                                   | Namibia                                                                                         |
| 161 | zaf | South Africa                              | South Africa                                                                                    |
| 162 | xsc | Rest of Southern African<br>Customs Union | Lesotho                                                                                         |
| 163 | xtw | Rest of the World                         | Antarctica, Bouvet<br>Island, British Indian<br>Ocean Territory, French<br>Southern Territories |

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## C Sectors in v12

Source: [GTAP 12 Data Base Sectors](#)

The v12 sectoral aggregation retains the 65-sector classification introduced in v11. Sector codes and definitions are unchanged from v11. See also the [Detailed Sector Breakdown](#).

See also: [v12 regions \(163\)](#) · [v12 model variables](#) · [GTAP-Invest s26 aggregation](#) (how these 65 sectors roll up to 26).

| id | label | Name                                         | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|----|-------|----------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1  | pdr   | Paddy rice                                   | Rice: seed, paddy (not husked)                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 2  | wht   | Wheat                                        | Wheat: seed, other                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 3  | gro   | Cereal grains<br>nec                         | Other Grains: maize (corn), sorghum, barley,<br>rye, oats, millets, other cereals                                                                                                                                                                                                                                                                                                                                                                                           |
| 4  | v_f   | Vegetables,<br>fruit, nuts                   | Veg & Fruit: vegetables, fruit and nuts, edible<br>roots and tubers, pulses                                                                                                                                                                                                                                                                                                                                                                                                 |
| 5  | osd   | Oil seeds                                    | Oil Seeds: oil seeds and oleaginous fruit                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 6  | c_b   | Sugar cane,<br>sugar beet                    | Cane & Beet: sugar crops                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 7  | pfb   | Plant-based<br>fibers                        | Fibres crops                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 8  | ocr   | Crops nec                                    | Other Crops: stimulant; spice and aromatic<br>crops; forage products; plants and parts of<br>plants used primarily in perfumery, pharmacy,<br>or for insecticidal, fungicidal or similar<br>purposes; beet seeds (excluding sugar beet<br>seeds) and seeds of forage plants; natural<br>rubber in primary forms or in plates, sheets<br>or strip, living plants; cut flowers and flower<br>buds; flower seeds, unmanufactured tobacco;<br>other raw vegetable materials nec |
| 9  | ctl   | Bovine cattle,<br>sheep and<br>goats, horses | Cattle: bovine animals, live, other ruminants,<br>horses and other equines, bovine semen                                                                                                                                                                                                                                                                                                                                                                                    |

| id | label | Name                                         | Description                                                                                                                                                                                                                                                                                                                                                                      |
|----|-------|----------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 10 | oap   | Animal products nec                          | Other Animal Products: swine; poultry; other live animals; eggs of hens or other birds in shell, fresh; reproductive materials of animals; natural honey; snails, fresh, chilled, frozen, dried, salted or in brine, except sea snails; edible products of animal origin n.e.c.; hides, skins and furskins, raw; insect waxes and spermaceti, whether or not refined or coloured |
| 11 | rmk   | Raw milk                                     | Raw milk                                                                                                                                                                                                                                                                                                                                                                         |
| 12 | wol   | Wool, silk-worm cocoons                      | Wool: wool, silk, and other raw animal materials used in textile                                                                                                                                                                                                                                                                                                                 |
| 13 | frs   | Forestry                                     | Forestry: forestry, logging and related service activities                                                                                                                                                                                                                                                                                                                       |
| 14 | fsh   | Fishing                                      | Fishing: hunting, trapping and game propagation including related service activities, fishing, fish farms; service activities incidental to fishing                                                                                                                                                                                                                              |
| 15 | coa   | Coal                                         | Coal: mining and agglomeration of hard coal, lignite and peat                                                                                                                                                                                                                                                                                                                    |
| 16 | oil   | Oil                                          | Oil: extraction of crude petroleum, service activities incidental to oil and gas extraction excluding surveying (part)                                                                                                                                                                                                                                                           |
| 17 | gas   | Gas                                          | Gas: extraction of natural gas, service activities incidental to oil and gas extraction excluding surveying (part)                                                                                                                                                                                                                                                               |
| 18 | oxt   | Other Extraction (formerly omn Minerals nec) | Other Mining Extraction (formerly omn): mining of metal ores; other mining and quarrying                                                                                                                                                                                                                                                                                         |
| 19 | cmt   | Bovine meat products                         | Cattle Meat: fresh or chilled; meat of buffalo, fresh or chilled; meat of sheep, fresh or chilled; meat of goat, fresh or chilled; meat of camels and camelids, fresh or chilled; meat of horses and other equines, fresh or chilled; other meat of mammals, fresh or chilled; meat of mammals, frozen; edible offal of mammals, fresh, chilled or frozen                        |

| id | label | Name                                 | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|----|-------|--------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 20 | omt   | Meat products<br>nec                 | Other Meat: meat of pigs, fresh or chilled; meat of rabbits and hares, fresh or chilled; meat of poultry, fresh or chilled; meat of poultry, frozen; edible offal of poultry, fresh, chilled or frozen; other meat and edible offal, fresh, chilled or frozen; preserves and preparations of meat, meat offal or blood; flours, meals and pellets of meat or meat offal, inedible; greaves                                                                                                                                                                                                                                                                                                                                           |
| 21 | vol   | Vegetable oils<br>and fats           | Vegetable Oils: margarine and similar preparations; cotton linters; oil-cake and other residues resulting from the extraction of vegetable fats or oils; flours and meals of oil seeds or oleaginous fruits, except those of mustard; vegetable waxes, except triglycerides; degreas; residues resulting from the treatment of fatty substances or animal or vegetable waxes; animal fats                                                                                                                                                                                                                                                                                                                                            |
| 22 | mil   | Dairy products                       | Milk: dairy products                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 23 | pcr   | Processed rice                       | Processed Rice: semi- or wholly milled, or husked                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 24 | sgr   | Sugar                                | Sugar and molasses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 25 | ofd   | Food products<br>nec                 | Other Food: prepared and preserved fish, crustaceans, molluscs and other aquatic invertebrates; prepared and preserved vegetables, pulses and potatoes; prepared and preserved fruits and nuts; wheat and meslin flour; other cereal flours; groats, meal and pellets of wheat and other cereals; other cereal grain products (including corn flakes); other vegetable flours and meals; mixes and doughs for the preparation of bakers' wares; starches and starch products; sugars and sugar syrups n.e.c.; preparations used in animal feeding; lucerne (alfalfa) meal and pellets; bakery products; cocoa, chocolate and sugar confectionery; macaroni, noodles, couscous and similar farinaceous products; food products n.e.c. |
| 26 | b_t   | Beverages and<br>tobacco<br>products | Beverages and Tobacco products                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 27 | tex   | Textiles                             | Manufacture of textiles                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 28 | wap   | Wearing<br>apparel                   | Manufacture of wearing apparel                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |

| id | label | Name                                      | Description                                                                                                                             |
|----|-------|-------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| 29 | lea   | Leather products                          | Manufacture of leather and related products                                                                                             |
| 30 | lum   | Wood products                             | Lumber: manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials |
| 31 | ppp   | Paper products, publishing                | Paper & Paper Products: includes printing and reproduction of recorded media                                                            |
| 32 | p_c   | Petroleum, coal products                  | Petroleum & Coke: manufacture of coke and refined petroleum products                                                                    |
| 33 | chm   | Chemical products                         | Manufacture of chemicals and chemical products                                                                                          |
| 34 | bph   | Basic pharmaceutical products             | Manufacture of pharmaceuticals, medicinal chemical and botanical products                                                               |
| 35 | rpp   | Rubber and plastic products               | Manufacture of rubber and plastics products                                                                                             |
| 36 | nmm   | Mineral products nec                      | Manufacture of other non-metallic mineral products                                                                                      |
| 37 | i_s   | Ferrous metals                            | Iron & Steel: basic production and casting                                                                                              |
| 38 | nfm   | Metals nec                                | Non-Ferrous Metals: production and casting of copper, aluminium, zinc, lead, gold, and silver                                           |
| 39 | fmp   | Metal products                            | Manufacture of fabricated metal products, except machinery and equipment                                                                |
| 40 | ele   | Computer, electronic and optical products | Manufacture of computer, electronic and optical products                                                                                |
| 41 | eeq   | Electrical equipment                      | Manufacture of electrical equipment                                                                                                     |
| 42 | ome   | Machinery and equipment nec               | Manufacture of machinery and equipment n.e.c.                                                                                           |
| 43 | mvh   | Motor vehicles and parts                  | Manufacture of motor vehicles, trailers and semi-trailers                                                                               |
| 44 | otn   | Transport equipment nec                   | Manufacture of other transport equipment                                                                                                |
| 45 | omf   | Manufactures nec                          | Other Manufacturing: includes furniture                                                                                                 |
| 46 | ely   | Electricity                               | Electricity; steam and air conditioning supply                                                                                          |
| 47 | gdt   | Gas manufacture, distribution             | Gas manufacture, distribution                                                                                                           |

| id | label | Name                                       | Description                                                                                                                                                                           |
|----|-------|--------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 48 | wtr   | Water                                      | Water supply; sewerage, waste management and remediation activities                                                                                                                   |
| 49 | cns   | Construction                               | Construction: building houses factories offices and roads                                                                                                                             |
| 50 | trd   | Trade                                      | Wholesale and retail trade; repair of motor vehicles and motorcycles                                                                                                                  |
| 51 | afs   | Accommodation, Food and service activities | Accommodation, Food and service activities                                                                                                                                            |
| 52 | otp   | Transport nec                              | Land transport and transport via pipelines                                                                                                                                            |
| 53 | wtp   | Water transport                            | Water transport                                                                                                                                                                       |
| 54 | atp   | Air transport                              | Air transport                                                                                                                                                                         |
| 55 | whs   | Warehousing and support activities         | Warehousing and support activities                                                                                                                                                    |
| 56 | cmn   | Communication                              | Information and communication                                                                                                                                                         |
| 57 | ofi   | Financial services nec                     | Other Financial Intermediation: includes auxiliary activities but not insurance and pension funding                                                                                   |
| 58 | ins   | Insurance (formerly isr)                   | Insurance (formerly isr): includes pension funding, except compulsory social security                                                                                                 |
| 59 | rsa   | Real estate activities                     | Real estate activities                                                                                                                                                                |
| 60 | obs   | Business services nec                      | Other Business Services nec                                                                                                                                                           |
| 61 | ros   | Recreational and other services            | Recreation & Other Services: recreational, cultural and sporting activities, other service activities; private households with employed persons (servants)                            |
| 62 | osg   | Public Administration and defense          | Other Services (Government): public administration and defense; compulsory social security, activities of membership organizations n.e.c., extra-territorial organizations and bodies |
| 63 | edu   | Education                                  | Education                                                                                                                                                                             |
| 64 | hht   | Human health and social work activities    | Human health and social work                                                                                                                                                          |
| 65 | dwe   | Dwellings                                  | Dwellings: ownership of dwellings (imputed rents of houses occupied by owners)                                                                                                        |

## D Variables in v12

Extracted from <https://www.gtap.agecon.purdue.edu/models/setsVariables.asp>

Note: The set, variable, and parameter definitions documented here are properties of the **GTAP v7 model**, not the underlying database release. They are unchanged when moving from the v11 Data Base to the v12 Data Base — only the sectoral and regional dimensions over which they are indexed change ([65 sectors](#), [163 regions](#) in v12). For the GTAP-Invest aggregation used in simulations, see [s26 sectors](#) and [r50 regions](#).

### D.1 Sets

| Variable Label | Variable Name                           |
|----------------|-----------------------------------------|
| NSAV_COMM      | Non-Savings Commodities (NS)            |
| TRAD_COMM      | Traded Commodities (TC)                 |
| DEMD_COMM      | Demanded Commodities (DC)               |
| PROD_COMM      | Produced Commodities (PC)               |
| ENDW_COMM      | Endowment Commodities (EC)              |
| ENDWS_COMM     | Sluggish Endowment Commodities (ECS)    |
| ENDWM_COMM     | Mobile Endowment Commodities (ECM)      |
| CGDS_COMM      | Capital Goods Commodities (“cgds”)      |
| ENDWC_COMM     | Capital Endowment Commodity (“capital”) |

### D.2 Subsets

| Variable Label | Variable Name |
|----------------|---------------|
| PROD_COMM      | in NSAV_COMM  |
| DEMD_COMM      | in NSAV_COMM  |
| CGDS_COMM      | in NSAV_COMM  |
| ENDW_COMM      | in DEMD_COMM  |
| TRAD_COMM      | in DEMD_COMM  |
| TRAD_COMM      | in PROD_COMM  |
| CGDS_COMM      | in PROD_COMM  |
| ENDWS_COMM     | in ENDW_COMM  |
| ENDWM_COMM     | in ENDW_COMM  |
| ENDWC_COMM     | in NSAV_COMM  |
| ENDWC_COMM     | in ENDW_COMM  |

### D.3 Example: The 3x3 (3 regions x 3 sectors) economy

| Variable Label | Variable Name                                                          |
|----------------|------------------------------------------------------------------------|
| REG            | = {usa, eu, row}                                                       |
| NSAV_COMM      | = {land, labor, capital, food, manufacturing, services, capital goods} |
| TRAD_COMM      | = {food, manufacturing, services}                                      |
| DEMD_COMM      | = {land, labor, capital, food, manufacturing, services}                |
| PROD_COMM      | = {food, manufacturing, services, capital goods}                       |
| ENDW_COMM      | = {land, labor, capital}                                               |
| ENDWS_COMM     | = {land, capital}                                                      |
| ENDWM_COMM     | = {labor}                                                              |
| CGDS_COMM      | = {capital goods}                                                      |
| ENDWC_COMM     | = {capital}                                                            |

### D.4 Value flows evaluated at agents' Prices

EVOA<sub>i,r</sub> value of endowment commodity i output or supplied, in region r, evaluated at agent's prices

- $EVOA_{i,r} = P_{Si,r} * Q_{Oi,r}$  with  $i = ENDW\_COMM$  and  $r$

EVFA<sub>i,j,r</sub> value of purchases of demanded commodity i by firms in sector j, in region r, evaluated at agent's prices

- $EVFA_{i,j,r} = PFE_{i,j,r} * QFE_{i,j,r}$   $i = TRAD\_COMM$ ;  $j = ENDW\_COMM$ ;  $r = REG$

VDFA<sub>i,j,r</sub> value of purchases of domestic tradeable commodity i by firms in sector j of region r evaluated at agents' prices

- $VDFA_{i,j,r} = PFD_{i,j,r} * QFD_{i,j,r}$   $i = TRAD\_COMM$ ;  $j = ENDW\_COMM$ ;  $r = REG$

VIFA<sub>i,j,r</sub> value of purchases of imported tradeable commodity i by firms in sector j of region r evaluated at agents' prices

- $VIFA_{i,j,r} = PFM_{i,j,r} * QFM_{i,j,r}$   $i = TRAD\_COMM$ ;  $j = ENDW\_COMM$ ;  $r = REG$

VDPA<sub>i,r</sub> value of expenditure on domestic tradable commodity i, by private household in region r evaluated at agent's prices

- $VDPA_{i,r} = PPD_{i,r} * QPD_{i,r}$   $i = TRAD\_COMM$ ;  $r = REG$

VIPA<sub>i,j,r</sub> value of expenditure on imported tradeable commodity i by firms in sector j of region r evaluated at agents' prices

- $VIPA_{i,j,r} = PPM_{i,j,r} * QPM_{i,j,r}$   $i = TRAD\_COMM$ ;  $r = REG$

VDGA<sub>i</sub> value of government's expenditure on domestic tradable commodity *i*, in region *r*, evaluated at agent's prices

- $VDGA_{ir} = PGDir * QGDir \ i = TRAD\_COMM; r = REG$

VIGA<sub>i</sub> value of government's expenditure on imported tradable commodity *i*, in region *r*, evaluated at agent's prices

- $VIGA_{ir} = PGMir * QGMir \ i = TRAD\_COMM; r = REG$

SAVE<sub>r</sub> value of (net) savings in region *r*

- $SAVE_r = PSAVE_r * QSAVE_r \ r = REG$

VKBr value of beginning-of-period capital stock in region *r*

- $VKBr = PCGDSr * KBr \ r = REG$

VDEPr value of capital depreciation expenditure in region *r*

- $VDEPr = PCGDSr * KBr \ r = REG$

## D.5 Value flows evaluated at market prices

VFM<sub>ijr</sub> value of purchases of endowment commodity *i* by firms in sector *j* in region *r*, evaluated at market prices

- $VFM_{ijr} = PMir * QFEijr \ i = ENDWM\_COMM; j = PROD\_COMM; r = REG$
- $VFM_{ijr} = PMESijr * QFEijr \ i = ENDWS\_COMM; j = PROD\_COMM; r = REG$

VDFM<sub>ijr</sub> value of purchases of domestic tradable commodity *i* by firms in sector *j* in region *r*, evaluated at market prices

- $VDFM_{ijr} = PMir * QFDijr \ i = TRAD\_COMM; j = PROD\_COMM$

VIFM<sub>ijr</sub> value of purchases of imported tradable commodity *i* by firms in sector *j* in region *r*, evaluated at market prices

- $VIFM_{ijr} = PIMir * QFMijr \ i = TRAD\_COMM; j = PROD\_COMM; r = REG$

VDPM<sub>ir</sub> value of private household's purchases of domestic tradable commodity *i* in region *r*, evaluated at market prices

- $VDPM_{ir} = PMir * QPDir \ i = TRAD\_COMM; r = REG$

VIPM<sub>ir</sub> value of private household's purchases of imported tradable commodity *i* in region *r*, evaluated at market prices

- $VIPM_{ir} = PIMir * QPMir \ i = TRAD\_COMM; r = REG$

VDGMir value of government's expenditure on domestic tradable commodity i, in region r, evaluated at market prices

- $VDGMir = PMir * QGDir \text{ } i = \text{TRAD\_COMM}; r = \text{REG}$

VIGMir value of government's expenditure on imported tradable commodity i, in region r, evaluated at market prices

- $VIGMir = PIMir * QGMir \text{ } i = \text{TRAD\_COMM}; r = \text{REG}$

VXMDirs value of exports of tradable commodity i from source r to destination s, evaluated at (exporter's) market prices

- $VXMDirs = PMir * QXSirs \text{ } i = \text{TRAD\_COMM}; r = \text{REG}; s = \text{REG}$

VIMSirs value of imports of tradable commodity i from source r to destination s, evaluated at (importer's) market prices

- $VIMSirs = PMSir * QXSirs \text{ } i = \text{TRAD\_COMM}; r = \text{REG}; s = \text{REG}$

VSTir value of sales of tradable commodity i to the international transport sector in region r, evaluated at market prices

- $VSTir = PMir * QSTir \text{ } i = \text{MARG\_COMM}; r = \text{REG}$

## D.6 Value flows evaluated at world prices

VXWDirs value of exports of tradable commodity i from source r to destination s, evaluated at world (fob) prices

- $VXWDirs = PFOBirs * QXSirs \text{ } i = \text{TRAD\_COMM}; r = \text{REG}; s = \text{REG}$

VIWSirs value of imports of tradable commodity i from source r to destination s, evaluated at world (cif) prices

- $VIWSirs = PCIFirs * QXSirs \text{ } i = \text{TRAD\_COMM}; r = \text{REG}; s = \text{REG}$

## D.7 Technology Parameters

ESUBVAj with j = PROD\_COMM substitution parameter between primary factors in the CES value-added nest of the nested CES production function of sector j of all regions (i.e. elasticity of substitution between primary production factors; for example, in a situation where land doesn't play a role in production, hence labor and capital are the only primary factors, this parameter indicates how sensitive is the K/L ratio to a 1 percent change in the wage/rental ratio)

ESUBDi with i = TRAD\_COMM substitution parameter between domestic and composite imported commodities in the Armington utility/production structure of agent/sector i in all regions

ESUBMi with i = TRAD\_COMM substitution parameter among imported commodities from different sources in the Armington utility/production structure of agent/sector i in all regions.

## D.8 CDE Preference Parameters and Associated Elasticities

SUBPAR<sub>ir</sub> with  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$  substitution parameter for tradable commodity  $i$  in the CDE minimum expenditure function of region  $r$

INCPAR<sub>ir</sub> with  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$  expansion parameter for tradable commodity  $i$  in the CDE minimum expenditure function of region  $r$ .

ALPHA<sub>ir</sub> 1 - sub. parameter in the CDE minimum expenditure function

- $\text{ALPHA}_{ir} = 1 - \text{SUBPAR}_{ir}$   $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

APE<sub>ikr</sub> Allen partial elast.of sub between composite  $i$  and  $k$  in  $r$

- $\text{APE}_{ikr} = \text{ALPHA}_{ir} + \text{ALPHA}_{kr} - \text{SnCONSHR}_{nr} * \text{ALPHA}_{nr}$   $i = k = n = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

$\text{APE}_{iir} = 2.0 * \text{ALPHA}_{ir} - \text{SnCONSHR}_{nr} * \text{ALPHA}_{nr} - \text{ALPHA}_{ir} / \text{CONSHR}_{ir}$

EY<sub>ir</sub> income elasticity of private household demand for  $i$  in  $r$

- $\text{EY}_{ir} = (1 / \text{SnCONSHR}_{nr} * \text{INCPAR}_{nr}) * (\text{INCPAR}_{ir} * (1.0 - \text{ALPHA}_{ir}) + \text{SnCONSHR}_{nr} * \text{INCPAR}_{nr} * \text{ALPHA}_{nr}) + (\text{ALPHA}_{ir} - \text{SnCONSHR}_{nr} * \text{ALPHA}_{nr})$   $i = n = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

EP<sub>ikr</sub> uncompensated cross-price elasticity private household demand for  $i$  wrt  $k$  in  $r$

- $\text{EP}_{ikr} = (\text{APE}_{ikr} - \text{EY}_{ir}) * \text{CONSHR}_{kr}$   $i = k = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

## D.9 Mobility Parameter

ETRAE<sub>i</sub> with  $i = \text{ENDW\_COMM}$  transformation parameter between uses for a sluggish primary factor  $i$  in the one level CET production function (i.e. this parameter indicates how easy/difficult it is to transfer a sluggish factor (say, capital) from one sector to another; the closer is ETRAE to zero, the more immobile is the factor between alternative uses)

RORFLEX<sub>r</sub> with  $r = \text{REG}$  flexibility of expected net rate of return on capital stock in region  $r$  with respect to investment (if a region's capital stock increases by 1%, then it is expected that the net rate of return on capital will decline by RORFLEX%)

RORDELTA binary coefficient that determines the mechanism of allocating investment across regions (when RORDELTA=1, investment is allocated across regions to equate the change in the expected rates of return,  $\text{rore}(r)$ , when RORDELTA=0, investment is allocated across regions to maintain the existing composition of capital stocks).

## D.10 Value Flows

VOAir value of non-saving commodity i output or supplied in region r evaluated at agents' prices

- $VOAir = EVOAir\ i = ENDW\_COMM; r = REG$
- $VOAir = S_j VFA_{jir}\ i = PROD\_COMM; j = DEMD\_COMM; r = REG$

VFAir value of purchases of demanded commodity i by firms in sector j of region r evaluated at agents' prices

- $VFA_{jir} = EVFA_{jir}\ i = ENDW\_COMM; j = PROD\_COMM; r = REG$
- $VFA_{jir} = VDF_{jir} + VIFA_{jir}\ i = TRAD\_COMM; j = PROD\_COMM; r = REG$

VOMir value of non-saving commodity i output or supplied in region r evaluated at market prices

- $VOMir = S_j VFM_{jir}\ i = ENDW\_COMM; j = PROD\_COMM; r = REG$
- $VOMir = VDMir + VSTir + S_s VXM_{Dir}\ i = MARG\_COMM; r = REG; s = REG$
- $VOMir = VDMir + S_s VXM_{Dir}\ i = NMRG\_COMM; r = REG; s = REG$
- $VOMir = VOAir\ i = CGDS\_COMM; r = REG$

VDMir value of domestic sales of tradable commodity i in region r evaluated at market prices

- $VDMir = VDPMir + VDMir + S_j VDF_{jir}\ i = TRAD\_COMM; j = PROD\_COMM; r = REG$

VIMir value of aggregate imports of tradable commodity i in region r evaluated at market prices

- $VIMir = VIPMir + VIGMir + S_j VIF_{jir}\ i = TRAD\_COMM; j = PROD\_COMM; r = REG$

VPAir value of private household expenditure on tradable commodity i in region r evaluated at agents' prices

- $VPAir = VDP_{Air} + VIP_{Air}\ i = TRAD\_COMM; r = REG$

PRIVEXPr total consumption expenditure by private household in region r

- $PRIVEXPr = S_i VPAir\ i = TRAD\_COMM$

VGAir value of government expenditure on tradable commodity i in region r evaluated at agents' prices

- $VGAir = VDG_{Air} + VIG_{Air}\ i = TRAD\_COMM; r = REG$

GOVEXPr total consumption expenditure by government in region r

- $GOVEXPr = S_i VGAir\ i = TRAD\_COMM; r = REG$

INCOMEr total expenditure equals net income in region r

- $INCOMEr = PRIVEXPr + GOVEXPr + SAVEr\ r = REG$

REGINVR gross investment in region r that equals value of output of “capital goods” sector

- $REGINVR = SkVOAkr \text{ } k = CGDS\_COMM$

NETINVR net investment in region r

- $NETINVR = SkVOAkr - VDEPr \text{ } k = CGDS\_COMM$

GLOBINV global net investment

- $GLOBINV = SrNETINV = SrSAVER \text{ } r = REG$

INVKERATIOr ratio of gross investment to end-of-period capital stock in region r

- $INVKERATIOr = REGINVR / (VKBr + NETINVR) \text{ } r = REG$

GRNETRATIOr ratio of gross to net rate of return on capital in regin r (VOAcapital,r is gross return to capital)

- $GRNETRATIOr = SkVOAkr / (SkVOAkr - VDEPr) \text{ with } k = ENDWC\_COMM; r = REG$

GDPPr gross domestic product in region r (trade is valued at worl prices)

- $GDPPr = SiVPAir + SiVGAir + SkVOAkr + SiSsVXWDirs + SmVSTms - SiSsVIWSirs \text{ } i = TRAD\_COMM; k = CGDS\_COMM; r = REG; s = REG$

VT international margin suply

- $VT = SiSrVSTir \text{ } i = TRAD\_COMM; r = REG$

VXWir value of exports of tradable commodity i from source r evaluated at world (fob) prices

- $VXWir = SsVXWDirs + VSTir \text{ } i = MARG\_COMM; r = REG$
- $VXWir = SsVXWDirs \text{ } i = NMARG\_COMM; r = REG$

VXWREGIONr value of exports from source r evaluated at world (fob) prices

- $VXWREGIONr = SiVXWir \text{ } i = TRAD\_COMM; r = REG$

VXWCOMMODi value of exports of tradable commodity i evaluated at world (fob) prices

- $VXWCOMMODi = SrVXWir \text{ } i = TRAD\_COMM; r = REG$

VIWir value of imports of tradable commodity i into region r evaluated at world (cif) prices

VIWir =  $SsVIWSir \text{ } i = TRAD\_COMM; r = REG; s = REG$

VIWREGIONr value of imports into region r evaluated at world (cif) prices

VIWREGIONr =  $SiVIWir \text{ } i = TRAD\_COMM; r = REG$

VIWCOMMODi value of imports of tradable commodity i evaluated at world (cif) prices

VIWCOMMODi =  $SrVIWir \text{ } i = TRAD\_COMM; r = REG$

VXWLD value of worldwide commodity exports evaluated at world (fob) prices

VXWLD=  $\sum_r \text{VXWREGION}_r$   $r = \text{REG}$

PW\_PMir ratio of world (fob) to domestic market prices for tradable commodity i in region

$\text{PW\_PMir} = \text{SsVXWDirs} / \text{SsVXMDirs}$   $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$ ;  $s = \text{REG}$

VOWir value of output of tradable commodity i in region r, evaluated at world (fob) prices

$\text{VOWir} = \text{VDMir} * \text{PW\_PMir} + \text{SsVXWDirs}$   $i = \text{MARG\_COMM}$ ;  $r = \text{REG}$ ;  $s = \text{REG}$

$\text{VOWir} = \text{VDMir} * \text{PW\_PMir} + \text{SsVXWDirs}$   $i = \text{NMRG\_COMM}$ ;  $r = \text{REG}$ ;  $s = \text{REG}$

VWOWi value of world supply of tradable commodity i evaluated at world (fob) prices

$\text{VWOWi} = \text{SrVOWiri} = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

VTMFSDmirs int'l margin usage, by margin, freight, source, and destination m = MARG\_COMM; i = TRAD\_COMM; r = REG; s = REG

VTFS\_DIRS aggregate value of svces in the shipment of i from r to s

$\text{VTFS_DIRS} = \sum_m \text{VTMFSDmirs}$  In a balanced data base  $\text{VIWSirs} = \text{VXWDirs} + \text{VTFS_DIRS}$   $i = \text{TRAD\_COMM}$ ;  $m = \text{MARG\_COMM}$ ;  $r = \text{REG}$ ;  $s = \text{REG}$

VTMPROVm international margin services provision

$\text{VTMPROVm} = \sum_r \text{VSTmr}$   $m = \text{MARG\_COMM}$ ;  $r = \text{REG}$

VTRPROVr international margin supply, by region

$\text{VTRPROVr} = \sum_m \text{VSTmr}$   $m = \text{MARG\_COMM}$ ;  $r = \text{REG}$

VTMUSEm international margin services usage, by type

$\text{VTMUSEm} = \sum_i \sum_r \text{SsVTMFSDmirs}$   $m = \text{MARG\_COMM}$ ;  $i = \text{TRAD\_COMM}$ ;  $r = s = \text{REG}$  In a balanced data base,  $\text{VTMPROV} = \text{VTMUSE}$

VTMUSESHRmirs share of i,r,s usage in global demand for m

$\text{VTMUSESHRmirs} = \text{VTFS_DIRS} / \text{VT}$   $m = \text{MARG\_COMM}$ ;  $i = \text{TRAD\_COMM}$ ;  $r = s = \text{REG}$  if  $\text{VTMUSEm} <> 0.0$  then  $\text{VTMUSESHRmirs} = \text{VTMFSDmirs} / \text{VTMUSEm}$

VTSUPPSHRmr share of region r in global supply of margin m

$\text{VTSUPPSHRmr} = \text{VTRPROVr} / \text{VT}$  if  $\text{VTMPROVm} <> 0.0$  then  $\text{VTSUPPSHRmr} = \text{VSTmr} / \text{VTMPROVm}$   $m = \text{MARG\_COMM}$ ;  $r = \text{REG}$

VTUSE international margin services usage;

$\text{VTUSE} = \sum_m \sum_i \sum_r \text{SsVTMFSDmirs}$   $m = \text{MARG\_COMM}$ ;  $i = \text{TRAD\_COMM}$ ;  $r = s = \text{REG}$

VWOUi value of world output of i at user prices

$\text{VWOUi} = \sum_s [\text{VPAis} + \text{VGAis}] + \sum_j \text{VFAijs}$   $s = \text{REG}$ ;  $j = \text{PROD\_COMM}$

VENDWREGr value of primary factors, at mkt prices, by region

$\text{VENDWREGr} = \sum_i \text{VOMir}$   $i = \text{ENDOW\_COMM}$ ;  $r = \text{REG}$

VENDWWLD value of primary factors, at mkt prices, worldwide

$\text{VENDWWLD} = \sum_r \text{VENDWREGr}$   $r = \text{REG}$

VPAEVir private household expend. on i in r valued at agent's prices, for EV calculation

$$VPAEVir = q_{pevir} i = TRAD\_COMM, r = REG$$

VPAREGEVr private consumption expenditure in region r, for EV calculation

$$VPAREGEVr = SiVPAEVir i = TRAD\_COMM, r = REG \quad YGr \text{ regional government consumption expenditure, in region } r \quad r = REG$$

## D.11 Shares

SHRDFMijr share of domestic sales of tradable commodity i used by firms in sector j of region r evaluated at market prices

$$SHRDFMijr = VDFMijr / VDMir \quad i = TRAD\_COMM; j = PROD\_COMM; r = REG$$

SHRDPMi share of domestic sales of commodity i used by private household in region r evaluated at market prices

$$SHRDPMir = VDPMir / VDMir \quad i = TRAD\_COMM; r = REG$$

SHRDGMi share of domestic sales of commodity i used by the government in region r evaluated at market prices

$$SHRDGMir = VDMir / VDMir \quad i = TRAD\_COMM; r = REG$$

SHRIFMijr share of aggregate imports of tradable commodity i used by firms in sector j of region r evaluated at market prices

$$SHRIFMijr = VIFMijr / VIMir \quad i = TRAD\_COMM; j = PROD\_COMM; r = REG$$

SHRIPMir share of aggregate imports of commodity i used by private household in region r evaluated at market prices

$$SHRIPMir = VIPMir / VIMir \quad i = TRAD\_COMM; r = REG$$

SHRIGMir share of aggregate imports of commodity i used by the government in region r evaluated at market prices

$$SHRIGMir = VIGMir / VIMir \quad i = TRAD\_COMM; r = REG$$

FMSHRijr share of imports in the composite for tradable commodity i used by firms in sector j of region r evaluated at agents' prices

$$FMSHRijr = VIFAir / VFAir \quad i = TRAD\_COMM; j = PROD\_COMM; r = REG$$

PMSHRir share of imports in the composite for tradable commodity i used by private household in region r evaluated at agents' prices

$$PMSHRir = VIPAir / VPAir \quad i = TRAD\_COMM; r = REG$$

GMSHRir share of imports in the composite for tradable commodity i used by the government in region r evaluated at agents' prices

$$GMSHRir = VIGAir / VGAir \quad i = TRAD\_COMM; r = REG$$

CONSHR<sub>ir</sub> budget share of the composite for tradable i in total private household expenditure in region r evaluated at agents' prices

$$\text{CONSHR}_{ir} = \text{VPA}_{ir} / \text{PRIVEXP}_{ir} \quad i = \text{TRAD\_COMM}; r = \text{REG}$$

MSHRS<sub>irs</sub> market share of source r in the aggregate imports of tradable commodity i in region s evaluated at market prices

$$\text{MSHRS}_{irs} = \text{VIMS}_{irs} / \text{SrVIMS}_{irs} \quad i = \text{TRAD\_COMM}; r = s = \text{REG}$$

SVA<sub>ijr</sub> share of endowment commodity i in value-added of sector j of region r evaluated at agents' prices

$$\text{SVA}_{ijr} = \text{VFA}_{ijr} / \text{SkVFA}_{kjr} \quad i = \text{ENDW\_COMM}; j = \text{PROD\_COMM}; k = \text{ENDW\_COMM}; r = \text{REG}$$

REVSHR<sub>ijr</sub> share of endowment commodity i used by firms in sector j of region r evaluated at market prices

$$\text{REVSHR}_{ijr} = \text{VFM}_{ijr} / \text{SkVFM}_{kjr} \quad i = \text{ENDW\_COMM}; j = \text{PROD\_COMM}; k = \text{PROD\_COMM}; r = \text{REG}$$

FOBSHR<sub>irs</sub> share of fob price in the cif price for tradable commodity i exported from source r to destination s

$$\text{FOBSHR}_{irs} = \text{VXWD}_{irs} / \text{VIWSCOST}_{irs} \quad i = \text{TRAD\_COMM}; r = s = \text{REG}$$

XSHRPRIV<sub>r</sub> private expenditure share in regional income

$$\text{XSHRPRIV}_r = \text{PRIVEXP}_r / \text{INCOMER}_r \quad r = \text{REG}$$

XSHRGOV<sub>r</sub> government expenditure share in regional income

$$\text{XSHRGOV}_r = \text{GOVEXP}_r / \text{INCOMER}_r \quad r = \text{REG}$$

XSHRSAVER<sub>r</sub> saving share in regional income

$$\text{XSHRSAVER}_r = \text{SAVER}_r / \text{INCOMER}_r \quad r = \text{REG}$$

SHRDM<sub>ir</sub> share of domestic sales of i in r  $i = \text{TRAD\_COMM}; r = \text{REG}$

$$\text{SHRDM}_{ir} = \text{VDM}_{ir} / \text{VOM}_{ir}$$

SHRST<sub>m</sub> share of sales of m to global transport services in r  $m = \text{MARG\_COMM}; r = \text{REG}$

$$\text{SHRST}_m = \text{VST}_m / \text{VOM}_m$$

SHRXMD<sub>irs</sub> share of export sales of i to s in r  $i = \text{TRAD\_COMM}; r = s = \text{REG}$

$$\text{SHRXMD}_{irs} = \text{VXMD}_{irs} / \text{VOM}_{ir} \quad i = \text{TRAD\_COMM}; r = s = \text{REG}$$

SHREM<sub>ijr</sub> share of mobile endowments i used by sector j at mkt prices

$$\text{SHREM}_{ijr} = \text{VFM}_{ijr} / \text{VOM}_{ir} \quad i = \text{ENDWM\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$$

TRNSHR<sub>irs</sub> share of transport price in the cif price for tradable commodity i exported from source r to destination s

$$\text{TRNSHR}_{irs} = \text{VTFSD}_{irs} / \text{VIWSCOST}_{irs} \quad i = \text{TRAD\_COMM}; r = s = \text{REG}$$

XWCONSHR<sub>ir</sub> expansion-parameter-weighted consumption share

$XWCONSHR_{ir} = CONSHR_{ir} * INCPAR_{ir} / UELASPRIV_r \quad i = \text{TRAD\_COMM}; r = \text{REG}$   
 $XSHRPRIVEV_r$  private expenditure share in regional income, for EV calculation  $r = \text{REG}$   
 $XSHRPRIVEV_r = PRIVEXPEV_r / INCOMEEV_r \quad r = \text{REG}$   
 $XSHRGOVEV_r$  government expenditure share in regional income, for EV calculation  $r = \text{REG}$   
 $XSHRGOVEV_r = GOVEXPEV_r / INCOMEEV_r \quad r = \text{REG}$   
 $XSHRSAVEEV_r$  saving share in regional income, for EV calculation  $r = \text{REG}$   
 $XSHRSAVEEV_r = SAVEEV_r / INCOMEEV_r \quad r = \text{REG}$   
 $XWCONSHREVir$  expansion-parameter-weighted consumption share, for EV calculation  
 $XWCONSHREVir = CONSHREVir * INCPAR_{ir} / UELASPRIVEV_r \quad i = \text{TRAD\_COMM}, r = \text{REG}$   
 $CONSHREVir$  share of private household consn devoted to good  $i$  in  $r$ , for EV calculation  
 $CONSHREVir = VPAEVir / VPAREGEV_r$   
 $STC_{ijr}$  share of  $i$  in total costs of  $j$  in  $r$   
 $STC_{ijr} = VFA_{ijr} / \sum_k VFA_{kjr} \quad i = k = \text{DEMD\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$

## D.12 Quantity Variables

$QO_{ir}$  quantity of non-saving commodity  $i$  output or supplied in region  $r \mid i = \text{NSAV\_COMM} \quad r = \text{REG}$   
 $QOES_{ijr}$  quantity of sluggish endowment  $i$  supplied to sector  $j$  firm of region  $r \mid i = \text{ENDWS\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$   
 $QDS_{ir}$  quantity of domestic sales of tradable commodity  $i$  in region  $r \mid i = \text{TRAD\_COMM}; r = \text{REG}$   
 $QXS_{irs}$  quantity of exports of tradable commodity  $i$  from source  $r$  to destination  $s \mid i = \text{TRAD\_COMM}; r = s = \text{REG}$   
 $QST_{ir}$  quantity of sales of marginal commodity  $i$  to the international transport sector in region  $r \mid i = \text{MARG\_COMM}; r = \text{REG}$   
 $QFE_{ijr}$  quantity of endowment  $i$  demanded by sector  $j$  firm in region  $r \mid i = \text{ENDW\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$   
 $QVA_{jr}$  quantity index of land-labor-capital composite (value-added) in sector  $j$  firm in region  $r \mid j = \text{PROD\_COMM}; r = \text{REG}$   
 $QF_{ijr}$  quantity of composite tradable commodity  $i$  demanded by sector  $j$  firm in region  $r \mid i = \text{TRAD\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$   
 $QFD_{ijr}$  quantity of domestic tradable  $i$  demanded by sector  $j$  firm in region  $r \mid i = \text{TRAD\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$   
 $QFM_{ijr}$  quantity of imported tradable  $i$  demanded by sector  $j$  firm in region  $r \mid i = \text{TRAD\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$

QPir quantity of composite tradable  $i$  demanded by private household in region  $r$  |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

QPD<sub>ir</sub> quantity of domestic tradable  $i$  demanded by private household in region  $r$  |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

QPM<sub>ir</sub> quantity of imported tradable  $i$  demanded by private household in region  $r$  |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

QG<sub>ir</sub> quantity of composite tradable commodity  $i$  demanded by government household in region  $r$  |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

QGD<sub>ir</sub> quantity of domestic tradable commodity  $i$  demanded by government household in region  $r$  |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

QGM<sub>ir</sub> quantity of imported tradable commodity  $i$  demanded by government household in region  $r$  |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

QIM<sub>ir</sub> quantity of aggregate imports of tradable commodity  $i$  demanded by region  $r$  using market prices as weights |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

QIW<sub>ir</sub> quantity of aggregate imports of tradable commodity  $i$  demanded by region  $r$  using cif prices as weights |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

QXW<sub>ir</sub> quantity of aggregate exports of tradable commodity  $i$  supplied from region  $r$  using fob prices as weights |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

QIWREG<sub>r</sub> volume of merchandise imports demanded by region  $r$  |  $r = \text{REG}$

QXWREG<sub>r</sub> volume of merchandise exports supplied by region  $r$  |  $r = \text{REG}$

QIWCOM<sub>i</sub> volume of global merchandise imports of tradable commodity  $i$  |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

QXWCOM<sub>i</sub> volume of global merchandise exports of tradable commodity  $i$  |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

QXWWLD volume of world trade

QOW<sub>i</sub> quantity index for world supply of tradable commodity  $i$  |  $i = \text{TRAD\_COMM}$

EXPAND<sub>ir</sub> Change in investment levels relative to endowment stock |  $i = \text{ENDWC\_COMM}$ ;  $r = \text{REG}$

QOWU<sub>i</sub> quantity index for world supply of good  $i$  at user prices |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

QTMFSD<sub>mirs</sub> international usage margin  $m$  on  $i$  from  $r$  to  $s$  |  $m = \text{MARG\_COMM}$ ;  $i = \text{TRAD\_COMM}$ ;  $r = s = \text{REG}$

QTM<sub>m</sub> global margin usage  $m = \text{MARG\_COMM}$

QCGDS<sub>r</sub> quantity of capital goods sector supplied in region  $r$  |  $r = \text{REG}$

QSAVE<sub>r</sub> quantity of savings demanded in region  $r$  |  $r = \text{REG}$

GLOBALCGDS quantity of global supply of capital for net investment

KSVCES<sub>r</sub> quantity of capital services in region  $r$  |  $r = \text{REG}$

KBr quantity of beginning-of-period capital stock in region  $r$   $r = \text{REG}$

KEr quantity of end-of-period capital stock in region  $r$   $r = \text{REG}$

QGDP $r$  quantity index for GDP in region  $r$   $r = \text{REG}$

WALRAS\_DEM quantity demanded in the omitted market - equals global demand for savings

WALRAS\_SUP quantity supplied in the omitted market - equals global supply of new capital goods composite

POPr population in region  $r$   $r = \text{REG}$

COMPVALADir composition of value added for good  $i$  and region  $r$   $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

## D.13 Price Variables

PMir market price of non-saving commodity  $i$  in region  $r$   $i = \text{NSAV\_COMM}$ ;  $r = \text{REG}$

PMESijr market price for sluggish endowment  $i$  supplied to firm  $j$  in region  $r$   $i = \text{ENDWS\_COMM}$ ;  $j = \text{PROD\_COMM}$ ;  $r = \text{REG}$

PSir supply price of non-saving commodity  $i$  in region  $r$   $i = \text{NSAV\_COMM}$ ;  $r = \text{REG}$

PFEijr demand price for endowment  $i$  by firms in sector  $j$  of region  $r$   $i = \text{ENDW\_COMM}$ ;  $j = \text{PROD\_COMM}$ ;  $r = \text{REG}$

PVAjr price of value-added in sector  $j$   $j = \text{PROD\_COMM}$ ;  $r = \text{REG}$

PFijr demand price for composite tradable  $i$  by firms in sector  $j$  of region  $r$   $i = \text{TRAD\_COMM}$ ;  $j = \text{PROD\_COMM}$ ;  $r = \text{REG}$

PFDijr demand price for domestic tradable  $i$  by firms in sector  $j$  of region  $r$   $i = \text{TRAD\_COMM}$ ;  $j = \text{PROD\_COMM}$ ;  $r = \text{REG}$

PFMijr demand price for imported tradable  $i$  by firms in sector  $j$  of region  $r$   $i = \text{TRAD\_COMM}$ ;  $j = \text{PROD\_COMM}$ ;  $r = \text{REG}$

PPir private household's demand price for composite tradable  $i$  in region  $r$   $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

PPDir private household's demand price for domestic tradable  $i$  in region  $r$   $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

PPMir private household's demand price for imported tradable  $i$  in region  $r$   $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

PGir government household's demand price for composite tradable  $i$  in region  $r$   $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

PGDir government household's demand price for domestic tradable  $i$  in region  $r$   $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

PGMir government household's demand price for imported tradable  $i$  in region  $r$   $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

PSAVER price of savings in region  $r$   $r = \text{REG}$

PCGDSr price of investment good in region  $r$  - equals  $\text{PS}(\text{cgds}, r)$   $r = \text{REG}$

PGDPr price index for GDP in region  $r$   $r = \text{REG}$

PPRIVr price index for private household expenditure in region  $r$   $r = \text{REG}$

PGOVR price index for government household expenditure in region  $r$   $r = \text{REG}$

PFOBirs world fob price of tradable commodity  $i$  exported from source  $r$  to destination  $s$  (prior to including transport margins)  $i = \text{TRAD\_COMM}$ ;  $r = s = \text{REG}$

PCIFirs world cif price of tradable commodity  $i$  imported from source  $r$  to destination  $s$  ) after including transport margins)  $i = \text{TRAD\_COMM}$ ;  $r = s = \text{REG}$

PMSirs market price by source of tradable commodity  $i$  imported from source  $r$  to destination  $s$   $i = \text{TRAD\_COMM}$ ;  $r = s = \text{REG}$

PIMir market price of aggregate imports of tradable commodity  $i$  in region  $r$   $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

PIWir world price of aggregate imports of tradable commodity  $i$  in region  $r$   $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

PXWir price index for aggregate exports of tradable commodity  $i$  from region  $r$   $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

PIWREGr price index of merchandise imports in region  $r$   $r = \text{REG}$

PXWREGr price index of merchandise exports from region  $r$   $r = \text{REG}$

PIWCOMi price index of global merchandise imports of tradable commodity  $i$   $i = \text{TRAD\_COMM}$

PXWCOMi price index of global merchandise exports of tradable commodity  $i$   $i = \text{TRAD\_COMM}$

PXWWLD price index of world trade

PRir ratio of domestic market price to market price of imports for tradable commodity  $i$  in region  $r$   $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

PWi world price index for total supply of tradable commodity  $i$  in region  $r$   $i = \text{TRAD\_COMM}$

PSWr price index received for tradable commodities produced in region  $r$  including sales of net investment to the global bank  $r = \text{REG}$

PDWr price index paid for tradable commodities used in region  $r$  including purchases of savings from the global bank  $r = \text{REG}$

TOTr terms of trade for region  $r$   $r = \text{REG}$

PTm price of margin services supplied  $m = \text{MARG\_COMM}$

PCGDSWLD world average price of capital goods (net investment weights)

PWUi world price index for total good  $i$  supplies at user prices  $i = \text{TRAD\_COMM}$

PTRANSirs cost index for international transport of  $i$  from  $r$  to  $s$   $i = \text{TRAD\_COMM}$ ;  $r = s = \text{REG}$

RENTAL<sub>r</sub> rental rate on capital stock in region  $r$  - equals  $PS(CGDS, r)$   $r = REG$

RORC<sub>r</sub> current net rate of return on capital stock in region  $r$   $r = REG$

RORER expected net rate of return on capital stock in region  $r$   $r = REG$

RORG global net rate of return on capital stock

Pr price index for disposition of income by regional household

PFACTREAL<sub>i</sub> ratio of return to primary factor  $i$  to cpi in  $r$   $i = ENDW\_COMM$ ;  $r = REG$

PFACTOR<sub>r</sub> market price index of primary factors, by region

PFACTWLD world price index of primary factors

## D.14 Technical Change Variables

AO<sub>i</sub> output augmenting technical change in sector  $j$  of region  $r$  |  $j = PROD\_COMM$ ;  $r = REG$

AFE<sub>i</sub><sub>j</sub> primary factor  $i$  augmenting technical change in sector  $j$  of region  $r$  |  $i = ENDW\_COMM$ ;  $j = PROD\_COMM$ ;  $r = REG$

AF<sub>i</sub><sub>j</sub> intermediate input  $i$  augmenting technical change in sector  $j$  of region  $r$  |  $i = TRAD\_COMM$ ;  $j = PROD\_COMM$ ;  $r = REG$

AVA<sub>j</sub> value-added augmenting technical change in sector  $j$  of region  $r$  |  $j = PROD\_COMM$ ;  $r = REG$

AMS<sub>i</sub> import  $i$  from region  $r$  augmenting tech change in region  $s$  |  $i = TRAD\_COMM$ ,  $r = s = REG$

AOSEC<sub>j</sub> output tech change of sector  $j$ , worldwide |  $j = PROD\_COMM$

AOREG<sub>r</sub> output tech change in region  $r$  |  $r = REG$

AOALL<sub>j</sub> output augmenting technical change in sector  $j$  of  $r$  |  $j = PROD\_COMM$ ;  $r = REG$

ESUBT<sub>j</sub> elasticity of substitution among composite intermediate inputs in production |  $j = PROD\_COMM$

AFCOM<sub>i</sub> intermediate tech change of input  $i$ , worldwide |  $i = TRAD\_COMM$

AFSEC<sub>j</sub> intermediate tech change of sector  $j$ , worldwide |  $j = PROD\_COMM$

AFREG<sub>r</sub> intermediate tech change in region  $r$  |  $r = REG$

AFALL<sub>i</sub><sub>j</sub> intermediate input  $i$  augmenting tech change by  $j$  in  $r$  |  $i = TRAD\_COMM$ ,  $j = PROD\_COMM$ ;  $r = REG$

AFECOM<sub>i</sub> factor input tech change of input  $i$ , worldwide |  $i = ENDW\_COMM$

AFESEC<sub>j</sub> factor input tech change of sector  $j$ , worldwide |  $j = PROD\_COMM$

AFERE<sub>r</sub> factor input tech change in region  $r$  |  $r = REG$

AFEALL<sub>i</sub><sub>j</sub> primary factor  $i$  augmenting tech change sector  $j$  in  $r$  |  $i = ENDW\_COMM$ ;  $j = PROD\_COMM$ ;  $r = REG$

AMSirs reduction in effective price associated with delivery of  $i$  from  $r$  to  $s$  |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$ ;  $s = \text{REG}$

ATMFSDmirs tech change in  $m$ 's shipping of  $i$  from region  $r$  to  $s$  |  $m = \text{MARG\_COMM}$ ;  $i = \text{TRAD\_COMM}$ ;  $r = s = \text{REG}$

ATMm tech change in mode  $m$ , worldwide; |  $m = \text{TRAD\_COMM}$

ATFi tech change shipping of  $i$ , worldwide |  $i = \text{TRAD\_COMM}$

ATSr tech change shipping from region  $r$  |  $r = \text{REG}$

ATDs tech change shipping to  $s$  |  $s = \text{REG}$

ATALLmirs tech change in  $m$ 's shipping of  $i$  from region  $r$  to  $s$  |  $m = \text{MARG\_COMM}$ ;  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$ ;  $s = \text{REG}$

AUr input-neutral shift in utility function |  $r = \text{REG}$

## D.15 Policy Variables

TOir power of the tax on output (or income) of non-savings commodity  $i$  in region  $r$  |  $i = \text{NSAV\_COMM}$ ;  $r = \text{REG}$

TFijr power of the tax on endowment commodity  $i$  demanded by sector  $j$  of region  $r$  |  $i = \text{ENDW\_COMM}$ ;  $j = \text{PROD\_COMM}$ ;  $r = \text{REG}$

TFDijr power of the tax on domestic tradable commodity  $i$  demanded by sector  $j$  of region  $r$  |  $i = \text{TRAD\_COMM}$ ;  $j = \text{PROD\_COMM}$ ;  $r = \text{REG}$

TFMijr power of the tax on imported tradable commodity  $i$  demanded by sector  $j$  of region  $r$  |  $i = \text{TRAD\_COMM}$ ;  $j = \text{PROD\_COMM}$ ;  $r = \text{REG}$

TPDir power of the tax on domestic tradable commodity  $i$  purchased by private household in region  $r$  |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

TPMir power of the tax on imported tradable commodity  $i$  purchased by private household in region  $r$  |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

TGDir power of the tax on domestic tradable commodity  $i$  purchased by government household in region  $r$  |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

TGMir power of the tax on imported tradable commodity  $i$  purchased by government household in region  $r$  |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

TXSirs power of the tax on exports of tradable commodity  $i$  from source  $r$  to destination  $s$  (levied in region  $r$ ) |  $i = \text{TRAD\_COMM}$ ;  $r = s = \text{REG}$

TMSirs power of the tax on imports of tradable commodity  $i$  from source  $r$  to destination  $s$  (levied in region  $s$ ) |  $i = \text{TRAD\_COMM}$ ;  $r = s = \text{REG}$

TXir power of the variable export tax on exports of tradable commodity from region  $r$  - destination generic |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

TMir power of the variable import tax (levy) on imports of tradable commodity i in region s - source generic | i = TRAD\_COMM; r = REG

TPr region-wide shock to tax on purchases by private household in region r | r = REG

ATPMir actual tax on imported traded commodity i purchased by private households in region r | i = TRAD\_COMM; r = REG

ATPDir actual tax on domestic traded commodity i purchased by private households in region r | i = TRAD\_COMM; r = REG

DGTAXir tax on government consumption of domestic good i in region r | r = REG

IGTAXir tax on government consumption of imported good i in region r | r = REG

TGCr government consumption tax payments in r

TGCr = SiDGTAXir + IGTAXir i = TRAD\_COMM; r = REG

DPTAXir tax on private consumption of domestic good i in region r

DPTAXir = VDPAir - VDPMir i = TRAD\_COMM; r = REG

IPTAXir tax on private consumption of imported good i in region r

IPTAXir = VIPAir - VIPMir i = TRAD\_COMM; r = REG

TPCr private consumption tax payments in r

TPCr = SiDPTAXir + IPTAXir i = TRAD\_COMM; r = REG

DFTAXijr tax on use of domestic intermediate good i by j in r

DFTAXijr = VDFAijr - VDFMijr i = TRAD\_COMM; j = PROD\_COMM; r = REG

IFTAXijr tax on use of imported intermediate good i by j in r

IFTAXijr = VIFAijr - VIFMijr i = TRAD\_COMM; j = PROD\_COMM; r = REG

TIUr firms' tax payments on intermediate goods usage in r

TIUr = SjSi(DFTAXijr + IFTAXijr) i = TRAD\_COMM; j = PROD\_COMM; r = REG

ETAXijr tax on use of endowment good i by industry j in region r

ETAXijr = VFAijr - VFMijr i = ENDW\_COMM; j = PROD\_COMM; r = REG

TFUr firms' tax payments on primary factor usage in r

TFUr = SiSjETAXijr i = ENDW\_COMM; j = PROD\_COMM; r = REG

PTAXir output tax on good i in region r

PTAXir = VOMir - VOAir i = NSAV\_COMM; r = REG

TOUTr production tax payments in r

TOUTr = SiPTAXir i = PROD\_COMM; r = REG

XTAXDir tax on exports of good i from source r to destination s

XTAXDir = VXWDir - VXMDir i = TRAD\_COMM; r = s = REG

TEX<sub>r</sub> export tax payments in *r*

$$\text{TEX}_r = \text{SiSsXTAXDir } i = \text{TRAD\_COMM}; r = s = \text{REG}$$

MTAX<sub>irs</sub> tax on imports of good *i* from source *r* in destination *s*

$$\text{MTAX}_{irs} = \text{VIMSirs} - \text{VIWSirs } i = \text{TRAD\_COMM}; r = s = \text{REG}$$

TIM<sub>r</sub> import tax payments in *r*

$$\text{TIM}_r = \text{SiSsMTAXisr } i = \text{TRAD\_COMM}; r = s = \text{REG}$$

TOTTAX<sub>r</sub> Total tax receipts in *r*

$$\text{TOTTAX}_r = \text{TPCr} + \text{TGCr} + \text{TIUr} + \text{TFUr} + \text{TOUTr} + \text{TEX}_r + \text{TIM}_r + \text{TINCr } r = \text{REG}$$

TGCR<sub>r</sub> change in ratio of government consumption tax to INCOME in region *r* *r* = REG

TPCR<sub>r</sub> change in ratio of private consumption tax to INCOME in region *r* *r* = REG

TIUR<sub>r</sub> change in ratio of tax on intermediate usage to INCOME in region *r* *r* = REG

TFUR<sub>r</sub> change in ratio of tax on primary factor usage to INCOME in region *r* *r* = REG

TOUTR<sub>r</sub> change in ratio of output tax to INCOME in region *r* *r* = REG

TEXPR<sub>r</sub> change in ratio of export tax to INCOME in region *r* *r* = REG

TIMPR<sub>r</sub> change in ratio of import tax to INCOME in region *r* *r* = REG

TINCr income tax payments in *r*

$$\text{TINCr} = \text{SiPTAXir } i = \text{ENDOW\_COMM}; r = \text{REG}$$

TINCR<sub>r</sub> change in ratio of income tax to INCOME in region *r* *r* = REG

DTAXR<sub>r</sub> change in ratio of taxes to INCOME in *r* *r* = REG

## D.16 Regional Household Preference Parameters and Shifters

DPARPRIV<sub>r</sub> private consumption distribution parameter

$$\text{DPARPRIV}_r = \text{UELASPRIV}_r * \text{XSHRPRIV}_r / \text{UTILELAS}_r \quad r = \text{REG}$$

DPARGOV<sub>r</sub> government consumption distribution parameter

$$\text{DPARGOV}_r = \text{XSHRGOV}_r / \text{UTILELAS}_r \quad r = \text{REG}$$

DPARSAVER<sub>r</sub> saving distribution parameter

$$\text{DPARSAVER}_r = \text{XSHRSAVER}_r / \text{UTILELAS}_r \quad r = \text{REG}$$

DPARSUM<sub>r</sub> sum of distribution parameters *r* = REG

dpavr change in average distribution parameter *r* = REG

dpsumr change in sum of the distribution parameters *r* = REG

dpprivr change in private consumption distribution parameter *r* = REG

dpgovr change in government consumption distribution parameter  $r = \text{REG}$

dpsaver change in saving distribution parameter  $r = \text{REG}$

## D.17 Slack Variables

profitslackjc slack variable in the ZEROPROFITS equation (this is exogenous as long as output level,  $QO(j)$ , is determined endogenously) |  $j = \text{PROD\_COMM}$ ;  $r = \text{REG}$

cgdslackr slack variable in the CAPGOODS equation (this is exogenous as long as output level of new capital goods,  $QO(\text{"cgds"})$ , is determined endogenously) |  $r = \text{REG}$

endwslackir slack variable in the MKTCLENDWM and ENDW\_SUPPLY equations (this is exogenous as long as primary factor rental rates,  $PM_i$  and  $PMES_{ij}$  are determined endogenously) |  $i = \text{ENDWS\_COMM}$ ;  $r = \text{REG}$

tradslackir slack variable in the MKTCLTRD equation (this is exogenous as long as market price of tradable,  $PM_i$ , is determined endogenously) |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

incomelackr slack variable in the INCOME equation (this is exogenous as long as income,  $Y$ , is determined endogenously) |  $r = \text{REG}$

psaveslackr slack variable in the SAVINGS equation (this is exogenous as long as level of savings,  $QSAVE$ , is determined endogenously) |  $r = \text{REG}$

walraslack slack variable in the WALRAS equation (this is endogenous as long as price of savings,  $PSAVE$ , is determined exogenously which is the case in a standard GE closure. When any one of the GE links is broken, this is swapped with  $PSAVE$ , the numeraire price, thereby forcing global savings to equal global investment).

incomelackr slack variable in the expression for regional income |  $r = \text{REG}$

## D.18 Value and Income Variables

vxwfobir percentage change in value of exports of tradable commodity  $i$  from source region  $r$  using fob weights (is identical to the linearized form of  $VXW_{ir}$ ) |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

vxwregr percentage change in value of merchandise exports from region  $r$  using fob weights (is identical to the linearized form of  $VXWREGr$ ) |  $r = \text{REG}$

vxwcomi percentage change in value of global merchandise exports of tradable commodity  $i$  using fob weights (is identical to the linearized form of  $VXWCOMMOD_i$ ) |  $i = \text{TRAD\_COMM}$

viwcifr percentage change in value of imports of tradable commodity  $i$  into region  $r$  using fob weights (is identical to the linearized form of  $VIW_{ir}$ ) |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

viwregr percentage change in value of merchandise imports into region  $r$  using cif weights (is identical to the linearized form of  $VIWREGION_{ir}$ ) |  $r = \text{REG}$

viwcomi percentage change in value of global merchandise imports of tradable commodity  $i$  using fob weights (is identical to the linearized form of  $VIWCOMMOD_i$ ) |  $i = \text{TRAD\_COMM}$

vxwwld percentage change in value of worldwide commodity exports using fob weights (is identical to the linearized form of VXWLD)

valuwui percentage change in value of global supply of tradable commodity i using fob weights (is identical to the linearized form of VWOWi) | i = TRAD\_COMM

valuwui value of world supply of good i at user prices | i = TRAD\_COMM

vgdpr percentage change in value of GDP in region r (is identical to the linearized form of GDP<sub>r</sub>) | r = REG

yr percentage change in regional household income (is identical to the linearized form of INCOME) | r = REG

ypr percentage change in private household expenditure (is identical to the linearized form of PRIVEXP). | r = REG

FY<sub>r</sub> primary factor income in r net of depreciation

FY<sub>r</sub> = SiVOM<sub>i</sub> - VDEP<sub>r</sub> | i = ENDW\_COMM; r = REG

fincomer pc change in factor income variable in r net of depreciation r = REG

## D.19 Utility Variables

U<sub>r</sub> per capita utility from aggregate household expenditure in region r r = REG

UP<sub>r</sub> per capita utility from private household expenditure in region r r = REG

UG<sub>r</sub> aggregate utility from government household expenditure in region r r = REG

UTILELAS<sub>r</sub> elasticity of cost of utility wrt utility

UTILELAS<sub>r</sub> = (UELASPRIV<sub>r</sub>\*XSHRPRIV<sub>r</sub> + XSHRGOV<sub>r</sub> + XSHRSAVER<sub>r</sub>)/DPARSUM<sub>r</sub> r = REG

uelasr pc change in elasticity of cost of utility wrt utility r = REG

ueprivr pc change in utility elasticity of private cons expenditure r = REG

uelasevr pc change in elasticity of cost of utility wrt utility, for EV calculation r = REG

ueprivevr pc change in utility elasticity of private cons expenditure, for EV calculation r = REG

## D.20 Welfare Variables

EVr equivalent variation, in \$ US million (positive figure indicates welfare improvement)  $r = \text{REG}$

WEV equivalent variation, in \$ US million, for the world (positive figure indicates welfare improvement)

ugevr per capita utility from gov't expend., for EV calculation  $r = \text{REG}$

upevr per capita utility from private expend., for EV calculation  $r = \text{REG}$

qsavevr total quantity of savings demanded, for EV calculation  $r = \text{REG}$

ypevr private consumption expenditure, in region  $r$ , for EV calculation  $r = \text{REG}$

ygevr government consumption expenditure, in region  $r$ , for EV calculation  $r = \text{REG}$

qpevir private household demand for commodity  $i$  in region  $r$ , for EV calculation  $i = \text{TRAD\_COMM}$ ,  $r = \text{REG}$

yevr regional household income, in region  $r$ , for EV calculation

ysavevr NET savings expenditure, for EV calculation

dpavevr average distribution parameter shift, for EV calculation  $r = \text{REG}$

## D.21 Trade Balance Variables

DTBALr change in trade balance of region  $r$ , in US\$ million (positive figure indicates increases in exports exceeds increases in imports) |  $r = \text{REG}$

DTBALiir change in trade balance for tradable commodity  $i$  in region  $r$ , in US\$ million (positive figure indicates increases in exports exceeds increases in imports) |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

## E Regions in v11:

Aggregate string: v11\_r160\_labels

| gtapv7_r160_id | gtapv7_r160_label | gtapv7_r160_name                 | gtapv7_r160_description          |
|----------------|-------------------|----------------------------------|----------------------------------|
| 1              | aus               | Australia                        | Australia                        |
| 2              | nzl               | New Zealand                      | New Zealand                      |
| 3              | xoc               | Rest of Oceania                  | Rest of Oceania                  |
| 4              | chn               | China                            | China                            |
| 5              | hkg               | China, Hong Kong SAR             | China, Hong Kong SAR             |
| 6              | jpn               | Japan                            | Japan                            |
| 7              | kor               | Republic of Korea                | Republic of Korea                |
| 8              | mng               | Mongolia                         | Mongolia                         |
| 9              | tw                | Taiwan Province of China         | Taiwan Province of China         |
| 10             | xea               | Rest of East Asia                | Rest of East Asia                |
| 11             | brn               | Brunei Darussalam                | Brunei Darussalam                |
| 12             | khm               | Cambodia                         | Cambodia                         |
| 13             | idn               | Indonesia                        | Indonesia                        |
| 14             | lao               | Lao People's Democratic Republic | Lao People's Democratic Republic |
| 15             | mys               | Malaysia                         | Malaysia                         |
| 16             | phl               | Philippines                      | Philippines                      |
| 17             | sgp               | Singapore                        | Singapore                        |
| 18             | tha               | Thailand                         | Thailand                         |
| 19             | vn                | Viet Nam                         | Viet Nam                         |
| 20             | xse               | Rest of Southeast Asia           | Rest of Southeast Asia           |
| 21             | afg               | Afghanistan                      | Afghanistan                      |
| 22             | bgd               | Bangladesh                       | Bangladesh                       |
| 23             | ind               | India                            | India                            |
| 24             | npl               | Nepal                            | Nepal                            |
| 25             | pak               | Pakistan                         | Pakistan                         |
| 26             | lka               | Sri Lanka                        | Sri Lanka                        |
| 27             | xsa               | Rest of South Asia               | Rest of South Asia               |
| 28             | can               | Canada                           | Canada                           |
| 29             | usa               | United States of America         | United States of America         |
| 30             | mex               | Mexico                           | Mexico                           |
| 31             | xna               | Rest of North America            | Rest of North America            |
| 32             | arg               | Argentina                        | Argentina                        |
| 33             | bol               | Bolivia (Plurinational State of) | Bolivia (Plurinational State of) |
| 34             | bra               | Brazil                           | Brazil                           |

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|    |     |                                       |                                       |
|----|-----|---------------------------------------|---------------------------------------|
| 35 | chl | Chile                                 | Chile                                 |
| 36 | col | Colombia                              | Colombia                              |
| 37 | ecu | Ecuador                               | Ecuador                               |
| 38 | pry | Paraguay                              | Paraguay                              |
| 39 | per | Peru                                  | Peru                                  |
| 40 | ury | Uruguay                               | Uruguay                               |
| 41 | ven | Venezuela (Bolivarian<br>Republic of) | Venezuela (Bolivarian<br>Republic of) |
| 42 | xsm | Rest of South America                 | Rest of South America                 |
| 43 | cri | Costa Rica                            | Costa Rica                            |
| 44 | gtm | Guatemala                             | Guatemala                             |
| 45 | hnd | Honduras                              | Honduras                              |
| 46 | nic | Nicaragua                             | Nicaragua                             |
| 47 | pan | Panama                                | Panama                                |
| 48 | slv | El Salvador                           | El Salvador                           |
| 49 | xca | Rest of Central America               | Rest of Central America               |
| 50 | dom | Dominican Republic                    | Dominican Republic                    |
| 51 | hti | Haiti                                 | Haiti                                 |
| 52 | jam | Jamaica                               | Jamaica                               |
| 53 | pri | Puerto Rico                           | Puerto Rico                           |
| 54 | tto | Trinidad and Tobago                   | Trinidad and Tobago                   |
| 55 | xcb | Caribbean                             | Caribbean                             |
| 56 | aut | Austria                               | Austria                               |
| 57 | bel | Belgium                               | Belgium                               |
| 58 | bgr | Bulgaria                              | Bulgaria                              |
| 59 | hrv | Croatia                               | Croatia                               |
| 60 | cyp | Cyprus                                | Cyprus                                |
| 61 | cze | Czechia                               | Czechia                               |
| 62 | dnk | Denmark                               | Denmark                               |
| 63 | est | Estonia                               | Estonia                               |
| 64 | fin | Finland                               | Finland                               |
| 65 | fra | France                                | France                                |
| 66 | deu | Germany                               | Germany                               |
| 67 | grc | Greece                                | Greece                                |
| 68 | hun | Hungary                               | Hungary                               |
| 69 | irl | Ireland                               | Ireland                               |
| 70 | ita | Italy                                 | Italy                                 |
| 71 | lva | Latvia                                | Latvia                                |
| 72 | ltu | Lithuania                             | Lithuania                             |
| 73 | lux | Luxembourg                            | Luxembourg                            |
| 74 | mlt | Malta                                 | Malta                                 |
| 75 | nld | Netherlands                           | Netherlands                           |
| 76 | pol | Poland                                | Poland                                |
| 77 | prt | Portugal                              | Portugal                              |
| 78 | rou | Romania                               | Romania                               |
| 79 | svk | Slovakia                              | Slovakia                              |
| 80 | svn | Slovenia                              | Slovenia                              |

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|     |     |                                                            |                                                            |
|-----|-----|------------------------------------------------------------|------------------------------------------------------------|
| 81  | esp | Spain                                                      | Spain                                                      |
| 82  | swe | Sweden                                                     | Sweden                                                     |
| 83  | gbr | United Kingdom of Great<br>Britain and Northern<br>Ireland | United Kingdom of Great<br>Britain and Northern<br>Ireland |
| 84  | che | Switzerland                                                | Switzerland                                                |
| 85  | nor | Norway                                                     | Norway                                                     |
| 86  | xef | Rest of EFTA                                               | Rest of EFTA                                               |
| 87  | alb | Albania                                                    | Albania                                                    |
| 88  | srb | Serbia                                                     | Serbia                                                     |
| 89  | blr | Belarus                                                    | Belarus                                                    |
| 90  | rus | Russian Federation                                         | Russian Federation                                         |
| 91  | ukr | Ukraine                                                    | Ukraine                                                    |
| 92  | xee | Rest of Eastern Europe                                     | Rest of Eastern Europe                                     |
| 93  | xer | Rest of Europe                                             | Rest of Europe                                             |
| 94  | kaz | Kazakhstan                                                 | Kazakhstan                                                 |
| 95  | kgz | Kyrgyzstan                                                 | Kyrgyzstan                                                 |
| 96  | tjk | Tajikistan                                                 | Tajikistan                                                 |
| 97  | uzb | Uzbekistan                                                 | Uzbekistan                                                 |
| 98  | xsu | Rest of Former Soviet<br>Union                             | Rest of Former Soviet<br>Union                             |
| 99  | arm | Armenia                                                    | Armenia                                                    |
| 100 | aze | Azerbaijan                                                 | Azerbaijan                                                 |
| 101 | geo | Georgia                                                    | Georgia                                                    |
| 102 | bhr | Bahrain                                                    | Bahrain                                                    |
| 103 | irn | Iran (Islamic Republic<br>of)                              | Iran (Islamic Republic<br>of)                              |
| 104 | irq | Iraq                                                       | Iraq                                                       |
| 105 | isr | Israel                                                     | Israel                                                     |
| 106 | jor | Jordan                                                     | Jordan                                                     |
| 107 | kwt | Kuwait                                                     | Kuwait                                                     |
| 108 | lbn | Lebanon                                                    | Lebanon                                                    |
| 109 | omn | Oman                                                       | Oman                                                       |
| 110 | pse | Palestine                                                  | Palestine                                                  |
| 111 | qat | Qatar                                                      | Qatar                                                      |
| 112 | sau | Saudi Arabia                                               | Saudi Arabia                                               |
| 113 | syr | Syrian Arab Republic                                       | Syrian Arab Republic                                       |
| 114 | tur | Turkey                                                     | Türkiye                                                    |
| 115 | are | United Arab Emirates                                       | United Arab Emirates                                       |
| 116 | xws | Rest of Western Asia                                       | Rest of Western Asia                                       |
| 117 | dza | Algeria                                                    | Algeria                                                    |
| 118 | egy | Egypt                                                      | Egypt                                                      |
| 119 | mar | Morocco                                                    | Morocco                                                    |
| 120 | tun | Tunisia                                                    | Tunisia                                                    |
| 121 | xnf | Rest of North Africa                                       | Rest of North Africa                                       |
| 122 | ben | Benin                                                      | Benin                                                      |
| 123 | bfa | Burkina Faso                                               | Burkina Faso                                               |

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|     |     |                                           |                                           |
|-----|-----|-------------------------------------------|-------------------------------------------|
| 124 | cmr | Cameroon                                  | Cameroon                                  |
| 125 | civ | Cote d'Ivoire                             | Côte d'Ivoire                             |
| 126 | gha | Ghana                                     | Ghana                                     |
| 127 | gin | Guinea                                    | Guinea                                    |
| 128 | mli | Mali                                      | Mali                                      |
| 129 | ner | Niger                                     | Niger                                     |
| 130 | nga | Nigeria                                   | Nigeria                                   |
| 131 | sen | Senegal                                   | Senegal                                   |
| 132 | tgo | Togo                                      | Togo                                      |
| 133 | xwf | Rest of Western Africa                    | Rest of Western Africa                    |
| 134 | caf | Central African Republic                  | Central African Republic                  |
| 135 | tcd | Chad                                      | Chad                                      |
| 136 | cog | Congo                                     | Congo                                     |
| 137 | cod | Democratic Republic of<br>the Congo       | Democratic Republic of<br>the Congo       |
| 138 | gnq | Equatorial Guinea                         | Equatorial Guinea                         |
| 139 | gab | Gabon                                     | Gabon                                     |
| 140 | xac | South-Central Africa                      | South-Central Africa                      |
| 141 | com | Comoros                                   | Comoros                                   |
| 142 | eth | Ethiopia                                  | Ethiopia                                  |
| 143 | ken | Kenya                                     | Kenya                                     |
| 144 | mdg | Madagascar                                | Madagascar                                |
| 145 | mwi | Malawi                                    | Malawi                                    |
| 146 | mus | Mauritius                                 | Mauritius                                 |
| 147 | moz | Mozambique                                | Mozambique                                |
| 148 | rwa | Rwanda                                    | Rwanda                                    |
| 149 | sdn | Sudan                                     | Sudan                                     |
| 150 | tza | United Republic of<br>Tanzania            | United Republic of<br>Tanzania            |
| 151 | uga | Uganda                                    | Uganda                                    |
| 152 | zmb | Zambia                                    | Zambia                                    |
| 153 | zwe | Zimbabwe                                  | Zimbabwe                                  |
| 154 | xec | Rest of Eastern Africa                    | Rest of Eastern Africa                    |
| 155 | bwa | Botswana                                  | Botswana                                  |
| 156 | swz | Eswatini                                  | Eswatini                                  |
| 157 | nam | Namibia                                   | Namibia                                   |
| 158 | zaf | South Africa                              | South Africa                              |
| 159 | xsc | Rest of Southern African<br>Customs Union | Rest of Southern African<br>Customs Union |
| 160 | xtw | Rest of the World                         | Rest of the World                         |

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## F Sectors in v11

### Description (Detailed Sector Breakdown)

| id | label | Name                                         | Description                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|----|-------|----------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1  | pdr   | Paddy rice                                   | Rice: seed, paddy (not husked)                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 2  | wht   | Wheat                                        | Wheat: seed, other                                                                                                                                                                                                                                                                                                                                                                                                                               |
| 3  | gro   | Cereal grains<br>nec                         | Other Grains: maize (corn), sorghum, barley, rye, oats, millets, other cereals                                                                                                                                                                                                                                                                                                                                                                   |
| 4  | v_f   | Vegetables,<br>fruit, nuts                   | Veg & Fruit: vegetables, fruit and nuts, edible roots and tubers, pulses                                                                                                                                                                                                                                                                                                                                                                         |
| 5  | osd   | Oil seeds                                    | Oil Seeds: oil seeds and oleaginous fruit                                                                                                                                                                                                                                                                                                                                                                                                        |
| 6  | c_b   | Sugar cane,<br>sugar beet                    | Cane & Beet: sugar crops                                                                                                                                                                                                                                                                                                                                                                                                                         |
| 7  | pfb   | Plant-based<br>fibers                        | Fibres crops                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| 8  | ocr   | Crops nec                                    | Other Crops: stimulant; spice and aromatic crops; forage products; plants and parts of plants used primarily in perfumery, pharmacy, or for insecticidal, fungicidal or similar purposes; beet seeds (excluding sugar beet seeds) and seeds of forage plants; natural rubber in primary forms or in plates, sheets or strip, living plants; cut flowers and flower buds; flower seeds, unmanufactured tobacco; other raw vegetable materials nec |
| 9  | ctl   | Bovine cattle,<br>sheep and<br>goats, horses | Cattle: bovine animals, live, other ruminants, horses and other equines, bovine semen                                                                                                                                                                                                                                                                                                                                                            |
| 10 | oap   | Animal<br>products nec                       | Other Animal Products: swine; poultry; other live animals; eggs of hens or other birds in shell, fresh; reproductive materials of animals; natural honey; snails, fresh, chilled, frozen, dried, salted or in brine, except sea snails; edible products of animal origin n.e.c.; hides, skins and furskins, raw; insect waxes and spermaceti, whether or not refined or coloured                                                                 |
| 11 | rmk   | Raw milk                                     | Raw milk                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| 12 | wol   | Wool,<br>silk-worm<br>cocoons                | Wool: wool, silk, and other raw animal materials used in textile                                                                                                                                                                                                                                                                                                                                                                                 |

| id | label | Name                                         | Description                                                                                                                                                                                                                                                                                                                                                                                |
|----|-------|----------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 13 | frs   | Forestry                                     | Forestry: forestry, logging and related service activities                                                                                                                                                                                                                                                                                                                                 |
| 14 | fsh   | Fishing                                      | Fishing: hunting, trapping and game propagation including related service activities, fishing, fish farms; service activities incidental to fishing                                                                                                                                                                                                                                        |
| 15 | coa   | Coal                                         | Coal: mining and agglomeration of hard coal, lignite and peat                                                                                                                                                                                                                                                                                                                              |
| 16 | oil   | Oil                                          | Oil: extraction of crude petroleum, service activities incidental to oil and gas extraction excluding surveying (part)                                                                                                                                                                                                                                                                     |
| 17 | gas   | Gas                                          | Gas: extraction of natural gas, service activities incidental to oil and gas extraction excluding surveying (part)                                                                                                                                                                                                                                                                         |
| 18 | oxt   | Other Extraction (formerly omn Minerals nec) | Other Mining Extraction (formerly omn): mining of metal ores; other mining and quarrying                                                                                                                                                                                                                                                                                                   |
| 19 | cmt   | Bovine meat products                         | Cattle Meat: fresh or chilled; meat of buffalo, fresh or chilled; meat of sheep, fresh or chilled; meat of goat, fresh or chilled; meat of camels and camelids, fresh or chilled; meat of horses and other equines, fresh or chilled; other meat of mammals, fresh or chilled; meat of mammals, frozen; edible offal of mammals, fresh, chilled or frozen                                  |
| 20 | omt   | Meat products nec                            | Other Meat: meat of pigs, fresh or chilled; meat of rabbits and hares, fresh or chilled; meat of poultry, fresh or chilled; meat of poultry, frozen; edible offal of poultry, fresh, chilled or frozen; other meat and edible offal, fresh, chilled or frozen; preserves and preparations of meat, meat offal or blood; flours, meals and pellets of meat or meat offal, inedible; greaves |
| 21 | vol   | Vegetable oils and fats                      | Vegetable Oils: margarine and similar preparations; cotton linters; oil-cake and other residues resulting from the extraction of vegetable fats or oils; flours and meals of oil seeds or oleaginous fruits, except those of mustard; vegetable waxes, except triglycerides; degreas; residues resulting from the treatment of fatty substances or animal or vegetable waxes; animal fats  |
| 22 | mil   | Dairy products                               | Milk: dairy products                                                                                                                                                                                                                                                                                                                                                                       |

| id | label | Name                           | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|----|-------|--------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 23 | pcr   | Processed rice                 | Processed Rice: semi- or wholly milled, or husked                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 24 | sgr   | Sugar                          | Sugar and molasses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 25 | ofd   | Food products<br>nec           | Other Food: prepared and preserved fish, crustaceans, molluscs and other aquatic invertebrates; prepared and preserved vegetables, pulses and potatoes; prepared and preserved fruits and nuts; wheat and meslin flour; other cereal flours; groats, meal and pellets of wheat and other cereals; other cereal grain products (including corn flakes); other vegetable flours and meals; mixes and doughs for the preparation of bakers' wares; starches and starch products; sugars and sugar syrups n.e.c.; preparations used in animal feeding; lucerne (alfalfa) meal and pellets; bakery products; cocoa, chocolate and sugar confectionery; macaroni, noodles, couscous and similar farinaceous products; food products n.e.c. |
| 26 | b_t   | Beverages and tobacco products | Beverages and Tobacco products                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 27 | tex   | Textiles                       | Manufacture of textiles                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 28 | wap   | Wearing apparel                | Manufacture of wearing apparel                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 29 | lea   | Leather products               | Manufacture of leather and related products                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 30 | lum   | Wood products                  | Lumber: manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 31 | ppp   | Paper products, publishing     | Paper & Paper Products: includes printing and reproduction of recorded media                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| 32 | p_c   | Petroleum, coal products       | Petroleum & Coke: manufacture of coke and refined petroleum products                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 33 | chm   | Chemical products              | Manufacture of chemicals and chemical products                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 34 | bph   | Basic pharmaceutical products  | Manufacture of pharmaceuticals, medicinal chemical and botanical products                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 35 | rpp   | Rubber and plastic products    | Manufacture of rubber and plastics products                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |

| id | label | Name                                       | Description                                                                                   |
|----|-------|--------------------------------------------|-----------------------------------------------------------------------------------------------|
| 36 | nmm   | Mineral products nec                       | Manufacture of other non-metallic mineral products                                            |
| 37 | i_s   | Ferrous metals                             | Iron & Steel: basic production and casting                                                    |
| 38 | nfm   | Metals nec                                 | Non-Ferrous Metals: production and casting of copper, aluminium, zinc, lead, gold, and silver |
| 39 | fmp   | Metal products                             | Manufacture of fabricated metal products, except machinery and equipment                      |
| 40 | ele   | Computer, electronic and optical products  | Manufacture of computer, electronic and optical products                                      |
| 41 | eeq   | Electrical equipment                       | Manufacture of electrical equipment                                                           |
| 42 | ome   | Machinery and equipment nec                | Manufacture of machinery and equipment n.e.c.                                                 |
| 43 | mvh   | Motor vehicles and parts                   | Manufacture of motor vehicles, trailers and semi-trailers                                     |
| 44 | otn   | Transport equipment nec                    | Manufacture of other transport equipment                                                      |
| 45 | omf   | Manufactures nec                           | Other Manufacturing: includes furniture                                                       |
| 46 | ely   | Electricity                                | Electricity; steam and air conditioning supply                                                |
| 47 | gdt   | Gas manufacture, distribution              | Gas manufacture, distribution                                                                 |
| 48 | wtr   | Water                                      | Water supply; sewerage, waste management and remediation activities                           |
| 49 | cns   | Construction                               | Construction: building houses factories offices and roads                                     |
| 50 | trd   | Trade                                      | Wholesale and retail trade; repair of motor vehicles and motorcycles                          |
| 51 | afs   | Accommodation, Food and service activities | Accommodation, Food and service activities                                                    |
| 52 | otp   | Transport nec                              | Land transport and transport via pipelines                                                    |
| 53 | wtp   | Water transport                            | Water transport                                                                               |
| 54 | atp   | Air transport                              | Air transport                                                                                 |
| 55 | whs   | Warehousing and support activities         | Warehousing and support activities                                                            |
| 56 | cmn   | Communication                              | Information and communication                                                                 |

| id | label | Name                                    | Description                                                                                                                                                                           |
|----|-------|-----------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 57 | ofi   | Financial services nec                  | Other Financial Intermediation: includes auxiliary activities but not insurance and pension funding                                                                                   |
| 58 | ins   | Insurance (formerly isr)                | Insurance (formerly isr): includes pension funding, except compulsory social security                                                                                                 |
| 59 | rsa   | Real estate activities                  | Real estate activities                                                                                                                                                                |
| 60 | obs   | Business services nec                   | Other Business Services nec                                                                                                                                                           |
| 61 | ros   | Recreational and other services         | Recreation & Other Services: recreational, cultural and sporting activities, other service activities; private households with employed persons (servants)                            |
| 62 | osg   | Public Administration and defense       | Other Services (Government): public administration and defense; compulsory social security, activities of membership organizations n.e.c., extra-territorial organizations and bodies |
| 63 | edu   | Education                               | Education                                                                                                                                                                             |
| 64 | hht   | Human health and social work activities | Human health and social work                                                                                                                                                          |
| 65 | dwe   | Dwellings                               | Dwellings: ownership of dwellings (imputed rents of houses occupied by owners)                                                                                                        |

# G Variables in v11

Extracted from <https://www.gtap.agecon.purdue.edu/models/setsVariables.asp>

## G.1 Sets

| Variable Label | Variable Name                           |
|----------------|-----------------------------------------|
| NSAV_COMM      | Non-Savings Commodities (NS)            |
| TRAD_COMM      | Traded Commodities (TC)                 |
| DEMD_COMM      | Demanded Commodities (DC)               |
| PROD_COMM      | Produced Commodities (PC)               |
| ENDW_COMM      | Endowment Commodities (EC)              |
| ENDWS_COMM     | Sluggish Endowment Commodities (ECS)    |
| ENDWM_COMM     | Mobile Endowment Commodities (ECM)      |
| CGDS_COMM      | Capital Goods Commodities (“cgds”)      |
| ENDWC_COMM     | Capital Endowment Commodity (“capital”) |

## G.2 Subsets

| Variable Label | Variable Name |
|----------------|---------------|
| PROD_COMM      | in NSAV_COMM  |
| DEMD_COMM      | in NSAV_COMM  |
| CGDS_COMM      | in NSAV_COMM  |
| ENDW_COMM      | in DEMD_COMM  |
| TRAD_COMM      | in DEMD_COMM  |
| TRAD_COMM      | in PROD_COMM  |
| CGDS_COMM      | in PROD_COMM  |
| ENDWS_COMM     | in ENDW_COMM  |
| ENDWM_COMM     | in ENDW_COMM  |
| ENDWC_COMM     | in NSAV_COMM  |
| ENDWC_COMM     | in ENDW_COMM  |

## G.3 Example: The 3x3 (3 regions x 3 sectors) economy

| Variable Label | Variable Name                                                          |
|----------------|------------------------------------------------------------------------|
| REG            | = {usa, eu, row}                                                       |
| NSAV_COMM      | = {land, labor, capital, food, manufacturing, services, capital goods} |
| TRAD_COMM      | = {food, manufacturing, services}                                      |
| DEMD_COMM      | = {land, labor, capital, food, manufacturing, services}                |
| PROD_COMM      | = {food, manufacturing, services, capital goods}                       |
| ENDW_COMM      | = {land, labor, capital}                                               |
| ENDWS_COMM     | = {land, capital}                                                      |
| ENDWM_COMM     | = {labor}                                                              |
| CGDS_COMM      | = {capital goods}                                                      |
| ENDWC_COMM     | = {capital}                                                            |

## G.4 Value flows evaluated at agents' Prices

EVOA<sub>i,r</sub> value of endowment commodity *i* output or supplied, in region *r*, evaluated at agent's prices

- $EVOA_{i,r} = P_{Si,r} * Q_{Oi,r}$  with  $i = ENDW\_COMM$  and  $r$

EVFA<sub>i,j,r</sub> value of purchases of demanded commodity *i* by firms in sector *j*, in region *r*, evaluated at agent's prices

- $EVFA_{i,j,r} = P_{FEi,j,r} * Q_{FEi,j,r}$        $i = TRAD\_COMM; j = ENDW\_COMM; r = REG$

VDFA<sub>i,j,r</sub> value of purchases of domestic tradeable commodity *i* by firms in sector *j* of region *r* evaluated at agents' prices

- $VDFA_{i,j,r} = P_{FDi,j,r} * Q_{FDi,j,r}$        $i = TRAD\_COMM; j = ENDW\_COMM; r = REG$

VIFA<sub>i,j,r</sub> value of purchases of imported tradeable commodity *i* by firms in sector *j* of region *r* evaluated at agents' prices

- $VIFA_{i,j,r} = P_{FMi,j,r} * Q_{FMi,j,r}$        $i = TRAD\_COMM; j = ENDW\_COMM; r = REG$

VDPA<sub>i,r</sub> value of expenditure on domestic tradable commodity *i*, by private household in region *r* evaluated at agent's prices

- $VDPA_{i,r} = P_{PDi,r} * Q_{PDi,r}$        $i = TRAD\_COMM; r = REG$

VIPA<sub>i,r</sub> value of expenditure on imported tradeable commodity *i* by firms in sector *j* of region *r* evaluated at agents' prices

- $VIPA_{i,r} = P_{PMi,r} * Q_{PMi,r}$        $i = TRAD\_COMM; r = REG$

VDGA<sub>i</sub> value of government's expenditure on domestic tradable commodity *i*, in region *r*, evaluated at agent's prices

- $VDGAir = PGDir * QGDir \quad i = \text{TRAD\_COMM}; r = \text{REG}$

VIGAi value of government's expenditure on imported tradable commodity i, in region r, evaluated at agent's prices

- $VIGAir = PGMir * QGMir \quad i = \text{TRAD\_COMM}; r = \text{REG}$

SAVER value of (net) savings in region r

- $SAVER = PSAVER * QSAVER \quad r = \text{REG}$

VKBr value of beginning-of-period capital stock in region r

- $VKBr = PCGDSr * KBr \quad r = \text{REG}$

VDEPr value of capital depreciation expenditure in region r

- $VDEPr = PCGDSr * KBr \quad r = \text{REG}$

## G.5 Value flows evaluated at market prices

VFMIjr value of purchases of endowment commodity i by firms in sector j in region r, evaluated at market prices

- $VFMIjr = PMir * QFEijr \quad i = \text{ENDWM\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$
- $VFMIjr = PMESijr * QFEijr \quad i = \text{ENDWS\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$

VDFMIjr value of purchases of domestic tradable commodity i by firms in sector j in region r, evaluated at market prices

- $VDFMIjr = PMir * QFDijr \quad i = \text{TRAD\_COMM}; j = \text{PROD\_COMM}$

VIFMIjr value of purchases of imported tradable commodity i by firms in sector j in region r, evaluated at market prices

- $VIFMIjr = PIMir * QFMijr \quad i = \text{TRAD\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$

VDPMir value of private household's purchases of domestic tradable commodity i in region r, evaluated at market prices

- $VDPMir = PMir * QPDir \quad i = \text{TRAD\_COMM}; r = \text{REG}$

VIPMir value of private household's purchases of imported tradable commodity i in region r, evaluated at market prices

- $VIPMir = PIMir * QPMir \quad i = \text{TRAD\_COMM}; r = \text{REG}$

VDGMir value of government's expenditure on domestic tradable commodity i, in region r, evaluated at market prices

- $VDGMir = PMir * QGDir \quad i = \text{TRAD\_COMM}; r = \text{REG}$

VIGMir value of government's expenditure on imported tradable commodity i, in region r, evaluated at market prices

- $VIGMir = PIMir * QGMir \quad i = TRAD\_COMM; r = REG$

VXMDirs value of exports of tradable commodity i from source r to destination s, evaluated at (exporter's) market prices

- $VXMDirs = PMir * QXSirs \quad i = TRAD\_COMM; r = REG; s = REG$

VIMSirs value of imports of tradable commodity i from source r to destination s, evaluated at (importer's) market prices

- $VIMSirs = PMSir * QXSirs \quad i = TRAD\_COMM; r = REG; s = REG$

VSTir value of sales of tradable commodity i to the international transport sector in region r, evaluated at market prices

- $VSTir = PMir * QSTir \quad i = MARG\_COMM; r = REG$

## G.6 Value flows evaluated at world prices

VXWDirs value of exports of tradable commodity i from source r to destination s, evaluated at world (fob) prices

- $VXWDirs = PFOBirs * QXSirs \quad i = TRAD\_COMM; r = REG; s = REG$

VIWSirs value of imports of tradable commodity i from source r to destination s, evaluated at world (cif) prices

- $VIWSirs = PCIFirs * QXSirs \quad i = TRAD\_COMM; r = REG; s = REG$

## G.7 Technology Parameters

ESUBVAj with j = PROD\_COMM substitution parameter between primary factors in the CES value-added nest of the nested CES production function of sector j of all regions (i.e. elasticity of substitution between primary production factors; for example, in a situation where land doesn't play a role in production, hence labor and capital are the only primary factors, this parameter indicates how sensitive is the K/L ratio to a 1 percent change in the wage/rental ratio)

ESUBDi with i = TRAD\_COMM substitution parameter between domestic and composite imported commodities in the Armington utility/production structure of agent/sector i in all regions

ESUBMi with i = TRAD\_COMM substitution parameter among imported commodities from different sources in the Armington utility/production structure of agent/sector i in all regions.

## G.8 CDE Preference Parameters and Associated Elasticities

SUBPAR<sub>ir</sub> with  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$  substitution parameter for tradable commodity  $i$  in the CDE minimum expenditure function of region  $r$

INCPAR<sub>ir</sub> with  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$  expansion parameter for tradable commodity  $i$  in the CDE minimum expenditure function of region  $r$ .

ALPHA<sub>ir</sub> 1 - sub. parameter in the CDE minimum expenditure function

- $\text{ALPHA}_{ir} = 1 - \text{SUBPAR}_{ir}$   $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

APE<sub>ikr</sub> Allen partial elast.of sub between composite  $i$  and  $k$  in  $r$

- $\text{APE}_{ikr} = \text{ALPHA}_{ir} + \text{ALPHA}_{kr} - \text{SnCONSHR}_{nr} * \text{ALPHA}_{nr}$   $i = k = n = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

$\text{APE}_{iir} = 2.0 * \text{ALPHA}_{ir} - \text{SnCONSHR}_{nr} * \text{ALPHA}_{nr} - \text{ALPHA}_{ir} / \text{CONSHR}_{ir}$

EY<sub>ir</sub> income elasticity of private household demand for  $i$  in  $r$

- $\text{EY}_{ir} = (1 / \text{SnCONSHR}_{nr} * \text{INCPAR}_{nr}) * (\text{INCPAR}_{ir} * (1.0 - \text{ALPHA}_{ir}) + \text{SnCONSHR}_{nr} * \text{INCPAR}_{nr} * \text{ALPHA}_{nr}) + (\text{ALPHA}_{ir} - \text{SnCONSHR}_{nr} * \text{ALPHA}_{nr})$   $i = n = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

EP<sub>ikr</sub> uncompensated cross-price elasticity private household demand for  $i$  wrt  $k$  in  $r$

- $\text{EP}_{ikr} = (\text{APE}_{ikr} - \text{EY}_{ir}) * \text{CONSHR}_{kr}$   $i = k = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

## G.9 Mobility Parameter

ETRAE<sub>i</sub> with  $i = \text{ENDW\_COMM}$  transformation parameter between uses for a sluggish primary factor  $i$  in the one level CET production function (i.e. this parameter indicates how easy/difficult it is to transfer a sluggish factor (say, capital) from one sector to another; the closer is ETRAE to zero, the more immobile is the factor between alternative uses)

RORFLEX<sub>r</sub> with  $r = \text{REG}$  flexibility of expected net rate of return on capital stock in region  $r$  with respect to investment (if a region's capital stock increases by 1%, then it is expected that the net rate of return on capital will decline by RORFLEX%)

RORDELTA binary coefficient that determines the mechanism of allocating investment across regions (when RORDELTA=1, investment is allocated across regions to equate the change in the expected rates of return,  $\text{rore}(r)$ , when RORDELTA=0, investment is allocated across regions to maintain the existing composition of capital stocks).

## G.10 Value Flows

VOAir value of non-saving commodity i output or supplied in region r evaluated at agents' prices

- $VOAir = EVOAir \quad i = ENDW\_COMM; r = REG$
- $VOAir = S_j VFA_{jir} \quad i = PROD\_COMM; j = DEMD\_COMM; r = REG$

VFAijr value of purchases of demanded commodity i by firms in sector j of region r evaluated at agents' prices

- $VFA_{ijr} = EVFA_{ijr} \quad i = ENDW\_COMM; j = PROD\_COMM; r = REG$
- $VFA_{ijr} = VDFAI_{ijr} + VIFA_{ijr} \quad i = TRAD\_COMM; j = PROD\_COMM; r = REG$

VOMir value of non-saving commodity i output or supplied in region r evaluated at market prices

- $VOMir = S_j VFM_{ijr} \quad i = ENDW\_COMM; j = PROD\_COMM; r = REG$
- $VOMir = VDMir + VSTir + S_s VXM_{Dir} \quad i = MARG\_COMM; r = REG; s = REG$
- $VOMir = VDMir + S_s VXM_{Dir} \quad i = NMRG\_COMM; r = REG; s = REG$
- $VOMir = VOAir \quad i = CGDS\_COMM; r = REG$

VDMir value of domestic sales of tradable commodity i in region r evaluated at market prices

- $VDMir = VDPMir + VDMir + S_j VDFM_{ijr} \quad i = TRAD\_COMM; j = PROD\_COMM; r = REG$

VIMir value of aggregate imports of tradable commodity i in region r evaluated at market prices

- $VIMir = VIPMir + VIGMir + S_j VIFM_{ijr} \quad i = TRAD\_COMM; j = PROD\_COMM; r = REG$

VPAir value of private household expenditure on tradable commodity i in region r evaluated at agents' prices

- $VPAir = VDPAir + VIPAir \quad i = TRAD\_COMM; r = REG$

PRIVEXPr total consumption expenditure by private household in region r

- $PRIVEXPr = S_i VPAir \quad i = TRAD\_COMM$

VGAir value of government expenditure on tradable commodity i in region r evaluated at agents' prices

- $VGAir = VDMAir + VIGAir \quad i = TRAD\_COMM; r = REG$

GOVEXPr total consumption expenditure by government in region r

- $GOVEXPr = S_i VGAir \quad i = TRAD\_COMM; r = REG$

INCOMEr total expenditure equals net income in region r

- $INCOMER = PRIVEXPr + GOVEXPr + SAVER \quad r = REG$

REGINVR gross investment in region r that equals value of output of “capital goods” sector

- $REGINVR = SkVOAkr \quad k = CGDS\_COMM$

NETINVR net investment in region r

- $NETINVR = SkVOAkr - VDEPr \quad k = CGDS\_COMM$

GLOBINV global net investment

- $GLOBINV = SrNETINV = SrSAVER \quad r = REG$

INVKERATIOr ratio of gross investment to end-of-period capital stock in region r

- $INVKERATIOr = REGINVR / (VKBr + NETINVR) \quad r = REG$

GRNETRATIOr ratio of gross to net rate of return on capital in region r (VOAcapital,r is gross return to capital)

- $GRNETRATIOr = SkVOAkr / (SkVOAkr - VDEPr) \quad \text{with } k = ENDWC\_COMM; r = REG$

GDPr gross domestic product in region r (trade is valued at world prices)

- $GDP_r = SiVPAir + SiVGAir + SkVOAkr + SiSsVXWDirs + SmVSTms - SiSsVIWSirs \quad i = TRAD\_COMM; k = CGDS\_COMM; r = REG; s = REG$

VT international margin supply

- $VT = SiSrVSTir \quad i = TRAD\_COMM; r = REG$

VXWir value of exports of tradable commodity i from source r evaluated at world (fob) prices

- $VXWir = SsVXWDirs + VSTir \quad i = MARG\_COMM; r = REG$
- $VXWir = SsVXWDirs \quad i = NMRG\_COMM; r = REG$

VXWREGIONr value of exports from source r evaluated at world (fob) prices

- $VXWREGIONr = SiVXWir \quad i = TRAD\_COMM; r = REG$

VXWCOMMODi value of exports of tradable commodity i evaluated at world (fob) prices

- $VXWCOMMODi = SrVXWir \quad i = TRAD\_COMM; r = REG$

VIW<sub>ir</sub> value of imports of tradable commodity i into region r evaluated at world (cif) prices

$$VIW_{ir} = S_s VIW_{Sis} \quad i = \text{TRAD\_COMM}; r = \text{REG}; s = \text{REG}$$

VIWREGION<sub>r</sub> value of imports into region r evaluated at world (cif) prices

$$VIWREGION_r = S_i VIW_{ir} \quad i = \text{TRAD\_COMM}; r = \text{REG}$$

VIWCOMMOD<sub>i</sub> value of imports of tradable commodity i evaluated at world (cif) prices

$$VIWCOMMOD_i = S_r VIW_{ir} \quad i = \text{TRAD\_COMM}; r = \text{REG}$$

VXWLD value of worldwide commodity exports evaluated at world (fob) prices

$$VXWLD = S_r VXWREGION_r \quad r = \text{REG}$$

PW\_PMir ratio of world (fob) to domestic market prices for tradable commodity i in region

$$PW\_PMir = S_s VXWD_{irs} / S_s VXMD_{irs} \quad i = \text{TRAD\_COMM}; r = \text{REG}; s = \text{REG}$$

VOW<sub>ir</sub> value of output of tradable commodity i in region r, evaluated at world (fob) prices

$$VOW_{ir} = VDM_{ir} * PW\_PMir + S_s VXWD_{irs} + VST_{ir} \quad i = \text{MARG\_COMM}; r = \text{REG}; s = \text{REG}$$

$$VOW_{ir} = VDM_{ir} * PW\_PMir + S_s VXWD_{irs} \quad i = \text{NMRG\_COMM}; r = \text{REG}; s = \text{REG}$$

VWOW<sub>i</sub> value of world supply of tradable commodity i evaluated at world (fob) prices

$$VWOW_i = S_r VOW_{ir} \quad i = \text{TRAD\_COMM}; r = \text{REG}$$

VTMFSD<sub>mirs</sub> int'l margin usage, by margin, freight, source, and destination m = MARG\_COMM; i = TRAD\_COMM; r = REG; s = REG

VTFSDDirs aggregate value of svces in the shipment of i from r to s

$$VTFSDDirs = S_m VTMFSD_{mirs} \quad \text{In a balanced data base } VIW_{Sirs} = VXWD_{irs} + VTFSDDirs \quad i = \text{TRAD\_COMM}; m = \text{MARG\_COMM}; r = \text{REG}; s = \text{REG}$$

VTMPROV<sub>m</sub> international margin services provision

$$VTMPROV_m = S_r VST_{mr} \quad m = \text{MARG\_COMM}; r = \text{REG}$$

VTRPROV<sub>r</sub> international margin supply, by region

$$VTRPROV_r = S_m VST_{mr} \quad m = \text{MARG\_COMM}; r = \text{REG}$$

VTMUSE<sub>m</sub> international margin services usage, by type

$$VTMUSE_m = S_i S_r S_s VTMFSD_{mirs} \quad m = \text{MARG\_COMM}; i = \text{TRAD\_COMM}; r = s = \text{REG} \quad \text{In a balanced data base, } VTMPROV = VTMUSE$$

VTMUSESHR<sub>mirs</sub> share of i,r,s usage in global demand for m

$$VTMUSESHR_{mirs} = VTFSDDirs / VT \quad m = \text{MARG\_COMM}; i = \text{TRAD\_COMM}; r = s = \text{REG} \quad \text{if } VTMUSE_m <> 0.0 \text{ then } VTMUSESHR_{mirs} = VTMFSD_{mirs} / VTMUSE_m$$

VTSUPPSHR<sub>mr</sub> share of region r in global supply of margin m

$$VTSUPPSHR_{mr} = VTRPROV_r / VT \quad \text{if } VTMPROV_m <> 0.0 \text{ then } VTSUPPSHR_{mr} = VST_{mr} / VTMPROV_m \quad m = \text{MARG\_COMM}; r = \text{REG}$$

VTUSE international margin services usage;

$VTUSE = S_m S_i S_r S_s V_{TMFS} D_{mir}$   $m = MARG\_COMM; i = TRAD\_COMM; r = s = REG$

VWOU<sub>i</sub> value of world output of *i* at user prices

$VWOU_i = S_s [(VPA_{is} + VGA_{is}) + S_j VFA_{ijs}]$   $s = REG; j = PROD\_COMM$

VENDWREG<sub>r</sub> value of primary factors, at mkt prices, by region

$VENDWREG_r = S_i VOM_{ir}$   $i = ENDOW\_COMM; r = REG$

VENDWWLD value of primary factors, at mkt prices, worldwide

$VENDWWLD = S_r VENDWREG_r$   $r = REG$

VPAE<sub>Vir</sub> private household expend. on *i* in *r* valued at agent's prices, for EV calculation

$VPAE_{Vir} = q_{pevir}$   $i = TRAD\_COMM, r = REG$

VPAREGE<sub>Vir</sub> private consumption expenditure in region *r*, for EV calculation

$VPAREGE_{Vir} = S_i VPAE_{Vir}$   $i = TRAD\_COMM, r = REG$  YGr regional government consumption expenditure, in region *r*  $r = REG$

## G.11 Shares

SHRDFM<sub>ijr</sub> share of domestic sales of tradable commodity *i* used by firms in sector *j* of region *r* evaluated at market prices

$SHRDFM_{ijr} = VDFM_{ijr} / VDM_{ir}$   $i = TRAD\_COMM; j = PROD\_COMM; r = REG$

SHRDPM<sub>i</sub> share of domestic sales of commodity *i* used by private household in region *r* evaluated at market prices

$SHRDPM_{ir} = VDP_{mir} / VDM_{ir}$   $i = TRAD\_COMM; r = REG$

SHRDGM<sub>i</sub> share of domestic sales of commodity *i* used by the government in region *r* evaluated at market prices

$SHRDGM_{ir} = VDG_{mir} / VDM_{ir}$   $i = TRAD\_COMM; r = REG$

SHRIFM<sub>ijr</sub> share of aggregate imports of tradable commodity *i* used by firms in sector *j* of region *r* evaluated at market prices

$SHRIFM_{ijr} = VIFM_{ijr} / VIM_{ir}$   $i = TRAD\_COMM; j = PROD\_COMM; r = REG$

SHRIPM<sub>i</sub> share of aggregate imports of commodity *i* used by private household in region *r* evaluated at market prices

$SHRIPM_{ir} = VIP_{mir} / VIM_{ir}$   $i = TRAD\_COMM; r = REG$

SHRIGM<sub>i</sub> share of aggregate imports of commodity *i* used by the government in region *r* evaluated at market prices

$SHRIGM_{ir} = VIG_{mir} / VIM_{ir}$   $i = TRAD\_COMM; r = REG$

FMSHR<sub>ijr</sub> share of imports in the composite for tradable commodity i used by firms in sector j of region r evaluated at agents' prices

$$\text{FMSHR}_{ijr} = \text{VIFA}_{ijr} / \text{VFA}_{ijr} \quad i = \text{TRAD\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$$

PMSHR<sub>ir</sub> share of imports in the composite for tradable commodity i used by private household in region r evaluated at agents' prices

$$\text{PMSHR}_{ir} = \text{VIPA}_{ir} / \text{VPA}_{ir} \quad i = \text{TRAD\_COMM}; r = \text{REG}$$

GMSHR<sub>ir</sub> share of imports in the composite for tradable commodity i used by the government in region r evaluated at agents' prices

$$\text{GMSHR}_{ir} = \text{VIGA}_{ir} / \text{VGA}_{ir} \quad i = \text{TRAD\_COMM}; r = \text{REG}$$

CONSHR<sub>ir</sub> budget share of the composite for tradable i in total private household expenditure in region r evaluated at agents' prices

$$\text{CONSHR}_{ir} = \text{VPA}_{ir} / \text{PRIVEXP}_r \quad i = \text{TRAD\_COMM}; r = \text{REG}$$

MSHRS<sub>irs</sub> market share of source r in the aggregate imports of tradable commodity i in region s evaluated at market prices

$$\text{MSHRS}_{irs} = \text{VIMS}_{irs} / \text{SrVIMS}_{irs} \quad i = \text{TRAD\_COMM}; r = s = \text{REG}$$

SVA<sub>ijr</sub> share of endowment commodity i in value-added of sector j of region r evaluated at agents' prices

$$\text{SVA}_{ijr} = \text{VFA}_{ijr} / \text{SkVFA}_{kjr} \quad i = \text{ENDW\_COMM}; j = \text{PROD\_COMM}; k = \text{ENDW\_COMM}; r = \text{REG}$$

REVSHR<sub>ijr</sub> share of endowment commodity i used by firms in sector j of region r evaluated at market prices

$$\text{REVSHR}_{ijr} = \text{VFM}_{ijr} / \text{SkVFM}_{kjr} \quad i = \text{ENDW\_COMM}; j = \text{PROD\_COMM}; k = \text{PROD\_COMM}; r = \text{REG}$$

FOBSHR<sub>irs</sub> share of fob price in the cif price for tradable commodity i exported from source r to destination s

$$\text{FOBSHR}_{irs} = \text{VXWD}_{irs} / \text{VIWSCOST}_{irs} \quad i = \text{TRAD\_COMM}; r = s = \text{REG}$$

XSHRPRIV<sub>r</sub> private expenditure share in regional income

$$\text{XSHRPRIV}_r = \text{PRIVEXP}_r / \text{INCOMER} \quad r = \text{REG}$$

XSHRGOV<sub>r</sub> government expenditure share in regional income

$$\text{XSHRGOV}_r = \text{GOVEXP}_r / \text{INCOMER} \quad r = \text{REG}$$

XSHRSAVER<sub>r</sub> saving share in regional income

$$\text{XSHRSAVER}_r = \text{SAVER}_r / \text{INCOMER} \quad r = \text{REG}$$

SHRDM<sub>ir</sub> share of domestic sales of i in r  $i = \text{TRAD\_COMM}; r = \text{REG}$

$$\text{SHRDM}_{ir} = \text{VDM}_{ir} / \text{VOM}_{ir}$$

SHRST<sub>m</sub> share of sales of m to global transport services in r  $m = \text{MARG\_COMM}; r = \text{REG}$

$$\text{SHRST}_{mr} = \text{VST}_{mr} / \text{VOM}_{mr}$$

$$\text{SHRXMD}_{irs} \text{ share of export sales of } i \text{ to } s \text{ in } r \quad i = \text{TRAD\_COMM}; r = s = \text{REG}$$

$$\text{SHRXMD}_{irs} = \text{VXMD}_{irs} / \text{VOM}_{ir} \quad i = \text{TRAD\_COMM}; r = s = \text{REG}$$

$$\text{SHREMI}_{jr} \text{ share of mobile endowments } i \text{ used by sector } j \text{ at mkt prices}$$

$$\text{SHREMI}_{jr} = \text{VFM}_{ijr} / \text{VOM}_{ir} \quad i = \text{ENDWM\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$$

$$\text{TRNSHR}_{irs} \text{ share of transport price in the cif price for tradable commodity } i \text{ exported from source } r \text{ to destination } s$$

$$\text{TRSHR}_{irs} = \text{VTFSD}_{irs} / \text{VIWSCOST}_{irs} \quad i = \text{TRAD\_COMM}; r = s = \text{REG}$$

$$\text{XWCONSHR}_{ir} \text{ expansion-parameter-weighted consumption share}$$

$$\text{XWCONSHR}_{ir} = \text{CONSHR}_{ir} * \text{INCPAR}_{ir} / \text{UELASPRIV}_{ir} \quad i = \text{TRAD\_COMM}; r = \text{REG}$$

$$\text{XSHRPRIVEV}_r \text{ private expenditure share in regional income, for EV calculation} \quad r = \text{REG}$$

$$\text{XSHRPRIVEV}_r = \text{PRIVEXPEV}_r / \text{INCOMEEV}_r \quad r = \text{REG}$$

$$\text{XSHRGOVEV}_r \text{ government expenditure share in regional income, for EV calculation} \quad r = \text{REG}$$

$$\text{XSHRGOVEV}_r = \text{GOVEXPEV}_r / \text{INCOMEEV}_r \quad r = \text{REG}$$

$$\text{XSHRSAVEEV}_r \text{ saving share in regional income, for EV calculation} \quad r = \text{REG}$$

$$\text{XSHRSAVEEV}_r = \text{SAVEEV}_r / \text{INCOMEEV}_r \quad r = \text{REG}$$

$$\text{XWCONSHREVI}_{ir} \text{ expansion-parameter-weighted consumption share, for EV calculation}$$

$$\text{XWCONSHREVI}_{ir} = \text{CONSHREVI}_{ir} * \text{INCPAR}_{ir} / \text{UELASPRIVEV}_r \quad i = \text{TRAD\_COMM}, r = \text{REG}$$

$$\text{CONSHREVI}_{ir} \text{ share of private household consn devoted to good } i \text{ in } r, \text{ for EV calculation}$$

$$\text{CONSHREVI}_{ir} = \text{VPAEVI}_{ir} / \text{VPAREGEV}_r$$

$$\text{STC}_{ijr} \text{ share of } i \text{ in total costs of } j \text{ in } r$$

$$\text{STC}_{ijr} = \text{VFA}_{ijr} / \sum_k \text{VFA}_{kjr} \quad i = k = \text{DEMD\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$$

## G.12 Quantity Variables

QOir quantity of non-saving commodity i output or supplied in region r | i = NSAV\_COMM r = REG

QOESijr quantity of sluggish endowment i supplied to sector j firm of region r | i = ENDWS\_COMM; j = PROD\_COMM; r = REG

QDSir quantity of domestic sales of tradable commodity i in region r | i = TRAD\_COMM; r = REG

QXSirs quantity of exports of tradable commodity i from source r to destination s | i = TRAD\_COMM; r = s = REG

QSTir quantity of sales of marginal commodity i to the international transport sector in region r | i = MARG\_COMM; r = REG

QFEijr quantity of endowment i demanded by sector j firm in region r | i = ENDW\_COMM; j = PROD\_COMM; r = REG

QVAjr quantity index of land-labor-capital composite (value-added) in sector j firm in region r | j = PROD\_COMM; r = REG

QFijr quantity of composite tradable commodity i demanded by sector j firm in region r | i = TRAD\_COMM; j = PROD\_COMM; r = REG

QFDijr quantity of domestic tradable i demanded by sector j firm in region r | i = TRAD\_COMM; j = PROD\_COMM; r = REG

QFMijr quantity of imported tradable i demanded by sector j firm in region r | i = TRAD\_COMM; j = PROD\_COMM; r = REG

QPir quantity of composite tradable i demanded by private household in region r | i = TRAD\_COMM; r = REG

QPDir quantity of domestic tradable i demanded by private household in region r | i = TRAD\_COMM; r = REG

QPMir quantity of imported tradable i demanded by private household in region r | i = TRAD\_COMM; r = REG

QGir quantity of composite tradable commodity i demanded by government household in region r | i = TRAD\_COMM; r = REG

QGDir quantity of domestic tradable commodity i demanded by government household in region r | i = TRAD\_COMM; r = REG

QGMir quantity of imported tradable commodity i demanded by government household in region r | i = TRAD\_COMM; r = REG

QIMir quantity of aggregate imports of tradable commodity i demanded by region r using market prices as weights | i = TRAD\_COMM; r = REG

QIWir quantity of aggregate imports of tradable commodity i demanded by region r using cif prices as weights | i = TRAD\_COMM; r = REG

QXW<sub>ir</sub> quantity of aggregate exports of tradable commodity *i* supplied from region *r* using fob prices as weights | *i* = TRAD\_COMM; *r* = REG

QIWREGr volume of merchandise imports demanded by region *r* | *r* = REG

QXWREGr volume of merchandise exports supplied by region *r* | *r* = REG

QIWCOM<sub>i</sub> volume of global merchandise imports of tradable commodity *i* | *i* = TRAD\_COMM; *r* = REG

QXWCOM<sub>i</sub> volume of global merchandise exports of tradable commodity *i* | *i* = TRAD\_COMM; *r* = REG

QXWWLD volume of world trade

QOW<sub>i</sub> quantity index for world supply of tradable commodity *i* | *i* = TRAD\_COMM

EXPAND<sub>ir</sub> Change in investment levels relative to endowment stock | *i* = ENDWC\_COMM; *r* = REG

QOWU<sub>ir</sub> quantity index for world supply of good *i* at user prices *i* = TRAD\_COMM; *r* = REG

QTMFSD<sub>mirs</sub> international usage margin *m* on *i* from *r* to *s* *m* = MARG\_COMM; *i* = TRAD\_COMM; *r* = *s* = REG

QTM<sub>m</sub> global margin usage *m* = MARG\_COMM

QCGDS<sub>r</sub> quantity of capital goods sector supplied in region *r* *r* = REG

QSAVER<sub>r</sub> quantity of savings demanded in region *r* *r* = REG

GLOBALCGDS quantity of global supply of capital for net investment

KSVCES<sub>r</sub> quantity of capital services in region *r* *r* = REG

KBr quantity of beginning-of-period capital stock in region *r* *r* = REG

KEr quantity of end-of-period capital stock in region *r* *r* = REG

QGDP<sub>r</sub> quantity index for GDP in region *r* *r* = REG

WALRAS\_DEM quantity demanded in the omitted market - equals global demand for savings

WALRAS\_SUP quantity supplied in the omitted market - equals global supply of new capital goods composite

POPr population in region *r* *r* = REG

COMPVALAD<sub>ir</sub> composition of value added for good *i* and region *r* *i* = TRAD\_COMM; *r* = REG

## G.13 Price Variables

PMir market price of non-saving commodity  $i$  in region  $r$   $i = \text{NSAV\_COMM}; r = \text{REG}$

PMESijr market price for sluggish endowment  $i$  supplied to firm  $j$  in region  $r$   $i = \text{ENDWS\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$

PSir supply price of non-saving commodity  $i$  in region  $r$   $i = \text{NSAV\_COMM}; r = \text{REG}$

PFEijr demand price for endowment  $i$  by firms in sector  $j$  of region  $r$   $i = \text{ENDW\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$

PVAjr price of value-added in sector  $j$   $j = \text{PROD\_COMM}; r = \text{REG}$

PFijr demand price for composite tradable  $i$  by firms in sector  $j$  of region  $r$   $i = \text{TRAD\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$

PFDir demand price for domestic tradable  $i$  by firms in sector  $j$  of region  $r$   $i = \text{TRAD\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$

PFMijr demand price for imported tradable  $i$  by firms in sector  $j$  of region  $r$   $i = \text{TRAD\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$

PPir private household's demand price for composite tradable  $i$  in region  $r$   $i = \text{TRAD\_COMM}; r = \text{REG}$

PPDir private household's demand price for domestic tradable  $i$  in region  $r$   $i = \text{TRAD\_COMM}; r = \text{REG}$

PPMir private household's demand price for imported tradable  $i$  in region  $r$   $i = \text{TRAD\_COMM}; r = \text{REG}$

PGir government household's demand price for composite tradable  $i$  in region  $r$   $i = \text{TRAD\_COMM}; r = \text{REG}$

PGDir government household's demand price for domestic tradable  $i$  in region  $r$   $i = \text{TRAD\_COMM}; r = \text{REG}$

PGMir government household's demand price for imported tradable  $i$  in region  $r$   $i = \text{TRAD\_COMM}; r = \text{REG}$

PSAVer price of savings in region  $r$   $r = \text{REG}$

PCGDSr price of investment good in region  $r$  - equals  $\text{PS}(\text{cgds}, r)$   $r = \text{REG}$

PGDPr price index for GDP in region  $r$   $r = \text{REG}$

PPRIVr price index for private household expenditure in region  $r$   $r = \text{REG}$

PGOVR price index for government household expenditure in region  $r$   $r = \text{REG}$

PFOBirs world fob price of tradable commodity  $i$  exported from source  $r$  to destination  $s$  (prior to including transport margins)  $i = \text{TRAD\_COMM}; r = s = \text{REG}$

PCIFirs world cif price of tradable commodity  $i$  imported from source  $r$  to destination  $s$  ) after including transport margins)  $i = \text{TRAD\_COMM}; r = s = \text{REG}$

PMSirs market price by source of tradable commodity i imported from source r to destination s i = TRAD\_COMM; r = s = REG

PIMir market price of aggregate imports of tradable commodity i in region r i = TRAD\_COMM; r = REG

PIWir world price of aggregate imports of tradable commodity i in region r i = TRAD\_COMM; r = REG

PXWir price index for aggregate exports of tradable commodity i from region r i = TRAD\_COMM; r = REG

PIWREGr price index of merchandise imports in region r r = REG

PXWREGr price index of merchandise exports from region r r = REG

PIWCOMi price index of global merchandise imports of tradable commodity i i = TRAD\_COMM

PXWCOMi price index of global merchandise exports of tradable commodity i i = TRAD\_COMM

PXWWLD price index of world trade

PRir ratio of domestic market price to market price of imports for tradable commodity i in region r i = TRAD\_COMM; r = REG

PWi world price index for total supply of tradable commodity i in region r i = TRAD\_COMM

PSWr price index received for tradable commodities produced in region r including sales of net investment to the global bank r = REG

PDWr price index paid for tradable commodities used in region r including purchases of savings from the global bank r = REG

TOTr terms of trade for region r r = REG

PTm price of margin services supplied m = MARG\_COMM

PCGDSWLD world average price of capital goods (net investment weights)

PWUi world price index for total good i supplies at user prices i = TRAD\_COMM

PTRANSirs cost index for international transport of i from r to s i = TRAD\_COMM; r = s = REG

RENTALr rental rate on capital stock in region r - equals PS(CGDS,r) r = REG

RORCr current net rate of return on capital stock in region r r = REG

ROREr expected net rate of return on capital stock in region r r = REG

RORG global net rate of return on capital stock

Pr price index for disposition of income by regional household

PFACTREALir ratio of return to primary factor i to cpi in r i = ENDOW\_COMM; r = REG

PFACTORr market price index of primary factors, by region

PFACTWLD world price index of primary factors

## G.14 Technical Change Variables

AOir output augmenting technical change in sector j of region r | j = PROD\_COMM; r = REG

AFEijr primary factor i augmenting technical change in sector j of region r | i = ENDW\_COMM; j = PROD\_COMM; r = REG

AFijr intermediate input i augmenting technical change in sector j of region r | i = TRAD\_COMM; j = PROD\_COMM; r = REG

AVAjr value-added augmenting technical change in sector j of region r | j = PROD\_COMM; r = REG

AMSirs import i from region r augmenting tech change in region s | i = TRAD\_COMM, r = s = REG

AOSECj output tech change of sector j, worldwide | j = PROD\_COMM

AOREGr output tech change in region r | r = REG

AOALLjr output augmenting technical change in sector j of r | j = PROD\_COMM; r = REG

ESUBTj elasticity of substitution among composite intermediate inputs in production | j = PROD\_COMM

AFCOMi intermediate tech change of input i, worldwide | i = TRAD\_COMM

AFSECj intermediate tech change of sector j, worldwide | j = PROD\_COMM

AFREGr intermediate tech change in region r | r = REG

AFALLijr intermediate input i augmenting tech change by j in r | i = TRAD\_COMM, j = PROD\_COMM; r = REG

AFECOMi factor input tech change of input i, worldwide | i = ENDW\_COMM

AFESECj factor input tech change of sector j, worldwide | j = PROD\_COMM

AFEREGr factor input tech change in region r | r = REG

AFEALLijr primary factor i augmenting tech change sector j in r | i = ENDW\_COMM; j = PROD\_COMM; r = REG

AMSirs reduction in effective price associated with delivery of i from r to s | i = TRAD\_COMM; r = REG; s = REG

ATMFSDmirs tech change in m's shipping of i from region r to s | m = MARG\_COMM; i = TRAD\_COMM; r = s = REG

ATMm tech change in mode m, worldwide; | m = TRAD\_COMM

ATFi tech change shipping of i, worldwide | i = TRAD\_COMM

ATSr tech change shipping from region r | r = REG

ATDs tech change shipping to s | s = REG

ATALLmirs tech change in m's shipping of i from region r to s | m = MARG\_COMM; i = TRAD\_COMM; r = REG; s = REG

AUr input-neutral shift in utility function |  $r = \text{REG}$

## G.15 Policy Variables

TOir power of the tax on output (or income) of non-savings commodity  $i$  in region  $r$  |  $i = \text{NSAV\_COMM}$ ;  $r = \text{REG}$

TFijr power of the tax on endowment commodity  $i$  demanded by sector  $j$  of region  $r$  |  $i = \text{ENDW\_COMM}$ ;  $j = \text{PROD\_COMM}$ ;  $r = \text{REG}$

TFDijr power of the tax on domestic tradable commodity  $i$  demanded by sector  $j$  of region  $r$  |  $i = \text{TRAD\_COMM}$ ;  $j = \text{PROD\_COMM}$ ;  $r = \text{REG}$

TFMijr power of the tax on imported tradable commodity  $i$  demanded by sector  $j$  of region  $r$  |  $i = \text{TRAD\_COMM}$ ;  $j = \text{PROD\_COMM}$ ;  $r = \text{REG}$

TPDir power of the tax on domestic tradable commodity  $i$  purchased by private household in region  $r$  |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

TPMir power of the tax on imported tradable commodity  $i$  purchased by private household in region  $r$  |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

TGDir power of the tax on domestic tradable commodity  $i$  purchased by government household in region  $r$  |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

TGMir power of the tax on imported tradable commodity  $i$  purchased by government household in region  $r$  |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

TXSirs power of the tax on exports of tradable commodity  $i$  from source  $r$  to destination  $s$  (levied in region  $r$ ) |  $i = \text{TRAD\_COMM}$ ;  $r = s = \text{REG}$

TMSirs power of the tax on imports of tradable commodity  $i$  from source  $r$  to destination  $s$  (levied in region  $s$ ) |  $i = \text{TRAD\_COMM}$ ;  $r = s = \text{REG}$

TXir power of the variable export tax on exports of tradable commodity from region  $r$  - destination generic |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

TMir power of the variable import tax (levy) on imports of tradable commodity  $i$  in region  $s$  - source generic |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

TPr region-wide shock to tax on purchases by private household in region  $r$  |  $r = \text{REG}$

ATPMir actual tax on imported traded commodity  $i$  purchased by private households in region  $r$  |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

ATPDir actual tax on domestic traded commodity  $i$  purchased by private households in region  $r$  |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

DGTAXir tax on government consumption of domestic good  $i$  in region  $r$  |  $r = \text{REG}$

IGTAXir tax on government consumption of imported good  $i$  in region  $r$  |  $r = \text{REG}$

TGCr government consumption tax payments in  $r$

TGCr = SiDGTAXir + IGTAXir  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

DPTAX<sub>ir</sub> tax on private consumption of domestic good *i* in region *r*

$$DPTAX_{ir} = VDPA_{ir} - VDPM_{ir} \quad i = \text{TRAD\_COMM}; r = \text{REG}$$

IP<sub>TAX</sub><sub>ir</sub> tax on private consumption of imported good *i* in region *r*

$$IPTAX_{ir} = VIPA_{ir} - VIPM_{ir} \quad i = \text{TRAD\_COMM}; r = \text{REG}$$

TPC<sub>r</sub> private consumption tax payments in *r*

$$TPC_r = SiDPTAX_{ir} + IPTAX_{ir} \quad i = \text{TRAD\_COMM}; r = \text{REG}$$

DFTAX<sub>ijr</sub> tax on use of domestic intermediate good *i* by *j* in *r*

$$DFTAX_{ijr} = VDFA_{ijr} - VDFM_{ijr} \quad i = \text{TRAD\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$$

IFTAX<sub>ijr</sub> tax on use of imported intermediate good *i* by *j* in *r*

$$IFTAX_{ijr} = VIFA_{ijr} - VIFM_{ijr} \quad i = \text{TRAD\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$$

TIU<sub>r</sub> firms' tax payments on intermediate goods usage in *r*

$$TIU_r = S_j Si(DFTAX_{ijr} + IFTAX_{ijr}) \quad i = \text{TRAD\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$$

ETAX<sub>ijr</sub> tax on use of endowment good *i* by industry *j* in region *r*

$$ETAX_{ijr} = VFA_{ijr} - VFM_{ijr} \quad i = \text{ENDW\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$$

TFU<sub>r</sub> firms' tax payments on primary factor usage in *r*

$$TFU_r = SiS_j ETAX_{ijr} \quad i = \text{ENDW\_COMM}; j = \text{PROD\_COMM}; r = \text{REG}$$

PTAX<sub>ir</sub> output tax on good *i* in region *r*

$$PTAX_{ir} = VOM_{ir} - VOA_{ir} \quad i = \text{NSAV\_COMM}; r = \text{REG}$$

TOU<sub>Tr</sub> production tax payments in *r*

$$TOU_{Tr} = SiPTAX_{ir} \quad i = \text{PROD\_COMM}; r = \text{REG}$$

XTAXD<sub>irs</sub> tax on exports of good *i* from source *r* to destination *s*

$$XTAXD_{irs} = VXWD_{irs} - VXMD_{irs} \quad i = \text{TRAD\_COMM}; r = s = \text{REG}$$

TEX<sub>r</sub> export tax payments in *r*

$$TEX_r = SiS_s XTAXD_{irs} \quad i = \text{TRAD\_COMM}; r = s = \text{REG}$$

MTAX<sub>irs</sub> tax on imports of good *i* from source *r* in destination *s*

$$MTAX_{irs} = VIMS_{irs} - VIWS_{irs} \quad i = \text{TRAD\_COMM}; r = s = \text{REG}$$

TIM<sub>r</sub> import tax payments in *r*

$$TIM_r = SiS_s MTAX_{irs} \quad i = \text{TRAD\_COMM}; r = s = \text{REG}$$

TOTTAX<sub>r</sub> Total tax receipts in *r*

$$TOTTAX_r = TPC_r + TGC_r + TIU_r + TFU_r + TOU_{Tr} + TEX_r + TIM_r + TINC_r \quad r = \text{REG}$$

TGCR<sub>r</sub> change in ratio of government consumption tax to INCOME in region *r* *r* = REG

TPCR<sub>r</sub> change in ratio of private consumption tax to INCOME in region *r* *r* = REG

TIUR<sub>r</sub> change in ratio of tax on intermediate usage to INCOME in region  $r$   $r = \text{REG}$   
 TFUR<sub>r</sub> change in ratio of tax on primary factor usage to INCOME in region  $r$   $r = \text{REG}$   
 TOUTR<sub>r</sub> change in ratio of output tax to INCOME in region  $r$   $r = \text{REG}$   
 TEXPR<sub>r</sub> change in ratio of export tax to INCOME in region  $r$   $r = \text{REG}$   
 TIMPR<sub>r</sub> change in ratio of import tax to INCOME in region  $r$   $r = \text{REG}$   
 TINCr income tax payments in  $r$   
 TINCr = SiPTAX<sub>i</sub>  $i = \text{ENDOW\_COMM}$ ;  $r = \text{REG}$   
 TINCR<sub>r</sub> change in ratio of income tax to INCOME in region  $r$   $r = \text{REG}$   
 DTAXR<sub>r</sub> change in ratio of taxes to INCOME in  $r$   $r = \text{REG}$

## G.16 Regional Household Preference Parameters and Shifters

DPARPRIV<sub>r</sub> private consumption distribution parameter  
 DPARPRIV<sub>r</sub> = UELASPRIV<sub>r</sub>\*XSHRPRIV<sub>r</sub>/UTILELAS<sub>r</sub>  $r = \text{REG}$   
 DPARGOV<sub>r</sub> government consumption distribution parameter  
 DPARGOV<sub>r</sub> = XSHRGOV<sub>r</sub>/UTILELAS<sub>r</sub>  $r = \text{REG}$   
 DPARSAYER saving distribution parameter  
 DPARSAYER = XSHRSAYER/UTILELAS<sub>r</sub>  $r = \text{REG}$   
 DPARSUM<sub>r</sub> sum of distribution parameters  $r = \text{REG}$   
 dpavr change in average distribution parameter  $r = \text{REG}$   
 dpsumr change in sum of the distribution parameters  $r = \text{REG}$   
 dpprivr change in private consumption distribution parameter  $r = \text{REG}$   
 dpgovr change in government consumption distribution parameter  $r = \text{REG}$   
 dpsaver change in saving distribution parameter  $r = \text{REG}$

## G.17 Slack Variables

profitslackjc slack variable in the ZEROPROFITS equation (this is exogenous as long as output level,  $QO(j)$ , is determined endogenously) |  $j = \text{PROD\_COMM}$ ;  $r = \text{REG}$

cgdslackr slack variable in the CAPGOODS equation (this is exogenous as long as output level of new capital goods,  $QO(\text{"cgds"})$ , is determined endogenously) |  $r = \text{REG}$

endwslackir slack variable in the MKTCLENDWM and ENDW\_SUPPLY equations (this is exogenous as long as primary factor rental rates,  $PM_i$  and  $PMES_{ij}$  are determined endogenously) |  $i = \text{ENDWS\_COMM}$ ;  $r = \text{REG}$

tradslackir slack variable in the MKTCLTRD equation (this is exogenous as long as market price of tradable,  $PM_i$ , is determined endogenously) |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

incomelackr slack variable in the INCOME equation (this is exogenous as long as income,  $Y$ , is determined endogenously) |  $r = \text{REG}$

psaveslackr slack variable in the SAVINGS equation (this is exogenous as long as level of savings,  $QSAVE$ , is determined endogenously) |  $r = \text{REG}$

walraslack slack variable in the WALRAS equation (this is endogenous as long as price of savings,  $PSAVE$ , is determined exogenously which is the case in a standard GE closure. When any one of the GE links is broken, this is swapped with  $PSAVE$ , the numeraire price, thereby forcing global savings to equal global investment).

incomelackr slack variable in the expression for regional income |  $r = \text{REG}$

## G.18 Value and Income Variables

vxwfobir percentage change in value of exports of tradable commodity  $i$  from source region  $r$  using fob weights (is identical to the linearized form of  $VXW_{ir}$ ) |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

vxwregr percentage change in value of merchandise exports from region  $r$  using fob weights (is identical to the linearized form of  $VXW_{REGIONr}$ ) |  $r = \text{REG}$

vxwcomi percentage change in value of global merchandise exports of tradable commodity  $i$  using fob weights (is identical to the linearized form of  $VXW_{COMMODi}$ ) |  $i = \text{TRAD\_COMM}$

viwcifir percentage change in value of imports of tradable commodity  $i$  into region  $r$  using fob weights (is identical to the linearized form of  $VIW_{ir}$ ) |  $i = \text{TRAD\_COMM}$ ;  $r = \text{REG}$

viwregr percentage change in value of merchandise imports into region  $r$  using cif weights (is identical to the linearized form of  $VIW_{REGIONir}$ ) |  $r = \text{REG}$

viwcomi percentage change in value of global merchandise imports of tradable commodity  $i$  using fob weights (is identical to the linearized form of  $VIW_{COMMODi}$ ) |  $i = \text{TRAD\_COMM}$

vxwwld percentage change in value of worldwide commodity exports using fob weights (is identical to the linearized form of  $VXWLD$ )

valuewi percentage change in value of global supply of tradable commodity  $i$  using fob weights (is identical to the linearized form of  $VWOW_i$ ) |  $i = \text{TRAD\_COMM}$

valuwui value of world supply of good  $i$  at user prices |  $i = \text{TRAD\_COMM}$

vgdpr percentage change in value of GDP in region  $r$  (is identical to the linearized form of  $\text{GDP}_r$ ) |  $r = \text{REG}$

yr percentage change in regional household income (is identical to the linearized form of  $\text{INCOME}$ ) |  $r = \text{REG}$

ypr percentage change in private household expenditure (is identical to the linearized form of  $\text{PRIVEXP}$ ). |  $r = \text{REG}$

FYr primary factor income in  $r$  net of depreciation

$\text{FY}_r = \text{SiVOMir} - \text{VDEPr}$  |  $i = \text{ENDW\_COMM}$ ;  $r = \text{REG}$

fincomer pc change in factor income variable in  $r$  net of depreciation  $r = \text{REG}$

## G.19 Utility Variables

Ur per capita utility from aggregate household expenditure in region  $r$   $r = \text{REG}$

UPr per capita utility from private household expenditure in region  $r$   $r = \text{REG}$

UGr aggregate utility from government household expenditure in region  $r$   $r = \text{REG}$

UTILELASr elasticity of cost of utility wrt utility

$\text{UTILELAS}_r = (\text{UELASPRIV}_r * \text{XSHRPRIV}_r + \text{XSHRGOV}_r + \text{XSHRSAVE}_r) / \text{DPARSUM}_r$   $r = \text{REG}$

uelasr pc change in elasticity of cost of utility wrt utility  $r = \text{REG}$

ueprivr pc change in utility elasticity of private cons expenditure  $r = \text{REG}$

uelasevr pc change in elasticity of cost of utility wrt utility, for EV calculation  $r = \text{REG}$

ueprivevr pc change in utility elasticity of private cons expenditure, for EV calculation  $r = \text{REG}$

## G.20 Welfare Variables

EVr equivalent variation, in \$ US million (positive figure indicates welfare improvement)  $r = \text{REG}$

WEV equivalent variation, in \$ US million, for the world (positive figure indicates welfare improvement)

ugevr per capita utility from gov't expend., for EV calculation  $r = \text{REG}$

upevr per capita utility from private expend., for EV calculation  $r = \text{REG}$

qsaveevr total quantity of savings demanded, for EV calculation  $r = \text{REG}$

ypevr private consumption expenditure, in region  $r$ , for EV calculation  $r = \text{REG}$

ygevr government consumption expenditure, in region  $r$ , for EV calculation  $r = \text{REG}$

qpevir private household demand for commodity i in region r, for EV calculation i = TRAD\_COMM,  
r = REG

yevr regional household income, in region r, for EV calculation

ysaveevr NET savings expenditure, for EV calculation

dpavevr average distribution parameter shift, for EV calculation r = REG

## **G.21 Trade Balance Variables**

DTBALr change in trade balance of region r , in US\$ million (positive figure indicates increases in exports exceeds increases in imports) | r = REG

DTBALiir change in trade balance for tradable commodity i in region r , in US\$ million (positive figure indicates increases in exports exceeds increases in imports) | i = TRAD\_COMM; r = REG

## **Part II**

# **GTAP-InVEST aggregation (s26\_r50)**

# H GTAP-Invest aggregation (s26\_r50)

This section documents the **aggregated classification used inside GTAP-Invest** — a 26-sector  $\times$  50-region rollup of the underlying GTAP Data Base, identified by the aggregate string `v12_s26_r50`. This is the resolution at which GTAP-Invest scenarios are actually solved and at which results are reported.

The aggregation collapses the [65 native GTAP sectors](#) into 26 (mostly 1:1, with four composite sectors — `PFD`, `P_C`, `MNF`, `SER` — bundling 43 of the originals) and the [163 native GTAP regions](#) into 50 (countries of interest kept individual; rest grouped into continental/economic blocs such as `EUR`, `XSS`, `XLA`). Mappings are sourced from the `ee_r264_correspondence.csv` and `*_extended.csv` files produced by the GTAP-Invest econ-extraction pipeline.

For the full underlying GTAP classification, see [GTAP Database reference](#).

## H.1 Contents

- [r50 regions](#) — the 50 GTAP-Invest regions, with the member `v12` region codes (`gtapv7_r163_label1`) that compose each one.
- [s26 sectors](#) — the 26 GTAP-Invest sectors, with the member `v12` sector codes that compose each one and a flag for which are aggregations vs. passthroughs.

# I Regions in r50 (GTAP-Invest aggregation)

Aggregate string: v12\_s26\_r50 (used in combination with s26 sectors)

This is the 50-region aggregation used by GTAP-Invest. Each of the 163 v12 regions (or 160 v11 regions) maps to exactly one r50 region. The mapping is drawn from the ee\_r264\_correspondence.csv file shipped with GTAP-Invest, columns gtapv7\_r50\_id / gtapv7\_r50\_label / gtapv7\_r50\_name.

See also: s26 sectors (the matching sector aggregation).

Two minor data inconsistencies in the source correspondence file are preserved here verbatim: **argentina** is lowercase, and **Rest of Centra Asia** is missing an ‘l’ (Central). Downstream code keys on these exact strings, so they should not be silently “fixed” in documentation without coordinating with the pipeline.

| gtapv7_r50_id | gtapv7_r50_label | gtapv7_r50_name                                      | Member v12 regions<br>(gtapv7_r163_label)                                                                                             |
|---------------|------------------|------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| 1             | ANZ              | Australia and New Zealand                            | aus, nzl                                                                                                                              |
| 2             | ARG              | argentina                                            | arg                                                                                                                                   |
| 3             | BGD              | Bangladesh                                           | bgd                                                                                                                                   |
| 4             | BRA              | Brazil                                               | bra                                                                                                                                   |
| 5             | BWA              | Botswana                                             | bwa                                                                                                                                   |
| 6             | CAN              | Canada                                               | can                                                                                                                                   |
| 7             | CHL              | Chile                                                | chl                                                                                                                                   |
| 8             | CHN              | China and Hong Kong                                  | chn, hkg                                                                                                                              |
| 9             | COD              | Democratic Republic of the Congo                     | cod                                                                                                                                   |
| 10            | COL              | Colombia                                             | col                                                                                                                                   |
| 11            | CRI              | Costa Rica                                           | cri                                                                                                                                   |
| 12            | ETH              | Ethiopia                                             | eth                                                                                                                                   |
| 13            | EUR              | European Union                                       | aut, bel, bgr, cyp, cze, deu, dnk, esp, est, fin, fra, grc, hrv, hun, irl, ita, ltu, lux, lva, mlt, nld, pol, prt, rou, svk, svn, swe |
| 14            | GAB              | Gabon                                                | gab                                                                                                                                   |
| 15            | GBR              | United Kingdom of Great Britain and Northern Ireland | gbr                                                                                                                                   |
| 16            | HND              | Honduras                                             | hnd                                                                                                                                   |

| gtapv7_r50_id | gtapv7_r50_label | gtapv7_r50_name                        | Member v12 regions<br>(gtapv7_r163_label)                                                         |
|---------------|------------------|----------------------------------------|---------------------------------------------------------------------------------------------------|
| 17            | IDN              | Indonesia                              | idn                                                                                               |
| 18            | IND              | India                                  | ind                                                                                               |
| 19            | JPN              | Japan                                  | jpn                                                                                               |
| 20            | KEN              | Kenya                                  | ken                                                                                               |
| 21            | KOR              | Republic of Korea                      | kor                                                                                               |
| 22            | MENA             | Middle East and<br>North Africa        | dza, egy, mar, tun, xnf                                                                           |
| 23            | MEX              | Mexico                                 | mex                                                                                               |
| 24            | MNG              | Mongolia                               | mng                                                                                               |
| 25            | MYS              | Malaysia                               | mys                                                                                               |
| 26            | NAM              | Namibia                                | nam                                                                                               |
| 27            | NGA              | Nigeria                                | nga                                                                                               |
| 28            | NOR              | Norway                                 | nor                                                                                               |
| 29            | NPL              | Nepal                                  | npl                                                                                               |
| 30            | PAK              | Pakistan                               | pak                                                                                               |
| 31            | PER              | Peru                                   | per                                                                                               |
| 32            | PHL              | Philippines                            | phl                                                                                               |
| 33            | RUS              | Russia                                 | rus                                                                                               |
| 34            | THA              | Thailand                               | tha                                                                                               |
| 35            | TUR              | Turkey                                 | tur                                                                                               |
| 36            | TZA              | United Republic of<br>Tanzania         | tza                                                                                               |
| 37            | UGA              | Uganda                                 | uga                                                                                               |
| 38            | USA              | United States of<br>America            | usa                                                                                               |
| 39            | VNM              | Viet Nam                               | vnm                                                                                               |
| 40            | XCA              | Rest of Centra Asia                    | arm, aze, geo, kaz, kgz,<br>tjk, uzb                                                              |
| 41            | XEF              | Rest of European Free<br>Trade Area    | che, xef                                                                                          |
| 42            | XER              | Rest of Europe                         | alb, blr, srb, ukr, xee,<br>xer                                                                   |
| 43            | XESF             | Rest of East and<br>Southern Africa    | bdi, com, mdg, moz,<br>mus, mwi, rwa, sdn,<br>swz, xec, xsc, zmb, zwe                             |
| 44            | XSA              | Rest of South Asia                     | afg, xsa                                                                                          |
| 45            | XSE              | Rest of Southeast Asia                 | brn, khm, lao, xse                                                                                |
| 46            | XSMC             | Rest of South America<br>and Caribbean | bol, dom, hti, jam, pri,<br>tto, ven, xca, xcb, xsm                                               |
| 47            | XTW              | Rest of the World                      | xea, xna, xoc, xtw                                                                                |
| 48            | XWCF             | Rest of Western and<br>Central Africa  | ago, ben, bfa, caf, civ,<br>cmr, cog, gha, gin,<br>gnq, mli, mrt, ner, sen,<br>stp, tcd, tgo, xwf |

| gtapv7_r50_id | gtapv7_r50_label | gtapv7_r50_name | Member v12 regions<br>(gtapv7_r163_label)                                  |
|---------------|------------------|-----------------|----------------------------------------------------------------------------|
| 49            | XWS              | Middle East     | are, bhr, irn, irq, isr,<br>jor, kwt, lbn, omn, pse,<br>qat, sau, syr, xws |
| 50            | ZAF              | South Africa    | zaf                                                                        |

## I.1 Notes on the v12 → r50 mapping

- The 4 new v12 regions broken out from v11 aggregates — Mauritania (mrt), Angola (ago), São Tomé and Príncipe (stp), Burundi (bdi) — all roll up into pre-existing r50 buckets (xwcf for the first three; xesf for bdi), so r50 membership is stable across the v11 → v12 transition.
- XTW collects everything that doesn’t fit elsewhere: Rest of East Asia (incl. DPRK), Rest of North America (Bermuda, Greenland, Saint Pierre and Miquelon), Rest of Oceania (Pacific island states), Taiwan (twn), Macao, and the v12 **xtw** catch-all (Antarctica, BIOT, Bouvet, French Southern Territories).
- XEF (“Rest of European Free Trade Area”) includes Switzerland — Switzerland is its own v12 region but is grouped with Iceland and Liechtenstein at the r50 level.
- EUR is the EU27 (no UK).

## J Sectors in s26 (GTAP-Invest aggregation)

Aggregate string: `v12_s26_r50` (used in combination with `r50` regions)

This is the 26-sector aggregation used by GTAP-Invest. Each of the [65 v12 sectors](#) (same set as [v11](#)) maps to exactly one s26 sector. Labels/names below were extracted from the `gtapv7_c26_*` columns of an `*_extended.csv` produced by the GTAP-Invest econ extraction pipeline.

See also: [r50 regions](#) (the matching region aggregation).

22 of the 26 sectors are 1:1 passthroughs from v12 (same code, same name). The remaining 4 — `PFD`, `P_C`, `MNF`, `SER` — are aggregations across multiple v12 sectors and account for 43 of the 65 v12 codes.

| gtapv7_c26_id | gtapv7_c26_label | gtapv7_c26_name                           | Member v12 sectors                                                                                   |
|---------------|------------------|-------------------------------------------|------------------------------------------------------------------------------------------------------|
| 1             | C_B              | Sugar cane, sugar beet                    | c_b                                                                                                  |
| 2             | CMT              | Bovine meat products                      | cmt                                                                                                  |
| 3             | COA              | Coal                                      | coa                                                                                                  |
| 4             | CTL              | Bovine cattle, sheep<br>and goats, horses | ctl                                                                                                  |
| 5             | ELY              | Electricity                               | ely                                                                                                  |
| 6             | FRS              | Forestry                                  | frs                                                                                                  |
| 7             | FSH              | Fishing                                   | fsh                                                                                                  |
| 8             | GAS              | Gas                                       | gas                                                                                                  |
| 9             | GRO              | Cereal grains nec                         | gro                                                                                                  |
| 10            | MIL              | Dairy products                            | mil                                                                                                  |
| 11            | MNF              | Manufactures                              | tex, wap, lea, lum,<br>ppp, chm, bph, rpp,<br>nmm, i_s, nfm, fmp,<br>ele, eeq, ome, mvh,<br>otn, omf |
| 12            | OAP              | Animal products nec                       | oap                                                                                                  |
| 13            | OCR              | Crops nec                                 | ocr                                                                                                  |
| 14            | OIL              | Oil                                       | oil                                                                                                  |
| 15            | OMT              | Meat products nec                         | omt                                                                                                  |
| 16            | OSD              | Oil seeds                                 | osd                                                                                                  |
| 17            | OXT              | Minerals nec                              | oxt                                                                                                  |
| 18            | P_C              | Refined petroleum                         | p_c                                                                                                  |
| 19            | PDR              | Paddy rice                                | pdr                                                                                                  |
| 20            | PFB              | Plant-based fibers                        | pfb                                                                                                  |
| 21            | PFD              | Processed food                            | vol, pcr, sgr, ofd, b_t                                                                              |
| 22            | RMK              | Raw milk                                  | rmk                                                                                                  |

| gtapv7_c26_id | gtapv7_c26_label | gtapv7_c26_name            | Member v12 sectors                                                                                     |
|---------------|------------------|----------------------------|--------------------------------------------------------------------------------------------------------|
| 23            | SER              | Services                   | gdt, wtr, cns, trd, afs,<br>otp, wtp, atp, whs,<br>cmn, ofi, ins, rsa, obs,<br>ros, osg, edu, hht, dwe |
| 24            | V_F              | Vegetables, fruit, nuts    | v_f                                                                                                    |
| 25            | WHT              | Wheat                      | wht                                                                                                    |
| 26            | WOL              | Wool, silk-worm<br>cocoons | wol                                                                                                    |

## J.1 Notes on the v12 → s26 mapping

- **Crops (12)**: pdr, wht, gro, v\_f, osd, c\_b, pfb, ocr, ctl, oap, rmk, wol all pass through 1:1, preserving the full agriculture detail GTAP-Invest needs for the SEALS land-use coupling.
- **Extraction (6)**: frs, fsh, coa, oil, gas, oxt all pass through 1:1. Note that oxt is the v12 name (was omn “Minerals nec” in earlier versions); the s26 name “Minerals nec” follows the older convention.
- **Meat and dairy (3)**: cmt, omt, mil pass through 1:1; mil (Dairy products) is separate from rmk (Raw milk).
- **PFD** “Processed food” aggregates vegetable oils & fats (vol), processed rice (pcr), sugar (sgr), other food (ofd), and beverages & tobacco (b\_t).
- **P\_C** “Refined petroleum” is the v12 p\_c “Petroleum, coal products” — same content, renamed.
- **MNF** “Manufactures” aggregates all 18 secondary-manufacturing sectors (textiles through other manufactures).
- **ELY** “Electricity” is kept separate (energy detail), while all other service / utility / infrastructure sectors aggregate into **SER**.
- **SER** “Services” aggregates 19 sectors covering gas distribution, water, construction, trade, transport (land/water/air/warehousing), communication, finance/insurance, real estate, business and recreational services, government, education, health, and dwellings.

## J.2 Reverse mapping from v12 → s26

| v12 label | s26 label |
|-----------|-----------|
| pdr       | PDR       |
| wht       | WHT       |
| gro       | GRO       |
| v_f       | V_F       |
| osd       | OSD       |
| c_b       | C_B       |
| pfb       | PFB       |
| ocr       | OCR       |
| ctl       | CTL       |

| v12 label | s26 label |
|-----------|-----------|
| oap       | OAP       |
| rmk       | RMK       |
| wol       | WOL       |
| frs       | FRS       |
| fsh       | FSH       |
| coa       | COA       |
| oil       | OIL       |
| gas       | GAS       |
| oxt       | OXT       |
| cmt       | CMT       |
| omt       | OMT       |
| vol       | PFD       |
| mil       | MIL       |
| pcr       | PFD       |
| sgr       | PFD       |
| ofd       | PFD       |
| b_t       | PFD       |
| tex       | MNF       |
| wap       | MNF       |
| lea       | MNF       |
| lum       | MNF       |
| ppp       | MNF       |
| p_c       | P_C       |
| chm       | MNF       |
| bph       | MNF       |
| rpp       | MNF       |
| nmm       | MNF       |
| i_s       | MNF       |
| nfm       | MNF       |
| fmp       | MNF       |
| ele       | MNF       |
| eeq       | MNF       |
| ome       | MNF       |
| mvh       | MNF       |
| otn       | MNF       |
| omf       | MNF       |
| ely       | ELY       |
| gdt       | SER       |
| wtr       | SER       |
| cns       | SER       |
| trd       | SER       |
| afs       | SER       |
| otp       | SER       |
| wtp       | SER       |
| atp       | SER       |
| whs       | SER       |

| v12 label | s26 label |
|-----------|-----------|
| cmn       | SER       |
| ofi       | SER       |
| ins       | SER       |
| rsa       | SER       |
| obs       | SER       |
| ros       | SER       |
| osg       | SER       |
| edu       | SER       |
| hht       | SER       |
| dwe       | SER       |