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GlobeTERM, combining multi-country and sub-national detail

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This paper describes a method of combining national Global Trade Analysis Project (GTAP) regions with sub-national detail. The approach extends the sub-national TERM methodology to create a family of models named GlobeTERM. In each model, the master database includes 74 sectors, based on GTAP with electricity split into 9 generation sectors plus a distribution sector. The other 64 sectors are those in GTAP Data Base version 11c. In most examples, one country within GTAP is split into sub-national regions, while retaining the other 159 GTAP regions in the master database. Examples include China, Germany, UK and USA. Another version represents Europe's regions at the NUTS-2 level. Using the US version of GlobeTERM, an illustrative simulation examines the impacts of the imposition of large bilateral tariffs between USA and China. The aggregation for this scenario depicts swing states separately. While almost all US regions lose in the short run from the imposition of high bilateral tariffs, there are winning and losing states in the long run amid national losses.

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1. Introduction

The approach outlined here starts with a GTAP Data Base (Corong et al. 2017; Aguiar et al. 2023) and extends the TERM database procedures to form multi-country, regionally disaggregated databases (Wittwer and Horridge, 2018). Electricity has been split into 9 generation sectors plus distribution, resulting in 74 industries in the 160 countries/composite countries of GTAP version 11c. Section 6 outlines differences between GTAP-Power and GlobeTERM representation of electricity. The US version, GlobeUSA, includes 151 US sub-national regions, covering all states and providing sub-state detail for USDA agricultural regions in the mid-West and California, plus the remaining 159 GTAP regions. The European version, GlobeEuro, splits 31 European GTAP regions into 295 NUTS-2 regions, while retaining the other 129 regions. Another example is GlobeChina, covering

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31 Chinese provinces/municipalities and 190 regions in total. GlobeUK and GlobeDE disaggregate UK and Germany respectively to NUTS-2 regions.

The TERM (The Enormous Regional Model) methodology has been used to generate bottom-up regional models of single countries. Bottom-up models treat regions of a country as a group of separate economies connected by trade in goods and services and by flows of capital and labor. Databases of TERM models are formed mainly by splitting national input-output databases. Regional accounts data and actual trade by port data provide splitting shares to the sub-national level. A modified gravity formulae computes estimates of interregional trade flows.

The task detailed in this study is how we move from a single country TERM to a multi-country database and model with sub-national detail. In extending a TERM approach to cover multiple countries, we aim to preserve the national detail in GTAP, including international trade, trade taxes and international trade margins. Sub-national data are treated as shares of original national data to avoid over-riding national totals.

1.1 An outline of single country TERM applications

The Enormous Regional Model (TERM) advanced sub-national multi-regional CGE modelling by depicting more sectors and regions than earlier models. The first application of TERM was to analyse the Australian drought of 2002-03. The model includes 38 sectors and 45 bottom-up regions (Horridge et al., 2003). This level of regional detail enabled authors to distinguish between urban regions that were relatively unaffected by drought, and agricultural regions in which there were marked falls in income.

Since the initial application, TERM models have been developed for many countries, including Austria, Brazil, Canada, China, Finland, Germany, Italy, Japan, Indonesia, Korea, New Zealand, Poland, South Africa, Sri Lanka, Sweden, United States and Vietnam. The applications of TERM-based models have proliferated.

In Australian applications, the number of regions depicted in the master database has grown to over 300 regions by census data (Wittwer and Horridge, 2010). Modifications include the addition of dynamic theory and additional theory to deal with water allocation in irrigation sectors (Dixon et al., 2011; Wittwer, 2012). Further drought studies have included Wittwer and Griffith (2012), Wittwer (2019) and Wittwer and Waschik (2021), the latter including the impacts of bushfires. Other analyses of agricultural issues include Wittwer et al. (2005a) and Wittwer et al. (2006), covering a hypothetical crop disease outbreak, and Wittwer et al. (2005b) investigating the effects of improved weed management. Wittwer and Banerjee (2015) examined irrigation infrastructure scenarios. Wittwer (2009) and Qureshi et al. (2012) analysed urban water scenarios. Anderson et al. (2010) examined trade policy scenarios. Wittwer and Anderson (2021) analysed COVID impacts on Australia's wine market and regions. Grafton and Wittwer (2022) outlined climate change impacts. Wittwer (2024a), using an early version of GlobeTERM, detailed bilateral tariff scenarios.

Brazilian applications have covered land use change (Carvalhoa et al., 2017; Ferreira Filho et al., 2015; Ferreira Filho and Horridge, 2017; Ferreira Filho and Horridge, 2021; Tanure et al., 2020) and agricultural scenarios (Ferrarini et al., 2019; Ferrarini et al., 2020; Ferreira Filho and Horridge, 2015; Ferreira Filho and Horridge, 2020; Silva et al., 2017; Stocco et al., 2020;). Other studies have examined government funding of regions (Riberio et al., 2017; Riberio et al., 2019) oil spill impacts (Riberio et al., 2020), biofuel scenarios (Giesecke, et al., 2009), income distribution (Ferreira Filho and Horridge, 2006a; Ferreira Filho et al., 2010) and trade policy scenarios (Ferreira Filho and Horridge, 2006b).

Applications in China include Horridge and Wittwer (2008), Wittwer and Horridge (2009), Lee and Lin (2015) and Feng et al. (2018). Wittwer and Horridge (2018) extended the regional representation from 31 provinces/municipalities to 365 prefectures.

Finnish applications include analysis of energy scenarios (Peura at al., 2018), forestry (Kujala et al., 2017), hunting tourism (Matilainen et al., 2016), extreme weather events (Simola et al., 2011) and transport investment (Metsäranta et al., 2014). Törmä et al. (2015) examined mining impacts in the context of an environmental accident. Another study examined the impacts of public funding in small towns (Törmä 2008).

TERM modelling studies in Poland have covered major transport infrastructure investments (Rokicki et al., 2021) and R&D impacts (Zawalińska et al., 2017). Horridge and Rokicki (2017) examined the impact of European Union accession on regional incomes.

Horridge and Wittwer (2006) used IndoTERM, the Indonesian version of TERM, to examine the regional impacts of higher energy prices. Horridge et al. (2006) examined the impacts of the national rice import policy on West Java. Pambudi and Smyth (2008) undertook foreign investment scenarios, and Pambudi et al. (2009) analysed the economic aftermath of Bali bombing. Horridge et al. (2015) modelled efficiency improvements at a major port. A study modelling major road and sea transport efficiency improvements followed (Horridge et al., 2016). Other studies include analysis of a moratorium on palm oil expansion (Yusuf et al., 2017) and energy scenarios (Hartono et al., 2021; Patunru and Yusuf, 2016; Yusuf et al., 2017)

The first short course with a TERM model relied heavily on the efforts of Jan van Heerden, using a South African database (see https://www.copsmodels.com/term.htm#Training). Applications in South Africa include analysis of a value-added tax increase (Roos et al., 2019) and energy transition scenarios (Bohlmann et al., 2019).

Wittwer (2017a) documents USAGE-TERM. There has been ongoing demand for analysis using the model from within federal departments in Washington DC.

Applications have included civil disruption (Dixon et al., 2017a; Dixon et al., 2017), Californian drought (Wittwer, 2015), an illustrative tourism scenario (Wittwer 2019, chapter 6) and a foot and mouth scenario (Wittwer, 2024b).

The strategy and methodology for devising a TERM database, outlined in Horridge (2011), is reproducible. GEMPACK software plays an integral role in devising massive multi-regional databases (Horridge et al. 2019). The website archive https://www.copsmodels.com/archivep.htm, in addition to including databases for TERM models for many countries, contains an array of items dealing with database preparation and balancing, for national ORANIG-style models and TERM-style models[1].

2. Initial multi-country sub-national efforts and evolving GlobeTERM

Mark Horridge in 2010 prepared an example of adding top-down sub-national detail to GTAP[2]. Models combining bottom-up sub-national detail combined with GTAP followed. An early example of such a model covered 30 regions in China and three regions in the rest of the world with 26 sectors (Zhang et al. 2013). An updated model represents China's provinces and 4 regions covering the rest of the world in 22 sectors with dynamics (Peng et al., 2025). A US application combined IMPLAN state-level data and GTAP data for 15 US regions plus 15 international regions and 15 sectors (Caron et al., 2015). Rutherford and Schreiber (2019) based US detail on a 71 sector sub-national database covering 51 US regions. The data were linked to 43 sector and 32 sector aggregations of GTAP covering 21 international regions. Each of these models included energy accounts and theoretical modifications to enable substitution between different types of electricity. In each case, the GTAP database was aggregated in the regional and sectoral dimensions.

Countryman et al. (2016) kept almost all the regions in GTAP 9.1 other than composites disaggregated to prepare a master database covering 120 countries plus a composite rest of world region and 51 US regions. 31 sectors were represented in the master database, the level at which BEA and GTAP 9.1 sectors concord. In a Canadian application, Lysenko et al. (2015) aggregated GTAP to 19 sectors to harmonize with Canadian provincial tables available at the time.

Each of the sub-national representations above relied on either sub-national input-output tables or national accounts data to split one country into sub-national regions. The TERM approach uses such data as control totals at the sub-national level, but supplements these sources with other data, including small region census data on industry employment, and agricultural and mining output data at

[1] Items TPMH0047 and TPMH0058 at this archive link concern ORANI-G databases. Items TPMH0168 and TPMH0182 detail creation and balancing of TERM databases. TMGW0214 details the programs used to create GlobeTERM.

[2] See https://www.copsmodels.com TPMH0100.

the small region level. The methodology enables the practitioner to split regions below the provincial or state level at which national accounts data are available. The aim is to work with the maximum possible level of sectoral disaggregation.

An initial effort to represent sub-national, bottom-up detail in a multi-country model using the TERM methodology concerned Australia and New Zealand, based on separate TERM databases. The combined master database included 132 sectors in 88 Australian regions and 17 New Zealand regions. This harmonized disaggregated national CGE databases for both countries, combined with bilateral, international trade data[3]. This approach has one advantage, in that it has a high level of sectoral and sub-national regional disaggregation. A disadvantage is that it deals only with two countries. Moreover, harmonizing sectors from two separate national databases is a non-trivial task.

Preparation of a NUTS-2 European version of TERM followed (Wittwer, 2022). It was apparent that the most efficient starting point for devising the European NUTS-2 database is to use an existing multi-country database, namely GTAP[4]. The alternative would be to revisit efforts already undertaken by contributors to the GTAP Data Base in processing Eurostat input-output tables, fitting international trade data and balancing the database. Once more than two countries are considered in the database, the restriction to 65 GTAP sectors, or 74 in the GlobeTERM case, is a minor disadvantage relative to the advantages of using an existing resource.

The European model was the first version of GlobeTERM. It was not global, in that the GTAP Data Base was aggregated to include separate European regions plus a Rest of World region. The latter was excluded from the endogenous regions in the model. That is, exports from European countries to the Rest of the World appeared in an export array in the database and model. Imports from the Rest of the World to European appeared in an import slice in the trade array. Trade between Rest of the World countries, plus producer and user transaction for these regions, were omitted from the database and model. Wittwer (2024a) presents a dynamic, but truncated version of GlobeTERM (that is, with some countries omitted from the model) with regional disaggregation applied to Australia.

While modeling with truncated GlobeTERM in many applications may be defensible, there may be some scenarios in which a truly global GlobeTERM is preferable. In truncated GlobeTERM applications, a Rest of World region varies from aggregation to aggregation. Some of the assumptions concerning the exogenous rest of world in single country models such as ORANIG (Horridge 2006), or TERM may become less defensible as the ratio of economic activity in the endogenous part of the model rises relative to that in the exogenous rest of the world. For example, the default in these models is that import supplies are

[3] See https://www.copsmodels.com/archivep.htm tpgw0199.

[4] https://www.gtap.agecon.purdue.edu/databases/default.asp

infinitely elastic, which may make little sense if the Rest of the World composite region excluded from truncated GlobeTERM is a small share of global economic activity. Moreover, an exogenous Rest of the World region enables the nominal exchange rate relative to this region to be exogenous. In many applications, this may be of little importance. But this would become a perilous assumption if, for example, the only economy omitted from the endogenous part of the model was Comoros.

The version of GlobeTERM presented here has several enhancements relative to earlier versions. First, there is an explicit effort to preserve international trade data, splitting it between sub-national origins (for exports) or sub-national destinations (for imports). There are four quadrants in the trade array of GlobeTERM, namely (1) intra-domestic, (2) sub-national exports to other countries, (3) sub-national imports from other countries and (4) international trade between other countries. The modified gravity estimator used in devising the trade array in TERM is confined to the first quadrant described above. The second quadrant uses regional export shares to split sales to other countries, the third uses regional import shares to split purchases from other countries and the fourth quadrant retains the original international trade data of GTAP.

Other enhancements in GlobeTERM include adding destinations to export taxes and origins to import taxes. The single country TERM model does not include bilateral international trade or tax details, and therefore is not suitable for examining, for example, the impacts of bilateral and retaliatory tariff shocks. That is, the advantages of GlobeTERM over TERM are analogous to the advantages of GTAP over a single country model. International transport margins from GTAP are now included in GlobeTERM.

3. Preparing a TERM-style database

3.1 Reconfiguring the GTAP Data Base

Mark Horridge of the Centre of Policy Studies has devised coding that puts almost all transactions in the core master GTAP Data Base (version 6 format) into three data arrays (accessible at https://www.copsmodels.com/msplitcom.htm)[5]. These are shown in Table 1. The advantage of this configuration is that it simplifies the task of moving these data to a TERM-style database.

[5] A program to convert format version 7 of GTAP to version 6 and vice versa is downloadable from https://www.copsmodels.com/archivep.htm TPMH0203.

Table 1. GTAP represented in three data arrays

Coefficient	Dimensions
NAT(c,s,u,r,t)	c∈COST, s∈SRC, u∈USER, r∈REG, t∈TYP
MAKE(c,j,r)	c∈COM, j∈IND, r∈REG
TRADE0(f,c,r,d)	f∈FTYP, c∈COM, r∈REG, d∈REG

Source: Author's inference; see footnote 5.

NAT includes all intermediate costs, where COM is the commodity subset of COST. The TYP set includes basic values "BAS" and indirect taxes "TAX". NAT includes primary factors as subset of COST, including capital rentals (CAP), different labor occupations (LAB), land and natural endowments. COST also includes production taxes. The "TAX" element of TYP includes indirect taxes for commodities. For factors, GTAP provides a split between "BAS" and "TAX". In preparation of GlobeTERM, we add "BAS" and "TAX" to provide the costs to industries of using factors. The set SRC includes domestic ("dom") and imported ("imp") elements. In the USER dimension, NAT includes sales to intermediate users in industries (IND) plus final users, namely households, investment and government spending. Some slices within the NAT array are empty: the factors are limited to the "dom" slice of SRC.

The MAKE array details the value of commodity output by each industry. In the case of the GTAP Data Base, each industry produces a unique commodity so the MAKE array for each national slice is diagonal.

The TRADE0(f,c,r,d) array details bilateral trade flows between all nations in the database for 65 commodities. FTYP identifies basic transactions ("bas"), three international transport margins for land, water and air, and two trade taxes, export taxes ("exptax") and import taxes "imptax." In TRADE0, REG r refers to the country of origin and REG d to the destination.

3.2 Formatting national data to TERM data matrices

A TERM-style database consists of the matrices shown in Table 2. In this step, GTAP data are converted to the TERM format for nation n. This task may use a two-region version of GTAP, aggregated to the country of interest and the rest of the world. GTAP data from the arrays in Table 1 can be formatted to TERM arrays in Table 2 using the formulae that follow. First, the domestic and imported slices of the USE array are calculated:

Table 2. Core TERM data arrays for nation n (starting database for construction of TERM model)

Array	Dimensions	Description
CAP(j,n)	j∈IND, n∈REG	Rentals to capital: industry j, region n
LAB(j,o,n)	j∈IND, o∈OCC, n∈REG	Wages: occupation o, industry j, region n
LND(j,n)	j∈IND, n∈REG	Rentals to land: industry j, region n
PTX(j,n)	j∈IND, n∈REG	Production taxes: industry j, region n
USE(c,s,u,n)	c∈COM, s∈SRC, u∈USR, n∈REG	User value of commodity c sold to user u in region n at basic prices
TAX(c,s,u,n)	c∈COM, s∈SRC, u∈USR, n∈REG	Tax on commodity c sold to user u in region n
INVEST(c,j,n)	c∈COM, j∈IND, n∈REG	Expenditure at purchasers' prices on c for capital creation in j in nation n
STOCKS(c,n)	c∈COM, n∈REG	Inventory adjustment for c in region n
TRADE(c,s,o,n)	c∈COM, s∈SRC, o∈REG, n∈REG	Basic value of trade flows of c from source s from o to n
TRADMAR(c,s,m,o,n)	c∈COM, s∈SRC, m∈MAR, o∈REG, n∈REG	Basic value of margin m to facilitate flows of c from source s from o to n
SUPPMAR0(m,o,n,p)	m∈MAR, o∈REG, n∈REG, p∈REG	Basic value of margin m produced in p to facilitate flows from o to n

Source: Horridge (2011).

$$USE(c, "dom", u, n) = NAT(c, "dom", u, n, "bas") \tag{1}$$

$$\begin{aligned} USE(c, "imp", u, n) &= NAT(c, "imp", u, n, "bas") \\ &+ \sum_{o \neq n} USHRIM(c, u, n).\,[TRADE0("exptax", c, o, n) \\ &\qquad + \sum_{m \in int\, m} \sum_{o \neq n} TRADE0(m, c, o, n)], \\ &for\ c \in COM, u \in USR, n \in REG. \end{aligned} \tag{2}$$

The need for separate calculations for the domestic and imported slices of USE reflects a difference between a single country and multiple country database. In a single country database, there is no information on export taxes imposed in the import origin or on international transport margins (set INTM, a subset of MAR). These are added to the import value to calculate the equivalent of a single country transaction.

In (2), the user share USHRIM is:

$$\begin{aligned} USHRIM(c, u, n) &= \frac{USE(c, "imp", u, n)}{\sum_{uu} USE(c, "imp", uu, n)}, \\ &for\ c \in COM, u \in USR, n \in REG. \end{aligned} \tag{3}$$

The set USR shown in Table 2 differs from set USER in Table 1 in that it includes exports ("exp") as a final user. In a single country TERM database, exports at basic prices are:

$$USE(c,\text{"}dom\text{"},\text{"}exp\text{"},n) = \sum_{d \neq n} TRADE0(\text{"}bas\text{"},c,n,d), \quad for\ c \in COM, n \in REG. \tag{4}$$

Note that USE(c,"imp","exp",n)=0.

Each USE transaction is accompanied by a commodity tax:

$$TAX(c,s,u,n) = NAT(c,s,u,n,\text{"}tax\text{"}), \quad for\ c \in COM, u \in USR, n \in REG. \tag{5}$$

Export taxes are:

$$TAX(c,\text{"}dom\text{"},\text{"}exp\text{"},n) = \sum_{d \neq n} TRADE0(\text{"}tax\text{"},c,n,d), \quad for\ c \in COM, n \in REG. \tag{6}$$

As above:

$$TAX(c,\text{"}imp\text{"},\text{"}exp\text{"},n) = 0, for\ c \in COM, n \in REG. \tag{7}$$

Primary factor rentals are calculated from the subset of primary elements of the COST set:

$$CAP(j,n) = \sum_{t \in TYP} NAT(\text{"}cap\text{"},\text{"}dom\text{"},j,n,t), \tag{8}$$

$$LND(j,n) = \sum_{t \in TYP} NAT(\text{"}lnd\text{"},\text{"}dom\text{"},j,n,t) + \sum_{t \in TYP} NAT(\text{"}natres\text{"},\text{"}dom\text{"},j,n,t), \tag{9}$$

$$PTX(j,n) = NAT(\text{"}ptax\text{"},\text{"}dom\text{"},j,n,\text{"}tax\text{"}), \quad for\ j \in IND, n \in REG \tag{10}$$

Note that $NAT(\text{"}ptax\text{"},\text{"}dom\text{"},j,n,\text{"}bas\text{"}) = 0$.

Labor costs include the five labor occupations within GTAP, where OCC is the occupational subset of COST:

$$LAB(j,o,n) = \sum_{t} NAT(o,\text{"}dom\text{"},j,n,t), \quad for\ j \in IND, o \in OCC, n \in REG \tag{11}$$

The treatment of investment in TERM differs from GTAP. Whereas standard GTAP has investment with identical commodity composition distributed over all industries, there is provision within TERM for the composition of investment to vary across industries, represented by a satellite investment array. Dixon et al. (2019) and van der Mensbrugghe (2025) have added specific industry capital and investment to versions of GTAP. We expect that investment in the livestock industry, for example, would include own-inputs. Investments in health might include substantial investments in amenities. Data from statistical agencies on investment composition by industry is scarce. INVEST is calculated as:

$$INVEST(c,j,n) = \sum_{t \in TYP} \sum_{s} NAT(c,s,\text{"}inv\text{"},n,t) \, . \left(\frac{CAP(j,n)}{\sum_{jj} CAP(jj,n)} \right) , \quad for\ c \in COM, j \in IND, n \in REG \tag{12}$$

At present, the feature of industry-specific commodity mixes in investment remains undeveloped in GlobeTERM. Adjustments to the commodity composition of INVEST by industry could be undertaken at this stage. However, this would require adjustments to core data which do not, for example, include livestock as an investment commodity.

The internationally traded cells in TRADE array at basic prices are based on the non-diagonal elements of all FTYP slices of the TRADE0 array:

$$TRADE(c,\text{"}imp\text{"},r,n) = \sum_{f} TRADE0(f,c,r,n) , \quad for\ f \in FTYP, c \in COM, r \in REG, n \in REG, r \neq n. \tag{13}$$

The diagonal elements of TRADE are:

$$TRADE(c,\text{"}dom\text{"},n,n) = \sum_{u \in USER} USE(c,\text{"}dom\text{"},u,n) , \quad for\ c \in COM, n \in REG. \tag{14}$$

Note that TRADE(c,"imp",n,n) =0.

The MAKE array is unchanged from Table 1, and STOCKS are zero in the original data. At this stage, domestic margins demand TRADMAR and margins supply SUPPMAR0 are zero. That is, at this point, the TRADE array includes the value of domestic margins. Next, domestic margins are separated to populate TRADMAR.

3.3 Splitting domestic margins sectors into direct and margins usage

The domestic margins in GlobeTERM are trade (wholesale & retail), land transport, air transport, water transport and electricity transmission & distribution. Whereas trade and transport margins apply to all merchandise commodities, the electricity margins apply only to sales of generated electricity (see section 6.1).

This treatment of margins in the single country case assumes that margins are supplied within the country rather than imported. The GTAP version 11c database includes transport margins that are assigned to international trade. GlobeTERM includes both domestically supplied margins, created by splitting direct use of margins commodities, and the international transport margins of GTAP. The latter are most important in the case of international shipping, dominating margins activity within the water transport sector.

Concerning domestic margins, the default assumption in preparing GlobeTERM is that 80% of wholesale & retail trade activity by user is assigned as a margin rather than direct usage. For domestic land and water transport, the margins share is 70%, for air transport 20% and electricity distribution, 90%. If better information on margins shares emerges, we can alter the program used to create margins. For example, a lower land transport margins share may be appropriate for households than other users. Alterations to margins may be necessary in specific projects dealing, for example, with transport issues. An alternative is to develop a CGE model specifically to analyze transport (Dixon et al., 2017; Taylor and Waschik, 2022).

The transfer of domestic margins from TRADE(m,s,r,n) adds a margin (MAR) dimension to each transaction (i.e., TRADMAR(c,s,m,r,n)). By assumption, margins on all transactions other than known international transport costs are domestically sourced. Although the USE array is not altered to separate margins, moving values from margins commodities in TRADE to TRADMAR starts with estimates of a split of USE into direct and indirect transactions. In the following, P(m,u) is the share of the basic value of domestic commodity m that is a margin on the delivery of commodities to u within the nation. For example, 70% of land transport services are allocated as margins use (i.e., P("landtrans",u)= 0.7). DUSE is direct use, and MUSE is the margins use of a margins commodity:

$$DUSE(m,\text{"}dom\text{"},u,n) = (1 - P(m,u)).USE(m,\text{"}dom\text{"},u,n), \quad (15)$$

$$\begin{aligned} &MUSE(m,u,n) = P(m,u).USE(m,\text{"}dom\text{"},u,n), \\ &for\ m \in MAR, s \in SRC, u \in USR, n \in REG \end{aligned} \quad (16)$$

For non-margins, DUSE(c,s,u,n)=USE(c,s,u,n). Next, margins use (MARGIN) is allocated to merchandise commodity transactions (MERCH, a subset of COM)[6]. This requires judgments on the proportion of the margin allocated to each sale. The simplest assumption is that a merchandise commodity's value share of total merchandise sales is equal to its margin share. A commodity weighting W is added to reflect, for example, differences in transport costs per unit value. With the simplest assumption, W=1 for all commodities:

[6] Since electricity distribution is a margin, it is allocated to electricity generation sales by user. This requires similar calculations to the merchandise subset.

$$\begin{aligned} &MARGIN(c,s,u,m,n) \\ &\quad = MUSE(m,u,n).W(c).DUSE(c,s,u,n) \\ &\quad / \left(\sum_d \sum_t W(c).DUSE(d,t,u,n) \right), \\ &for\ c \in MERCH, m \in MAR, s \in SRC, u \in USR, n \in REG. \end{aligned} \tag{17}$$

Shares of trade by origin (TRADShr) are used to allocate domestic margins:

$$TRADShr(c,s,r,n) = TRADE(c,s,r,n) / \sum_o TRADE(c,s,o,n) \tag{18}$$

$$\begin{aligned} &TRADMAR(c,s,m,r,n) \\ &= TRADShr(c,s,r,d). \sum_{u \in USR} MARGIN(c,s,m,u,n), \\ &for\ m \in MAR, c \in MERCH, s \in SRC, r \in REG, n \in REG. \end{aligned} \tag{19}$$

The TRADE array for the MAR subset is modified:

$$\begin{aligned} &TRADE(m,"dom",n,n) \\ &\quad = \sum_{u \in USER} USE(c,"dom",u,n) \\ &\quad - \sum_r \sum_s \sum_c TRADMAR(c,s,m,r,n), \\ &for\ m \in MAR, c \in MERCH, s \in SRC, r \in REG, n \in REG. \end{aligned} \tag{20}$$

The supply of domestic margins, SUPPMAR0 is set equal to TRADMAR (i.e., demand) summed across commodities and origins:

$$\begin{aligned} &SUPPMAR0(m,n,n,n) = \sum_r \sum_c \sum_s TRADMAR(c,s,m,r,n), \\ &for\ m \in MAR, n \in REG. \end{aligned} \tag{21}$$

Since there is only one domestic region, no distribution of domestic SUPPMAR0 across different regions is necessary at this stage.

Finally, STOCKS equal zero in the GTAP Data Base.

3.4 Preparing for GlobeTERM

A broad overview of the differences between the GTAP and original TERM database structure is that GTAP is global, whereas TERM representation is for a single country. This implies that within GTAP, all exports sales from a given country are assigned to a destination in which demands are endogenous. All imports are supplied by other countries with endogenous production functions. This contrasts with TERM, in which export sales are not assigned a specific country destination: prices are determined by down-sloping export demand curves rather than endogenous demands in other countries. Similarly, import supplies in TERM are exogenous and usually assumed to be infinitely elastic in the absence of import supply theory.

In the three data array reconfigured version of the core GTAP Data Base, the NATIONAL array includes domestic and imported slices (Table 1). The import slice corresponds to the sum of origins in the TRADE0 array, which has zero or near zero diagonal elements. The USE array in TERM, covering the flow details other than taxes of the commodity subset of the COST set in the GTAP NATIONAL array, has an import slice which corresponds to the import slice of the TERM TRADE array.

Table 3. Standard TERM v. GlobeTERM

	Standard TERM	*GlobeTERM*
1	Single country, multiple sub-national regions	Multi-country, multiple sub-national regions
2	Identical technologies (cost structures) in industries across all regions	Technologies vary across nations; identical technologies at sub-national level within nations
3	International trade data split using shares based on ports	International import data split using sub-national demand shares + limited port data; export data split using supply shares/port data
4	Single import source in USE array	All imports are from regions endogenous to the model, implying no "import" slice
5	Inter-regional trades estimated using modified gravity assumption	Inter-regional trades estimated using modified gravity assumption: if multiple countries are sub-national, as in the European variant, GTAP trade data provide control national totals
6	Two tiers of trade: International, sub-national	Single trade array identifying origin and destination

Source: Author.

It follows that to convert TERM to GlobeTERM, the distinction between domestic and import slices could be removed. The GTAP convention is to keep domestic flows array distinct from an international trade array. This implies that the diagonal elements of the latter are empty prior to aggregation. The GlobeTERM method which follows combines these arrays eventually by filling the diagonal elements with own-country flows.

Table 3 summarises differences between national inputs into a single-country TERM database and a multi-country GlobeTERM database.

In devising GlobeTERM, we aim to provide a multi-regional, sub-national database, based closely on the existing TERM database generation process. Our aim is to devise a reproducible methodology. The use of modified TERM database generation programs and theoretical structure limits the modifications required to implement GlobeTERM.

3.5 Modifying single country TERM to represent all GTAP regions

In moving to a multi-country GlobeTERM framework without sub-national representation, Table 3 row 6 is where modifications start prior to splitting the database into sub-national regions. The export column, which in TERM represents exports to regions outside the model, will disappear when the model is global. The import slices, which represent purchases from regions outside the model, will also disappear. Note that in (13) and (14), the single region version of TERM populates mutually-exclusive cells in the domestic and import slices of the TRADE array. That is, for exposition, we can keep the domestic v. import distinction, but all the transactions could be reported without loss of information by dropping this distinction.

Now, we may think of modifications using the full 160 region GTAP version 11c. When we prepare a multi-country version, (13) is modified, with TRADE now excluding international trade margins and export taxes.

$$TRADE(c,"imp",r,n) = TRADE0("bas",c,r,n), \quad for\ c \in COM, r \in REG, n \in REG, r \neq n. \tag{22}$$

The export column calculated in (4) no longer applies. Instead, exports appear in the TRADE array in the import slice with 160 origins and 160 destinations, as in (22).

Export taxes (EXPTAX) and import taxes (IMPTAX) now appear in new arrays:

$$EXPTAX(c,r,n) = TRADE0("exptax",c,r,n), \tag{23}$$

$$IMPTAX(c,r,n) = TRADE0("imptax",c,r,n), \quad for\ c \in COM, r \in REG, n \in REG, r \neq n. \tag{24}$$

International transport margins TRANMAR, denoted by set INTM, a subset of MAR, are:

$$TRANMAR(c,m,r,n) = TRADE0(m,c,r,n), \quad for\ m \in INTM, c \in COM, r \in REG, n \in REG, r \neq n. \tag{25}$$

4. Generating a GlobeTERM database: GlobeUSA example

4.1 Sub-national data sources

Splitting a national database into regions following the TERM methodology requires regional production shares (R001), household and government consumption shares (R003 and R005) and international trade shares (exports R004 and imports MShr) of national activity. In addition to these regional estimates, the TERM procedure requires an array of bilateral distances between sub-national regions. This is necessary for estimating sub-national trades using a modified gravity assumption. Latitude and longitude coordinates are readily available for most sub-national regions and countries from online searches. Relative distances can be computed either with a "flat earth" assumption, which loses accuracy when calculations involve a large range of latitudes, or by accounting for the earth's curvature[7].

Wittwer (2024b), in analyzing a hypothetical US outbreak of foot and mouth disease in livestock, details the preparation of a US version of TERM (USAGE-TERM), which included disaggregated agricultural detail suitable for mapping to the 74 sectors of GlobeTERM. The sources for regional activity estimates for USAGE-TERM include USDA Census of Agriculture data (see https://quickstats.nass.usda.gov/), international trade data by port for regional export and import shares (https://usatrade.census.gov/) and the Global Power Plant Database (see footnote 9). US Energy Information Administration provides updated coal mining data by county (www.eia.gov/coal/data.cfm). BEA released county level data with four-digit NAICS industry detail for 2010. The corresponding 2020 census data provided only two-digit NAICS and consequently were not used in the most recent USAGE-TERM preparation. However, BEA provided GDP estimates for each county, used to scale local economic activity estimates (see https://www.bea.gov/data/gdp/gdp-county-metro-and-other-areas).

In addition, BEA national accounts data at the state level provide control totals at a relatively broad sectoral level. BEA also provide some state level household expenditure estimates to which we can scale initial spending values by region (from https://www.bea.gov/data/consumer-spending/state). An array of regional activity estimates covers over 400 sectors at the county level. These shares are aggregated in creation of the master database of USAGE-TERM, with an emphasis on agricultural and food processing activities, to 170 sectors.

In preparing USAGE-TERM, county level activity estimates are aggregated to 321 USDA Farm Resource region and 26 non-agricultural rest of state regions. In GlobeTERM, the 347 regions of USAGE-TERM are aggregated to 151, preserving USDA regions in states of the Mid-West plus California. Sectoral shares are aggregated to 74 sectors in preparation for database splitting. Given that the regional data are not overriding national data, there is little complication in relying on regional estimates from different years. Both farm census data and national accounts data align with 2017, the year of version 11c of GTAP.

[7] A GEMPACK version of the latter is available at https://www.copsmodels.com/archivep.htm TPMH0180.

4.2 Splitting the multi-region national database into sub-national regions

There are modifications to the initial TERM splitting procedure when applied to GlobeTERM. First, nations are divided into those that are split and those that are not. In the US case, USA is split into 151 regions following the usual TERM procedure. For the 159 nations/regions in the GlobeUSA example that are not split, most of the data reconfigured from the NATIONAL array, as in section 2.2, are copied to the initial sub-national database without change. For convenience, each array of regional shares carries three dimensions: (1) Industry or commodity; (2) region and (3) nation. For "USA", there are 151 regions.

Industry splits use R001 shares. In sub-national region (SR) r in nation n (REG1, a subset of REG where sub-national detail is prepared), the splits for capital (CAPR), land (LNDR), labor (LABR), production taxes (PTXR) and MAKE (MAKR) are:

$$CAPR\big(j,n(r)\big) = R001\,(j,r,n).\,CAP(j,n),\\ for\ i \in IND, n(r) \in SR(n). \tag{26}$$

$$LNDR\big(j,n(r)\big) = R001\,(j,r,n).\,LND(j,n),\\ for\ i \in IND, n(r) \in SR(n). \tag{27}$$

$$LABR\big(j,o,n(r)\big) = R001\,(j,r,n).\,LAB(j,o,n),\\ for\ i \in IND, o \in OCC, n(r) \in SR(n). \tag{28}$$

$$PTXR\big(j,n(r)\big) = R001\,(j,r,n).\,PTX(j,n),\\ for\ i \in IND, n(r) \in SR(n). \tag{29}$$

$$MAKR\big(c,j,n(r)\big) = R001(j,r,n).\,MAKE(c,j,n),\\ for\ i \in IND, n(r) \in SR(n). \tag{30}$$

In (26) to (29), we assume that industry j has the same technology in all sub-national regions of nation n. In the case of regional electricity generation, this assumption is not used. Section 6 outlines the disaggregation of electricity generation, enabling different generating technologies in different regions.

The allocation of margins in (15) and (16) results in a split of the USE array into direct (DUSE) and margins (MUSE) arrays. User share (USh(c,s,u,r,n)) estimates split both arrays into sub-national components. For the industry subset of users, the user share is equal to R001. These shares also split the INVEST array. Among final users, household shares equal R003 and government shares R005. The split for all users is:

$$DUSER0\big(c,s,u,n(r)\big) = USh(c,s,u,r,n).\,DUSE(c,s,u,n),\\ for\ c \in COM, s \in SRC, u \in USR, n(r) \in SR(n). \tag{31}$$

Regional commodity taxes (TAXR0) and margins (MUSER0) are calculated as:

$$TAXR0\big(c,s,u,n(r)\big) = USh(c,s,u,r,n).TAX(c,s,u,n),\\ for\ c \in COM, s \in SRC, u \in USR, n(r) \in SR(n). \tag{32}$$

$$MUSER0\big(m,s,u,n(r)\big) = USh(m,s,u,r,n).MUSE(m,u,n),\\ for\ m \in MAR, s \in SRC, u \in USR, n(r) \in SR(n). \tag{33}$$

In the TERM model, following regional splitting, DUSER and MUSER are combined in a single array (USER0).

The national satellite investment array is split using R002:

$$INVESTR\big(c,j,n(r)\big) = R002\,(j,r,n).INVEST\,(c,j,n),\\ for\ c \in COM, j \in IND, n(r) \in SR(n). \tag{34}$$

4.3 Devising the regional trade array

The database at this stage includes sub-national production cost structures, regional household and government consumption by commodity, regional exports by port of exit and regional imports by port. All the splits are consistent with the starting database.

We divide the TRADR0 array (i.e., TRADE array with sub-national detail) in GlobeTERM into four quadrants. For the US case, these are:

1) Sub-national trades between US regions (set SR(n)) and within 159 single region nations (set REG0);
2) Exports from US regions to 159 GTAP regions (sales from SR(n) to REG0);
3) Imports to US regions from 159 GTAP regions (sales from REG0 to SR(n)); and
4) International trade between 159 GTAP regions (REG0).

Since sub-national trades do not pass through customs, comprehensive data is not available on such trades. So how do we deal with the first quadrant? The US Census Bureau prepares the Commodity Flow Survey (CFS). But these data are often incompatible with the trade flows in a CGE database. They concentrate on bulky goods which account for a small proportion of the value of total trade. Beyond including origins and destinations that may align with a multi-regional CGE database, the CFS presents data on throughput at transport nodes. For example, a consignment of grain originating in the Mississippi Valley may be transported to a node where it is loaded onto a hopper for the river journey to New Orleans. There it is loaded onto a ship for export. The main insight from the CFS is that in the US regional case, movement of bulk commodities inside the Mississippi and Snake-Columbia Valleys relies on water transport, whereas elsewhere reliance is almost exclusively on land transport (Wittwer, 2017b). In

USAGE-TERM, bulk commodities are split into two, so that water transport is used in the Mississippi and Snake-Columbia Valleys but not elsewhere (Wittwer 2024b). This split has not been applied to GlobeTERM.

For the first quadrant of TRADR0, the modified gravity method devised by Horridge (2011) estimates inter-regional trade shares (Sh) between US regions. First, we calculate domestic supply (DomSupply) as regional output minus international exports, noting that TRADE is recalculated in (22):

$$\begin{aligned} &DomSupply(c, n(r)) \\ &\quad = \sum_i MAKE(i, c, n(r)) \\ &\quad - \sum_d (R004(c, r, d) . TRADE(c, "imp", r, d)), \\ &for\ c \in COM, n(r) \in SR(n). \end{aligned} \tag{35}$$

An initial share estimate uses a modified gravity formula:

$$\begin{aligned} &Sh(c, n(o), n(d)) \propto \frac{\sqrt{DomSupply(c, o)}}{DIST(o, d)^{k(c)}}, \\ &for\ c \in COM, o \in SR(n), d \in SR(n). \end{aligned} \tag{36}$$

where DIST is the distance between a pair of regions, and k(c) is a commodity-specific parameter assigned a value of between 0.5 and 2.0, increasing for less tradable commodities.

The shares for diagonal cells of each commodity slice of TRADR0 (Sh(c,n(o),n(o))) depend on how tradable a commodity is, being set equal to 1.0 for non-tradable commodities such as housing. In the case of strictly local commodities, regional supply is equal to regional demand. For tradable commodities, a minimum level of local shares Sh(c,o,o) is calculated as regional supply divided by regional demand (DUSE) multiplied by parameter F, with a value between 0.5 (for tradable commodities) and 1.0 (not tradable):

$$\begin{aligned} &Sh(c, o, o) = min\left\{\frac{DomSupply(c, o)}{DUSE(c, "dom", o)}, 1\right\} . F, \\ &for\ c \in COM, o \in SR(n). \end{aligned} \tag{37}$$

Subsequent scaling of this quadrant of the TRADR0 array fits target totals:

$$\sum_o TRADR0(c, "dom", o, d) = \sum_u DUSE(c, "dom", u, d), \tag{38}$$

$$\sum_{d} TRADR0(c,\text{"dom"},o,d) = \sum_{u} DomSupply(c,o), \quad for\ c \in COM, o \in SR(n), d \in SR(n). \tag{39}$$

In GlobeUSA, sub-national trades in this quadrant are calculated as:

$$\sum_{d} TRADR0(c,\text{"dom"},o,d) = Sh(c,o,d) \sum_{u} DUSER0(c,\text{"dom"},u,d), \quad for\ c \in COM, o \in SR(n), d \in SR(n). \tag{40}$$

When splitting the initial database for multiple countries, as in GlobeEuro, the formula for the first quadrant is complicated by availability of international trade data relevant to regions within the quadrant. In (41), H is a binary matrix, equal to 1 for sub-national regions n(r) that are in nation n and 0 otherwise.

$$\begin{aligned} &TRADR0\big(c,\text{"dom"},n(r),n(d)\big) \\ &= H(r,d).Sh(c,n,d).\sum_{u} DUSE(c,\text{"dom"},u,n) \\ &+ \big(1 \\ &- H(r,d)\big).R004(c,r,n).MShr(c,r,d).TRADE(c,\text{"dom"},n,d), \\ &for\ c \in COM, n(r) \in SR(n), n(d) \in SR(d). \end{aligned} \tag{41}$$

Since R004 summed across region r and MShr summed across region d both equal 1.0, international trades at the regional level sum to initial TRADE data from GTAP at the national level in this quadrant.

In the REG0 subset of regions, the domestic slice of the TRADR0 array has only the diagonal elements populated:

$$TRADR0(c,\text{"dom"},r,r) = \sum_{u} DUSE(c,\text{"dom"},u,r), \quad for\ c \in COM, r \in REG0. \tag{42}$$

The second quadrant concerns exports from sub-national regions to nations that remain unsplit. Trades are based on regional export shares (R004), based on port data for merchandise and output shares for services:

$$TRADR0(c,\text{"imp"},n(r),d) = R004(c,r,d).TRADE(c,\text{"imp"},n,d), \quad for\ c \in COM, n(r) \in SR(r), d \in REG1. \tag{43}$$

R004 uses known data. An example of a producer of an export product in a region without ports is East Central-Kansas, a large producer of wheat. The gravity assumption allocates East Central-Kansas’ wheat sales across US regions.

Some wheat will be used domestically, and some may eventually be exported through a port. The latter will appear in the TRADR0 matrix twice, as a sale from East Central-Kansas to the port region, and as part of the port region's sales to a foreign destination.

International transport margins are split from national (TRANMAR) into sub-national regions (TRANMARR):

$$TRANMARR(c,m,o(r),d) \\ = R004(c,r,d).TRANMAR(c,m,o,d), \\ for\ c \in COM, o(r) \in SR(o), o \in REG1, d \in REG0. \tag{44}$$

Export taxes are split similarly:

$$EXPTAXR(c,n(r),d) = R004(c,r,d).EXPTAX(c,n,d), \\ for\ c \in COM, n(r) \in SR(n), d \in REG0. \tag{45}$$

The third quadrant concerns imports to sub-national regions from unsplit nations. MShr refers to import shares, which are by port for merchandise, with a similar double entry, as applies to exports, in the TRADR0 matrix to deal with international imports to regions without ports. TRADR0, TRANMARR and IMPTAXR are calculated as:

$$TRADR0(c,"imp",o,n(r)) \\ = Mshr(c,r,n).TRADE(c,"imp",o,n), \\ for\ c \in COM, o \in REG0, n(r) \in SR(r), \tag{46}$$

$$TRANMARR\big(c,m,o,n(r)\big) \\ = Mshr(c,r,n).TRANMAR(c,m,o,n), \\ for\ m \in INTM, c \in COM, n(r) \in SR(r), o \in REG0, \tag{47}$$

$$IMPTAXR\big(c,d,n(r)\big) = MShr(c,n(r),n).IMPTAX(c,d,n), \\ for\ c \in COM, n(r) \in SR(r), d \in REG, \tag{48}$$

In the fourth quadrant, bilateral trades between unsplit nations are taken from (13) without modification:

$$TRADR0(\boldsymbol{c},"imp",r,n) = TRADE0(\text{bas},c,r,n), \\ for\ c \in COM, r \in REG0, n \in REG0. \tag{49}$$

Similarly, EXPTAXR follows from (23), IMPTAXR from (24) and TRANMARR from (25) and in this quadrant.

The GTAP Data Base also provides the supply of international transport margins by country of origin, denoted VST. The regional supply TSUPMAR is:

$$TSUPMAR\big(m,n(p)\big) = R004(m,p,n).VST(m,n), \\ for\ m \in INTM, n(p) \in SR(n). \tag{50}$$

Next, we calculate regional domestic margins demands (MARGINR0 and MARGINR). These are based on regional user shares of national margins demand:

$$MARGINR0\big(c,s,u,m,n(r)\big) = USh(c,s,u,r,n).MARGIN(c,s,u,m,n), \quad (51)$$
$$for\ c \in COM, s \in SRC, u \in USR, m \in MAR, n(r) \in SR(n).$$

For distance-based margins (subset DMAR), an average distance DISTA is calculated iteratively for each transaction. It first appears in the suite of TERM database generation programs before the TRADER0 array is calculated using regional distance pairs, and then is modified:

$$DISTA(c,s,n(r)) = \sum_{n(d)} DIST(n(d),n(r)).TRADER0(c,s,n(d),n(r)) / \sum_{n(d)} TRADER0(c,s,n(d),n(r)), \quad (52)$$
$$for\ c \in COM, s \in SRC, n(r) \in SR(n).$$

The database generation programs are rerun until the two most recent computations of DISTA are almost identical. Footnote 1 includes links to publicly available TERM database generation programs.

Regional margins demands are modified by a parameter MWGT (a margins weight). This weight increases, for example, the margins requirement on islands. Alaska has larger weight than regions of the bottom 48 states, and Hawaii an even larger weight. The DMAR subset demands are modified:

$$MARGINR\big(c,s,u,m,n(r)\big) = MARGIN0\big(c,s,u,m,n(r)\big).MWGT(n(r),m).\sqrt{DISTA(c,s,n(r))} \quad (53)$$
$$for\ c \in COM, s \in SRC, u \in USR, m \in DMAR, n(r) \in SR(n).$$

For margins that are not distance related (i.e., NMAR=trade margins in GlobeTERM), demand for margins is calculated as:

$$TRADMARR0(c,s,m,n(o),n(d)) = MWGT(n(d),m).Sh(c,n(o),n(d)).\sum_{u} MARGINR0(c,s,m,u,d) \quad (54)$$
$$for\ c \in COM, s \in SRC, m \in DMAR, n(o) \in SR(o), n(d) \in SR(d).$$

For distance-related margins, the margins requirement increases with the square root of the distance between origin and destination:

$$TRADMARR0(c,s,m,n(o),n(d)) = MWGT(n(d),m).Sh(c,n(o),n(d)).\sum_u MARGIN(c,s,m,u,n(d)).\sqrt{DIST(n(o),n(d))}$$
$$for\ c \in COM, s \in SRC, m \in DMAR, n(o) \in SR(n), n(d) \in SR(d). \tag{55}$$

The "dom" and "imp" sources of TRADER0 and TRADMARR0 populate mutually exclusive cells in the origin x destination dimensions. After creation of the database, the sources are combined as the distinction is redundant. The arrays TRADER and TRADMARR include the same data summed over "dom" and "imp" sources. Similarly, VUSER is the sum of USER0 over sources and TAXR the sum of TAXR0 over sources.

The supply of domestic margins SUPPMARR includes three regional dimensions, namely the origin and destination of the good being delivered, plus the origin of the margins. The first pass at estimating SUPPMARR is:

$$SUPPMARR(m,n(o),n(d),n(r)) = 0.5.(Sh(m,n(r),n(d)) + Sh(m,n(r),n(o))).\sum_c TRADMAR(c,m,n(o),n(d)),$$
$$for\ m \in MAR, n(o) \in SR(n), n(d) \in SR(n), n(r) \in SR(n). \tag{56}$$

Subsequent scaling ensures that SUPPMAR sums to TRADMAR over common dimensions. In order to ease the representation of many regions within GlobeTERM, SUPPMARR is added up over the commodity source origin to create MARSUPP, following modifications prepared by Mark Horridge:[8]

$$MARSUPP(m,d,r) = \sum_o SUPPMARR(m,o,d,r),$$
$$for\ m \in MAR, d \in SR(n), r \in SR(n). \tag{57}$$

4.3 Identities within TERM and GlobeTERM

The VUSER array in TERM/GlobeTERM includes commodity sales by user and region, but not the origin. The TRADER and TRADMARR arrays include the origin and destination of each transaction by commodity, but not the user. Therefore, we require an identity that ensures that the VUSER array summed across users is equal to the trade arrays summed across origins. The inclusion of trade taxes and international trade margins, as shown in section 3.5, are in GlobeTERM but not TERM. First, BORDER is the basic value plus export taxes:

[8] See https://www.copsmodels.com/archivep.htm item TPMH0192.

$$\begin{aligned} &BORDER(c,o,d) \\ &\qquad = TRADER(c,o,d) \\ &\qquad + TRADTAX(c,o,\text{"}exptax\text{"},d), \\ &for\ c \in COM, o \in RREG, d \in RREG. \end{aligned} \tag{58}$$

In (58), the set RREG combines sub-national regions (SR(n)) and unsplit national regions (REG0). The identity linking the use side to the trade side includes import taxes, international transport margins from (43) and domestic margins:

$$\begin{aligned} &\sum_u VUSER(c,u,d) \\ &\qquad = \sum_o (BORDER(c,o,d) \\ &\qquad + TRADTAX(c,o,\text{"}imptax\text{"},d) \\ &\qquad + \sum_m TRADMAR(c,m,o,d) \\ &\qquad + \sum_{tm} TRANMAR(c,tm,o,d)), \\ &for\ c \in COM, u \in USER, d \in RREG. \end{aligned} \tag{59}$$

The identity linking costs components to the industry output array MAKR is unchanged from TERM (Horridge, 2011). Industry costs are:

$$\begin{aligned} &COST(j,d) = CAPR(j,d) + LNDR(j,d) + \sum_o LAB(j,o,d) \\ &\qquad + PTXR(j,d) \\ &\qquad + \sum_c (VUSER(c,j,d) + TAXR(c,j,d)), \\ &for\ j \in IND, d \in RREG. \end{aligned} \tag{60}$$

There are modifications in the identity linking regional commodity demands (DEMANDS) to regional commodity supply. For non-margins (set NONMAR = COM – MAR), the following holds as in TERM:

$$\begin{aligned} &\sum_j MAKR(c,j,d) = \sum_r TRADER(c,d,r) \\ &for\ c \in NONMAR, d \in RREG. \end{aligned} \tag{61}$$

For non-transport margins, the TERM identity also holds:

$$\sum_j MAKR(m,j,p) = \sum_d (TRADER(m,p,d) + MARSUPP(m,d,p)), \quad for\ m \in NMAR, p \in RREG. \tag{62}$$

The identity for transport margin commodities now includes the supply of international transport margins TSUPMAR:

$$\sum_j MAKR(m,j,p) = \sum_d TRADER(m,p,r) + \sum_d MARSUPP(m,d,p) + TSUPMAR(m,p), \quad for\ m \in INTM, p \in RREG. \tag{63}$$

The identity linking domestic margins supply and demand is:

$$\sum_r \sum_c TRADMARR(c,m,r,d) = \sum_p MARSUPP(m,d,p), \quad for\ m \in MAR, d \in RREG. \tag{64}$$

The identity linking the satellite investment matrix to the investment user is also as in TERM:

$$\sum_j INVESTR(c,j,r) = USE(c,"inv",r) + TAX(c,"inv",r), \quad for\ c \in COM, r \in RREG. \tag{65}$$

Finally, the supply of and demand for international transport margins must be equal:

$$\sum_r \sum_d \sum_c TRANMARR(c,m,r,d) = \sum_p TSUPMAR(m,p), \quad for\ m \in INTM. \tag{66}$$

5. Theoretical modifications in moving from TERM to GlobeTERM

Wittwer and Horridge (2018) in Section 3 outline the theory of TERM. Instead of repeating identical equations in TERM here, we confine detail to segments of the theory and national accounting that are altered in GlobeTERM. A global model requires modifications to accommodate global constraints. For example, expenditure-side GDP at the national level does not require the balance of trade to be exogenous and zero. But at the global level, this is a necessary condition. To impose this, national or regional consumption functions require the addition of a scalar (global) shifter. (67) links aggregate nominal consumption (*c*) in region d to aggregate nominal labor income (*wl*), a consumption function shifter (*f*) and λ, a slack variable that accommodates the global constraint. All lower case variables that follow are in percentage change terms unless otherwise specified.

$$c(d) = wl(d) + f(d(n)) + \lambda, \quad for\ d \in RREG, n \in REG. \tag{67}$$

5.1 Prices

At the macroeconomic level, the nominal exchange rate (i.e., relative to the rest of the world) typically is the numeraire in TERM models. This disappears when the rest of world is included in the model. In GlobeTERM, the numeraire may be global CPI (*pgcpi*), which is the share weighted sum of regional CPIs (*pcpi*), where (SHRC) is region *d*'s share of global household consumption. By making λ endogenous, *pgcpi* can be exogenous:

$$pgcpi = \sum_{d} SHRC(d)\, pcpi(d), \quad for\ d \in RREG. \tag{68}$$

The inclusion of supply of and demand for international transport margins requires additional equations. The global composite margins price ptsm_p is the share-weighted sum of region-specific prices inclusive of technological change, where atsm is technological change and pbas the basic (producer) price:

$$TSUPMAR_{P(m)}.\, ptsm\_p(m) = \sum_{p} TSUPMAR(m,p).\,(pbas(m,p) + atsm(m,p)), \quad for\ m \in INTM. \tag{69}$$

Demand for country-specific international transport margins follows a CES form (σ_i is the CES parameter). Global supply is denoted by *xtsm_p*:

$$xtsm(m,p) - atsm(m,p) = xtsm_{p(m)} - \sigma_i(m).\left[pbas(m,p) + atsm(m,p) - ptsm_{p(m)}\right], \quad for\ m \in INTM, p \in RREG. \tag{70}$$

The global sum of international transport margins, where *xtranmar* is the quantity demanded, is:

$$
\begin{aligned}
&TRANMARR\_COD(m).\,xtsm\_p(m) \\
&= \sum_{c}\sum_{o}\sum_{d} TRANSMARR\,(c,m,o,d)\,.\,xtranmar\,(c,m,o,d), \\
&for\ m \in INTM.
\end{aligned} \tag{71}
$$

We distinguish between prices at different points of transaction. The border price *pb* includes export taxes (*xt* is the power of the export tax):

$$
\begin{aligned}
&pb\,(c,o,d) = pbas\,(c,o) + xt\,(c,o,d), \\
&for\ c \in COM, o \in RREG, d \in RREG.
\end{aligned} \tag{72}
$$

The international margins inclusive border price *pcif* for commodity *c* from origin *o* to destination *d* is calculated as:

$$
\begin{aligned}
&VCIF\,(c,o,d).\,pcif\,(c,o,d) \\
&\qquad = BORDER\,(c,o,d).\,pb(c,o,d) \\
&\qquad + \sum_{m} TRANMAR\,(c,m,o,d).\,ptsm\_p(m)\,, \\
&for\ c \in COM, o \in RREG, d \in RREG.
\end{aligned} \tag{73}
$$

The duty-paid price *pduty* includes import taxes (mt is the power of the import tax):

$$
\begin{aligned}
&pduty\,(c,o,d) = pcif\,(c,o,d) + mt(c,o,d), \\
&for\ c \in COM, o \in RREG, d \in RREG.
\end{aligned} \tag{74}
$$

For domestically-sourced goods, there are no international transport margins and no trade taxes, so pduty(c,o,d)=pbas(c,o,d), when *o* and *d* are in the same nation.

The origin-specific delivered price to *pusers, pdlv*, includes domestic margins and international transport margins plus trade taxes. The domestic margins price *psm* calculated as an average of all domestic suppliers is:

$$
\begin{aligned}
&MARSUPP_{P(m,d)}.\,psm(m,d) \\
&\qquad = \sum_{p} MARSUPP\,(m,d,p).\,pbas(m,p)\,, \\
&for\ m \in MAR, d \in RREG\,.
\end{aligned} \tag{75}
$$

The delivered price, which includes a technological shift term for margins (*atm*) is:

$$DELIVRD(c,r,d).pdlv(c,r,d) = DUTYPAID(c,r,d).pduty(c,r,d) + \sum_{m} TRADMAR(c,m,r,d).(psm(m,r,d) + atm(c,m,r,d)) \quad for\ c \in COM, r \in RREG, d \in RREG. \tag{76}$$

In (76), DUTYPAID is the sum of VCIF and import taxes.

5.2 Modifying the source-specific CES equations

In the single-country TERM theory elaborated in Wittwer and Horridge (2018), separate CES equations concern substitutability by source between sub-national and international trades. Sub-national substitution occurs within the TRADE array, where there are not distinct international origins. Substitution between domestic and imported origins occurs in the VUSER array. In general, higher CES parameters are assigned to sub-national than international substitution.

Figure 1 shows the different levels of substitutability within GlobeTERM. The user-composite demands are calculated in three different CES nests. The top CES nest is between a domestic composite and import composite for each commodity by region. Underneath that, there are separate nests for sub-national substitutability between origins and import substitutability between origins. The sub-national nest may apply to one country, as in the US example of GlobeTERM, or many, as in the European version.

The variable $xuse\_u$ is the share-weighted sum of all intermediate and final demand users, where $xuse$ denotes user-specific demands.

$$xuse\_u(c,d) = VUSER(u,c,d) / \sum_{u} VUSER(u,c,d).xuse(u,c,d) \quad for\ c \in COM, d \in RREG. \tag{77}$$

Since nothing is purchased from outside the model, there is no distinction between domestic and imported origins in the VUSER array in GlobeTERM. To allow greater substitutability between domestic sources than between domestic and foreign sources, we modify the theory concerning substitution within the TRADE array. We use the binary H array (equal to 1 for regions within the same nation and 0 elsewhere) to calculate distinct CES price indexes for domestic and foreign goods.

In the following, DELIVRDH is the delivered composite value of goods from domestic sources and puseh its price. The term atrad is a source-specific preference variable.

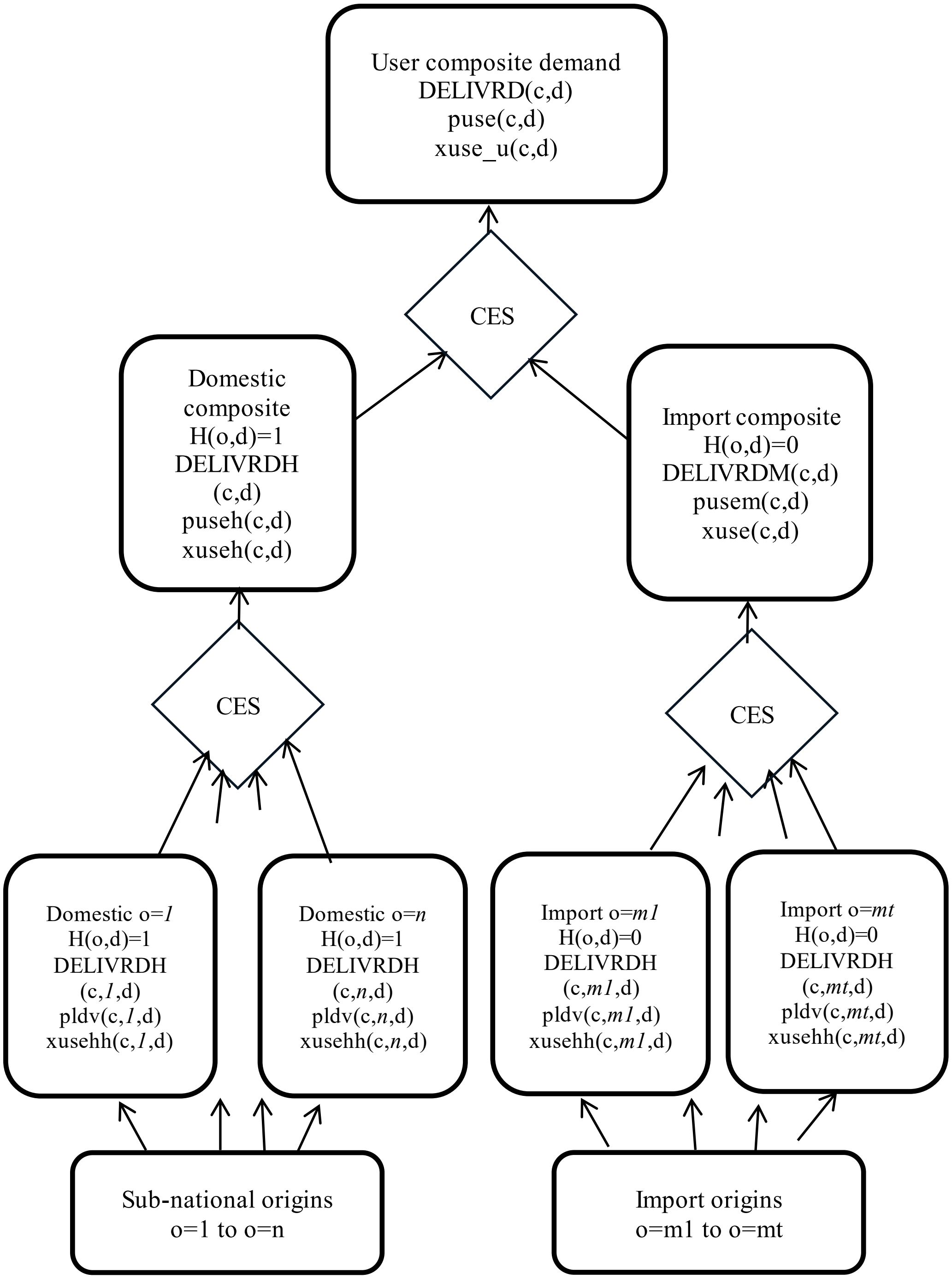

Figure 1. Sourcing of user-composite demands

Source: Author's own figure.

$$DELIVRDH(c,d).puseh(c,d) = \sum_{o} H(o,d).DELIVRD(c,o,d).\left(pdlv(c,o,d) + atrad(c,o,d)\right), \quad for\ c \in COM, d \in RREG. \tag{78}$$

The corresponding price index for imports (*pusem*), where DELIVRDM denotes the composite import value, is:

$$DELIVRDM(c,d).pusem(c,d) = \sum_{o}\left(1 - H(o,d)\right).DELIVRD(c,o,d).(pdlv(c,o,d) + atrad(c,o,d)) \quad for\ c \in COM, d \in RREG. \tag{79}$$

The all-source composite delivered price (*puse*), where DELIVRD is the sum of DEVIVRDH and DELIVRDM, is given by:

$$DELIVRD(c,d).puse(c,d) = DELIVRDH(c,o,d).puseh + DELIVRDM(c,o,d).pusem \quad for\ c \in COM, d \in RREG. \tag{80}$$

CES substitutability between domestic and imported composite follows. The domestic composite commodity is *xuseh* and the imported composite *xusem*. The domestic-import CES parameter is σ_{hm}.

$$xuseh(c,d) = xuse_{u(c,d)} - \sigma_{hm}(c).\left(puseh(c,d) - puse(c,d)\right), \tag{81}$$

$$xusem(c,d) = xuse\_u(c,d) - \sigma_{hm}(c).(pusem(c,d) - puse(c,d)), \quad for\ c \in COM, d \in RREG. \tag{82}$$

In the equation solving for source-specific domestic demands (*xusehh*), σ_h is the CES parameter for substitution between domestic sources.

$$xusehh(c,o,d) - atrad(c,o,d) = H(r,d).(xuseh(c,d) - \sigma_h(c).(pdlv(c,o,d) + atrad(c,o,d) - puseh(c,d))), \quad for\ c \in COM, o \in RREG, d \in RREG. \tag{83}$$

Next, we solve for specific-source import demands *xm*, where σ_m is the CES parameter for substitution between imported sources.

$$xusemm(c,o,d) - atrad(c,o,d) = (1 - H(o,d)).(xusem(c,d) - \sigma_m(c).(pdlv(c,o,d) + atrad(c,o,d) - pusem(c,d))), \quad (84)$$

$$for\ c \in COM, o \in RREG, d \in RREG.$$

The ordinary change in origin-specific export tax revenue (delEXPTAX) is calculated as:

$$delEXPTAX(c,o,d) = 0.01.EXPTAXR(c,o,d).((xtrad(c,o,d) + pbas(c,o)) + 0.01.BORDAR(c,o,d).xt(c,o,d), \quad (85)$$

$$for\ c \in COM, o \in RREG, d \in RREG.$$

The corresponding equation for import tax revenue (delIMPTAX) is:

$$delIMPTAX(c,o,d) = 0.01.IMPTAXR(c,o,d).((xtrad(c,o,d) + pbas(c,o)) + 0.01.DUTYPAID(c,o,d).mt(c,o,d), \quad (86)$$

$$for\ c \in COM, o \in RREG, d \in RREG.$$

5.3 National accounts

There are several complications concerning national accounts in GlobeTERM relative to TERM. First, the TRADER array includes both sub-national and international trades. Second, the addition of trade taxes necessitates choosing the appropriate prices for national accounting.

In GlobeTERM as in TERM, the GDP price weights and quantity contributions are calculated in ordinary change terms. For final demands (set FIN0, covering household consumption, investment and government consumption), the purchasers' value and prices are added over all commodities as in standard TERM. The equation for the final demand price component of GDP in ordinary change terms is:

$$delPGDPE(f,d) = 0.01.\sum_{c} PUR(c,f,d).ppur(c,f,d), \quad (87)$$

$$for\ f \in FIN0, d \in RREG.$$

In (87), PUR(c,f,d) =VUSER(c,f,d)+TAXR(c,f,d) and *ppur* is equal to *puse* plus the power of the commodity tax.

The stocks component (superscript *st*) follows, where STK is the level of stocks for each commodity:

$$delPGDPE("stok", r) = 0.01.\sum_{c} STOCK(c,r).pdom(c,r) \quad for\ d \in RREG. \tag{88}$$

The net margins component is based on a region's total supply of margins minus a region's total use of margins.

$$delPGDPE("netmar", r) = 0.01.(\sum_{m} MARSUPP\_D(m,r).pbas(m,r) - MARSUPP\_P(m,r).psm(m,r)), \quad for\ r \in RREG. \tag{89}$$

The international trade components of GDP levels and variables require the use of the binary H array, and includes export taxes. The international export component is:

$$delXGDPE("exp", r) = 0.01.\sum_{c}\sum_{d}\Big(\big(1 - H(r,d)\big).TRAD(c,d,r) + EXPTAXR(c,d,r)\Big).xtrad(c,r,d) + 0.01.\sum_{m} TSUPMAR(m,r).xtsm(m,r) \quad for\ r \in RREG. \tag{90}$$

The international import component includes international transport margins:

$$delPGDPE("imp", r) = -0.01.\sum_{c}\sum_{d}\big(1 - H(d,r)\big).VCIF(c,d,r).pcif(c,d,r), \quad for\ r \in RREG. \tag{91}$$

Since international and inter-regional trades are in the same array, a modified binary H* array applies to inter-regional exports and imports, in which the diagonal plus foreign elements are set to zero. For inter-regional exports ("rexp"), we have:

$$delPGDPE("rexp", d) = 0.01. \sum_r \sum_d H^* (d, r).TRADR(c, d, r).pbas(c, d), \quad for\ c \in COM, r \in RREG, d \in RREG. \tag{92}$$

The equation for inter-regional imports ("rimp") is:

$$delPGDPE("rimp", d) = -0.01. \sum_o \sum_c H^*(o, d).TRADR(c, o, d).pbas(c, o), \quad for\ c \in COM, o \in RREG, d \in RREG. \tag{93}$$

The nominal value of expenditure-side GDP (GDPEXP) is an add up of values on the RHS of (87) to (93), covering the set GDPECAT (i.e, "HOU", "INV", "GOV", "STOK", "exp", "imp", "rexp","rimp", "netmar"). The regional GDP price *pgdpe* is calculated as:

$$GDPEXP(d).pgdpe(d) = 100. \sum_g delPGDPE(g, d), \quad for\ g \in GDPECAT, d \in RREG. \tag{94}$$

The corresponding ordinary change components for GDP in quantity terms are shown in (95) to (101).

$$delXGDPE(f, d) = 0.01. \sum_c PUR(c, f, d).xfin(c, f, d), \quad for\ f \in FIN0, d \in RREG. \tag{95}$$

In (95), *xfin* refers to final demand quantities in SET FIN0 ("HOU", "INV", "GOV"). The contribution of changes in inventories or stocks (*xst*) follows:

$$delXGDPE("stok", r) = 0.01. \sum_c STOCK(c, r)\, xst(c, r), \quad for\ c \in COM, d \in RREG. \tag{96}$$

In the net margins contribution, *sx* is the quantity of margin supplied:

$$delXGDPE("netmar",r) = 0.01\left(\sum_{o}\sum_{m}(\sum_{e}(SUPPMAR(m,o,e,r).sx(m,o,e,r)) - (\sum_{p}SUPPMAR(m,o,r,p).sx(m,o,r,p))\right), \tag{97}$$

$$for\ m \in MAR, o \in RREG, r \in RREG, d \in RREG.$$

The international export component of real GDP is:

$$delXGDPE("exp",r) = 0.01.\sum_{c}\sum_{d}((1-H(r,d)).TRAD(c,d,r) + EXPTAXR(c,d,r)).xtrad(c,r,d) + 0.01.\sum_{m}TSUPMAR(m,r).xtsm(m,r), \tag{98}$$

$$for\ r \in RREG.$$

For the international import component, the calculation is:

$$delXGDPE(\text{imp},r) = -0.01.\sum_{c}\sum_{o}\Big((1-H(o,r)).TRAD(c,o,r) + EXPTAXR(c,o,r)\Big).xtrad(c,o,r) - 0.01.\sum_{m}\sum_{e}\sum_{o}(TRANMAR(e,m,o,r)).xtranmar(e,m,o,r)), \tag{99}$$

$$for\ r \in RREG.$$

The inter-regional export and import contributions are:

$$delXGDPE("rexp",r) = 0.01\sum_{c}\sum_{d}(1 - H^{*}(r,d)).TRADR(c,r,d).xtrad(c,r,d), \tag{100}$$

$$for\ c \in COM, d \in RREG, r \in RREG,$$

$$delXGDPE("rimp",r) = -0.01\sum_{c}\sum_{o}(1 - H^{*}(o,d)).TRADR(c,o,r).xtrad(c,o,r), \tag{101}$$

$$for\ c \in COM, o \in RREG, r \in RREG.$$

The % change in real GDP (*xgdpe*) is:

$$GDPEXP(d).xgdpe(d) = 100.\sum_{g} delXGDPE(g,d), \quad for\ g \in GDPECAT, d \in RREG. \tag{102}$$

The add-up of income-side GDP in values and change forms includes a modification to standard TERM accounting, in that export and import tax revenues (formerly embedded in the TRADE matrix, as in (13)) are included in the tax contribution.

6. Disaggregation of electricity in GlobeTERM

An assumption that has obvious limitations, at least in some sectors, within the default GlobeTERM and TERM database creation procedure, outlined in Wittwer and Horridge (2018), is that of identical technologies across sub-national regions within a given nation. We know that some regions within a country have mainly coal-generated electricity, while wind farms may dominate generation in other regions. The dominance of greenhouse gas mitigation scenarios in CGE modelling provides an additional reason early in GlobeTERM preparation to disaggregate the single electricity sector in the GTAP Data Base into 9 generation sectors plus a distribution sector. The sectors are ElecCoal, ElecGas, ElecGeoTherm, ElecHydro, ElecNuc, ElecOil, ElecOth, ElecSolar, ElecWind and ElecDist.

To compare, GTAP-Power includes seven types of baseload generation and four types of peak generation (Peters, 2016; Chepeliev 2020). Data in GTAP-Power has been compiled from various international and numerous national sources. At the national level, the data are of better quality than in GlobeTERM. The objective in GlobeTERM is to recognise regional differences, notably regions relatively intensive in fossil-fuel electricity generation that face substantial structural adjustment issues with decarbonization.

Data used in GlobeTERM is downloadable from the Global Power Plant Database[9]. This database aims to include every major power station in the world. Clearly, the ambition of such a database may fall short of actuality in some instances. In addition, ongoing investment in renewable energy plants plus ongoing retirement of fossil-fueled plants implies that there are difficulties in keeping a global power station database up to date. Nevertheless, sectoral splitting of electricity is an important step towards many potential applications of the model. The global database includes estimates of electricity output (GWh) for 2017 by type of generation, with latitude and longitude coordinates. This is sufficient to provide estimates of both the split of electricity in each country by type of generation, and of regional shares by type of generation in each country.

[9] Downloaded from https://github.com/wri/global-power-plant-database.

The international input-output convention concerning electricity generation, transmission and distribution is that transmission and distribution are margin costs accompanying sales of generated electricity.[10] GlobeTERM aligns with the international convention: the depiction of margins is undertaken in a subsequent step.

The reconfigured GTAP Data Base shown in Table 1 is in a format suitable for splitting using a sequence of database splitting programs developed by Mark Horridge (i.e., https://www.copsmodels.com/msplitcom.htm). The programs have been modified for the present task to capture differences in technologies for different generation types. For example, all initial coal sales to electricity are assigned to coal-generated electricity, all gas sales to gas-generated electricity and all oil and petroleum sales to oil-generated electricity. The initial activity share of the GTAP electricity sector assigned to electricity distribution in each region is 0.5.

Following the split of electricity, the multi-national database includes 74 sectors: 47 merchandise commodities as in GTAP, 12 utilities (expanded from 3) and 16 services as in GTAP.

7. Illustrative bilateral tariffs imposed by USA and China using GlobeUSA

The threat of tariff escalation has worsened following the election of Trump in 2024. In this illustrative application using GlobeUSA, bilateral tariff increases of 100 percentage points are imposed on all metals, computing/electronic/optical products, electrical equipment, machinery & equipment, motor vehicles and other transport equipment between USA and China. That is, if the initial tariff is 5%, it is increased to 105% in the scenario. In addition, China imposes a tariff increase of 100% on imports from USA of wheat, other cereals and oilseeds.

The aggregation of the 310 region, 74 sector GlobeUSA master database for this application is to 20 regions and 25 sectors. The regions include the US swing states Arizona, Georgia, Michigan, North Carolina, Nevada, Pennsylvania and Wisconsin, plus Nebraska, Ohio, Oregon, South Carolina, Tennessee, Washington and the Rest of USA. Other regions include China, Oceania, South America, Europe and the Rest of the World.

The sectoral dimension includes the following 5 primary sectors: wheat, other cereals, oilseeds, other agriculture/forestry/fishing and mining. Ten manufacturing sectors include those with tariff hikes, namely metals, computer/electronic/optical products, electric equipment, machinery & equipment, motor vehicles and other transport equipment. The remaining

[10] From https://www.abs.gov.au/methodologies/australian-national-accounts-input-output-tables-methodology/2018-19: "This table [Table 5.14] shows the electricity margin associated with the supply of domestic and imported products to intermediate usage and final use categories. In this case the supplied products are entirely in the product group Electricity generation."

manufactures are food, food products nec, textiles/clothing/footwear and other manufactures. Other sectors include electricity, other utilities, construction, trade, accommodation & food, transport, education, health & social work activities, education and other services. All scenarios are run with GEMPACK (Horridge et al., 2019).

At the regional level, relative outcomes depend partly on the commodity composition of output, and whether there is significant production of commodities directly affected by the tariffs. Table 4 shows shares of value-added for the affected and not directly affected agricultural and manufacturing sectors. Arizona, for example, appears to be less exposed to tariffs shocks than Michigan,

which has higher shares of value-added for both affected crops and affected manufactures.

Table 4. Shares of affected sectors in regional value-added (%)

Region	Affected crops	Other agri., forestry, fishing	Affected manufactures	Other manufactures
AZ	0.03	0.44	5.23	4.63
GA	0.21	1.42	4.82	8.15
MI	0.40	0.90	11.10	6.59
NC	0.28	1.02	4.62	11.11
NV	0.00	0.01	1.25	4.90
PA	0.13	0.76	4.32	6.61
WI	0.36	1.75	7.12	6.75
MT	1.25	3.25	1.30	7.01
NE	1.95	5.36	5.65	7.61
OH	0.45	0.71	7.63	8.23
OR	0.11	1.87	10.82	4.39
SC	0.15	0.86	8.01	9.71
TN	0.38	1.22	5.13	6.67
WA	0.09	1.15	5.14	4.65
RoUSA	0.25	0.82	4.99	6.31
China	1.06	7.21	11.42	12.68
Oceania	0.33	2.24	2.64	3.33
SthAmerica	1.47	4.59	3.90	8.22
Europe	0.24	1.54	8.46	8.34
RoWorld	0.89	5.39	7.84	8.22

Source: GTAP Data Base; GlobeTERM database.

The simulation is run with both short-run and long-run settings. In the short run, we assume the regional real wages are fixed, so that any weakening/strengthening of the labor market occurs entirely by decreases/increases in employment levels. Rates of return on capital vary in the short term, affecting industry-level investment, with insufficient time for capital stocks to adjust. In the short run, a consumption function links aggregate household consumption to regional labor income. Aggregate government consumption is fixed[11]. Source: GTAP Data Base; GlobeTERM database

The regional terms-of-trade (Table 5, column (5)) may be an important explanator of regional impacts. This is calculated from the RHS of (89) to (93). In (103), REGX is the value of international plus interregional exports from region d. The regional export price index (*pregx*) is calculated as:

$$\begin{aligned} REGX(d).pregx(d) &= 100.(delPGDPE("exp",d) + delPGDPE("rexp",d)) \\ &+ \sum_m(\sum_q(MARSUPP(m,q,d).pbas(m,d)) - MARSUPP(m,d,d).pbas(m,d), \\ &for\ d \in RREG. \end{aligned} \tag{103}$$

In (104), REGM is the value of international plus interregional imports to region d. The calculation of the regional import price index (*pregm*) is:

$$\begin{aligned} REGM(d).pregm(d) &= 100.(delPGDPE("imp",d) + delPGDPE("rimp",d)) \\ &+ \sum_m(\sum_q(MARSUPP(m,d,q).pbas(m,q) - MARSUPP(m,d,d).pbas(m,d)), \\ &for\ m \in MAR, r \in RREG, d \in RREG, q \in RREG. \end{aligned} \tag{104}$$

The regional terms-of-trade (*ptoft*, shown in Table 5, column (5)) is equal to (103) minus (104). Regional exports (*xregx*) and imports (*xregm*) in Table 6 (columns (4) and (5)) are calculated similarly, based on equations (97) to (101).

We expect a terms-of-trade reduction to reduce employment in the short-run via the marginal product of labor (MPL)/wage relationship:

$$MPL\left(\frac{K}{L}\right) = \frac{W}{P_c}\frac{P_c}{P_g}. \tag{105}$$

[11] An earlier version of GlobeTERM with short-run and long-run closures is downloadable from https://www.copsmodels.com/archivep.htm TPGW0211. In GEMPACK TABLO code, the convention of naming each equation after a variable it may solve for provides a default closure. A handful of closure swaps implement either short-run or long-run settings.

Table 5. Short-run regional macroeconomic impacts (% change from base)

	RealHou (1)	RealInv (2)	RealGDP (3)	AggEmploy (4)	ptoft (5)	xregx (6)	xregm (7)
AZ	-0.23	-0.49	-0.29	-0.19	0.00	-0.81	-0.62
GA	-0.34	-0.87	-0.50	-0.30	0.02	-0.87	-0.60
MI	-0.39	-1.46	-0.48	-0.35	-0.19	-0.89	-1.05
NC	-0.04	-0.27	-0.01	0.00	0.00	0.10	-0.08
NV	-0.13	-0.29	-0.05	-0.09	-0.24	0.06	-0.22
PA	-0.09	-0.34	-0.08	-0.05	-0.05	-0.19	-0.28
WI	-0.01	-0.37	0.02	0.03	0.01	0.20	0.15
MT	-0.31	-1.39	-0.28	-0.27	-0.30	-0.07	-0.47
NE	-0.11	-1.32	-0.02	-0.07	-0.27	0.21	-0.44
OH	-0.18	-0.97	-0.23	-0.14	-0.02	-0.27	-0.44
OR	0.14	0.22	0.09	0.18	0.41	0.53	0.47
SC	-0.30	-0.95	-0.41	-0.26	-0.04	-0.84	-0.78
TN	-0.07	-0.30	-0.05	-0.03	0.03	0.09	-0.03
WA	-0.37	-0.93	-0.49	-0.33	0.02	-1.24	-0.80
RoUSA	-0.29	-1.14	-0.40	-0.25	-0.10	-1.74	-1.55
All USA	-0.26	-0.99	-0.35	-0.22	-0.17	-3.43	-2.87
China	-0.44	-0.26	-0.36	-0.40	-1.16	-4.09	-4.40
Oceania	-0.05	-0.13	-0.01	-0.01	-0.28	0.23	0.04
SthAmerica	0.05	0.28	0.05	0.09	0.24	0.32	0.51
Europe	0.04	0.00	0.04	0.08	0.24	0.66	0.63
RoWorld	0.08	0.09	0.06	0.12	0.50	1.59	1.63

Notes: RealHou=aggregate real consumption; RealInv=aggregate real investment; RealGDP = real GDP; AggEmploy = aggregate employment; ptoft = regional terms-of-trade; xregx/ mregx =regional plus international exports/imports. The "All USA" variables ptoft, xregx and mregx are the share-weighted sums of international variables only, as sub-national trade variables sum to zero in the national case.

Source: Author's modeling.

In (105), the value of the marginal product of labor to employers (MPL) is the product of two ratios. The first is the real wage as seen by workers, assumed exogenous in short term, and the second is the consumer price index (Pc) divided by the price deflator for GDP (Pg). Since Pc includes the prices of imports but not exports, and Pg includes the prices of exports but not imports, Pc/Pg increases as the terms-of-trade fall (Table 5, column (5)). With fixed short-run real wages, an increase in Pc/Pg causes an increase in MPL, requiring a fall in the capital/labor ratio (K/L). Since K is fixed in the short run, we might expect L to fall.

The link between national terms-of-trade and employment holds for most US regions and for countries outside USA. In the exceptions, namely AZ, NC, TN and Oceania, there is compositional change that complicates the macro relationship. Employment falls in AZ, GA, TN and WA despite small terms-of-trade gains or zero losses (Table 5). There is a substantial switch from Chinese imports to domestic supplies of tariff-affected commodities. Knowing the share of tariff-affected commodities in a state's regional GDP is not a sufficient guide to a state's macro outcome. Oregon's share of tariff-affected manufactures in regional GDP is 10.88% (Table 4). Yet it experiences the largest terms-of-trade gain of any US region, with an increase in employment and a resultant increase in real GDP relative to base. This is because it is a substantial winner from the switch to domestic manufactures arising from the prohibitive tariff on Chinese imports. In the base data, Oregon's ports receive imports of manufactures but do not export to other countries. Activity losses in the state from reduced imports in the scenario are small relative to the gains by increased sales of the state's manufactures to US destinations (Table 6). Note that national US losses in export and import volumes relative to base are larger in percentage terms than for any US region. This is because interstate exports and imports, which make a positive contribution to trade volumes in most regions, carry zero weight at the national level (Table 4, columns (6) and (7)).

Table 6. Contributions to short-run trade volumes in USA regions (% change from base)

	Exports (xregx)				Imports (xregm)			
	Interstate	Foreign	Margins	Total	Interstate	Foreign	Margins	Total
AZ	0.15	-0.98	0.01	-0.81	0.12	-0.74	0.00	-0.62
GA	0.01	-0.88	0.00	-0.87	0.20	-0.84	0.05	-0.60
MI	0.40	-1.30	0.01	-0.89	0.06	-1.11	0.00	-1.05
NC	0.12	-0.04	0.02	0.10	0.04	-0.08	-0.03	-0.08
NV	-0.02	0.06	0.02	0.06	-0.19	-0.03	0.00	-0.22
PA	0.15	-0.36	0.02	-0.19	0.09	-0.34	-0.03	-0.28
WI	0.18	0.02	0.01	0.20	0.18	-0.04	0.01	0.15
MT	0.02	-0.10	0.01	-0.07	0.12	-0.57	-0.02	-0.47
NE	0.18	0.02	0.01	0.21	-0.40	-0.04	-0.01	-0.44
OH	0.16	-0.44	0.01	-0.27	0.32	-0.77	0.01	-0.44
OR	0.52	0.01	0.00	0.53	0.50	-0.09	0.07	0.47
SC	0.12	-0.97	0.01	-0.84	0.13	-0.91	0.00	-0.78
TN	0.02	0.04	0.03	0.09	0.21	-0.20	-0.03	-0.03
WA	0.06	-1.31	0.01	-1.24	0.19	-1.03	0.04	-0.80
RoUSA	0.08	-1.82	0.00	-1.74	0.09	-1.68	0.04	-1.55

Source: Author's modeling.

China loses relative to base in the scenario, due to the importance of USA as a destination for tariff-affected goods (Table 5). In turn, Oceania, where China accounts for a large share of exports, terms-of-trade suffer due to a decline in China's demand as China's imports fall with the loss in real GDP. In South America, Europe and the Rest of the World, trade diversion due to the bilateral tariffs between China and USA improves the terms-of-trade, with consequent increases in real GDP and employment, and increased export and import volumes relative to base.

Table 7. Long-run regional macroeconomic impacts (% change from base)

	Real Hou	Real Inv	Real GDP	Agg Employ	Real wage	Agg. Capital	ptoft	xregx	xregm
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
AZ	0.10	0.46	0.04	0.20	0.00	0.41	0.04	-0.56	-0.17
GA	-0.81	-0.29	-0.76	-0.26	-0.45	-0.45	0.02	-0.79	-0.67
MI	-0.76	-0.69	-0.68	-0.23	-0.43	-0.42	-0.13	-1.17	-1.35
NC	1.07	0.97	0.85	0.68	0.49	1.20	0.04	0.23	0.83
NV	0.83	0.99	0.74	0.56	0.36	1.04	-0.14	0.25	0.69
PA	0.70	0.78	0.59	0.49	0.30	0.92	-0.02	0.01	0.31
WI	1.18	1.25	1.05	0.74	0.54	1.45	-0.04	0.84	0.95
MT	-0.32	-0.38	-0.17	-0.02	-0.21	0.07	-0.20	-0.03	-0.26
NE	0.81	0.02	0.78	0.55	0.35	1.04	-0.19	0.76	0.40
OH	0.00	0.03	-0.01	0.14	-0.05	0.24	0.01	0.00	0.02
OR	1.45	1.36	1.23	0.87	0.67	1.76	0.19	0.89	1.43
SC	-0.31	-0.17	-0.35	-0.01	-0.21	0.01	0.07	-0.97	-0.84
TN	0.82	0.97	0.70	0.56	0.36	1.07	0.07	0.31	0.66
WA	-0.66	-0.33	-0.62	-0.19	-0.38	-0.28	-0.02	-1.02	-0.80
RoUSA	-0.52	-0.49	-0.48	-0.11	-0.31	-0.20	-0.04	-1.49	-1.40
USA	-0.32	-0.24	-0.29	0	-0.20	0	-0.05	-3.46	-2.77
China	-0.89	0.65	-0.17	0	-0.73	0	-1.35	-4.38	-5.40
Oceania	0.02	-0.08	0.00	0	0.01	0	0.03	0.08	0.08
SthAmerica	-0.05	0.31	0.01	0	0.10	0	0.44	0.64	0.72
Europe	0.05	-0.10	0.00	0	0.08	0	0.21	0.44	0.58
RoWorld	0.11	-0.15	0.02	0	0.18	0	0.51	1.62	1.77

Source: Author's modeling.

In a long-run setting, we assume that there is sufficient time for industries to adjust capital stocks to restore base rates-of-return. Investment to capital ratios are fixed in each industry. At the same time, national aggregate capital stocks are exogenous. In the labor market, national employment levels are exogenous. Workers can move between regions within a country (i.e, US states in this example), with inter-regional adjustment being through both employment and real wages. If a region's share of national employment falls, its real wages will also fall relative to national real wages. In each country, the ratio of the nominal balance of trade to nominal GDP is exogenous.

Table 8. Industry outputs (long run, % change from base)

	AZ	GA	MI	NC	NV	PA	WI	All USA	China
OthAgrForFsh	0.1	0.0	0.3	0.0	0.3	0.1	0.1	0.1	0.5
Wheat	-0.8	-0.5	-0.3	-0.1	..	-0.1	0.0	-1.0	0.9
OthCereals	-1.0	-0.5	-0.5	-0.4	-0.1	-0.4	-0.3	-1.1	1.7
OilSeeds	..	-11.4	-10.6	-6.9	..	-8.6	-8.5	-15.0	6.7
Mining	0.2	0.0	0.4	0.3	0.7	0.2	0.6	0.1	1.9
OthFood	-0.6	1.0	0.1	0.2	0.1	-0.2	-0.3	0.2	0.1
FoodPrdsNEC	0.0	0.0	1.0	0.3	0.4	0.2	0.1	0.2	0.3
TCFs	-1.5	-1.7	-0.8	0.0	-0.8	-1.1	-0.8	-1.1	3.0
OthManufact	-0.2	-0.3	0.5	0.7	0.6	0.4	0.6	0.0	1.9
Metals	1.2	1.1	-0.6	2.6	3.5	2.3	4.5	1.2	0.1
ComputrOptc	4.7	2.2	0.1	9.0	11.2	10.6	15.8	4.3	-12.9
ElectricEqp	2.2	7.5	-0.1	7.3	7.9	7.5	7.8	5.0	-5.2
MachineNEC	1.1	-0.4	-1.8	3.5	5.1	2.5	3.9	0.1	-0.2
MotorVehicle	-6.5	-8.1	-4.9	1.7	3.3	-0.2	3.3	-1.9	0.8
OthTransEqp	1.4	-0.8	1.8	2.2	4.0	2.6	3.8	0.6	0.0
Electricity	0.1	-0.3	0.2	0.5	0.8	0.4	0.8	0.0	0.4
OthUtilities	0.0	-0.4	0.3	0.4	0.7	0.3	0.4	-0.1	-0.1
Construction	0.2	-0.4	0.1	0.6	0.9	0.6	0.3	-0.2	0.7
TradeWR	0.6	0.5	0.0	0.5	0.7	0.5	0.9	0.5	0.1
AccomFood	0.1	-0.7	-0.5	1.1	0.6	0.7	0.7	-0.3	-0.6
Transport	0.2	0.1	-0.1	-0.1	0.3	0.0	0.2	0.1	-0.1
OthServices	0.1	-0.3	0.1	0.6	0.6	0.4	0.4	-0.1	-0.1
Education	-0.2	-0.4	0.1	0.1	-0.3	0.0	-0.8	-0.3	-0.5
HealthSocRes	0.1	-1.0	-0.9	1.5	1.0	0.9	1.4	-0.4	-1.0
Dwellings	0.4	-1.2	-1.0	2.1	1.6	1.3	2.0	-0.4	-0.8

Notes: negligible output level denoted by "..".

Source: Author's modeling.

With sufficient time for industry capital stock adjustments and migration of labor between regions, the losers among swing states are Georgia and Michigan. Metals, computer/electronic/optical products and electric equipment benefit from tariffs, but motor vehicles, and, in Michigan, machinery & equipment suffer losses relative to base. Among manufactures, textiles/clothing/footwear (TCFs) and motor vehicles have falls in output relative to base nationally and in most states (Table 8). Motor vehicles suffer due to a cessation of sales to China, though China accounts for little more than 2% of US sales in the base, and tariff-induced input cost rises.

Although China imposes high tariffs on wheat and other cereals for imports from USA, they are less exposed to the Chinese market than oilseeds. Sales to China account for 24% of US oilseed sales. Although the competitiveness of wheat and other cereals increases relative to oilseeds, all agricultural sectors lose relative to base as labor and capital move into tariff-protected manufactures.

As in the short run, US trade volumes reduce nationally relative to base. Within states, interstate trade generally increases relative to base with the largest beneficiary being Oregon, with small international merchandise exports. This contrasts with the composite Rest of USA where foreign export losses contribute 1.9% to the loss in overall export volumes of 1.6% (Table 9).

Table 9. Contributions to long-run trade volumes in USA regions (% change from base)

	Exports (xregx)				Imports (xregm)			
	Interstate	Foreign	Margins	Total	Interstate	Foreign	Margins	Total
AZ	0.24	-0.86	0.01	-0.62	0.46	-0.70	0.02	-0.21
GA	0.15	-0.97	-0.05	-0.87	0.10	-0.87	0.02	-0.75
MI	0.57	-1.78	-0.01	-1.22	0.02	-1.36	-0.06	-1.40
NC	0.19	-0.06	0.02	0.15	0.94	-0.07	-0.11	0.76
NV	0.12	0.05	0.03	0.20	0.75	0.00	0.03	0.78
PA	0.20	-0.29	0.06	-0.03	0.65	-0.33	-0.04	0.28
WI	0.75	0.01	0.12	0.87	0.94	0.01	0.02	0.97
MT	0.25	-0.33	0.02	-0.06	0.33	-0.61	0.00	-0.28
NE	0.70	0.02	0.04	0.77	0.38	-0.01	0.04	0.41
OH	0.37	-0.41	0.04	0.00	0.66	-0.72	0.06	0.00
OR	0.84	-0.03	0.30	1.11	1.38	0.00	0.09	1.47
SC	0.20	-1.22	-0.03	-1.04	0.16	-1.04	-0.06	-0.93
TN	0.20	0.01	0.11	0.32	0.93	-0.26	-0.04	0.62
WA	0.27	-1.35	-0.03	-1.11	0.14	-1.02	0.03	-0.84
RoUSA	0.30	-1.85	-0.05	-1.60	0.14	-1.64	0.01	-1.49

Source: Author's modeling.

While there are winners and losers at the macroeconomic state level in the long run with sufficient time for reallocation of both labor and capital, national level outcomes in the long run remain negative. Real GDP falls by 0.29% (Table 7, column (3)): since aggregate labor and capital are fixed, negative indirect tax contributions account for the fall. National aggregate private consumption falls by 0.32%. Real wages fall by 0.20%. Yet long-run outcomes differ markedly across US regions.

8. Conclusion

The GlobeTERM approach provides a method of devising sub-national detail for any single country or multiple countries combined with the multi-country detail of GTAP plus electricity detail. Inputs required include sub-national activity share estimates for each of the 74 sectors of national level global database plus an array of inter-regional distances. GlobeTERM combines a modified gravity method, as in TERM, with use of bilateral international trade data in estimating the trade array of the database. Source shares used to estimate inter-regional trades, in addition to the gravity assumption, depend on a distance factor, in which it is hard to transport commodities are traded relatively less over distances. Local commodities such as housing are assigned lower tradability. The same suite of programs can generate sub-national details for any country combined with 159 regions in the rest of the world. A multi-country sub-national application, as in GlobeEuro, requires only relatively minor modifications to the data programs. The reproducibility of the task is apparent from the relative ease with which GlobeTERM versions have been prepared with sub-national details for various countries, including USA, China, Germany, UK and multi-country Europe. The website www.copsmodels.com/archivep.htm (item TPGW0211) contains several aggregation examples of variants of GlobeTERM while item TPGW0214 includes the sequence of programs used to generate GlobeTERM.

Although core regional data requirements are relatively modest, the bilateral tariff scenario presented here points to one data source that could be utilized better. The US Census Bureau provides trade data by commodity at the port level, which was the source of regional trade shares. However, the data are also available for the origin of imports and destination of exports by port, as used by Countryman et al. (2017). In future research, specific projects with sufficient resourcing may add this detail to trade data by port. The GlobeTERM approach, as in TERM, enables the practitioner to revise regional data inputs and create an updated master database rapidly.

Concerning model extensions, a priority is to include dynamics in GlobeTERM, which will include a financial module based on Dixon et al. (2021). As is evident from a number of the models already developed combining sub-national detail with GTAP, variants of GlobeTERM could be enhanced by adding energy and greenhouse gas accounts.

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