Creating a Disaggregated CGE Model for Trade Policy Analysis: GTAP-MVH

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Abstract
Thousands of economists spread across almost every country use the GTAP model to analyse trade policies including trade wars and trade agreements. GTAP has an impressive regional coverage (140 countries), but the standard commodity coverage (57 commodities/industries) can cause frustration when tariffs on narrowly defined products are being negotiated. This article sets out a method for disaggregating commodities/industries in computable general equilibrium models such as GTAP and applies it to GTAP’s motor vehicle sector. The method makes use of readily available highly disaggregated trade data supplemented by detailed input–output data where available and data from a variety of other sources such as commercial market reports.

JEL Codes: C68, F13, F14, F17

Keywords
GTAP disaggregation, motor vehicle sector, intra-NAFTA tariffs

Introduction
For over 50 years, computable general equilibrium (CGE) models have been used in analysing the effects of changes in trade policies and have now become a standard tool.¹ CGE-based analyses have been helpful in identifying indirect effects. While it may be obvious that the motor vehicle industry in the US benefits from...
higher tariffs on imported finished vehicles, it may not be so obvious that export-oriented activities such as US higher educational services are harmed. As captured by a CGE model, the vehicle industry and higher education are linked via the real exchange rate. Less imported vehicles strengthen the exchange rate and hurt the export prospects of industries such as higher education.

The world’s best known and most widely used CGE trade model is GTAP. Its full database consists of mutually consistent input–output tables, trade flows and protection rates in 140 countries. Documentation of GTAP’s theory and data can be found in Hertel (1997), Corong, Hertel, McDougall, Tsigas, and van der Mensbrugghe (2017) and Aguiar, Narayanan, and McDougall (2016). Flexible aggregation programmes are available to form versions of GTAP with manageable regional disaggregation highlighting regions of interest for particular applications. Later in this article we describe simulations with a 10-region version of GTAP. The regions are shown in Table 1.

While GTAP’s regional detail is more than adequate for most purposes, the standard commodity/industry detail does not fully meet the requirements for convincing analysis to support contemporary trade negotiations. The database for the standard GTAP model distinguishes 57 sectors. At this level of disaggregation, key sectors in trade negotiations are often represented as a single amalgam of activities at various stages of a supply chain. For example, the production of all motor vehicle products in each country is represented in standard GTAP as a single sector, denoted by motor vehicles (mvh). This means that there is no recognition of differences between brakes, transmissions, interior trimming, finished vehicles, etc., in input requirements, sales patterns and rates of protection.

In the second section, we set out a method for disaggregating commodities/industries in computable general equilibrium models such as GTAP and apply it to GTAP’s motor vehicle sector. The method makes use of readily available highly

| No. | Regions                                      |
|-----|---------------------------------------------|
| 1   | USA                                         |
| 2   | Canada                                      |
| 3   | Mexico                                      |
| 4   | Japan                                       |
| 5   | South Korea                                 |
| 6   | China                                       |
| 7   | Germany                                     |
| 8   | EU26 (= EU28 less Germany and the UK)       |
| 9   | UK                                          |
| 10  | Rest of the World (ROWs)                    |

Source: Author’s own.
disaggregated trade data supplemented by detailed input–output data where available and data from a variety of other sources such as commercial market reports. Using our disaggregation method, we split GTAP’s mvh sector into nine commodities/industries to create GTAP-MVH. In the third section we describe illustrative simulations with GTAP-MVH, showing the effects of tariffs imposed by North American Free Trade Agreement (NAFTA) countries on finished vehicles while leaving tariffs on parts unchanged. Concluding remarks are given in the fourth section.

Transforming Standard GTAP into GTAP-MVH

In simplified form (omitting taxes and international transport margins), the database for the GTAP model is represented by Table 2. Part A is referred to as the NATIONAL matrix for region d. It shows flows of domestic commodities and imported commodities (undifferentiated by region of origin) to industries in

| Table 2. Database for a GTAP Model |
|-----------------------------------|
| Part A. NATIONAL Matrix for Region d |

| Industries in Region d | Final Demands in Region d (excludes exports) | Total Demand in d |
|-----------------------|---------------------------------------------|------------------|
| Domestic inputs mvh   | (a)                                         | (c)              |
|                       | (e)                                         |                  |
| Imported inputs mvh   | (b)                                         | (d)              |
|                       | (e)                                         |                  |
| Primary factors       |                                             |                  |
| Industry outputs in d |                                             |                  |

| Part B. TRADE Matrix for Commodity c |

| Destination Region | USA | Canada | … | … | … | ROW |
|--------------------|-----|--------|---|----|----|-----|
| Source region      | USA | Canada | … | … | … | ROW |
|                    | USA |        |   |    |    |     |
| Source region      | CAN |        |   |    |    |     |

Source: Author’s own.
region $d$ and to final users excluding exports. It also shows the use of primary factors by industries in region $d$. Part B is referred to as the TRADE matrix. For each commodity, it shows sources and destinations of international trade flows. The data in the two parts satisfy two balance conditions. First, the $c$th row sum in the imports part of $d$’s NATIONAL matrix equals the sum across sources of $d$’s imports of $c$ from the TRADE matrix (sum of $d$th column of the TRADE matrix for commodity $c$). Second, the $c$th row sum in the domestic part of $d$’s NATIONAL matrix plus $d$’s exports of $c$ from the TRADE matrix (sum of the $d$th row in the TRADE matrix for commodity $c$) equals $d$’s output of $c$ obtained as the $c$th column sum in the industry part of $d$’s NATIONAL matrix.

In Table 2, without loss of generality, we have marked mvh as the first industry and first commodity. The disaggregation task described in this section is to replace the mvh part of the TRADE matrix with matrices for each sub-mvh commodity and to split the mvh column and the two mvh rows in the NATIONAL matrix for each country $d$ into sub-mvh industries and commodities. As will become apparent in subsection ‘Disaggregation Theory’, (a) to (e) in the NATIONAL matrix represent different disaggregation formulas. These formulas split GTAP data items: the disaggregated database reproduces the original database when re-aggregated.

In the rest of this section, we describe the theory (subsection ‘Disaggregation Theory’) and data (subsection ‘Disaggregation Data’) by which we disaggregated GTAP’s mvh industry/commodity into nine North American Industrial Classification System (NAICS)-based industries/commodities. We also briefly describe some disaggregation results (subsection ‘Sales Matrices for Disaggregated mvh Products: Outcomes of the Disaggregation Procedures’). As mentioned already, we performed the disaggregation on a 10-region version of GTAP (see Table 1). It was also convenient from a computational and data-management point of view to aggregate GTAP’s 56 non-mvh industries/commodities into 17. For example, in GTAP-MVH the 12 GTAP agricultural industries/commodities are aggregated into one. The full list of 26 (=9 + 17) industries/commodities in GTAP-MVH is in Table 3, with the disaggregated mvh industries/commodities shaded and in bold type.

Highly disaggregated trade data are available for almost every country to provide a basis for disaggregation of TRADE matrices. By contrast, the input–output matrices that underlie NATIONAL matrices are usually published at a relatively aggregated level, much more aggregated than the trade data. In our disaggregation theory, we start by assuming that satisfactory disaggregated TRADE matrices can be formed, although as we will see in subsection ‘Disaggregation Data’, this may require considerable work on concording commodity/industry classifications between trade and input–output data. To disaggregate NATIONAL matrices we need data for disaggregated commodities/industries on outputs, inputs and sales. For our mvh disaggregation task, direct data for these variables are not available for most countries. We estimate the missing data taking account of what is available: trade data and detailed input–output data for some key countries. The estimates become the basis for splitting shares that are applied to the original GTAP data.
| No. | Sectors               | Description                                           | NAICS Codes         | Original GTAP Sectors                                                                 |
|-----|-----------------------|-------------------------------------------------------|---------------------|--------------------------------------------------------------------------------------|
| 1   | Agriculture           | Agriculture                                           | 1111–1123           | Paddy rice; wheat; cereal grains n.e.c.; vegetables, fruits, nuts; oil seeds; sugarcane, sugar beet; plant-based fibres; crops n.e.c.; bovine cattle, sheep and goats, horses; animal products n.e.c.; raw milk; wool, silk-worm cocoons. |
| 2   | ForFishMinng          | Forestry, fishery and mining                          | 1130–2131           | Forestry; fishing; coal, oil, gas; minerals n.e.c.                                    |
| 3   | FoodBevTob            | Food, beverages and tobacco products                  | 3111–3122           | Bovine meat products; meat products n.e.c.; vegetable oils and fats; dairy products; processed rice; sugar; food products n.e.c.; beverages and tobacco products. |
| 4   | TCF                   | Textile, clothing and footwear                        | 3131–3160           | Textiles; wearing apparel; leather products.                                           |
| 5   | WoodProd              | Wood products                                         | 3211–3219           | Wood products.                                                                        |
| 6   | NMetMinrlPrd          | Non-metal mineral materials                           | 3271–3279           | Mineral products n.e.c.                                                               |
| 7   | PaperPublish          | Paper, printing and publishing                        | 3221–3231, 48A000–5111A0 | Paper products, publishing.                                                           |
| 8   | PetrolCoal            | Petroleum and coal products                           | 3241                | Petroleum, coal products.                                                             |
| 9   | ChemRubPlast          | Chemicals, rubber and plastic products                | 3251–3262           | Chemicals, rubber and plastic products.                                               |
| 10  | FeMetal               | Ferrous metal                                         | 3311, 3312, 331510  | Ferrous metals.                                                                       |
| 11  | OthMetals             | Non-ferrous metals                                    | 3313–3314, 331520   | Metals n.e.c.                                                                         |
| 12  | MetalProd             | Fabricated metal products                             | 3321–3329           | Metal products.                                                                       |
| 13  | Automobile            | Automobile manufacturing                              | 336111             | Motor vehicles and parts                                                               |
| 14  | MVGasEngPrts          | Motor vehicle gasoline engine and engine parts         | 336312             | Motor vehicles and parts                                                               |
| No. | Sectors          | Description                                                   | NAICS Codes | Original GTAP Sectors |
|-----|------------------|---------------------------------------------------------------|-------------|-----------------------|
| 15  | MVSteerSuspn     | Motor vehicle steering, suspension component (except spring) manufacturing | 336330      |                       |
| 16  | MVBrakes         | Motor vehicle brakes and brake systems                        | 336340      |                       |
| 17  | MVPwrTrTrain     | Motor vehicle transmission and power train parts               | 336350      |                       |
| 18  | MVSeatInter      | Motor vehicle interior trim, seats and seat parts              | 336360      |                       |
| 19  | MVMtlStamp       | Motor vehicle metal stamping                                  | 336370      |                       |
| 20  | OthMVParts       | Other motor vehicle parts manufacturing                       | 336390      |                       |
| 21  | TruckUteTrlr     | Manufacturing of trucks, utility vehicles, trailers, motor homes and campers | 336112, 336120, 336212, 336213, 336214 |                       |
| 22  | OthTransEq       | All other transportation equipment manufacturing               | 3364–3369   | Transport equipment n.e.c. |
| 23  | ElectrnicsEq     | Electronic equipment                                           | 3341–3345   | Electronic equipment.  |
| 24  | OthMachEq        | Other machinery and equipment                                 | 3331–3339, 3346–3359, 3391, | Machinery and equipment n.e.c. |
| 25  | OthManuf         | Other manufacturing products, n.e.c.                          | 3371–3379   | Manufactures n.e.c.    |
| 26  | Services         | Services                                                      | 2211–2334, 4200–8140 | Electricity; gas manufacture, distribution; water; construction; trade; transport n.e.c.; water transport; air transport; communication; financial services n.e.c.; insurance; business services n.e.c.; recreational and other services; public administration, defence, education, health; dwellings. |

**Source:** Author’s own.
Disaggregation Theory

The central part of our disaggregation theory is a system of equations in which we treat trade flows in disaggregated products as observable exogenous variables. This allows us to make full use of comprehensive disaggregated trade data published by the United Nations. The equations also rely on the availability of detailed input–output data for one or more leading producer countries in the sector being disaggregated.

In the case of mvh, the inputs to the disaggregation equation system are data (adjusted to 2015 levels where required) on: trade flows for disaggregated mvh products; US and Canadian input–output data for these products; and initial estimates (described in subsection ‘Disaggregation Data’) for outputs of and demands for mvh products in regions other than the USA and Canada.

Endogenous Variables in the Disaggregation Equation System for mvh

In formal terms, we estimate for 2015 the US dollar values of:

- \( VQ(n,s) \) for \( n \in \text{MVH, } s \in \text{OTHREG} \)
  where MVH is the set of nine mvh industries/commodities; \( VQ(n,s) \) is the value of output of commodity \( n \) in region \( s \); and OTHREG is the set of eight regions in Table 1 excluding Canada and the USA. We do not estimate \( VQ(n,\text{US}) \) and \( VQ(n,\text{Canada}) \). These are known from detailed input–output data for the two countries.

- \( Z(n,j,s) \) for \( n, j \in \text{MVH, } s \in \text{OTHREG} \)
  where \( Z(n,j,s) \) is the value of mvh product \( n \) (domestic plus imported) flowing to mvh industry \( j \) in region \( s \). For \( s = \text{USA and Canada} \), \( Z(n,j,s) \) is known from detailed input–output data.

- \( Z\text{dom}(n,j,s) \) and \( Z\text{imp}(n,j,s) \) for \( n, j \in \text{MVH, } s \in \text{OTHREG} \)
  where \( Z\text{dom}(n,j,s) \) and \( Z\text{imp}(n,j,s) \) are the values of the flows of domestically produced and imported mvh-commodity \( n \) to mvh-industry \( j \) in region \( s \). For \( s = \text{USA and Canada} \), \( Z\text{dom}(n,j,s) \) and \( Z\text{imp}(n,j,s) \) are known from detailed input–output data.

- \( OD(n,f,s) \) for \( n \in \text{MVH, } f \in \text{NonMVH, } s \in \text{OTHREG} \)
  where \( OD(n,f,s) \), other domestic demand, is the value of mvh-commodity \( n \) (domestic plus imported) used in region \( s \) by domestic purchaser \( f \) in the set NonMVH. This is the set of domestic purchasers outside the mvh sector. These are non-mvh industries and final demanders (households, capital creators and government but not exports). For \( s = \text{USA and Canada} \), \( OD(n,f,s) \) is known from detailed input–output data.

- \( OD\text{dom}(n,f,s) \) and \( OD\text{imp}(n,f,s) \) for \( n \in \text{MVH, } f \in \text{NonMVH, } s \in \text{OTHREG} \)
  where \( OD\text{dom}(n,f,s) \) and \( OD\text{imp}(n,f,s) \) are the values of domestically produced and imported mvh-commodity \( n \) used in region \( s \) by domestic purchaser \( f \) in the set NonMVH. For \( s = \text{USA and Canada} \), \( OD\text{dom}(n,f,s) \) and \( OD\text{imp}(n,f,s) \) are known from detailed input–output data.
• \(\text{ABS}(n,d)\) for \(n \in \text{MVH}, d \in \text{OTHREG}\)
where \(\text{ABS}(n,d)\) is the value of total absorption (domestic plus imported) of mvh-commodity \(n\) in region \(d\). For \(s = \text{USA and Canada}\), \(\text{ABS}(n,d)\) is known from detailed input–output data.
We also estimate
• \(\text{ADJ}(n,d)\) for \(n \in \text{MVH}, d \in \text{OTHREG}\)
where \(\text{ADJ}(n,d)\) is an adjustment factor on demand for and supply of mvh-commodity \(n\) in region \(d\). As we will see shortly, this factor is used to adjust our initial estimates of demand and supply variables to align estimates of absorption in each region based on supply (output plus imports less exports) and demand (intermediate and final use excluding exports). A value of \(\text{ADJ}(n,d)\) of greater than one adjusts demand variables up and supply variables down.
• \(A_{\text{USCAN}}(n,j)\) for \(n, j \in \text{MVH}\)
where \(A_{\text{USCAN}}(n,j)\) is the average input–output coefficient for Canada and the USA for the use of mvh-commodity \(n\) in mvh-industry \(j\). These average input–output coefficients are calculated from detailed input–output data for the two countries.
• \(\text{MSH}(n,d)\) for \(n \in \text{MVH}, d \in \text{OTHREG}\)
where \(\text{MSH}(n,d)\) is the share of the absorption of mvh-commodity \(n\) in region \(d\) accounted for by imports. Import shares in USA and Canadian absorption of disaggregated mvh commodities are known from detailed input–output and trade data.

**Exogenous Variables in the Disaggregation Equation System for mvh**

We base the estimates of the endogenous variables on values given by data or initial estimates of:

• \(\text{TR}(n,s,d)\) for \(n \in \text{MVH}, s, d \in \text{REG}\),
where \(\text{REG}\) is the set of 10 regions in Table 1; and \(\text{TR}(n,s,d)\) is the value of commodity \(n\) exported from region \(s\) to region \(d\).
• \(VQ_{\text{USCAN}}(n)\) for \(n \in \text{MVH}\),
where \(VQ_{\text{USCAN}}(n)\) is the aggregate value, calculated from USA and Canadian input–output data updated to 2015, of input \(n\) produced in the two countries.
• \(Z_{\text{USCAN}}(n,j)\) for \(n, j \in \text{MVH}\)
where \(Z_{\text{USCAN}}(n,j)\) is the aggregate value, calculated from USA and Canadian input–output data updated to 2015, of input \(n\) (domestic plus imported if \(n\) is a commodity) used in the production of \(j\) in the two countries.
• \(VQ1(n,s)\) for \(n \in \text{MVH}, s \in \text{OTHREG}\)
where \(VQ1(n,s)\) is our initial estimate of the value of commodity \(n\) produced in region \(s\).
• \(\text{OD1}(n,f,s)\) for \(n \in \text{MVH}, f \in \text{NonMVH}, s \in \text{OTHREG}\)
where \(\text{OD1}(n,f,s)\) is our initial estimate of the value of commodity \(n\) (domestic plus imported) used by purchaser \(f\) in region \(s\).
We make the estimates using the equation system listed below. In this system the variables to be estimated are in black normal type. The variables we take as given are in red italics.

**Equation System for Disaggregating mvh in the NATIONAL Matrices: Equations (1)–(11)**

Absorption of mvh-commodity \( n \) in region \( d \) calculated as imports + output − exports:

\[
\text{ABS}(n,d) = \sum_{s \in \text{Reg}} \sum_{s \neq d} TR(n,s,d) + VQ(n,d) - \sum_{s \in \text{Reg}} TR(n,d,s)
\]

for all \( n \in \text{MVH}, d \in \text{OTHREG} \) (1)

Absorption of mvh-commodity \( n \) in region \( d \) calculated as intermediate demands in the mvh sector and demand outside the mvh sector:

\[
\text{ABS}(n,d) = \sum_{j \in \text{MVH}} Z(n,j,d) + \sum_{f \in \text{NonMVH}} OD(n,f,d)
\]

for all \( n \in \text{MVH}, d \in \text{OTHREG} \) (2)

Calculation of mvh-mvh input–output coefficients from USA and Canadian input–output data:

\[
A_{\text{USCAN}}(n,j) = Z_{\text{USCAN}}(n,j) / VQ_{\text{USCAN}}(j)
\]

for all \( n, j \in \text{MVH} \) (3)

Intermediate use of mvh-commodity \( n \) in mvh-industry \( j \) in region \( d \) estimated by applying USA/Canada input–output coefficients and adjusting to reconcile absorption of \( n \) in \( d \) calculated by Equations (1) and (2):

\[
Z(n,j,d) = A_{\text{USCAN}}(n,j) * VQ(j,d) * \text{ADJ}(n,d)
\]

for all \( n, j \in \text{MVH}, d \in \text{OTHREG} \) (4)

Other (NonMVH) demands for \( n \) in region \( d \) after adjustment:

\[
\text{OD}(n,f,d) = OD\text{I}(n,f,d) * \text{ADJ}(n,d)
\]

for all \( n \in \text{MVH}, f \in \text{NonMVH}, d \in \text{OTHREG} \) (5)

Output of \( n \) in \( d \) after adjustment:

\[
VQ(n,d) = \frac{VQ\text{I}(n,d)}{\text{ADJ}(n,d)}
\]

for all \( n \in \text{MVH}, d \in \text{OTHREG} \) (6)

Calculation of the shares in \( d \)'s absorption of mvh commodity \( n \) accounted for by imports:
Calculations of import and domestic flows of mvh-commodities to users in region $d$:

$$Z_{imp}(n, j, d) = Z(n, j, d) \times MSH(n, d) \quad \text{for all } n, j \in MVH, d \in OTHREG \quad (8)$$

$$Z_{dom}(n, j, d) = Z(n, j, d) - Z_{imp}(n, j, d) \quad \text{for all } n, j \in MVH, d \in OTHREG \quad (9)$$

$$OD_{imp}(n, f, d) = OD(n, f, d) \times MSH(n, d), \quad n \in MVH,$$

$$f \in \text{NonMVH}, \ d \in OTHREG \quad (10)$$

$$OD_{dom}(n, f, d) = OD(n, f, d) - OD_{imp}(n, f, d), \quad n \in MVH,$$

$$f \in \text{NonMVH}, \ d \in OTHREG \quad (11)$$

**Solving the Equation System**

Substituting from Equations (3), (4), (5) and (6) into Equations (1) and (2) gives

$$\sum_{s \in s_{d}} TR(n, s, d) + \frac{VQ(n, d)}{ADJ(n, d)} = \sum_{s \in s_{d}} TR(n, d, s)$$

$$= \sum_{j \in MVH} \frac{Z_{USCAN}(n, j)}{VQ_{USCAN}(j)} \times \frac{VQ(n, d)}{ADJ(n, d)}$$

$$+ \sum_{f \in \text{NonMVH}} OD(n, f, d) \times ADJ(n, d)$$

for all $n \in MVH$ and $d \in OTHREG \quad (12)$

The values of the adjustment factors, $ADJ(n,d)$ can be computed from Equation (12). Once they have been computed the values of all the other unknowns in Equations (1)–(11) can be determined recursively.

**Deriving the GTAP-MVH Database by Applying SplitCom**

Using the solution from Equations (1) to (11), we can compute splitting shares that can be presented to SplitCom. This is a programme created by Horridge (2008a, 2008b). Users of SplitCom nominate the GTAP sectors to be disaggregated and the shares by which entries in the relevant columns and rows of the NATIONAL matrix for region $d$ should be allocated to the disaggregated subindustries and subcommodities. Having made an initial allocation, SplitCom undertakes a RAS procedure to ensure that the disaggregated database meets balance conditions and the condition that disaggregated cells add to the values in the origi-
Table 4. Splitting Shares for Creation of Database for GTAP-MVH

| Cell in Original GTAP Database | Splitting Share |
|-------------------------------|-----------------|
| **(a) Diagonal flow**          |                 |
| Domestic mvh–mvh flow for     |                 |
| region d                      | Zdom(n, j, d) / ∑_{m ∈ MVH} ∑_{k ∈ MVH} Zdom(m, k, d) n, j ∈ MVH |
| **(b) Diagonal flow**          |                 |
| Imported mvh–mvh flow for      |                 |
| region d                      | Zimp(n, j, d) / ∑_{m ∈ MVH} ∑_{k ∈ MVH} Zimp(m, k, d) n, j ∈ MVH |
| **(c) Rest of mvh domestic row** |         |
| Domestic mvh flow to user     |                 |
| f outside MVH (excluding      | ODdom(n, f, d) / ∑_{m ∈ MVH} ODdom(m, f, d) n ∈ MVH, f ∈ NonMVH |
| exports) in region d           |                 |
| **(d) Rest of mvh import row** |         |
| Imported mvh flow to user      |                 |
| f outside MVH (excluding      | ODimp(n, f, d) / ∑_{m ∈ MVH} ODimp(m, f, d) n ∈ MVH, f ∈ NonMVH |
| exports) in region d           |                 |
| **(e) Rest of mvh column**    |                 |
| Primary factor flows and flows | VQ(n, d) / ∑_{m ∈ MVH} VQ(m, d) n ∈ MVH |
| of domestic and imported non- |
| mvh intermediate inputs to the |
| mvh industry in region d       |                 |

**Source:** Author’s own.

**Note:** * Rather than using outputs as the basis for splitting shares for non-mvh inputs to mvh industries, a potentially preferable approach would be to use outputs multiplied by US–Canada input–output coefficients.

Table 4 shows the splitting shares, (a) to (e), that we used on the different parts of the GTAP NATIONAL matrix for region \(d\) (Table 2, Part A) in creating the NATIONAL matrix for region \(d\) in GTAP-MVH.

Disaggregation Data

To apply the theory described in subsection ‘Disaggregation Theory’, we need to assemble TRADE matrices for disaggregated mvh products \([TR(n,s,d)]\) and to make informed initial estimates for outputs of disaggregated mvh products in each region \([VQ1(n,d)]\) and non-export demands for these products outside the mvh sector \([OD1(n,f,d)]\).

Trade Data

The first data requirement for applying the theory described in subsection ‘Disaggregation Theory’ is TRADE matrices for disaggregated mvh products \([TR(n,s,d)]\).
We downloaded data for 2015 on import and export values for mvh products at the 6-digit HS (Harmonised code) level for the year 2015 from the COMTRADE database (UN Comtrade, 2018, Chapters 84 and 87). For each trade flow, the data show fob values, export taxes, import tariffs and international transport margins. We developed the disaggregated mvh TRADE matrices on the basis of fob values.

The main task in using the Comtrade data was to map and aggregate it into the nine mvh commodities in GTAP-MVH. To do this, we developed the concordance between 6-digit HS codes and GTAP-MVH commodities shown in Table 5. The concordance is based on Aguiar (2016) and a careful examination of HS codes and their descriptions, as well as the descriptions of the mvh commodities in NAICS (United States Census Bureau, 2017).

The COMTRADE data come in the form EXPORTS\(\left(c, s, d\right)\), that is, exports of commodity \(c\) from reporting region \(s\) to partner region \(d\), and IMPORTS\(\left(c, s, d\right)\), that is, imports of \(c\) to reporting region \(d\) from partner region \(s\). In principle, after conversion to compatible valuation bases, these two types of data must match, that is, for the same commodity \(c\) and the same country pair \(s, d\), we expect EXPORTS\(\left(c, s, d\right) = \text{IMPORTS}\left(c, s, d\right)\). However, it is well known that there are discrepancies in these data (see, e.g., Ferrantino, Liu, & Wang, 2012; Gehlhar, 1996; Shaar, 2017), which can be quite large.

There are several approaches handling import/export discrepancies. Gehlhar (1996) and Shaar (2017) compile reliability and data quality indices for all countries, and then accept the reported trade flows of the more reliable partner in each country pair. Calderon, Chong, and Stein (2007) give primacy to the data reported by the country with the higher income in each country pair. Here we adopted the second approach. Among GTAP-MVH’s 10 regions, we consider the USA, Canada, Japan, South Korea, Germany, EU26 and the UK as higher income countries, and the remaining regions (Mexico, China and RoW) as lower income countries. For trade flows from higher income countries to lower income countries, we adopted export values reported by the higher income countries. For trade flows from lower income countries to higher income countries, we adopted import values reported by higher income countries. For trade flows amongst similar income level country pairs, we adopted the average values of imports and exports.

To complete the preparation of the TRADE matrices for mvh products in GTAP-MVH, we scaled to ensure that when aggregated over all mvh products

\[
\sum_{n \in \text{MVH}} TR(n,s,d) = TR_{GTAP}(mvh,s,d) \quad \text{for all } s, d \in \text{REG}, s \neq d
\]  

(13)

where \(TR_{GTAP}(mvh,s,d)\) is the value of mvh exports from \(s\) to \(d\) in the original GTAP database.

Data to Inform our Initial Estimates for Outputs \([VQL(n,d)]\) and Non-export Demands for mvh Products Outside the mvh Sector \([ODL(n,f,d)]\)

For Canada, input–output data identify outputs and other demands for all nine disaggregated mvh commodities/industries (see Statistics Canada, 2017). For the
| mvh Commodities in GTAP-MVH | HS Code | Description |
|-----------------------------|---------|-------------|
| 13 Automobile manufacturing | 8702    | (Motor vehicles for the transport of 10 or more persons, including the driver) |
| 13 Motor vehicle gasoline engine and engine parts manufacturing | 840731–840734, 840820, 840891, 840899 | (Spark ignition reciprocating piston engines and parts) |
| 15 Motor vehicle steering, suspension component (except spring) manufacturing | 870880 | (Suspension systems and parts thereof) |
| 15 Motor vehicle steering, suspension component (except spring) manufacturing | 870894 | (Steering wheels, columns, boxes) |
| 16 Motor vehicle brakes and brake systems | 870830 | (Brakes and servo-brakes of motor vehicle) |
| 17 Motor vehicle transmission and power train parts | 870840 | (Gear boxes and parts thereof) |
| 17 Motor vehicle transmission and power train parts | 870850 | (Drive-axles with differential, whether/not provided with other transmission components and non-driving axles; parts thereof of the motor vehicles of headings 87.01–87.05.) |
| 18 Motor vehicle interior trim, seats and seat parts | 870821 | (Safety seat belts for motor vehicles) |
| 18 Motor vehicle interior trim, seats and seat parts | 870870 | (Road wheels and parts and accessories thereof) |
| 19 Motor vehicle metal stamping (fenders, tops, body parts, trim and moulding) | 8707 | (Bodies (including cabs), for the motor vehicles of headings 87.01–87.05) |
| 19 Motor vehicle metal stamping (fenders, tops, body parts, trim and moulding) | 870810 | (Bumpers and parts) |
| 19 Motor vehicle metal stamping (fenders, tops, body parts, trim and moulding) | 870829 | (Parts and accessories of bodies (incl. cabs) of the motor vehicles of 87.01–87.05, n.e.s. in 87.08) |
| mvh Commodities in GTAP-MVH | HS Code |
|----------------------------|---------|
| 20 Other motor vehicle parts manufacturing | 870891 (Radiators and parts)  
870892 (Silencers and exhaust pipes)  
870893 (Clutches and parts thereof, for tractors)  
870895 (Safety airbags with inflator system)  
870899 (Other parts and accessories for motor vehicle) |
| 21 Truck, utility vehicle, trailer, motor home, travel trailer and camper manufacturing | 870120 (Road tractors for semitrailers)  
8704 (Motor vehicles for the transport of goods.)  
8705 (Special purpose motor vehicles, other than those principally designed for the transport of persons or goods (e.g., breakdown lorries, crane lorries, fire fighting vehicles, concrete-mixer lorries, road sweeper lorries, spraying lorries, mobile work)  
8709 (Work trucks, self-propelled, not fitted with lifting or handling equipment, of the type used in factories, warehouses, dock areas or airports for short distance transport of goods; tractors of the type used on railway station platforms; parts of the fore)  
8710 (Tanks and other armoured fighting vehicles, motorised, whether or not fitted with weapons, and parts of such vehicles.)  
8716 (Trailers and semi-trailers; other vehicles, not mechanically propelled; parts thereof) excl. 871680 (Other vehicles, not mechanically propelled, n.e.s.) |

**Source:** Author's own.
USA, input–output data for these disaggregated commodities/industries are almost complete (see Dixon, Rimmer, & Waschik, 2017). Consequently, for these two countries we do not need initial estimates of outputs and other demands as inputs to Equations (1)–(11). Instead, as can be seen in these equations, we use input–output data from Canada and the USA to help us make judgements about input–output coefficients in the mvh sector for other countries.

For Japan, China and South Korea, shares of disaggregated mvh outputs and other demands in total mvh outputs and other demands were calculated directly from input–output data. These countries have useful levels of disaggregation for mvh in their input–output data, but less than the nine commodities/industries required. In these cases, we used US–Canada shares to complete the splits. For example, the Japanese input–output data distinguishes four mvh commodities/industries: (a) automobiles; (b) trucks, utility vehicles and trailers; (c) mvh gas engines and parts; and (d) other motor vehicle parts, see Ministry of Internal Affairs and Communications [MIC] (2016). The first three industries are the same as those required for GTAP-MVH. The last industry is an aggregation of the six remaining required mvh commodities/industries. We used the shares of these six in their aggregate sector from the US–Canada database to split the corresponding aggregate sector in the Japanese data into the six required mvh commodities/industries.

For the remaining countries/regions (Mexico, Germany, EU26, the UK and RoW) shares of disaggregated mvh outputs and other demands in total mvh outputs and other demands were calculated starting from data published by the United Nations Industrial Development Organization (UNIDO, 2018). These data provide information on two mvh sectors: (a) cars, trucks and trailers and (b) parts and accessories for motor vehicles. We disaggregated the parts commodity in the UNIDO data into ‘MV gas engines’ and ‘Other MV parts’, using data from Barnes reports (Barnes Reports, 2017a–c). At this stage, we had three mvh commodities. These were disaggregated to the required nine using the average US–Canada shares.

While the use of the US–Canada shares in assisting in the splits of outputs and demands for other countries is not ideal, it should be recalled that we are using this method only to obtain initial estimates, \(VQ1(n,d)\) and \(OD1(n,f,d)\) for \(n \in MVH, f \in NonMVH, d \in OTHREG\). These initial estimates are modified in our Equation system (1)–(11) taking account of detailed disaggregated data on trade.

**Sales Matrices for Disaggregated mvh Products: Outcomes of the Disaggregation Procedures**

Tables 6a–6i contain sales matrices for the nine mvh commodities in GTAP-MVH valued at market prices (production costs in the producing country). These are TRADE matrices with diagonal flows added to show intra-region sales. The tables were generated by disaggregating GTAP data for 2015 using the disaggregation procedures described in subsections ‘Disaggregation Theory’ and ‘Disaggregation Data’. For each commodity, the rows in the tables show sales from source regions
| Source | 1. USA | 2. Canada | 3. Mexico | 4. Japan | 5. South Korea | 6. China | 7. Germany | 8. EU26 | 9. UK | 10. RoW | Total |
|--------|--------|-----------|-----------|----------|----------------|---------|------------|---------|------|--------|-------|
| 1. USA | 108,861| 4,853     | 2,173     | 257      | 99             | 1,048   | 690        | 455     | 204  | 4,033  | 122,673|
| 2. Canada | 11,422 | 8,223     | 429       | 26       | 18             | 211     | 33         | 126     | 24   | 651    | 21,162|
| 3. Mexico | 14,612 | 1,812     | 8,892     | 142      | 45             | 517     | 1,293      | 382     | 132  | 3,971  | 31,799|
| 4. Japan | 26,910 | 3,149     | 2,434     | 30,372   | 1,297          | 13,937  | 2,270      | 7,067   | 3,636| 51,363 | 142,435|
| 5. South Korea | 7,090 | 1,127     | 512       | 517      | 7,016          | 3727    | 617        | 3,802   | 456  | 23,507 | 48,370|
| 6. China | 1,090  | 116       | 79        | 604      | 197            | 155,089 | 212        | 503     | 251  | 5,197  | 163,338|
| 7. Germany | 11,770 | 1,610     | 988       | 3,414    | 1,355          | 13,406  | 17,908     | 59,032  | 17,564| 34,460 | 161,507|
| 8. EU26 | 3,239  | 361       | 486       | 1,298    | 500            | 4,009   | 27,226     | 112,011 | 18,159| 29,217 | 196,506|
| 9. UK    | 2,364  | 250       | 77        | 454      | 113            | 2,201   | 3,468      | 10,286  | 8,603| 8,229  | 36,046|
| 10. RoW  | 2,455  | 276       | 784       | 1,450    | 249            | 655     | 2,774      | 6,667   | 1,813| 159,014| 176,136|
| Total   | 189,814| 21,778    | 16,856    | 38,534   | 10,890         | 194,798 | 56,491     | 200,331 | 50,841| 319,641| 1,099,973|

**Source:** Author's own calculations.
| Source   | 1. USA | 2. Canada | 3. Mexico | 4. Japan | 5. South Korea | 6. China | 7. Germany | 8. EU26 | 9. UK | 10. RoW | Total |
|----------|--------|-----------|-----------|----------|----------------|----------|-------------|---------|------|--------|-------|
| 1. USA   | 24,153 | 3,046     | 2,486     | 145      | 154            | 838      | 603         | 246     | 42   | 1,521  | 33,233|
| 2. Canada| 2,233  | 3,390     | 195       | 6        | 11             | 67       | 12          | 27      | 2    | 98     | 6,040 |
| 3. Mexico| 2,606  | 414       | 2,494     | 29       | 26             | 149      | 408         | 75      | 10   | 544    | 6,754 |
| 4. Japan | 1,827  | 274       | 385       | 41,840   | 277            | 1,531    | 273         | 527     | 103  | 2,675  | 49,713|
| 5. South Korea | 545 | 111       | 92        | 45       | 9,458          | 464      | 84          | 321     | 15   | 1,385  | 12,520|
| 6. China | 720    | 98        | 122       | 455      | 412            | 65,596   | 248         | 365     | 69   | 2,636  | 70,720|
| 7. Germany| 1,691 | 295       | 330       | 563      | 618            | 3,129    | 14,116      | 9,329   | 1,055| 3,796  | 34,921|
| 8. EU26  | 659    | 93        | 229       | 301      | 324            | 1,330    | 9,863       | 29,025  | 1,544| 4,563  | 47,933|
| 9. UK    | 402    | 54        | 30        | 88       | 62             | 611      | 1,053       | 1,926   | 1,154| 1,074  | 6,454 |
| 10. RoW  | 555    | 79        | 410       | 373      | 179            | 241      | 1,115       | 1,657   | 171  | 32,488 | 37,270|
| Total    | 35,391 | 7,854     | 6,772     | 43,845   | 11,521         | 73,957   | 27,774      | 43,498  | 4,165| 50,779 | 305,558|

**Source:** Author's own calculations.
| Source  | 1. USA | 2. Canada | 3. Mexico | 4. Japan | 5. South Korea | 6. China | 7. Germany | 8. EU26 | 9. UK | 10. RoW | Total |
|---------|--------|-----------|-----------|----------|----------------|----------|------------|--------|------|--------|-------|
| 1. USA  | 12,106 | 710       | 482       | 22       | 17             | 167      | 90         | 40     | 8    | 229    | 13,870|
| 2. Canada| 405    | 1,748     | 34        | 1        | 1              | 12       | 2          | 4      | 0    | 13     | 2,220 |
| 3. Mexico| 641    | 118       | 845       | 5        | 3              | 36       | 74         | 15     | 2    | 100    | 1,841 |
| 4. Japan | 244    | 43        | 49        | 1,113    | 21             | 204      | 27         | 57     | 13   | 269    | 16,038|
| 5. South Korea| 128   | 30        | 21        | 8        | 3,000          | 108      | 15         | 61     | 3    | 244    | 3,617 |
| 6. China | 224    | 35        | 36        | 106      | 71             | 21,295   | 57         | 91     | 20   | 616    | 22,552|
| 7. Germany| 304   | 62        | 57        | 76       | 62             | 559      | 4,978      | 1,347  | 176  | 511    | 8,132 |
| 8. EU26  | 125    | 21        | 42        | 43       | 34             | 250      | 1,384      | 9,090  | 272  | 647    | 11,909|
| 9. UK    | 38     | 6         | 3         | 6        | 3              | 58       | 74         | 147    | 856  | 77     | 1,269 |
| 10. RoW  | 120    | 20        | 85        | 61       | 22             | 52       | 179        | 288    | 34   | 11,651 | 12,511|
| Total   | 14,335 | 2,792     | 1,654     | 15,440   | 3,235          | 22,741   | 6,879      | 11,140 | 1,385 | 14,357 | 93,958|

**Source:** Author's own calculations.
Table 6d. Motor Vehicle Brakes and Brake Systems: Flows from Source to Destination (US$ Million, 2015)

| Source  | 1. USA | 2. Canada | 3. Mexico | 4. Japan | 5. South Korea | 6. China | 7. Germany | 8. EU26 | 9. UK | 10. RoW | Total |
|---------|--------|-----------|-----------|----------|----------------|----------|------------|--------|------|--------|-------|
| 1. USA  | 6,800  | 282       | 171       | 8        | 7              | 45       | 40         | 17     | 3    | 90     | 7,463 |
| 2. Canada| 121    | 751       | 9         | 0        | 0              | 3        | 1          | 1      | 0    | 4      | 891   |
| 3. Mexico| 237    | 46        | 492       | 2        | 1              | 10       | 32         | 6      | 1    | 38     | 865   |
| 4. Japan | 108    | 20        | 20        | 7,958    | 9              | 64       | 14         | 28     | 6    | 123    | 8,350 |
| 5. South Korea | 64     | 16        | 10        | 4        | 1,592          | 38       | 9          | 34     | 2    | 126    | 1,892 |
| 6. China | 225    | 37        | 34        | 100      | 73             | 10,370   | 67         | 101    | 20   | 638    | 11,666|
| 7. Germany| 160    | 34        | 28        | 38       | 33             | 209      | 2,664      | 788    | 93   | 279    | 4,326 |
| 8. EU26  | 80     | 14        | 25        | 26       | 22             | 113      | 1,038      | 4,768  | 173  | 427    | 6,685 |
| 9. UK    | 40     | 6         | 3         | 6        | 4              | 43       | 91         | 170    | 323  | 83     | 769   |
| 10. RoW  | 47     | 8         | 31        | 22       | 9              | 14       | 81         | 124    | 13   | 6,369  | 6,717 |
| Total   | 7,882  | 1,214     | 824       | 8,164    | 1,751          | 10,907   | 4,037      | 6,037  | 634  | 8,176  | 49,624|

Source: Author’s own calculations.
| Source  | 1. USA | 2. Canada | 3. Mexico | 4. Japan | 5. South Korea | 6. China | 7. Germany | 8. EU26 | 9. UK | 10. RoW | Total |
|---------|--------|-----------|-----------|----------|----------------|----------|------------|--------|-------|---------|-------|
| 1. USA  | 30,558 | 2,492     | 2,154     | 99       | 117            | 1,224    | 406        | 196    | 35    | 1,095   | 38,376|
| 2. Canada| 937    | 3,453     | 77        | 2        | 4              | 44       | 4          | 10     | 1     | 32      | 4,563 |
| 3. Mexico| 2,123  | 299       | 2,768     | 17       | 17             | 193      | 243        | 53     | 7     | 346     | 6,068 |
| 4. Japan | 3,022  | 404       | 599       | 36,192   | 377            | 4,028    | 330        | 756    | 154   | 3,461   | 49,323|
| 5. South Korea | 618    | 112       | 98        | 38       | 8,432          | 837      | 70         | 316    | 15    | 1,229   | 11,764|
| 6. China | 294    | 35        | 46        | 137      | 138            | 67,093   | 74         | 129    | 26    | 840     | 68,812|
| 7. Germany| 1,347  | 209       | 249       | 332      | 406            | 3,975    | 13,675     | 6,442  | 759   | 2,364   | 29,757|
| 8. EU26  | 340    | 43        | 112       | 116      | 138            | 1,091    | 3,727      | 24,809 | 720   | 1,838   | 32,933|
| 9. UK    | 137    | 16        | 10        | 22       | 17             | 332      | 262        | 568    | 2,058 | 285     | 3,709 |
| 10. RoW  | 297    | 38        | 207       | 149      | 79             | 205      | 437        | 769    | 83    | 30,053  | 32,317|
| Total    | 39,671 | 7,102     | 6,320     | 37,104   | 9,725          | 79,024   | 19,227     | 34,048 | 3,858 | 41,543  | 277,622|

**Source:** Author’s own calculations.
### Table 6f. Motor Vehicle Interior Trim, Seats and Seat Parts: Flows from Source to Destination (US$ Million, 2015)

| Source  | 1. USA | 2. Canada | 3. Mexico | 4. Japan | 5. South Korea | 6. China | 7. Germany | 8. EU26 | 9. UK | 10. RoW | Total |
|---------|--------|-----------|-----------|----------|----------------|----------|------------|--------|------|--------|-------|
| 1. USA  | 20,237 | 1,038 | 398 | 56 | 19 | 127 | 161 | 53 | 8 | 225 | 22,322 |
| 2. Canada | 276 | 3,261 | 12 | 1 | 4 | 1 | 2 | 0 | 5 | 3,563 |
| 3. Mexico | 435 | 72 | 1,934 | 6 | 2 | 12 | 55 | 8 | 1 | 41 | 2,565 |
| 4. Japan | 53 | 8 | 5 | 35,709 | 3 | 21 | 6 | 10 | 2 | 35 | 35,853 |
| 5. South Korea | 86 | 18 | 7 | 8 | 6,465 | 34 | 11 | 33 | 1 | 99 | 6,763 |
| 6. China | 490 | 69 | 40 | 362 | 105 | 40,142 | 136 | 163 | 28 | 805 | 42,340 |
| 7. Germany | 191 | 35 | 18 | 75 | 26 | 164 | 12,012 | 693 | 70 | 193 | 13,477 |
| 8. EU26 | 111 | 16 | 19 | 61 | 21 | 104 | 1,351 | 12,631 | 154 | 346 | 14,813 |
| 9. UK | 25 | 4 | 1 | 7 | 1 | 18 | 54 | 80 | 869 | 31 | 1,090 |
| 10. RoW | 138 | 20 | 50 | 110 | 17 | 28 | 226 | 272 | 25 | 13,132 | 14,018 |
| Total | 22,043 | 4,542 | 2,485 | 36,395 | 6,659 | 40,652 | 14,013 | 13,945 | 1,159 | 14,910 | 156,803 |

**Source:** Author's own calculations.
### Table 6g. Motor Vehicle Metal Stamping: Flows from Source to Destination (US$ Million, 2015)

| Source   | 1. USA | 2. Canada | 3. Mexico | 4. Japan | 5. South Korea | 6. China | 7. Germany | 8. EU26 | 9. UK | 10. RoW | Total |
|----------|--------|-----------|-----------|----------|----------------|----------|------------|---------|-------|---------|-------|
| 1. USA   | 19,696 | 1,155     | 758       | 37       | 28             | 316      | 175        | 67      | 9     | 330     | 22,571|
| 2. Canada| 439    | 4,513     | 213       | 5        | 8              | 91       | 12         | 26      | 2     | 76      | 5,385 |
| 3. Mexico| 354    | 387       | 2,182     | 18       | 12             | 139      | 291        | 50      | 5     | 291     | 3,728 |
| 4. Japan | 99     | 102       | 114       | 40,665   | 50             | 567      | 77         | 140     | 23    | 571     | 42,409|
| 5. South Korea | 77 | 108 | 72 | 30 | 7,170 | 452 | 63 | 225 | 9 | 776 | 8,980 |
| 6. China | 74     | 69        | 68        | 213      | 141            | 55,891   | 132        | 183     | 29    | 1,060   | 57,861|
| 7. Germany| 170   | 204       | 182       | 259      | 208            | 2,148    | 12,614     | 4,614   | 434   | 1,500   | 22,333|
| 8. EU26  | 68     | 66        | 129       | 142      | 111            | 928      | 5,267      | 19,119  | 647   | 1,835   | 28,312|
| 9. UK    | 23     | 21        | 10        | 23       | 12             | 237      | 312        | 538     | 1,034 | 239     | 2,448 |
| 10. RoW  | 67     | 66        | 271       | 207      | 72             | 198      | 701        | 980     | 84    | 20,076  | 22,723|
| Total    | 21,066 | 6,691     | 3,998     | 41,598   | 7,812          | 60,967   | 19,643     | 25,943  | 2,276 | 26,753  | 216,749|

**Source:** Author's own calculations.
### Table 6h. Other Motor Vehicle Parts: Flows from Source to Destination (US$ Million, 2015)

| Destination | 1. USA | 2. Canada | 3. Mexico | 4. Japan | 5. South Korea | 6. China | 7. Germany | 8. EU26 | 9. UK | 10. RoW | Total |
|-------------|--------|-----------|-----------|----------|----------------|---------|------------|--------|-------|---------|-------|
| 1. USA      | 46,474 | 9,667     | 8,058     | 498      | 439            | 3,228   | 2,131      | 1,128  | 182   | 6,147   | 77,952|
| 2. Canada   | 3,855  | 5,104     | 163       | 5        | 8              | 66      | 10         | 32     | 2     | 102     | 9,348 |
| 3. Mexico   | 5,421  | 411       | 5,850     | 31       | 23             | 179     | 448        | 107    | 13    | 681     | 13,164|
| 4. Japan    | 2,318  | 166       | 238       | 71,213   | 150            | 1,116   | 182        | 458    | 85    | 2,047   | 77,973|
| 5. South Korea | 3,238 | 314       | 265       | 140      | 11,846         | 1,587   | 264        | 1,307  | 56    | 4,966   | 23,985|
| 6. China    | 1,833  | 119       | 151       | 600      | 448            | 111,871 | 334        | 637    | 115   | 4,047   | 120,153|
| 7. Germany  | 3,138  | 262       | 300       | 541      | 490            | 3,336   | 30,865     | 11,839 | 1,263 | 4,245   | 56,279|
| 8. EU26     | 1,771  | 120       | 302       | 421      | 373            | 2,053   | 14,013     | 64,390 | 2,682 | 7,383   | 93,506|
| 9. UK       | 642    | 41        | 24        | 74       | 42             | 559     | 887        | 2,100  | 5,087 | 1,030   | 10,486|
| 10. RoW     | 1,233  | 84        | 446       | 431      | 171            | 308     | 1,312      | 2,524  | 246   | 64,499  | 71,255|

**Total**: 69,922 16,288 15,797 73,954 13,989 124,303 50,448 84,521 9,732 95,148 554,101

**Source**: Author's own calculations.
| Source   | 1. USA  | 2. Canada | 3. Mexico | 4. Japan | 5. South Korea | 6. China | 7. Germany | 8. EU26 | 9. UK  | 10. RoW | Total  |
|----------|---------|-----------|-----------|----------|----------------|----------|------------|---------|-------|--------|--------|
| 1. USA   | 260,896 | 23,877    | 5,898     | 548      | 337            | 1,318    | 2,610      | 1,838   | 630   | 16,180 | 314,132|
| 2. Canada| 33,973  | 14,597    | 371       | 18       | 20             | 85       | 40         | 163     | 24    | 834    | 50,124 |
| 3. Mexico| 28,325  | 1,856     | 15,612    | 63       | 32             | 135      | 1,011      | 320     | 85    | 3,309  | 50,748 |
| 4. Japan | 8,853   | 551       | 232       | 2,045    | 153            | 605      | 298        | 998     | 393   | 7,241  | 123,892|
| 5. South Korea | 2,122  | 179       | 44        | 35       | 30,840         | 147      | 74         | 489     | 45    | 3,012  | 36,986 |
| 6. China | 4,870   | 275       | 103       | 612      | 320            | 243,799  | 381        | 970     | 370   | 9,964  | 261,606|
| 7. Germany| 8,290  | 602       | 202       | 538      | 344            | 1242     | 79,734     | 17,817  | 4,045 | 10,376 | 123,188|
| 8. EU26   | 3,993   | 235       | 174       | 358      | 223            | 652      | 13,454     | 149,363 | 7,311 | 15,387 | 191,151|
| 9. UK     | 861     | 48        | 8         | 36       | 15             | 104      | 502        | 1,595   | 26,195| 1,275  | 30,639 |
| 10. RoW   | 4,272   | 253       | 396       | 571      | 158            | 152      | 1,948      | 5,000   | 1,037 | 227,306| 241,095|
| Total    | 356,456 | 42,473    | 23,042    | 107,345  | 32,443         | 248,179  | 100,052    | 178,551 | 40,135| 294,884| 1,423,560|

**Source:** Author's own.
| Region                  | 1. USA | 2. Canada | 3. Mexico | 4. Japan | 5. South Korea | 6. China | 7. Germany | 8. EU26 | 9. UK | 10. RoW | Total |
|------------------------|--------|-----------|-----------|----------|----------------|----------|------------|--------|------|--------|-------|
| 1. Automobile          | 54.0   | 38.9      | 2.0       | 0.1      | 0.1            | 1.0      | 0.2        | 0.6    | 0.1  | 3.1    | 100.0 |
| 2. MVGasEngPrts        | 37.0   | 56.1      | 3.2       | 0.1      | 0.2            | 1.1      | 0.2        | 0.4    | 0.0  | 1.6    | 100.0 |
| 3. MVSteerSuspn        | 18.2   | 78.8      | 1.5       | 0.0      | 0.1            | 0.5      | 0.1        | 0.2    | 0.0  | 0.6    | 100.0 |
| 4. MVBrakes            | 13.6   | 84.3      | 1.1       | 0.0      | 0.0            | 0.3      | 0.1        | 0.1    | 0.0  | 0.5    | 100.0 |
| 5. MVPwrTrTrain        | 20.5   | 75.7      | 1.7       | 0.0      | 0.1            | 1.0      | 0.1        | 0.2    | 0.0  | 0.7    | 100.0 |
| 6. MVSeatInter         | 7.7    | 91.5      | 0.3       | 0.0      | 0.0            | 0.1      | 0.0        | 0.1    | 0.0  | 0.2    | 100.0 |
| 7. MVMtlStamp          | 8.1    | 83.8      | 4.0       | 0.1      | 0.1            | 1.7      | 0.2        | 0.5    | 0.0  | 1.4    | 100.0 |
| 8. OthMVParts          | 41.2   | 54.6      | 1.7       | 0.1      | 0.1            | 0.7      | 0.1        | 0.3    | 0.0  | 1.1    | 100.0 |
| 9. TruckUteTrlr        | 67.8   | 29.1      | 0.7       | 0.0      | 0.0            | 0.2      | 0.1        | 0.3    | 0.0  | 1.7    | 100.0 |
| All mvh commodities    | 51.9   | 43.6      | 1.5       | 0.1      | 0.1            | 0.6      | 0.1        | 0.4    | 0.1  | 1.8    | 100.0 |

Source: Author's own.
where the commodity is produced, and the columns show the destination regions where the commodity is used. The row totals show output values of the commodity in the source regions. The column totals show absorption values of the commodity in the destination regions.

The tables show that, apart from the finished product automobiles, the main destination for a country’s motor vehicle commodities is usually the country itself. Exceptions include the production of gasoline engines by Mexico and the UK, and the production of Trucks, etc., by Canada and Mexico. In the case of automobiles, the principal user is often outside the source country. For example, the USA is the principal user of automobiles produced by Canada and Mexico. Rest of the world is the principal user of automobiles produced by Japan and South Korea. EU26 is the principal user of automobiles produced by Germany and the UK. EU26, RoW, China and Germany are the biggest producers of automobiles, while the USA and China are the biggest producers of trucks, utility vehicles, trailers, motor homes and campers. Japan and China are the biggest producers of nearly all mvh components.

The tables can be converted to percentages in either the row direction or the column direction to highlight sales and demand patterns. We can also create new tables to highlight the data for all products for a particular country. This is done in Table 7 which shows destination percentages in the sales of Canadian mvh products. The table shows that the USA is by far the biggest export market for Canadian mvh products. Exports to the US account for more than half of Canadian automobiles and trucks, etc., and over one third of Canadian gasoline engines and other motor vehicle parts. In total, exports to the US account for 51.9 per cent of Canada’s mvh output and 92 per cent of Canada’s mvh exports \(=\frac{100 \times 51.9}{56.4}\). RoW and Mexico rank second and third among export markets for Canada’s mvh products. But exports to these markets account for only small shares of Canadian output (1.8% and 1.5%).

**Illustrative GTAP-MVH Simulations**

During 2017 and 2018, mainly at the behest of the USA, the three NAFTA countries held lengthy trade negotiations. Numerous proposals were made, particularly with regard to the motor vehicle sector. In this section, we show how GTAP-MVH can be used to provide information to negotiators. We simulate the effects of two proposed sets of changes to the powers of the tariffs applying to imports of finished motor vehicles (commodities 13 and 21 in GTAP-MVH, see Table 3). In simulation 1 we impose the percentage increases in intra-NAFTA tariffs shown in the upper part of Table 8. In simulation 2, we impose the same increases as in simulation 1 plus a 25 per cent increase in the power of the US tariff on imports of finished vehicles from non-NAFTA countries. Because the initial tariff rates are zero or close to zero, the increases in Table 8 are the new levels of tariff rates.
For simulation purposes, we treat the tariffs as though they were imposed in 2016. Tables 9 and 10 show effects from simulations 1 and 2 on outputs in the 10 regions of GTAP-MVH for: the motor vehicle sector as a whole; finished motor vehicles (commodities 13 and 21); and motor vehicle parts (commodities 14–20). Regional macro effects from the two simulations are in Tables 11 and 12. All effects are expressed as percentage deviations from a baseline in which there are no tariff changes. While we do not explain the baseline or GTAP-MVH theory here, key features will be apparent from our explanation of the results.

**Simulation 1: Output Effects in the MVH Sector (Table 9)**

Output of motor vehicles and parts declines in the three NAFTA countries. While the motor vehicle sector in each of the three countries benefits from reduced competition from its NAFTA partners, it suffers an offsetting effect from reduced demand from its NAFTA partners. So why are the overall effects negative? This is because non-NAFTA countries gain market share in NAFTA destinations: in this simulation non-NAFTA countries do not suffer a tariff increase on their exports to NAFTA. The gain in market share for non-NAFTA countries in NAFTA markets explains why the motor vehicle sector is stimulated in non-NAFTA countries.

Because the tariffs are applied only on finished vehicles, the negative effects on the production of finished vehicles in NAFTA are larger than those for parts. Nevertheless, parts production generally declines in the three NAFTA countries, reflecting reductions in sales to NAFTA’s finished vehicles industries.

Against the general pattern of the other results, output of parts in Mexico initially increases slightly (0.034% in 2016, Table 9). At the macro level, Mexico experiences a bigger real devaluation than the other two NAFTA countries: Mexico is more dependent on motor vehicle exports than the other two countries. Greater real devaluation allows the Mexican parts sector to compete successfully outside NAFTA. This slight positive effect is offset in the long run by continuing

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**Table 8. Proposed Percentage Increases in Powers of Tariffs on Finished Vehicles: Commodities 13 and 21 in GTAP-MVH**

| On Imports From: | USA | Canada | Mexico |
|-----------------|-----|--------|--------|
| **Shocks in simulation 1** |     |        |        |
| USA             | 2.5 | 10.8   |        |
| Canada          | 0.7 | 6.4    |        |
| Mexico          | 1.1 | 3.1    |        |
| **Additional shock in simulation 2** |       |        |        |
| Non-NAFTA countries | 25.0 | 0.0    | 0.0    |

**Source:** Author’s own.
Table 9. Simulation 1 (Tariff Increases in NAFTA): Percentage Effects on Outputs of Motor Vehicles

|                      | 2016  | 2017  | 2018  | 2019  | 2020  | 2021  | 2022  | 2023  |
|----------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| **Motor vehicles and parts** |       |       |       |       |       |       |       |       |
| 1. USA               | -0.360| -0.390| -0.397| -0.398| -0.398| -0.399| -0.399| -0.399|
| 2. Canada            | -0.169| -0.285| -0.369| -0.425| -0.456| -0.469| -0.472| -0.467|
| 3. Mexico            | -0.095| -0.308| -0.506| -0.677| -0.818| -0.930| -1.020| -1.090|
| 4. Japan             | 0.106 | 0.171 | 0.213 | 0.239 | 0.259 | 0.272 | 0.283 | 0.292 |
| 5. South Korea       | 0.058 | 0.099 | 0.103 | 0.154 | 0.173 | 0.189 | 0.202 | 0.213 |
| 6. China             | 0.033 | 0.042 | 0.047 | 0.050 | 0.051 | 0.052 | 0.053 | 0.053 |
| 7. Germany           | 0.127 | 0.133 | 0.141 | 0.148 | 0.152 | 0.157 | 0.160 | 0.163 |
| 8. EU26              | 0.035 | 0.049 | 0.058 | 0.065 | 0.070 | 0.073 | 0.076 | 0.079 |
| 9. UK                | 0.085 | 0.091 | 0.099 | 0.106 | 0.111 | 0.115 | 0.119 | 0.122 |
| 10. RoW              | 0.036 | 0.054 | 0.065 | 0.072 | 0.077 | 0.079 | 0.081 | 0.083 |

| **Finished vehicles** |       |       |       |       |       |       |       |       |
| 1. USA               | -0.484| -0.493| -0.482| -0.470| -0.463| -0.459| -0.457| -0.456|
| 2. Canada            | -0.260| -0.400| -0.488| -0.534| -0.547| -0.538| -0.519| -0.493|
| 3. Mexico            | -0.163| -0.489| -0.774| -1.012| -1.202| -1.305| -1.464| -1.551|
| 4. Japan             | 0.194 | 0.241 | 0.277 | 0.302 | 0.323 | 0.331 | 0.342 | 0.349 |
| 5. South Korea       | 0.122 | 0.190 | 0.237 | 0.272 | 0.296 | 0.314 | 0.329 | 0.340 |
| 6. China             | 0.060 | 0.063 | 0.068 | 0.072 | 0.073 | 0.073 | 0.073 | 0.073 |
| 7. Germany           | 0.179 | 0.191 | 0.203 | 0.213 | 0.218 | 0.224 | 0.228 | 0.231 |
| 8. EU26              | 0.040 | 0.056 | 0.065 | 0.071 | 0.075 | 0.078 | 0.081 | 0.083 |
| 9. UK                | 0.090 | 0.100 | 0.109 | 0.118 | 0.123 | 0.129 | 0.133 | 0.136 |
| 10. RoW              | 0.045 | 0.069 | 0.083 | 0.091 | 0.096 | 0.098 | 0.100 | 0.101 |

| **Vehicle parts**     |       |       |       |       |       |       |       |       |
| 1. USA               | -0.128| -0.193| -0.231| -0.254| -0.269| -0.278| -0.284| -0.287|
| 2. Canada            | -0.042| -0.122| -0.199| -0.267| -0.323| -0.367| -0.401| -0.425|
| 3. Mexico            | 0.034 | 0.033 | -0.006| -0.056| -0.113| -0.171| -0.227| -0.280|
| 4. Japan             | 0.078 | 0.146 | 0.191 | 0.217 | 0.237 | 0.251 | 0.263 | 0.271 |
| 5. South Korea       | 0.007 | 0.027 | 0.046 | 0.063 | 0.078 | 0.092 | 0.104 | 0.115 |
| 6. China             | 0.022 | 0.033 | 0.039 | 0.042 | 0.044 | 0.045 | 0.045 | 0.045 |
| 7. Germany           | 0.064 | 0.061 | 0.064 | 0.067 | 0.070 | 0.072 | 0.074 | 0.076 |
| 8. EU26              | 0.027 | 0.037 | 0.046 | 0.054 | 0.060 | 0.065 | 0.068 | 0.072 |
| 9. UK                | 0.062 | 0.055 | 0.055 | 0.056 | 0.057 | 0.058 | 0.059 | 0.060 |
| 10. RoW              | 0.017 | 0.022 | 0.027 | 0.031 | 0.034 | 0.037 | 0.038 | 0.040 |

Source: Author’s own.
Table 10. Simulation 2 (Tariff Increases in NAFTA and US Tariffs on Non-NAFTA): Percentage Effects on Outputs of Motor Vehicles

|                | 2016  | 2017  | 2018  | 2019  | 2020  | 2021  | 2022  | 2023  |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|
| **Motor vehicles and parts** |       |       |       |       |       |       |       |       |
| 1. USA         | 4.143 | 4.713 | 5.059 | 5.168 | 5.138 | 5.045 | 4.967 | 4.89  |
| 2. Canada      | 4.470 | 7.876 | 10.271| 11.888| 12.907| 13.505| 13.866| 14.068|
| 3. Mexico      | 0.931 | 2.984 | 4.680 | 6.040 | 7.101 | 7.900 | 8.499 | 8.949 |
| 4. Japan       | -3.096| -3.818| -4.394| -4.781| -5.041| -5.131| -5.201| -5.236|
| 5. South Korea | -1.412| -2.104| -2.643| -3.040| -3.309| -3.499| -3.638| -3.736|
| 6. China       | -0.651| -0.803| -0.893| -0.933| -0.925| -0.911| -0.896| -0.880|
| 7. Germany     | -2.638| -2.647| -2.762| -2.812| -2.787| -2.776| -2.765| -2.751|
| 8. EU26        | -0.659| -0.863| -0.998| -1.076| -1.108| -1.124| -1.132| -1.134|
| 9. UK          | -2.097| -2.282| -2.490| -2.613| -2.648| -2.681| -2.698| -2.706|
| 10. RoW        | -0.477| -0.650| -0.756| -0.812| -0.825| -0.821| -0.809| -0.795|

|                | 2016  | 2017  | 2018  | 2019  | 2020  | 2021  | 2022  | 2023  |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|
| **Finished vehicles** |       |       |       |       |       |       |       |       |
| 1. USA         | 5.341 | 5.779 | 5.994 | 5.966 | 5.811 | 5.620 | 5.478 | 5.355 |
| 2. Canada      | 7.108 | 11.98 | 15.199| 17.192| 18.281| 18.770| 18.955| 18.960|
| 3. Mexico      | 1.522 | 4.572 | 7.011 | 8.926 | 10.387| 11.463| 12.247| 12.819|
| 4. Japan       | -4.424| -4.970| -5.541| -5.876| -6.113| -6.082| -6.114| -6.109|
| 5. South Korea | -2.620| -3.847| -4.721| -5.296| -5.612| -5.799| -5.911| -5.974|
| 6. China       | -0.922| -1.148| -1.279| -1.337| -1.315| -1.291| -1.266| -1.242|
| 7. Germany     | -3.476| -3.649| -3.873| -3.968| -3.941| -3.926| -3.903| -3.878|
| 8. EU26        | -0.654| -0.888| -1.033| -1.108| -1.129| -1.135| -1.133| -1.129|
| 9. UK          | -2.257| -2.528| -2.792| -2.944| -2.990| -3.028| -3.046| -3.054|
| 10. RoW        | -0.494| -0.725| -0.870| -0.948| -0.969| -0.965| -0.951| -0.932|

|                | 2016  | 2017  | 2018  | 2019  | 2020  | 2021  | 2022  | 2023  |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|
| **Vehicle parts** |       |       |       |       |       |       |       |       |
| 1. USA         | 1.865 | 2.643 | 3.196 | 3.557 | 3.769 | 3.871 | 3.916 | 3.925 |
| 2. Canada      | 0.448 | 1.450 | 2.511 | 3.513 | 4.394 | 5.115 | 5.684 | 6.121 |
| 3. Mexico      | -0.287| -0.351| -0.148| 0.153 | 0.503 | 0.865 | 1.215 | 1.542 |
| 4. Japan       | -2.667| -3.423| -3.999| -4.401| -4.670| -4.797| -4.879| -4.926|
| 5. South Korea | -0.483| -0.783| -1.076| -1.342| -1.575| -1.768| -1.926| -2.052|
| 6. China       | -0.535| -0.670| -0.748| -0.784| -0.783| -0.775| -0.766| -0.754|
| 7. Germany     | -1.624| -1.415| -1.384| -1.367| -1.334| -1.322| -1.317| -1.309|
| 8. EU26        | -0.665| -0.816| -0.936| -1.020| -1.068| -1.101| -1.125| -1.139|
| 9. UK          | -1.439| -1.254| -1.227| -1.222| -1.205| -1.208| -1.216| -1.221|
| 10. RoW        | -0.439| -0.488| -0.507| -0.510| -0.500| -0.490| -0.482| -0.473|

Source: Author’s own.
Table 11. Simulation 1 (Tariff Increases in NAFTA): Percentage Deviations in Macro Aggregates by Region

| Region | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|--------|------|------|------|------|------|------|------|------|
| **Real GDP** |      |      |      |      |      |      |      |      |
| USA    | -0.005 | -0.003 | -0.002 | -0.002 | -0.002 | -0.002 | -0.002 | -0.002 |
| Canada | -0.038 | -0.030 | -0.027 | -0.025 | -0.023 | -0.021 | -0.020 | -0.020 |
| Mexico | -0.036 | -0.054 | -0.070 | -0.081 | -0.090 | -0.097 | -0.102 | -0.106 |
| Japan  | 0.004  | 0.005  | 0.004  | 0.004  | 0.004  | 0.004  | 0.004  | 0.003  |
| South Korea | 0.006  | 0.004  | 0.004  | 0.005  | 0.005  | 0.005  | 0.005  | 0.004  |
| China  | 0.003  | 0.001  | 0.001  | 0.002  | 0.002  | 0.002  | 0.002  | 0.001  |
| Germany | 0.003 | 0.002  | 0.002  | 0.002  | 0.002  | 0.002  | 0.002  | 0.001  |
| EU26   | 0.001  | 0.001  | 0.002  | 0.002  | 0.002  | 0.002  | 0.002  | 0.002  |
| UK     | 0.002  | 0.001  | 0.002  | 0.002  | 0.002  | 0.002  | 0.002  | 0.002  |
| ROW    | 0.000  | 0.001  | 0.002  | 0.002  | 0.002  | 0.002  | 0.002  | 0.002  |

**Employment**

| Region | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|--------|------|------|------|------|------|------|------|------|
| USA    | -0.007 | -0.003 | -0.002 | -0.001 | -0.001 | -0.001 | 0.000  | 0.000  |
| Canada | -0.052 | -0.027 | -0.014 | -0.008 | -0.004 | -0.002 | 0.000  | 0.000  |
| Mexico | -0.060 | -0.048 | -0.041 | -0.035 | -0.029 | -0.024 | -0.019 | -0.015 |
| Japan  | 0.005  | 0.004  | 0.002  | 0.001  | 0.001  | 0.001  | 0.000  | 0.000  |
| South Korea | 0.007  | 0.003  | 0.002  | 0.001  | 0.001  | 0.001  | 0.001  | 0.000  |
| China  | 0.003  | 0.000  | 0.000  | 0.000  | 0.000  | 0.000  | 0.000  | 0.000  |
| Germany | 0.005 | 0.003  | 0.002  | 0.001  | 0.001  | 0.000  | 0.000  | 0.000  |
| EU26   | 0.001  | 0.001  | 0.001  | 0.001  | 0.001  | 0.001  | 0.000  | 0.000  |
| UK     | 0.002  | 0.001  | 0.001  | 0.001  | 0.001  | 0.000  | 0.000  | 0.000  |
| ROW    | 0.001  | 0.001  | 0.001  | 0.001  | 0.001  | 0.000  | 0.000  | 0.000  |

**Capital**

| Region | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|--------|------|------|------|------|------|------|------|------|
| USA    | 0.000  | -0.003 | -0.005 | -0.005 | -0.006 | -0.006 | -0.007 | -0.007 |
| Canada | 0.000  | -0.031 | -0.046 | -0.054 | -0.058 | -0.060 | -0.061 | -0.061 |
| Mexico | 0.000  | -0.039 | -0.067 | -0.089 | -0.106 | -0.119 | -0.130 | -0.138 |
| Japan  | 0.000  | 0.005  | 0.007  | 0.007  | 0.007  | 0.007  | 0.007  | 0.007  |
| South Korea | 0.000 | 0.005  | 0.006  | 0.007  | 0.008  | 0.008  | 0.008  | 0.008  |
| China  | 0.000  | 0.003  | 0.004  | 0.004  | 0.005  | 0.005  | 0.005  | 0.005  |
| Germany | 0.000 | 0.003  | 0.004  | -0.004 | 0.004  | 0.004  | 0.004  | 0.004  |
| EU26   | 0.000  | 0.002  | 0.003  | 0.004  | 0.005  | 0.005  | 0.005  | 0.006  |
| UK     | 0.000  | 0.002  | 0.003  | 0.003  | 0.004  | 0.004  | 0.004  | 0.004  |
| ROW    | 0.000  | 0.001  | 0.002  | 0.003  | 0.004  | 0.004  | 0.004  | 0.004  |

(Table 11 Continued)
### Table 11. Real private and public consumption

| Region   | 2016  | 2017  | 2018  | 2019  | 2020  | 2021  | 2022  | 2023  |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|
| USA      | −0.004| −0.003| −0.002| −0.002| −0.002| −0.002| −0.002| −0.002|
| Canada   | −0.023| −0.016| −0.012| −0.010| −0.007| −0.006| −0.005| −0.005|
| Mexico   | −0.028| −0.035| −0.043| −0.047| −0.048| −0.049| −0.049| −0.049|
| Japan    | 0.005 | 0.005 | 0.004 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| South Korea | 0.011 | 0.006 | 0.006 | 0.006 | 0.006 | 0.005 | 0.005 | 0.005 |
| China    | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | −0.001|
| Germany  | 0.001 | 0.002 | 0.002 | 0.003 | 0.002 | 0.002 | 0.002 | 0.002 |
| EU26     | −0.003| −0.001| 0.000 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| UK       | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| ROW      | −0.002| 0.000 | 0.000 | 0.001 | 0.001 | 0.001 | 0.000 | 0.000 |

**Source:** Author’s own.

### Table 12. Simulation 2 (Tariff Increases in NAFTA and US Tariffs on Non-NAFTA): Percentage Deviations in Macro Aggregates by Region

| Region   | 2016  | 2017  | 2018  | 2019  | 2020  | 2021  | 2022  | 2023  |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|
| USA      | −0.092| −0.084| −0.076| −0.074| −0.075| −0.078| −0.079| −0.080|
| Canada   | −0.104| 0.093 | 0.087 | 0.082 | 0.075 | 0.071 | 0.070 | 0.070 |
| Mexico   | 0.047 | 0.101 | 0.152 | 0.191 | 0.220 | 0.241 | 0.257 | 0.269 |
| Japan    | −0.048| −0.040| −0.035| −0.031| −0.028| −0.025| −0.025| −0.024|
| South Korea | −0.061| −0.052| −0.047| −0.043| −0.039| −0.037| −0.036| −0.035|
| China    | −0.005| 0.001 | 0.004 | 0.002 | 0.000 | −0.002| −0.004| −0.005|
| Germany  | −0.055| −0.019| −0.001| 0.008 | 0.014 | 0.016 | 0.016 | 0.016 |
| EU26     | 0.003 | 0.009 | 0.011 | 0.010 | 0.008 | 0.006 | 0.003 | 0.002 |
| UK       | −0.007| 0.000 | 0.004 | 0.004 | 0.005 | 0.004 | 0.003 | 0.002 |
| ROW      | 0.018 | 0.021 | 0.021 | 0.019 | 0.017 | 0.014 | 0.012 | 0.011 |

**Employment**

| Region   | 2016  | 2017  | 2018  | 2019  | 2020  | 2021  | 2022  | 2023  |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|
| USA      | −0.078| −0.034| −0.012| −0.003| −0.001| 0.000 | 0.000 | 0.000 |
| Canada   | 0.125 | 0.058 | 0.027 | 0.009 | −0.004| −0.008| −0.007| −0.006|
| Mexico   | 0.096 | 0.057 | 0.055 | 0.048 | 0.039 | 0.031 | 0.025 | 0.020 |
| Japan    | −0.072| −0.043| −0.026| −0.016| −0.008| −0.004| −0.003| −0.002|
| South Korea | −0.091| −0.056| −0.034| −0.021| −0.011| −0.007| −0.004| −0.003|

*(Table 12 Continued)*
(Table 12 Continued)

|                | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|----------------|------|------|------|------|------|------|------|------|
| 6. China       | −0.003 | 0.000 | 0.003 | 0.002 | 0.000 | −0.002 | −0.002 | −0.003 |
| 7. Germany     | −0.089 | −0.033 | −0.010 | 0.000 | 0.006 | 0.006 | 0.005 | 0.003 |
| 8. EU26        | 0.009 | 0.002 | 0.002 | 0.001 | −0.001 | −0.002 | −0.003 | −0.003 |
| 9. UK          | −0.008 | −0.010 | −0.006 | −0.004 | −0.002 | −0.002 | −0.002 | −0.002 |
| 10. ROW        | 0.024 | 0.008 | 0.002 | −0.001 | −0.003 | −0.003 | −0.003 | −0.003 |

**Capital**

|                | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|----------------|------|------|------|------|------|------|------|------|
| 1. USA         | 0.000 | −0.087 | −0.124 | −0.138 | −0.143 | −0.145 | −0.145 | −0.145 |
| 2. Canada      | 0.000 | 0.076 | 0.114 | 0.132 | 0.138 | 0.137 | 0.132 | 0.128 |
| 3. Mexico      | 0.000 | 0.117 | 0.192 | 0.254 | 0.303 | 0.341 | 0.369 | 0.390 |
| 4. Japan       | 0.000 | −0.020 | −0.030 | −0.035 | −0.037 | −0.037 | −0.036 | −0.036 |
| 5. South Korea | 0.000 | −0.025 | −0.040 | −0.049 | −0.054 | −0.056 | −0.057 | −0.056 |

**Real private and public consumption**

|                | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|----------------|------|------|------|------|------|------|------|------|
| 1. USA         | −0.058 | −0.045 | −0.031 | −0.023 | −0.021 | −0.021 | −0.020 | −0.020 |
| 2. Canada      | 0.171 | 0.133 | 0.108 | 0.087 | 0.068 | 0.057 | 0.052 | 0.049 |
| 3. Mexico      | 0.241 | 0.213 | 0.221 | 0.212 | 0.198 | 0.185 | 0.175 | 0.168 |
| 4. Japan       | −0.085 | −0.075 | −0.065 | −0.058 | −0.053 | −0.051 | −0.052 | −0.052 |
| 5. South Korea | −0.159 | −0.133 | −0.118 | −0.111 | −0.101 | −0.099 | −0.098 | −0.098 |

**Source:** Author’s own.

Negative adjustment in the finished motor vehicle industry in the NAFTA countries, reducing demand for Mexican parts within NAFTA.

Continuing negative adjustment of the finished motor vehicle industries in the NAFTA countries is caused by gradual downward adjustment in their capital stocks.
**Simulation 2: Output Effects in the MVH Sector (Table 10)**

This simulation imposes two sets of shocks: (a) the quite small intra-NAFTA tariff shocks that were applied in the first simulation and (b) a 25 per cent US tariff against imports of finished vehicles from non-NAFTA countries. The second set of shocks is dominant in most of our results.

The US tariff on finished motor vehicles from non-NAFTA countries stimulates output of both finished goods and parts in the USA. It also has a generally stimulatory effect in the motor vehicle sector in the other two NAFTA countries. Output of finished motor vehicles in these countries benefits from reduced competition in the US market from non-NAFTA countries. Parts production in Canada benefits from expansion in its own finished motor vehicle industry and that of the USA.

The results for parts production in Mexico in the early years of the simulation are negative. This is explained by a symmetrical argument to that given for the result for Mexican parts production in Table 9. This time Mexico is a major beneficiary from the US tariff on finished vehicles (includes trucks) from non-NAFTA countries. Associated real appreciation of the Mexican currency initially hurts its parts sales outside Mexico.

Motor vehicle production in non-NAFTA countries shows strongly negative effects, especially for Japan for which the USA is a major market (see Table 6a).

**Simulation 1: Regional Macro Results (Table 11)**

In the short run, raising tariffs within NAFTA reduces GDP in the NAFTA countries but increases GDP for other countries, which gain from diversion of demand by NAFTA countries away from their NAFTA partners. The NAFTA countries lose by increasing the costs of finished cars and trucks to their households and capital creators. These increases in costs reduce the number of people who can be employed at current real wages. Eventually wages adjust down so that employment in the NAFTA countries is restored gradually to baseline. This process is complete by 2023 for the USA and Canada, but still has some distance to go for Mexico. Even though the employment effects are eliminated in the long run, the GDP deviations for the NAFTA countries remain negative. This is because the NAFTA countries lose capital in the long run. With higher tariffs, capital must become more scarce for rates of return to be restored to baseline levels, or explained another way, reduced real wages mean that an economy’s $K/L$ ratio will fall implying, with $L$ returning to baseline, a long-run reduction in $K$.

The final panel in Table 11 shows percentage deviations in private and public consumption, which we assume move together. These deviations can be interpreted as welfare effects. In the long run, the intra-NAFTA tariffs reduce the welfare of all three NAFTA countries. Outside NAFTA the results are generally positive. Most of the non-NAFTA countries (or regions) identified in GTAP-MVH benefit from terms-of-trade improvements associated with improved competitiveness in NAFTA markets.
Simulation 2: Regional Macro Results (Table 12)

Raising tariffs on finished motor vehicles imported from outside NAFTA reduces employment in the USA in the short run (−0.078% in 2016) and capital in the long run (−0.145% in 2023). The explaining mechanisms can be understood from our commentary on K and L movements in Table 11. Together, the labour and capital effects leave US GDP reduced by the policy in both the short and long run.

For Canada and Mexico, the GDP effects in simulation 2 are positive in both the short and long run. In the short run, both countries experience employment gains associated with their improved competitiveness in the US motor vehicle market and in the long run both countries experience increases in their capital stock associated with higher real wages.

For Canada, the long-run employment effect is slightly negative (−0.006% in 2023). As illustrated in Figure 1, this is a very minor effect and should not be considered either policy relevant or reliable. What is reliable is that aggregate employment in the long run returns closely to baseline. Sometimes in our modelling, which involves difference equations, the return of employment to baseline exhibits damped oscillations of the type apparent in the figure.

For Japan and South Korea, the macro effects of the US tariff against their exports of finished motor vehicles are negative. Both these countries have significant exports of finished motor vehicles to the USA. For other non-NAFTA countries, the direct effects of US tariffs on finished motor vehicles, while negative, are small: these countries do not export large quantities of finished motor vehicles to the USA. For these countries, the negative direct effects can be outweighed by positive indirect effects.

![Figure 1. Percentage Deviations for Canada in Macro Variables: Simulation 2 (Colour Online)](image)

Source: Author’s own.
There are two types of positive indirect effects for non-NAFTA countries. First, US tariffs cause real appreciation in the USA (loss in competitiveness), reducing US exports of all products (not just motor vehicles). This is a source of gain for countries that compete with the USA in third markets. Second, US tariffs on finished vehicles from non-NAFTA counties are bad for investment in the USA. Investment in the US accounts for about 17 per cent of worldwide investment. The downward effect on US investment has a noticeable effect on worldwide investment. The negative impact on worldwide investment is stronger than the negative effect on worldwide saving. Consequently, worldwide interest rates fall. This leads to extra capital in many countries. Only the USA and countries with a strong link to the USA through exports to the USA of finished cars have negative results for aggregate capital. Countries which gain capital, wind up with extra GDP, but not necessarily extra consumption. Their consumption can be adversely affected by negative terms of trade effects, especially if they import a lot from the USA.

Concluding Remarks

Trade negotiations are often conducted in terms of narrowly defined commodities, well below the commodities/industries identified in standard CGE models. Most negotiators are lawyers rather than economists. In these circumstances, CGE analyses can be dismissed because to non-economists the models seem insufficiently focussed on the issues at hand. This is unfortunate because even when CGE models cannot capture the exact details of a proposed trade policy, they can still provide valuable insights. These general insights are mainly of the form of alerting negotiators that increases in protection are ineffective as a macro policy. They may save jobs in the protected sector, but they reduce employment in other parts of the economy.

Disaggregating industries and commodities in a CGE model increases the likelihood that the model can be applied directly in the analysis of a particular policy. This leaves the general messages intact while at the same time increasing the acceptability of the analysis and potentially producing new policy-specific messages. For example, with the disaggregated Motor vehicle sector included in GTAP-MVH, we found that tariffs on finished motor vehicle trade within NAFTA were not only negative at a macro level for the three NAFTA countries, but were also negative for output from their Motor vehicle sectors.

The disaggregation method that we have described in this article and implemented for the Motor vehicle sector is applicable to other sectors. In the GTAP model, it could be used to disaggregate sectors such as textiles, wearing apparel, fabricated metal products, other transport equipment, electronic equipment and other machinery. Detailed trade data, necessary for our disaggregation method, exist for products within all these sectors. Disaggregating these sectors would not only enhance the GTAP model as a tool for trade policy analysis, but would also be a step towards the development of new models required for analysing trade dominated by global supply chains.
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Notes

1. Early contributions include Evans (1972), Deardorff, Stern, and Baum (1977) and Dixon, Parmenter, Ryland, and Sutton (1977) and Dixon, Parmenter, Sutton, and Vincent (1982).
2. GTAP stands for Global Trade Analysis Project. The model was created by the GTAP research group at Purdue University.
3. The Chinese input–output database contains two mvh industries, namely Motor vehicles and MV parts, see Mai, Dixon, and Rimmer (2010). The South Korean input–output database contains three mvh industries, namely Motor vehicles; Mvh gas engines and Mvh parts, see Bank of Korea Economic Statistics System (2014).
4. Details of the baseline and theory of GTAP-MVH can be found in our working paper (Dixon, Rimmer, & Tran, 2019).
5. Walmsley and Minor (2017) produce a version of GTAP that they refer to as a supply chain model. The standard version of GTAP identifies flows of commodity $c$ from source country $s$ to destination country $d$ but then assumes that the source composition of imported $c$ in $d$ is the same for all users. Walmsley and Minor make a valuable contribution by equipping GTAP with data that identify imports by source country for each using agent in $d$. However, they do not address sectoral disaggregation. We consider this to be a fundamental requirement for converting GTAP into a model for analysing global supply chain trade.

References

Aguiar, A. (2016). Concordances—Six-digit HS sectors to GTAP sectors. GTAP Resource #5111. Retrieved from https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=5111
Aguiar, A., Narayanan, B., & McDougall, R. (2016). An overview of the GTAP 9 data base. Journal of Global Economic Analysis, 1(1), 181–208.
Bank of Korea Economic Statistics System. (2014). 2010 updated input-output tables. Retrieved from https://ecos.bok.or.kr/flex/EasySearch_e.jsp
Barnes Reports. (2017a). Automobile & motor vehicle mfg. industry NAICS 33611. 2017 World Industry & Market Outlook Report (pp. 1–139).
Barnes Reports. (2017b). Automobile gas engine & engine parts mfg. NAICS 33631. 2017 World Industry & Market Outlook Report (pp. 1–139).
United Nations Industrial Development Organization (UNIDO). (2018). *IDSB—Industrial demand-supply balance database.* United Nations Industrial Development Organization (UNIDO). Retrieved from https://www.unido.org/researchers/statistical-databases

United States Census Bureau. (2017). *North American industry classification system.* Retrieved from https://www.census.gov/eos/www/naics/

Walmsley, T., & Minor, P. (2017). Reversing NAFTA: A supply chain perspective (ImpactECON Working Paper, p. 30). Retrieved from https://impactecon.com/wp-content/uploads/2017/02/NAFTA-Festschrift-Paper-1.pdf