An Enhanced Analytical Framework for Evaluating the Effects of Trade Costs along Global Value Chains

By Caitlyn Carrico[a]

In this paper, I present a new multi-regional input-output (MRIO) database with tariffs differentiated by agent. To construct the MRIO, I apply the Broad Economic Categories (BEC) system of concordances to detailed trade and tariff data from the Tariff Analytical and Simulation Tool for Economists (TASTE) Database version 9 to obtain measures of trade and tariff revenues by end-use. I use this trade data by end use to expand the GTAP Database version 9.2, thus incorporating direct linkages from foreign suppliers to domestic producers, investors, and consumers. Further, the new database comprises distinct composite tariff rates for producers, investors, and consumers. I use a constrained optimization procedure to ensure MRIO trade flows aggregate to the original GTAP Database. Through illustrative simulations, I demonstrate the effect of (1) new cross-border trade linkages and (2) tariff escalation for trade policy analysis. I further demonstrate how the addition of differentiated tariffs in the MRIO enhances policy analysis beyond preceding versions of the MRIO.

JEL codes: E01, E16, F13, F15.

Keywords: MRIO, ICIO, International trade, Tariffs, Global value chains.

1. Introduction

The modern world economy is characterized by complex cross-border linkages comprising global value chains (GVCs). Over the past 20 years, global economic integration has deepened as firms increasingly rely on cross-border inputs to production, with seventy-five percent of world trade comprised of intermediate and investment goods by 2011. Further, production fragmentation has lengthened across regions, with growth in extra-regional value-added surpassing intra-regional value-added growth, globally (OECD 2015).

[a] Organisation for Economic Co-operation and Development, 2, rue André Pascal, Paris, France (e-mail: Caitlyn.Carrico@oecd.org). The views expressed in this paper are those of the author and do not reflect the official view of the OECD or of the governments of its member countries.

Reduced barriers to trade have facilitated the rise in globalization, through trade agreements as well as technological advances. Reductions have included lowered tariff rates, decreased time to trade, and product standard harmonization. Nonetheless, nominally low barriers to trade accumulate across extensive value chains.

Assessing the implications of trade-barrier amplification along global value chains necessitates an analytical framework which both comprises the complexity of cross-border linkages in GVCs and contains an accurate baseline of trade cost estimates. The current standard for GVC analysis relies on multi-regional input-output (MRIO) frameworks. An MRIO harmonizes input-output (IO) tables for multiple regions and links trade flows directly from producers in each region to importing firms and consumers in all other regions.
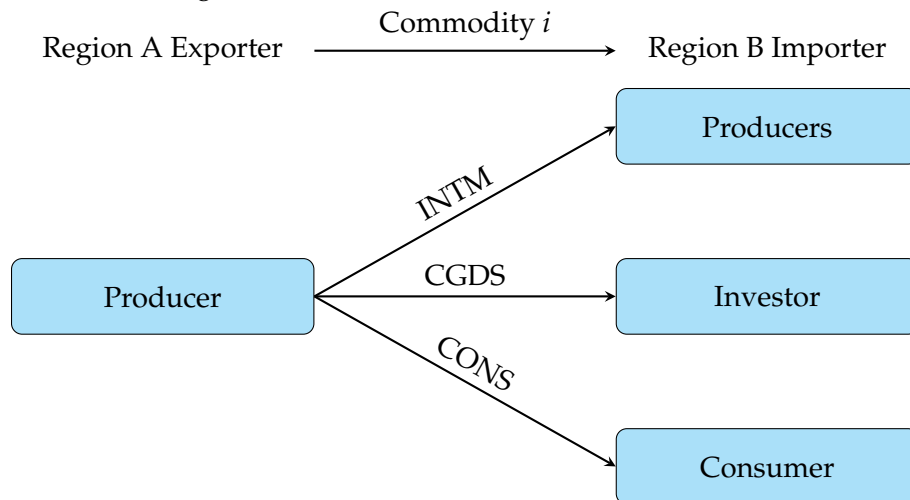

Figure 1. The MRIO Framework

Source: Author's diagram.

In construction, MRIOs build from IO tables and databases which contain bilateral trade flows by agent, being firms, consumers, and investors (Figure 1). MRIO databases differ by construction methodology, with resultantly differing implications for analyses. There are three principal methods of MRIO construction. All methods rely on similar base data requirements of IO data, national accounts statistics, and bilateral trade data. However, the methods differ by which supplementary information is used in the construction of the finalized database. The simplest method relies only on IO data and trade flows, and assumes proportional sourcing of imports for all agents. A more complex method builds on the first method by using concordances which map between products and end uses to differentiate between sourcing of imports across agents. The most advanced method, which I introduce in detail in this paper, additionally incorporates tariff revenues in order to differentiate composite tariff rates across agents.

Various research initiatives have undertaken the development of different versions of an MRIO database. Some initiatives construct MRIO databases from the ground up, so to speak, building from raw IO and trade data. These initiatives include WIOD, OECD-WTO TiVa, and UNCTAD-EORA. Other initiatives build upon the GTAP Database, an extensive collection of harmonized IO tables, national accounts statistics, and bilateral trade data, including the U.S. International Trade Commission (USITC) and the World Bank among countless other research groups and academics.

WIOD, the World Input-Output Database, was first launched in 2012 as a project funded by the European Commission. WIOD has had two releases: 2013 and 2016. The 2013 release covers 59 products and 35 sectors in 27 European economies and 13 other major economies from 1995 to 2011 (Timmer et al. 2015), and the 2017 release covers 56 sectors in 28 European economies and 15 other major economies from 2000 to 2014 (Timmer et al. 2016).

WIOD base data originates from National Statistical Institutes, the OECD, United Nations (UN) National Accounts statistics, and UN COMTRADE. To estimate the trade flow by use of importer, the WIOD initiative follows the second method aforementioned, using a concordance system to map from HS line to end use, which can be associated with an importing agent. For this mapping, WIOD developed a new concordance between the Harmonized System classification and the System of National Accounts end use categories, largely based on official concordances of the United Nations Statistics Division (UNSD) (Timmer 2012).

The OECD and the World Trade Organization (WTO) have a joint initiative on Trade in Value-added (TiVa). The 2016 edition has 34 sectors for 63 economies from 1995 to 2011 (OECD 2016a; OECD 2016b). The database of TiVa indicators is derived from an underlying MRIO database, comprised of the OECD Inter-Country Input-Output (ICIO) Tables. The OECD ICIO tables are developed from an OECD database of harmonised national IO Tables and the OECD Bilateral Trade Database by Industry and End-Use (BTDIxE) (OECD 2017a). The OECD also uses the second method in constructing the ICIO, using concordances to differentiate trade flows by end use. The OECD has developed their own extended version of the UNSD concordance system to map between HS and end use (OECD 2017b).

The UNCTAD-EORA Global Value Chain Database is comprised of value-added indicators derived from the EORA MRIO. The EORA MRIO database is comprised of input-output tables from national statistical agencies, Eurostat, ID-JETRO, and OECD, as well as data from UN National Accounts and UN COMTRADE. The database covers 25 to 500 sectors for 187 countries from 1990 to 2011 (Lenzen et al. 2013). The Eora26 MRIO has 26 harmonized sectors through 2013 (EORA 2017).

The USITC developed an ICIO from the GTAP Database, as documented in the well established Koopman et. al. (2014) paper. The 2014 paper documents an ICIO comprised of 41 sectors across 26 countries for year 2004, corresponding to the GTAP 7 Database. Koopman et al. use the BEC concordance system in con-

junction with data from UN COMTRADE to break out trade flows by SNA end use category. Over different iterations of research, USITC researchers varied their implementation of the BEC-SNA concordance system. In the 2012 NBER working paper proceeding Koopman et al. (2014), Koopman et al. (2012) used the the BEC-SNA concordance system to distinguish imports by intermediate and final end use whereas Koopman et al. (2010) used the BEC-SNA concordance system to distinguish imports by intermediate, final, and investment end use.

The World Bank Export of Value-Added Database consists of measures of value-added content in domestic output and exports. The Database was developed from multiple versions of the GTAP Database so as to cover years 1992, 1995, 1997, 2001, 2004, 2007 and 2011. The Database covers 27 sectors across 118 countries (Francois et al. 2014).

In this chapter, I follow the latter initiatives of the USITC and the World Bank in developing an MRIO from the GTAP Database, hereafter which I refer to as the GTAP MRIO. Further, I introduce the aforementioned third method of MRIO development which differentiates composite tariff rates across agents. With the contribution of tariff revenue information, I improve the accuracy of the MRIO construction process. The standard construction process for developing an MRIO database from the GTAP Database entails applying end use shares of tariff-exclusive trade values from UN COMTRADE to tariff-inclusive trade flows from the GTAP Database. However, by incorporating tariff revenues into the construction process, I apply tariff-inclusive end use shares to tariff-inclusive trade flows in the GTAP Database, maintaining price consistency throughout the process.

There are several methods of analyzing supply chain linkages in multi-regional input-output (MRIO) frameworks, including input-output (IO) analysis, econometrics, and computable general equilibrium (CGE). In this paper, I focus on MRIO analysis in CGE. CGE is an ideal method of analysis for analyzing supply chain linkages because general equilibrium effects are endogenized, with both quantity and price responses to simulated changes in the economy.

Various documented CGE models contain the supply chain cross-border linkages corresponding to the MRIO database, including the GTAP Supply Chain model (Walmsley et al. 2014), the GTAP HET model (Akgul et al. 2016), and the GTAP Public Procurement Model (Aguiar et al. 2016). In this paper, I use the GTAP Supply Chain model. An extension of the standard GTAP model (Hertel 1997), the GTAP Supply Chain model is a comparative static general equilibrium model of trade, with regional firms and households. The GTAP Supply Chain model is distinct from the standard GTAP model in its specification of inter-country trade linkages. While the standard GTAP model has composite imports across all agents, the GTAP Supply Chain model distinguishes imports between agents, which I further describe in *Section 2*. In addition to the introduction of these more specific inter-country linkages, the GTAP HET model and the GTAP Public Procurement Model introduce theoretical innovations, namely firm heterogeneity and procure-

ment preferences, respectively.

In the subsequent section, Methods, I will discuss in detail the development of the GTAP MRIO from the GTAP and TASTE Databases. I discuss the incorporation of trade flows and tariff revenues by end use into trade in the GTAP Database and procedures to maintain aggregate values in the original GTAP Database. In the third section, Alternate Methods, I review alternate approaches to MRIO development, discussing feasibilities, limitations, and future directions for research. In the fourth section, MRIO database, I provide summary statistics reviewing the new database and, in particular, highlighting the novel feature of the new database, differentiated tariffs. In the fifth section, I discuss the GTAP-SC model, and I detail the implementation of the GTAP MRIO database in an illustrative scenario of tariff removal on merchandise trade between member countries of the Trans-Pacific Partnership in the sixth section. In the seventh section, I demonstrate the impact of differentiated composite tariffs on analytical results through two illustrative studies of the importing consumer and the exporting producer, respectively. In the eighth and ninth sections, I perform comparative analyses. In section eight, I compare simulation results with an analogous tariff removal simulated with the standard GTAP model while, in section nine, I compare simulation results with analogous tariff removals simulated in the GTAP Supply Chain model with MRIO databases with proportional composite tariff rates. I conclude in section ten.

2. Methods

An MRIO framework extends the traditional IO framework by distinguishing bilateral imports by end use. End uses include imports used as intermediate inputs to production (INTM) as well as imports for final demands, including investment (CGDS) and consumption (CONS). Figure 1 provides an overview of trade in the MRIO framework, by which producers in region A export commodity i, broken out by end use, to corresponding importing agents (producers, investors, and consumers) in region B. This framework can be derived from the reconciliation of cost structure data available in IO tables with bilateral trade data.

In IO tables, commodity demands are specified for intermediate use (i.e., commodity production) or for final use by private households, investors, and the government. In bilateral trade data, such as from either the GTAP Database or the UN COMTRADE Database, country sourcing information is available for each commodity. However, neither GTAP nor UN COMTRADE Database contain information specifying whether a bilaterally traded commodity is intended for intermediate use or for final consumption. Further, the distribution of demand for imports of intermediate products across industries remains unknown in both the GTAP Database and the UN COMTRADE Database.

In order to capitalize on the information available in disaggregate trade data, such as from the UN COMTRADE Database, the MRIO literature uses a system of concordances from the United Nations Statistics Division (UNSD). This system
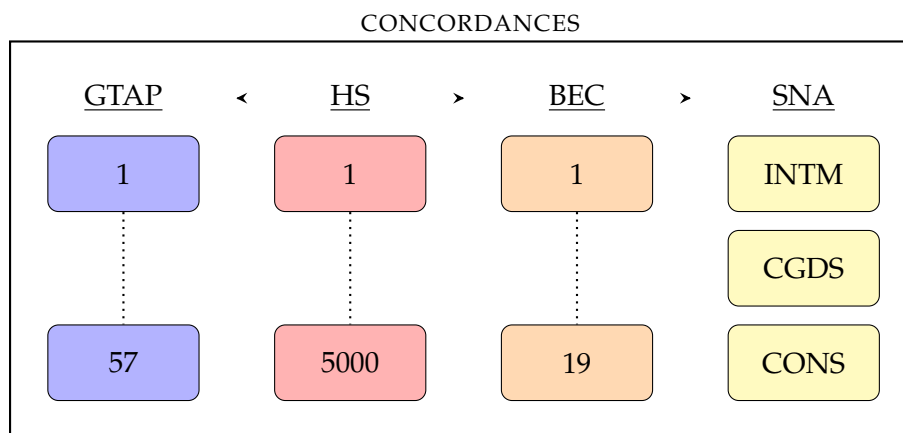
CONCORDANCES

Figure 2. Concordance System: HS to GTAP, HS to BEC to SNA

Source: Author's diagram.

is depicted in Figure 2, mapping between product categories from the HS line to Broad Economic Categories (BEC) and, in turn, from the BEC to the end use categories of the System of National Accounts (SNA) framework: capital goods, intermediate goods, and consumption goods. Notable MRIOs which reference these concordances include the World Input-Output Database (WIOD) (Timmer 2012) and the GTAP-based Inter-Country Input Output (ICIO) developed at the USITC (Tsigas et al. 2012). The WIOD team developed their own HS-BEC concordance; they developed a system of weights so that trade at each HS line would map to all three end use categories, based on the UNSD HS-BEC concordance. While USITC researchers initially used the UNSD HS-BEC concordance (Koopman et al. 2010), they later switched to using the WIOD HS-BEC concordance (Tsigas et al. 2012). In *Section 3.1*, I review the caveats of modified HS-BEC concordance systems.

2.1 An MRIO from the GTAP Database

In this paper, I build on the GTAP Database in order to construct an MRIO database, as did Johnson and Noguera (2012), Koopman et al. (2010), and Walmsley et al. (2014). The GTAP Database is a global database compiled from IO tables and trade data, among other data sources, which are globally reconciled. As depicted in Figure 3, trade data in the GTAP Database is available by either source or by agent.

Following Koopman et al. (2010) and Walmsley et al. (2014), I additionally draw on trade data external to the GTAP Database. I source this trade data from the Tariff Analytical and Simulation Tool for Economists (TASTE) Database which is based on UN COMTRADE data at the HS six digit level. From TASTE, I also acquire tariff
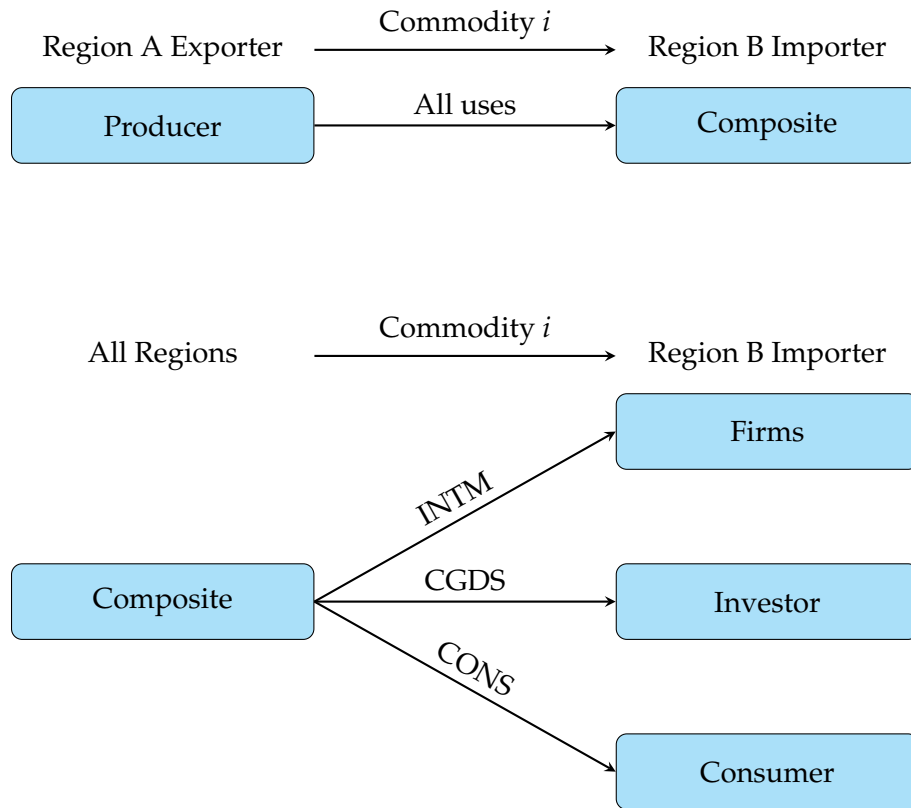
Figure 3. Trade Data in the Standard GTAP Database

Source: Author's diagram.

revenue data.

I follow Koopman et al. (2010). in applying the UNSD HS-BEC and BEC-SNA concordances. I also apply a concordance to aggregate from the HS six digit commodities of the bilateral UN COMTRADE data to the GTAP categories. This is depicted in Figure 2 and is further detailed in the following subsection 2.2. Then, following my own methods, I generate first estimates of MRIO trade data (subsection 2.3) which I optimize to maintain with the entirety of the GTAP Database (subsection 2.4). In subsection 2.5, I detail how I subsequently obtain differentiated composite tariffs in the MRIO database.

2.2 Mapping Trade Data to End Use

I begin by applying the UNSD HS-BEC concordance to map from the UN COM-TRADE trade data in TASTE, which has 5,052 unique HS codes, to the 19 BEC categories in Table 1. UNSD has three HS-BEC concordances which map from the BEC, Revision 4, to HS 1996, 2002, and 2007, respectively. In this paper I use the UNSD HS-BEC concordance for HS 2007 (UNSD 2007).

There are two cases in which an HS code is mapped to multiple BEC codes. This

Table 1. BEC to SNA Concordance

BEC[a]	BEC Description	SNA[b]
111	Primary food/bev for industry	INT
112	Primary food/bev for cons	CONS
121	Processed food/bev for industry	INT
122	Processed food/bev for cons	CONS
21	Primary industrial supplies n.e.s.	INT
22	Processed industrial supplies n.e.s.	INT
31	Primary fuels and lubricants	INT
321	Processed fuels and lubricants - motor spirit	INT, CONS
322	Processed fuels and lubricants - other	INT
41	Capital goods (except transport equipment)	CGDS
42	Capital goods - parts and accessories	INT
51	Transport equipment - passenger motor cars	CONS, CGDS
521	Transport equipment - other industrial	CGDS
522	Transport equipment - other non-industrial	CONS
53	Transport equipment - parts and accessories	INT
61	Durable consumer goods n.e.s	CONS
62	Semidurable consumer goods n.e.s	CONS
63	Nondurable consumer goods n.e.s	CONS
7	Goods n.e.s.	INT, CONS, CGDS

Notes: [a] Broad Economic Categories (BEC). [b] System of National Accounts (SNA).

Source: Author's compilation based on UNSD (2003).

occurs for HS codes 271011 and 271019, which are described as "Light petroleum oils & preparations" and "Petroleum oils & oils obtained from bituminous minerals (other than crude) & n.e.c.", respectively, according to UN COMTRADE Commodity List Reference. Both of these codes are dually mapped to BEC codes 321, which is described as "Motor Spirit", and 322, which is described as "Other Processed Fuels and Lubricants." To ensure that there is no double counting in the data, I assume that the value of trade at the HS line is split equally into the two corresponding BEC categories.

To implement the mapping between the BEC and the SNA, I use the concordance in Table 1 which is based on the UNSD official publication on the BEC, Classification by Broad Economic Categories (UNSD 2003). This concordance shows a single direct mapping for 17 of the 19 BEC categories. For the remaining two BEC categories 321 and 7, the UNSD indicates that the mapping is composed of a mix of end uses. Therefore, I make simplifying assumptions due to the lack of better information.

For the BEC category 321 defined as "Motor Spirit", I assume a proportional split of trade value between intermediate and consumption goods. That is to say that half of the trade value at a given HS category mapped to BEC category 321 would be allocated to intermediate use and the other half of the trade value would

be allocated to consumption goods. For the BEC category 7 defined as "Goods not elsewhere specified", I allocate one third of the trade value to intermediate goods, one third to capital goods, and one third to final consumption goods.

I next apply the GTAP-HS concordance which is a one-to-many mapping between the HS at the six digit level and the standard 57 GTAP sectors. The application of this concordance does not require any splitting of trade values. With the application of this concordance, I can now aggregate the data to be compatible with the GTAP Database.

The process of reformatting the trade data begins with aggregation of the value of imports indexed on the HS line h, GTAP sectors i, the BEC code b, SNA end use categories u, source country s, and reporting country r (TVW_{hibusr}). I sum over all HS lines to aggregate to the GTAP commodities. Simultaneously, I sum over each Broad Economic Category to each SNA end use category, respectively. This gives us the value of imports indexed on GTAP commodity i, SNA end use category u, source country s, and reporting country r (TVW_{iusr}). I perform the same calculation, incorporating the tariff revenue into the trade data at the HS 6 digit level to obtain TVM_{iusr}.

2.3 Applying Shares of Trade Value by End Use

With tariff-inclusive trade values TVM_{iusr} and tariff-exclusive trade values TVW_{iusr}, I proceed to calculate shares of trade value by end use which I will use to estimate the MRIO trade data. First, I compute the share of bilateral trade of a given commodity value designated for a particular use as

$$SHRM_{iusr} = \frac{TVM_{iusr}}{\sum_u TVM_{iusr}}$$

(1)

$$SHRW_{iusr} = \frac{TVW_{iusr}}{\sum_u TVW_{iusr}}$$

for market prices and for world prices. Specifically, $SHRM_{iusr}$ indicates the share of tariff-inclusive trade value of commodity i from s which is demanded for end use u in r. Likewise, $SHRW_{iusr}$ is the share of tariff-exclusive trade value.

I apply these use shares from the TASTE Database to the bilateral trade data in the standard GTAP Database Version 9.2 to acquire initial estimates of the GTAP MRIO tariff-inclusive trade $VIUMS^0_{iusr}$ and tariff-exclusive trade $VIUWS^0_{iusr}$. For trade at tariff-inclusive market prices, I apply $SHRM_{iusr}$ to standard GTAP bilateral trade data $VIMS^0_{isr}$, computing

$$VIUMS^0_{iusr} = SHRM_{iusr} * VIMS^0_{isr}$$

(2)

$$VIUWS^0_{iusr} = SHRW_{iusr} * VIWS^0_{isr}$$

I compute $VIUWS_{iusr}^0$ by applying $SHRW_{iusr}$ to standard GTAP bilateral trade data $VIWS_{isr}^0$.

I will note that this process only covers goods trade; services trade is not included. As accommodation, I split services out proportionately amongst the three end use categories. Hence, I presume that one third of each bilateral flow of services trade is imported by firms, investors, and consumers, respectively.

2.4 Optimization to Maintain GTAP Database - Market Priced Trade Values

Now I have my initial estimates of the MRIO trade data, $VIUMS_{iusr}^0$ and $VIUWS_{iusr}^0$. These estimates however were computed along only the source dimension of the standard GTAP Database, aggregating across end use u to $VIMS_{isr}^0$ and $VIWS_{isr}^0$, respectively. For the tariff-inclusive trade flows, I must also ensure that the MRIO trade data $VIUMS_{iusr}^0$ aggregates across sources s to the agent-specific trade flows in the standard GTAP Database, $VIFM_{ijr}^0$, $VIGM_{ir}^0$, and $VIPM_{ir}^0$.

End uses are defined more broadly than agent flows in the standard GTAP Database. End use, indexed by u, only consists of the three aforementioned categories of intermediate, investment, and consumption goods whereas there are 60 agents in the standard GTAP Database, consisting of 57 industries, investors, government, and the private household. I assign agents to end uses as follows: all 57 industries demand intermediate goods, investors demand investment goods, and both government and the private household demand consumption goods.

With this mapping between end uses and GTAP agents, I specify the aggregation of agent-indexed trade flows to use-indexed trade flows as follows. I define a new variable, the value of trade at market (tariff-inclusive) prices distinguished by dimensions of commodity i, end use u, and destination country r, as $VIUM_{iur}^0$.

$$VIUM_{i,'intm',r}^0 = \sum_{j=1}^{57} VIFM_{ijr}^0 \neq \sum_s VIUMS_{i,'intm',s,r}^0$$

$$VIUM_{i,'cgds',r}^0 = VIFM_{i,'cgds',r}^0 \neq \sum_s VIUMS_{i,'cgds',s,r}^0 \tag{3}$$

$$VIUM_{i,'cons',r}^0 = VIGM_{ir}^0 + VIPM_{ir}^0 \neq \sum_s VIUMS_{i,'cons',s,r}^0$$

Use-specific imports for intermediates, $u =' intm'$, aggregate over imports across the 57 standard GTAP industries, specified as $VIFM_{ijr}^0$. Use-specific imports for investment, $u =' cgds'$, equals standard GTAP investment import flow, $VIFM_{i,'cgds',r}^0$. Use-specific imports for consumption goods, $u =' cons'$, aggregate over imports for government $VIGM_{ir}^0$ and the private household $VIPM_{ir}^0$. Ideally, the original estimates of tariff-inclusive trade value, $VIUMS_{iusr}^0$, would aggregate to $VIUM_{iur}^0$.

However, there is a discrepancy between the import values aggregated across agents to use from the GTAP Database and the BEC-based use- and source-specific import values aggregated across sources.

I choose to adjust the BEC-based initial estimated use-specific trade flows in order to preserve the aggregate import values in the original GTAP Database. I define an optimization model which estimates a new use- and source-specific tariff-inclusive trade value, $VIUMS^1_{iusr}$. I specify constraints to ensure that $VIUMS^1_{iusr}$ aggregates to the original trade flows of the standard GTAP Database, along both source ($VIMS^0_{isr}$) and end use ($VIUM^0_{iur}$) dimension.

$$\forall(i,r)$$

$$\underset{VIUMS^1_{iusr}}{\text{minimize}} \quad \sum_u \sum_s \left\{ VIUMS^1_{iusr} * \log\left(\frac{VIUMS^1_{iusr}}{VIUMS^0_{iusr}}\right) \right\}$$

(4)

subject to:

$$\sum_s VIUMS^1_{iusr} = VIUM^0_{iur}$$

$$\sum_u VIUMS^1_{iusr} = VIMS^0_{isr}$$
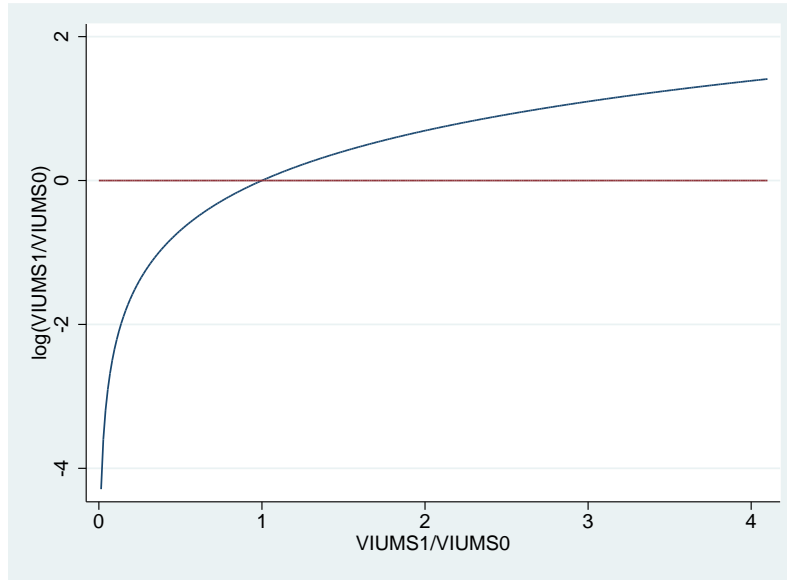
Figure 4. Log Ratio Scaling

Source: Author's graphics.

The model is based on the cross-entropy approach (McDougall 1999) and works as a mechanical, log-scaling procedure where $\log\left(\frac{VIUMS^1_{iusr}}{VIUMS^0_{iusr}}\right)$ is the scaling fac-

tor for new estimated MRIO trade value $VIUMS^1_{iusr}$. We can visualize the scaling mechanism in Figure 4. Because this is a minimization procedure, ideally $\frac{VIUMS^1_{iusr}}{VIUMS^0_{iusr}} = 1$, and, hence, $\log\left(\frac{VIUMS^1_{iusr}}{VIUMS^0_{iusr}}\right) = 0$. However, as if often the case, the new estimate must adjust to match the constraints of the original GTAP Database ($VIMS^0_{isr}$ and $VIUM^0_{iur}$), and the procedure encourages downward adjustment of estimates.[1]

2.5 Differentiated Composite Tariffs

An important contribution of this paper is the introduction of composite tariff rates in the MRIO. Agents, including, firms, investors, and consumers, demand different baskets of goods. Resultantly, each agent will only import from certain HS lines, which are covered differentially by tariff schedule. In an aggregate framework, such as the MRIO, the weighted average of the tariff rate across HS lines into a composite good, will differ by agent.

In this paper, I extend beyond the current MRIO literature to incorporate tariff revenues into the MRIO construction process. As previously discussed, I use different end use shares for tariff-inclusive vs tariff-exclusive imports which I then use to compute the initial estimates of the MRIO trade data ($VIUMS^0_{iusr}$ and $VIUWS^0_{iusr}$). From these pre-optimization estimates, I compute the initial estimated power of the tariff.

$$VPOT^0_{iusr} = \frac{VIUMS^0_{iusr}}{VIUWS^0_{iusr}} \tag{5}$$

Multiplying the inverse of the power of the tariff ($VPOT^0_{iusr}$), I compute a first estimate of the tariff-exclusive, use-specific import value ($VIUWS^p_{iusr}$).

$$VIUWS^p_{iusr} = VIUMS^1_{iusr} * (VPOT^0_{iusr})^{-1} \tag{6}$$

Prior to optimization, I use this first estimate to decompose the original bilateral import values at world prices ($VIWS^0_{isr}$) from the GTAP Database by end use.

$$VIUWS^s_{iusr} = VIWS^0_{isr} * \frac{VIUWS^p_{iusr}}{\sum_u VIUWS^p_{iusr}} \tag{7}$$

Because of the first optimization procedure, the distribution of market priced imports across agents in $VIUMS^1_{iusr}$ differs from $VIUMS^0_{iusr}$. As such, the new ratio of market-priced to world-priced bilateral trade by agent ($\frac{VIUMS^1_{iusr}}{VIUWS^s_{iusr}}$) is not always greater than or equal to one, indicating that are point where the market priced trade is less than the world priced trade, or the presence of a "false" subsidy. To correct for these "false" subsidies, I implement a second optimization procedure.

For this procedure, I implement an optimization to fit world-priced (tariff-exclusive)

---

[1] See Appendix A for corresponding GAMS program.

trade values to the standard GTAP Database while ensuring that all tariffs by end use are positive. Mechanically, the procedure works via the same log-scaling mechanism as the first optimization by which I fit market-priced trade flows to the standard GTAP Database.[2]

$$\forall(i,s,r)$$

$$\underset{VIUWS^1_{iusr}}{\text{minimize}} \quad \sum_u \sum_s \left\{ VIUWS^1_{iusr} * \log \left(\frac{VIUWS^1_{iusr}}{VIUWS^s_{iusr}} \right) \right\}$$

(8)

subject to:

$$\sum_u VIUWS^1_{iusr} = VIWS^0_{isr}$$

$$\sum_s VIUWS^1_{iusr} \leq VIUMS^1_{isur}$$

By this optimization procedure, I estimate a new tariff-exclusive value of trade $VIUWS^1_{iusr}$. The first constraint ensures that $VIUWS^1_{iusr}$ aggregates along the end use dimension u to the original world-priced trade flows in the standard GTAP Database ($VIWS^0_{isr}$). The second constraint ensures that all tariff revenue is non-negative by enforcing the condition that tariff-exclusive trade flows ($VIUWS^1_{iusr}$) must be less than tariff-inclusive trade flows ($VIUMS^1_{iusr}$). This is particularly clear when the second constraint is rearranged as $\frac{VIUMS^1_{isur}}{VIUWS^1_{iusr}} - 1 \geq 0$.[3]

The optimized value $VIUWS^1_{iusr}$ is classified by three dimensions, commodity i, source country s, and destination country r, and the optimization procedure itself occurs only along one dimension, end use u, so that changes in allocation of trade value only shift among the three end use categories. Because of the specificity and dimensionality of the optimization, the procedure is computationally intensive, with an estimated compute time of 50 days on a state-of-the-art computer. Due to this computational limitation, for the purposes of this paper, I perform these sequential optimizations over an aggregate database of 18 regions and 12 sectors (Tables 2 and 3).

2.6 Agent values at world prices

Bilateral import values by use must now be disaggregated across agents. I disaggregate each import value across agents using agent shares corresponding to the agent mapping to end uses as aforementioned. I begin with world-priced im-

---

[2] See Appendix B for corresponding GAMS program.

[3] While the optimization solves with optimal and feasible solutions, the outcome retains a small margin of error. As such, any remaining insignificant discrepancies are systematically eliminated.

port values, but without world-priced agent-specific information, I generate shares from market-priced agent-specific import values in the standard GTAP Database.

To disaggregate across firms, I apply the share of imports of good *i* for production of industry *j* out of total imports aggregated across all industries $\left(\frac{VIFM^0_{ijr}}{\sum_{j=1}^{57} VIFM^0_{ijr}} \right)$ to the bilateral value of tariff-exclusive intermediate imports ($VIUWS^1_{i,'intm',s,r}$). This application distributes the bilateral trade value across importing firms.

$$VIFWS_{ijsr} = VIUWS^1_{i,'intm',s,r} * \left(\frac{VIFM^0_{ijr}}{\sum_{j=1}^{57} VIFM^0_{ijr}} \right) \quad \forall j \neq 'cgds' \tag{9}$$

$$VIFWS_{ijsr} = VIUWS^1_{i,'cgds',s,r} \quad \forall j = 'cgds'$$

For investment goods, the agent and the end use are the same, so there is no need for further disaggregation. With these bilateral import values distributed across industries and the investor, I have the newly defined variable $VIFWS_{ijsr}$, being tariff-exclusive bilateral imports across firms and the investor.

Similarly, I disaggregate bilateral imports for consumption into imports for government and for the private household with government and household import shares.

$$VIGWS_{isr} = VIUWS^1_{i,'cons',s,r} * \left(\frac{VIGM^0_{ir}}{VIGM^0_{ir} + VIPM^0_{ir}} \right) \tag{10}$$

$$VIPWS_{isr} = VIUWS^1_{i,'cons',s,r} * \left(\frac{VIPM^0_{ir}}{VIGM^0_{ir} + VIPM^0_{ir}} \right)$$

I attain new tariff-exclusive bilateral import values for the government ($VIGWS_{isr}$) and for the private household ($VIPWS_{isr}$).

2.7 Agent values at market prices

To disaggregate use-specific market-priced import values across agents, I can implement either sourcing shares to agent-specific trade flows or agent shares to bilateral trade flows. These are mathematically equivalent as $VIUMS^1_{iusr}$ was optimized to satisfy the constraint $\sum_s VIUMS^1_{iusr} = VIUM^0_{iur}$. This ensures that summing the use-specific bilateral import value across sources is equal to the agent-specific import values from the standard GTAP Database aggregated to use level.

For firm imports, either I apply source shares to industry-specific imports ($VIFM_{ijr}$) or I disaggregate the bilateral value of intermediate imports ($VIUMS^1_{i,'intm',s,r}$) by

industry import shares.

$$VIFMS_{ijsr} = VIFM^0_{ijr} * \left(\frac{VIUMS^1_{i,'intm',s,r}}{\sum_s VIUMS^1_{i,'intm',s,r}} \right) = VIUMS^1_{i,'intm',s,r} * \left(\frac{VIFM^0_{ijr}}{\sum_{j=1}^{57} VIFM^0_{ijr}} \right) \forall j \neq \, 'cgds'$$

$$VIFMS_{ijsr} = VIFM^0_{ijr} * \left(\frac{VIUMS^1_{i,'cgds',s,r}}{\sum_s VIUMS^1_{i,'cgds',s,r}} \right) = VIUMS^1_{i,'cgds',s,r} \; \forall \, j \, = \, 'cgds'$$

(11)

Imports for investment ($VIFM^0_{i,'cgds',r}$) can be distributed across sources, though this is equal to the bilateral value of imports for investment ($VIUMS^1_{i,'cgds',s,r}$). From these distributions across industries and investment, I define $VIFMS_{ijsr}$ as the tariff-inclusive value of bilateral imports across firms and the investor.

Likewise, for the government and private household, I can apply either sourcing shares to government- or household-specific import demands ($VIGM^0_{ir}$ or $VIPM^0_{ir}$) or agent-shares to bilateral consumption imports ($VIUMS^1_{i,'cons',s,r}$).

$$VIGMS_{isr} = VIGM^0_{ir} * \left(\frac{VIUMS^1_{i,'cons',s,r}}{\sum_s VIUMS^1_{i,'cons',s,r}} \right) = VIUMS^1_{i,'cons',s,r} * \left(\frac{VIGM^0_{ir}}{VIGM^0_{ir} + VIPM^0_{ir}} \right)$$

$$VIPMS_{isr} = VIPM^0_{ir} * \left(\frac{VIUMS^1_{i,'cons',s,r}}{\sum_s VIUMS^1_{i,'cons',s,r}} \right) = VIUMS^1_{i,'cons',s,r} * \left(\frac{VIPM^0_{ir}}{VIGM^0_{ir} + VIPM^0_{ir}} \right)$$

(12)

From these computations, I obtain new variables $VIGMS_{isr}$ and $VIPMS_{isr}$, tariff-inclusive bilateral imports for the government and the household.

2.8 Agent values at agent prices

I now compute bilateral agent-priced import values across agents. I use sourcing shares from the newly estimated bilateral import values by use, $VIUMS^1_{i,'intm',s,r}$. I apply these market-priced shares $\left(\frac{VIUMS^1_{i,'intm',s,r}}{\sum_s VIUMS^1_{i,'intm',s,r}} \right)$ as there is no agent-priced source-specific information.

For firms, I apply sourcing shares computed from the value of bilateral intermediate imports ($VIUMS^1_{i,'intm',s,r}$) to the agent-priced industry-specific value of

imports ($VIFA^0_{ijr}$).

$$VIFAS_{ijsr} = VIFA^0_{ijr} * \left(\frac{VIUMS^1_{i,'intm',s,r}}{\sum_s VIUMS^1_{i,'intm',s,r}} \right) \forall j \neq 'cgds'$$

$$VIFAS_{ijsr} = VIFA^0_{ijr} * \left(\frac{VIUMS^1_{i,'cgds',s,r}}{\sum_s VIUMS^1_{i,'cgds',s,r}} \right) \forall j = 'cgds'$$

(13)

For investors, I apply sourcing shares computed from the value of bilateral investment imports ($VIUMS^1_{i,'cgds',s,r}$) to the agent-priced value of imports for investment ($VIFA^0_{i,'cgds',r}$). From these computations for firms and investors, I attain the new variable $VIFAS_{ijsr}$, the agent-priced value of bilateral imports across industries and investment.

I apply sourcing shares from the value of bilateral consumption imports ($VIUMS^1_{i,'cons',s,r}$) to agent-priced values of imports for the government ($VIGA^0_{ir}$) and the household ($VIPA^0_{ir}$).

$$VIGAS_{isr} = VIGA^0_{ir} * \left(\frac{VIUMS^1_{i,'cons',s,r}}{\sum_s VIUMS^1_{i,'cons',s,r}} \right)$$

$$VIPAS_{isr} = VIPA^0_{ir} * \left(\frac{VIUMS^1_{i,'cons',s,r}}{\sum_s VIUMS^1_{i,'cons',s,r}} \right)$$

(14)

I obtain new variables $VIGAS_{isr}$ and $VIPAS_{isr}$, defined as agent-priced bilateral imports for the government and the private household, respectively.

3. Alternate Methods

Thus far, I have detailed the methods which I have implemented to construct an MRIO. However, of course, there could be alternative approaches. In this section, I will describe different methods, some of which others have undertaken and some of which might be considered for future work.

3.1 HS-BEC and BEC-SNA Concordances

In the present paper, I seek to obtain the most direct information from the HS-BEC and BEC-SNA concordances as possible. As such, I aim to impose the least amount of additional assumptions on the concordances and resultantly on the data which I split using these concordances. Thus, if there is a one-to-one mapping between HS and BEC classifications, then I allocate all trade value from that HS

line to that BEC code. Likewise, for a one-to-one mapping between BEC and SNA. However, when there is not a one-to-one mapping, as described above for HS code 27100 or BEC codes 321 and 7, then the value of trade is allocated proportionately across corresponding categories of BEC or SNA, respectively.

Alternatively, one could seek further information through the imposition of additional assumptions during the application of the HS-BEC and BEC-SNA concordances, per Timmer et al. (2012) for the construction of WIOD. Timmer et al. reclassified over 700 products (at the HS-line) to new end use categories. Further, for certain products, they used weights by end use to break out trade values at the HS line to multiple end use categories. Koopman et al. (2014) adopt the modified concordances of Timmer et al. (2012) in their construction of the MRIO.

For the construction of the OECD-WTO TiVa database, the OECD uses the Bilateral Trade Database by Industry and End-use (BTDIxE), which is also constructed using an enhanced HS-BEC and BEC-SNA concordance system. They considered differences in SNA definitions across SNA releases for certain product categories, such as firearms, and they selected the SNA definition by release which they found most accurately reflected the end use of the good. In addition, they introduce six additional end use categories which correspond to multiple end-uses: personal computers, passenger cars, personal phones, packed medicines, precious goods, and miscellaneous (OECD 2017b).

Both Timmer et al. and the OECD make additional assumptions to enhance the HS-BEC and BEC-SNA concordance system, seeking to extract as much possible additional information from the bilateral trade data. Some of these modifications may be necessary advancements for more accurately implementing this concordance system. For example, indeed, reclassification may be necessary for certain HS-BEC-SNA mappings or certain SNA releases may offer more accuracy than others. However, it is unclear whether other modifications are introducing additional information with accuracy or whether they are introducing noise into the data.

Timmer et al. use weights and the OECD introduces additional end use categories. Weights may better allocate trade data across end uses, but without specific data to support these weights, their implementation remains discretionary. Likewise, nine end-use categories in total certainly offer more detail but also lose a generality intended to facilitate a more aggregate classification of tradeables.

Researchers would benefit from efforts to generate a comprehensive HS-BEC-SNA classification system agreed upon across institutions which are working to develop MRIO frameworks. This would enhance the comparability of statistics and analytical results across MRIOs. Such comparability would enhance transparency amongst researchers, policy-makers, and the public at large.

3.2 Estimating Differentiated Tariffs through Tariff Revenue Allocation

A major contribution of this paper is the introduction of tariffs differentiated by end use or agent. As aforementioned, in order to differentiate tariffs by agent,

I apply the HS-BEC-SNA concordance system to tariff revenue from TASTE. To ensure that the tariff revenue is positive after optimizing the market-priced (tariff-inclusive) trade estimates, I implement a second optimization procedure to adjust world-priced (tariff-exclusive) trade estimates. With the combination of these two procedures, I maintain differential tariffs across agents while ensuring aggregation to the original bilateral trade data in the standard GTAP Database.

An alternative to these two sequential optimization procedures would be to pursue an optimization model which comprises the first optimization procedure which fits tariff-inclusive trade flows as well as the second optimization procedure which both fits tariff-exclusive trade flows and ensures non-negative tariffs. This may be theorized as a multi-objective optimization procedure, with the constraints of the afore-described two optimization procedures. However, a complication is that the first procedure is indexed on commodity and destination country, optimizing across both source country and end use, whereas the second procedure is indexed on on commodity, source country, and destination country, only optimizing over end use. Such a procedure may be considered in future research.

I also explored analytical alternatives to the second optimization in effort to produce a readily accessible and replicable database at the full scale of 57 sectors and 141 regions. From the pre-optimization estimates of MRIO trade data ($VIUMS^0_{iusr}$ and $VIUWS^0_{iusr}$), I computed the initial estimated tariff revenue.

$$VTUS^0_{iusr} = VIUMS^0_{iusr} - VIUWS^0_{iusr} \qquad (15)$$

I used this initial estimate of tariff revenue to generate shares of tariff revenue by end use.

$$SHRT_{iusr} = \frac{VTUS^0_{iusr}}{\sum_u VTUS^0_{iusr}} \qquad (16)$$

I applied these use-specific shares to the original tariff revenue in the GTAP Database, being the difference between the bilateral market- and world-priced import values.

$$VTUS^1_{iusr} = SHRT_{iusr} * \left(VIMS^0_{isr} - VIWS^0_{isr} \right) \qquad (17)$$

I then computed the tariff-exclusive, use-specific import value ($VIUWS^1_{iusr}$) as the difference between the optimized tariff-inclusive, use-specific import value ($VIUMS^1_{iusr}$) and the tariff revenue ($VTUS^1_{iusr}$).

$$VIUWS^1_{iusr} = VIUMS^1_{iusr} - VTUS^1_{iusr} \qquad (18)$$

This analytical procedure, however, yielded an MRIO database that, although aggregated to the original GTAP Database, produced "false" subsidies. These "false" subsidies could be eliminated by using the MRIO trade data to generate end use shares and applying these shares to the bilateral trade data if the original GTAP Database. However, all differentiation of tariffs amongst agents was also washed out. This exercise reaffirmed the need for the second and sequential optimization procedure to ensure tariff differentiation across agents and aggregation to the orig-

inal GTAP Database, as aforementioned.

3.3 Adjusting Agent Demands for Imports vs Domestic Products

The method which I implement in the MRIO construction adjusts initial estimates of use-specific, tariff-inclusive ($VIUMS^0_{iusr}$) and tariff-exclusive ($VIUWS^0_{iusr}$) bilateral trade flows in order to preserve the GTAP Database. Now, these initial estimates are constructed in order to aggregate across the end use dimension in order to conserve the original bilateral trade flows in the standard GTAP Database. However, the initial estimates of tariff-inclusive ($VIUMS^0_{iusr}$) trade flows do not aggregate along the end use dimension to conserve the original unilateral agent-specific trade flows in the standard GTAP Database.

$$\sum_u VIUMS^0_{iusr} = VIMS^0_{isr}$$

$$\sum_u VIUWS^0_{iusr} = VIWS^0_{isr}$$

(19)

$$\sum_s VIUMS^0_{iusr} = VIUM^1_{iur} \neq VIUM^0_{iur}$$

The first optimization procedure ensures this conservation of aggregate tariff-inclusive estimates with the agent-specific trade flows in the standard GTAP Database. However, this then requires a secondary procedure (either distribution by shares or optimization) to ensure that new estimates of tariffs are non-negative. Thus, the conservation of the unilateral agent-specific trade flows in the standard GTAP database necessitates a readjustment of the initial estimates of tariff revenues and, hence, tariff rates by end use.

An alternative method would be to preserve the initial estimates of tariff revenues by end use and to change the agent-specific imports, diverging from the standard GTAP Database. For this method, I would keep the original estimates $VIUMS^0_{iusr}$ and $VIUWS^0_{iusr}$, with the difference being the estimated tariff revenue. From these values, I would compute agent-specific trade flows, for tariff-exclusive and tariff-inclusive trade flows.

For agent-specific computations of tariff-exclusive trade flows, estimates can be obtained by applying agent-based shares to $VIUWS^0_{iusr}$. These world-priced values aggregate across agents to $VIWS^0_{isr}$, preserving the standard GTAP Database. As aforementioned, there is no tariff-exclusive, agent-specific trade data in the standard GTAP Database, and as such, tariff-inclusive agent-shares are used to break out $VIWS^0_{isr}$.

$$VIFWS^1_{ijsr} = VIUWS^0_{i,'intm',s,r} * \frac{VIFM_{ijr}}{\sum_j VIFM_{ijr}} \quad \forall j \neq "cgds"$$

$$VIFWS^1_{ijsr} = VIUWS^0_{i,'cgds',s,r} \quad \forall j = "cgds"$$

(20)

$$VIGWS^1_{isr} = VIUWS^0_{i,'cons',s,r} * \frac{VIGM_{ir}}{VIGM_{ir} + VIPM_{ir}}$$

$$VIPWS^1_{isr} = VIUWS^0_{i,'cons',s,r} * \frac{VIPM_{ir}}{VIGM_{ir} + VIPM_{ir}}$$

For agent-specific computations of tariff-inclusive trade flows, I apply agent-based shares to $VIUMS^0_{iusr}$. These world-priced values aggregate across agents to $VIMS^0_{isr}$. However, they do not preserve the original unilateral agent import flows ($VIFM^0_{ijr}$, $VIGM^0_{ir}$, and $VIPM^0_{ir}$) in the standard GTAP Database.

$$VIFMS^1_{ijsr} = VIUMS^0_{i,'intm',s,r} * \frac{VIFM_{ijr}}{\sum_j VIFM_{ijr}} \quad \forall j \neq "cgds"$$

$$VIFMS^1_{ijsr} = VIUMS^0_{i,'cgds',s,r} \quad \forall j = "cgds"$$

(21)

$$VIGMS^1_{isr} = VIUMS^0_{i,'cons',s,r} * \frac{VIGM_{ir}}{VIGM_{ir} + VIPM_{ir}}$$

$$VIPMS^1_{isr} = VIUMS^0_{i,'cons',s,r} * \frac{VIPM_{ir}}{VIGM_{ir} + VIPM_{ir}}$$

Now, recall that in this alternate method, I aim to maintain the first estimates of the tariffs from the BEC-SNA concordance system applied to TASTE data. Thus, I do not want to alter $VIUMS_{i,u,s,r}$ or any of its agent-specific derivatives, $VIFMS^1_{ijsr}$, $VIGMS^1_{isr}$, and $VIPMS^1_{isr}$. In order to maintain the balance of the standard GTAP Database, I adjust the agent-specific demands for domestic products, generating new estimates $VDFM^1_{ijr}$, $VDGM^1_{ir}$, and $VDPM^1_{ir}$. I estimate these domestic demands as the difference between the total agent demands in the original standard GTAP Database and the newly estimated agent-specific, tariff-inclusive trade flows.

$$VDFM^1_{ijr} = (VDFM^0_{ijr} + VIFM^0_{ijr}) - \sum_s VIFMS^1_{ijsr}$$

$$VDGM^1_{ir} = (VDGM^0_{ir} + VIGM^0_{ir}) - \sum_s VIGMS^1_{isr}$$
$$\tag{22}$$

$$VDPM^1_{ir} = (VDPM^0_{ir} + VIPM^0_{ir}) - \sum_s VIPMS^1_{isr}$$

To estimate agent-priced trade flows by source, I apply the power of the agent tax to the market-priced trade flows by source. Thus, I preserve the initial market-priced estimates from the application of the BEC-SNA system to the TASTE Database and the agent taxes from the standard GTAP Database in the computation. However, aggregating the new agent-priced trade flows across sources does not preserve the original agent-priced trade flows in the standard GTAP Database, $VIFA^0_{ijr}$, $VIGA^0_{ir}$, and $VIPA^0_{ir}$.

$$VIFAS^1_{ijsr} = VIFMS^1_{ijsr} * \frac{VFA^0_{ijr}}{VFM^0_{ijr}}$$

$$VIGAS^1_{isr} = VIGMS^1_{ijsr} * \frac{VGA^0_{ir}}{VGM^0_{ir}}$$
$$\tag{23}$$

$$VIPAS^1_{isr} = VIPMS^1_{ijsr} * \frac{VPA^0_{ir}}{VPM^0_{ir}}$$

Likewise, to agent-priced estimate demand for domestic goods, I apply the power of the agent tax to the new estimates of market-priced domestic demand. Now, recall these market-priced domestic demand estimates are computed as residuals of total demand, comprising original demand for domestic and foreign goods in the standard GTAP Database, and the newly estimated demand for foreign products. Hence, I preserve the new division of demand for foreign and domestic products at both market and agent prices.

$$VDFA^1_{ijr} = VDFM^1_{ijr} * \frac{VFA^0_{ijr}}{VFM^0_{ijr}}$$

$$VDGA^1_{ir} = VDGM^1_{ir} * \frac{VGA^0_{ir}}{VGM^0_{ir}} \tag{24}$$

$$VDPA^1_{ir} = VDPM^1_{ir} * \frac{VPA^0_{ir}}{VPM^0_{ir}}$$

As discussed above, this method does not aggregate to preserve the agent-specific demand for foreign goods in the standard GTAP Database and accordingly does not preserve agent-specific demand for domestic goods either. However, this method does still preserve the agent-specific total demand for goods, at both market and agent prices, in the standard GTAP Database. In essence, this method reallocates agent demands for a given good *i* between foreign sources versus the domestic. Thus, this method presumes that the information attained from the BEC-SNA concordance system applied to the TASTE Database takes priority over the original domestic-foreign split of goods demand in the standard GTAP Database.

$$VFM^1_{ijr} = \sum_s VIFMS^1_{ijsr} + VDFM^1_{ijr} = VFM^0_{ijr}$$

$$VGM^1_{ir} = \sum_s VIGMS^1_{isr} + VDGM^1_{ir} = VGM^0_{ir} \tag{25}$$

$$VPM^1_{ir} = \sum_s VIPMS^1_{isr} + VDPM^1_{ir} = VPM^0_{ir}$$

$$VFA^1_{ijr} = \sum_s VIFAS^1_{ijsr} + VDFA^1_{ijr} = VFA^0_{ijr}$$

$$VGA^1_{ir} = \sum_s VIGAS^1_{isr} + VDGA^1_{ir} = VGA^0_{ir} \tag{26}$$

$$VPA^1_{ir} = \sum_s VIPAS^1_{isr} + VDPA^1_{ir} = VPA^0_{ir}$$

Although the agent-specific total demand for goods are preserved, the reallocation between foreign versus domestic sourcing does not guarantee that the new values for domestic demand are positive. Indeed, by this method, for certain products, sufficient demand is allocated to foreign sources such that the newly estimated domestic demand for the good is negative. Of course, a negative demand would be economically nonsensical and, hence, would require some alteration of the estimations of the demand for foreign goods, the residual demand for domestic goods, the agent tax, or some combination of all three. Further, more accurate information on the foreign-domestic demand split would assist in the estimating the domestic-foreign demand split. While these caveats presently preclude this method as an effective option, future research will further examine the which economic information merits the most conservation during the construction of MRIO databases.

4. Illustrative Descriptives of Composite Tariffs in the New GTAP MRIO

In the standard GTAP Database and the MRIO databases built with proportional tariffs, compound tariff rates differ by source but are the same across importing agents. With the new method as described above, I derive compound tariff rates which now differ across importing agent. Specifically, composite tariffs on imports for consumption differ from those on imports for intermediates and those on imports for investment. The differences vary by country-commodity pairing. These differences between composite tariffs reflect the different composition of import demand by agent at the HS line and the tariff rates applied at these HS lines.

Below, I will discuss composite tariff rates of consumer goods versus intermediate goods and versus investment goods, respectively, for the U.S., the E.U., Brazil, China, and India. I first focus on these differences in detail for U.S. consumers and U.S. firms as well as U.S. consumers and U.S. investors. Subsequently, I consider comparisons with patterns of composite rates on E.U. imports. I then consider composite rates on imports into three major emerging markets: Brazil, China, and India.

For the U.S., consider composite tariffs on consumer imports versus intermediate imports, as shown in Figure 5. Composite tariffs for consumer imports are across the board higher than those for intermediate imports of Electronics (ELE), Leather Goods (LEA), Motor Vehicles (MVH), Other Manufactured Goods (OMF), Textiles (TEX), and Wearing Apparel (WAP). Composite rates on intermediates are across the board higher for imports of Chemicals Rubbers and Plastics (CRP), Lumber (LUM), and Processed Foods (FOD). For Agriculture and Natural Resources (AGN) and Machinery and Equipment (OME), the composite tariff is less easily determined to be higher for either importing consumer or producer.

Consider in particular the imports of Agriculture and Natural Resources to the U.S. for consumers versus firms. Most tariffs are relatively low (less than 1 percent), except for goods from Japan, China, and the E.U. Here, tariffs for China
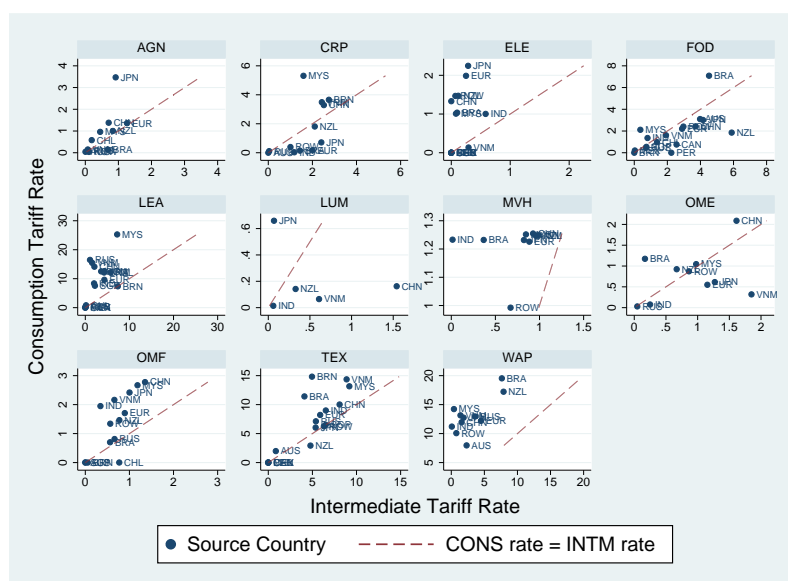
Figure 5. Composite Tariffs on Imports into the U.S.: Cons. vs.
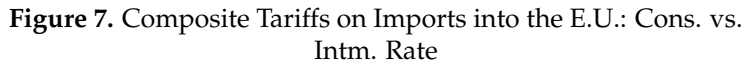Intm. Rate

Source: Author's calculations.

and the E.U. are close for consumers and producers, whereas consumers face relatively higher tariffs on Japanese products. Again, this difference is reflective of the underlying tariffs applied at the HS line for consumers and producers. Thus, consumers demand imports of agricultural products along tariff lines with higher rates than those demanded by firms, and firms demand imports of agricultural products along tariff lines with higher rates than those demanded by consumers.

Similarly, we can consider the difference between composite tariff rates on imports for consumption versus for investment purposes, as depicted for the U.S. in Figure 6. In this comparison, both consumer and investment goods are final products, whereas the prior comparison considered intermediate goods which are inputs into production. Composite tariffs on consumer goods were higher than those on investment goods for Electronics (ELE), Other Manufactured Goods (OMF), and Textiles (TEX). For Agriculture and Natural Resources (AGN), Chemicals Rubbers and Plastics (CRP), Lumber (LUM), Motor Vehicles (MVH), Machinery and Equipment (OME), and Wearing Apparel (WAP), the comparison of composite tariffs on imports was less clear, with some composite rates greater for either the consumer or investor and many rates about the same.

For the E.U., I again consider relative composite tariffs on consumer imports versus those applied on imports of either intermediates or investment goods, respectively, in Figure 7. As in the U.S., E.U. consumers face higher composite tariff rates on imports of Electronics (ELE), Leather Goods (LEA), Motor Vehicles (MVH), Other Manufactured Goods (OMF), Textiles (TEX), and Wearing Apparel (WAP), relative to E.U. firms. In addition, E.U. consumers also face higher composite rates
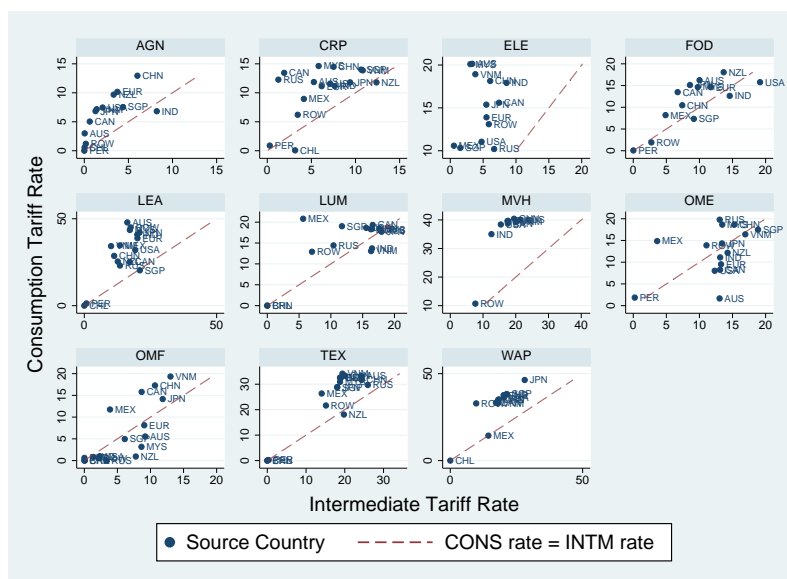
Figure 6. Composite Tariffs on Imports into the U.S.: Cons. vs. Invst. Rate

Source: Author's calculations.

Figure 7. Composite Tariffs on Imports into the E.U.: Cons. vs. Intm. Rate

Source: Author's calculations.

on imports of Agriculture and Natural Resources (AGN). Likewise, As in the U.S., firms face higher composite rates on Chemicals Rubbers and Plastics (CRP) and

Lumber (LUM), relative to consumers. In the E.U., composite rates on imports of Processed Food (FOD) and Machinery and Equipment (OME) are difficult to broadly characterize as higher for either consumers or firms, with the difference being more source specific.
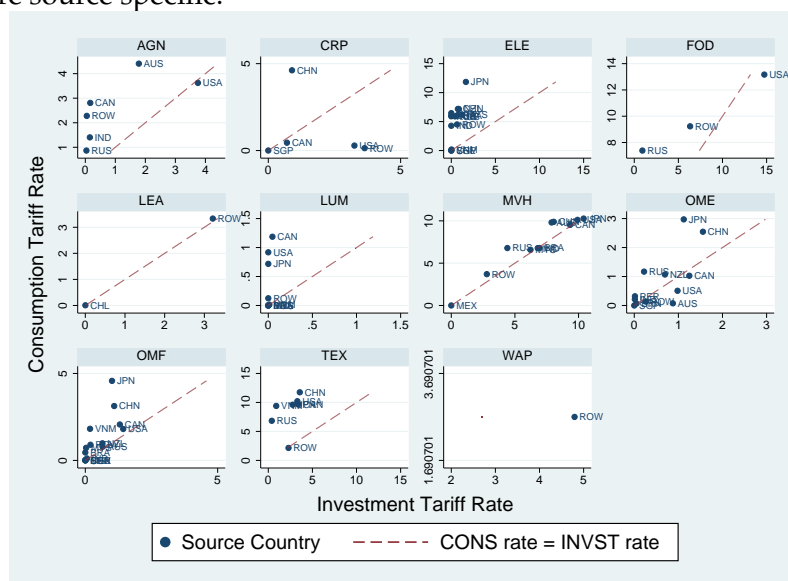
Figure 8. Composite Tariffs on Imports into the E.U.: Cons. vs. Invst. Rate

Source: Author's calculations.

In Figure 8, I illustrate differences in composite tariffs rates between the E.U. consumer and the E.U. investor. Akin to differences for E.U. consumers and firms, E.U. consumers face higher composite tariff rates on imports of Agriculture and Natural Resources (AGN), Electronics (ELE), Other Manufactured Goods (OMF), and Textiles (TEX), relative to E.U. investors. Further, E.U. consumers face higher composite rates on Lumber (LUM) than investors, whereas investors face higher rates on Wearing Apparel (WAP). Composite rates on imports of Chemicals Rubbers and Plastics (CRP), Processed Food (FOD), Leather Goods (LEA), Motor Vehicles (MVH), and Machinery and Equipment (OME) are less distinctly categorizable as higher for either consumers or investors.

I next consider differences in composite tariff rates in three of the largest emerging markets, Brazil, China, and India. I begin with Brazil. In Figure 9, I illustrate the differences between Brazil's composite tariff rates on imports for consumers versus imports for firms. Brazilian composite rates are nearly uniformly higher for consumers than firms, with the exceptions two exceptions. Composite rates on imports of Machinery and Equipment (OME) are mostly higher for firms whereas composite rates on imports of Other Manufactured Goods (OMF) may be higher for either consumers or firms, depending on source.

In figure 10, I examine differences between composite rates on imports for con-

Figure 9. Composite Tariffs on Imports into Brazil: Cons. vs. Intm. Rate

Source: Author's calculations.
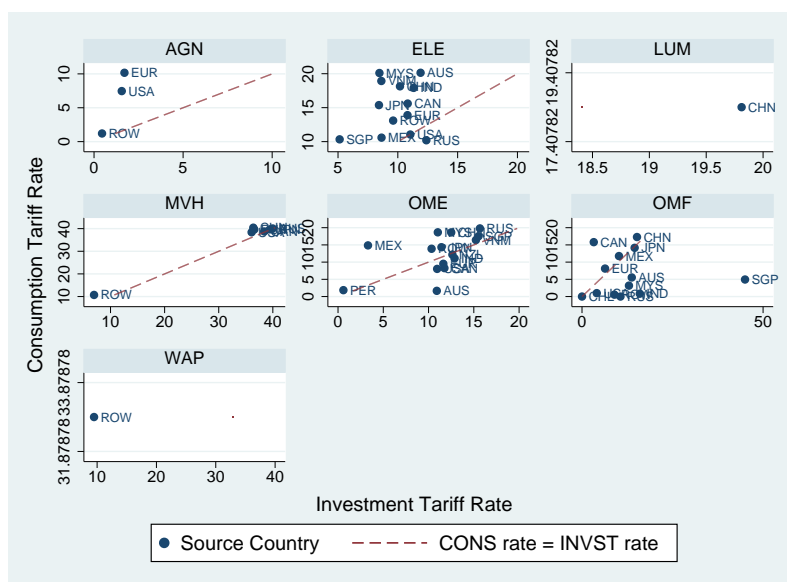
Figure 10. Composite Tariffs on Imports into Brazil: Cons. vs. Intm. Rate

Source: Author's calculations.

sumers and investors in Brazil. Consumers face higher composite rates on imports of Agriculture and Natural Resources (AGN), Electronics (ELE), and Wearing

Apparel (WAP), while investors face higher composite rates on imports of Lumber (LUM) and Other Manufactured Goods (OMF). For imports of Motor Vehicles (MVH) and Machinery and Equipment (OME), consumers or investors face higher or lower composite rates, depending on commodity source, with no overall characterization.
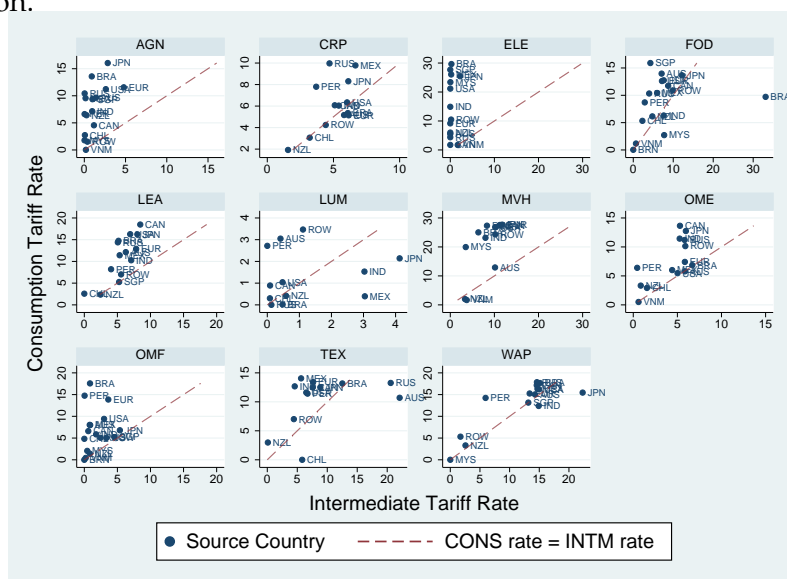
Figure 11. Composite Tariffs on Imports into China: Cons. vs. Intm. Rate

Source: Author's calculations.

Now I consider differences in composite tariffs in China. In Figure 11, I consider the differences between composite rates on imports for consumption versus for intermediate use. Consumer rates can be characterized as higher than intermediate rates across sources for Agriculture and Natural Resources (AGN), Electronics (ELE), Processed Food (FOD), Leather Goods (LEA), Motor Vehicles (MVH), Machinery and Equipment (OME), Other Manufactured Goods (OMF), and Textiles (TEX) imports. While composite rates are not categorizable as higher for intermediates across sources for any one commodity, differences in rates are source specific for imports of Chemicals Rubbers and Plastics (CRP), Lumber (LUM), and Wearing Apparel (WAP).

I also consider differences between composite tariff rates on imports into China for consumption versus investment (Figure 12). Relative to investors, consumers face higher composite rates on imports of Agriculture and Natural Resources (AGN), Chemicals Rubbers and Plastics (CRP), Electronics (ELE), Processed Food (FOD), Lumber (LUM), and Machinery and Equipment (OME). Relative to consumers, investors face higher composite rates on Leather Goods (LEA), Textiles (TEX), and Wearing Apparel (WAP). Differences in composite rates on imports of Motor Vehicles (MVH) and Other Manufactured Goods (OMF) are source specific, with com-
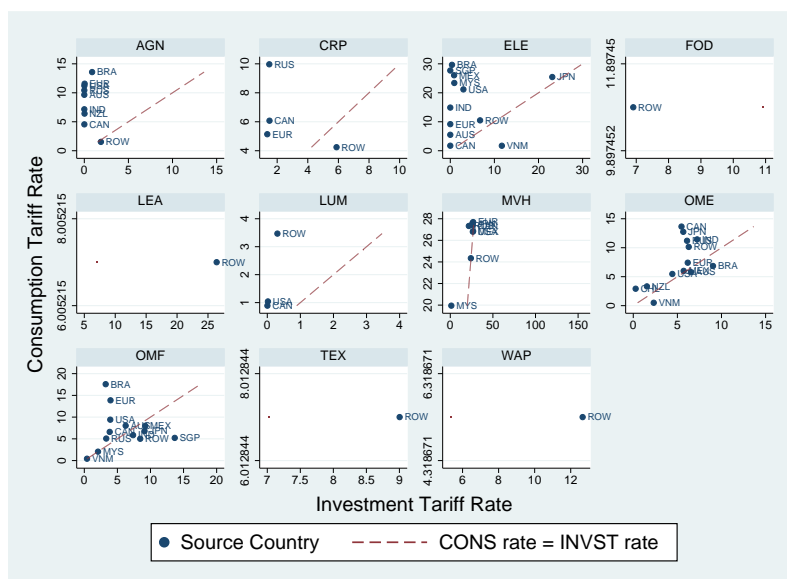
Figure 12. Composite Tariffs on Imports into China: Cons. vs. Invst. Rate

Source: Author's calculations.

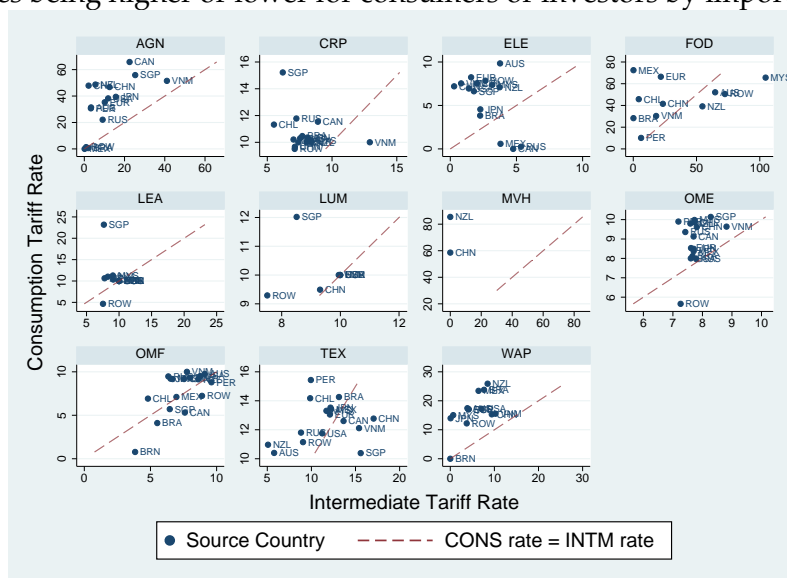posite rates being higher or lower for consumers or investors by import source.

Figure 13. Composite Tariffs on Imports into India: Cons. vs. Intm. Rate

Source: Author's calculations.

Lastly, I consider composite tariff rates on imports into India. In Figure 13, I examine differences in composite rates on imports for consumption versus in-

termediate use. Composite tariff rates are higher for consumers for Agriculture and Natural Resources (AGN), Chemicals Rubbers and Plastics (CRP), Electronics (ELE), Motor Vehicles (MVH), Machinery and Equipment (OME), Wearing Apparel (WAP), whereas composite rates are higher for firms of Processed Food (FOD), Leather Goods (LEA), Lumber (LUM), Other Manufactured Goods (OMF), and Textiles (TEX). For these two commodities, differences in composite tariffs between the consumer and the investor vary by import source.
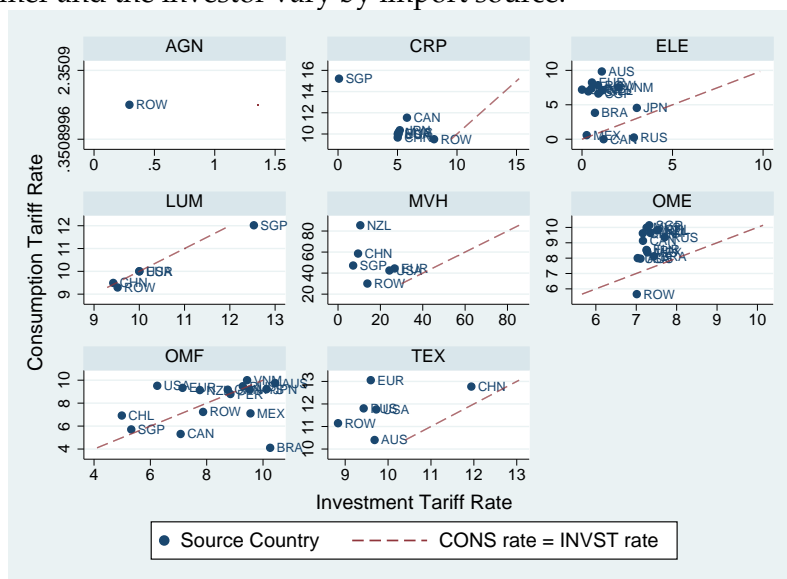
Figure 14. Composite Tariffs on Imports into India: Cons. vs. Invst. Rate

Source: Author's calculations.

I illustrate differences between composite tariff rates on imports of goods for consumption versus investment in Figure 14. Consumers face higher composite rates relative to investors for imports of Agriculture and Natural Resources (AGN), Chemicals Rubbers and Plastics (CRP), Electronics (ELE), Motor Vehicles (MVH), Machinery and Equipment (OME), and Textiles (TEX). Differences in composite rates between the consumer and investor are source-specific for imports of Lumber (LUM) and Other Manufactured Goods (OMF).

Among these three emerging economies, composite tariff rates on consumer goods are more consistently generalizable as higher than composite rates on imports for intermediate input or investment. This trend of higher composite rates on consumer imports is more widespread than in either the U.S. or E.U. economies. This may be indicative of higher protection for domestic industries in emerging economies as compared with more advanced economies, enabling domestic production and investment through lower tariffs while simultaneously incentivizing consumers to choose domestically produced goods through high tariffs.

Overall, these illustrations underline the diversity of composite tariff rates by

agents and source, a feature not previously available in the standard GTAP Database or earlier versions of MRIOs derived from the GTAP Database. Further, the illustrations reflect tariff escalation in that composite tariff rates on final goods imported by the consumer are often higher than the tariff rates on intermediate products imported by firms. I also find that compound tariff rates on investment goods were significantly higher. Together, this indicates that, despite the diversity of tariff rates, there is a clear trend for many commodities that consumers face higher composite rates than firms importing for production or investment.

By capturing these differences in composite tariff rates for consumers, I improve the utility of the MRIO database for policy analysis. The novelty of this enhanced differentiation becomes clear under the consideration of a tariff removal. Under the standard GTAP Database or any MRIO with proportional composite tariff rates across agents, the shock of a tariff removal would be equal across agents in that all importing agents would face the same changes in prices of imported goods. However, with this incorporation of differentiated composite tariff rates, consumers would face different changes in import prices for the same composite product than either firms or investors. In many cases, importing consumers would face greater benefits under the new framework which more accurately depicts the complexity of composite tariffs. Here, for many products, consumers would face a relatively lower price after the tariff removal whereas firms and investors would face relatively higher prices, as compared with the same tariff removal under a framework with proportional tariff rates for all agents.

5. Model

The GTAP MRIO Framework can be used with any CGE model with cross-border linkage between exporting producers and importing agents. As aforementioned, in this paper, I use the GTAP Supply Chain Model (Walmsley et al. 2014). The GTAP Supply Chain (GTAP-SC) model builds from the standard GTAP model (standard GTAP) to incorporate these direct cross-border supply-demand linkages.

Figure 15 demonstrates how GTAP-SC incorporates these cross-border linkages into the theory, in comparison with standard GTAP. Specifically, Figure 15 shows the differences in firm demand. In standard GTAP, firm output of commodity j, QO_{jr}, drives demand for intermediate input i, QF_{ijr}. This intermediate demand is met by either domestic, QFD_{ijr}, or foreign, QFM_{ijr}, demand, depending on input-specific trade elasticity σ_{Di}. Foreign demand is satisfied by a composite of imports, QFM_{ijr}, which is aggregate across all source regions s. Bilateral trade in standard GTAP, QXS_{is}, is affected by the aggregate demand for imports of a given commodity i, QIM_{ir}, and the input-specific trade elasticity σ_{Mi}.

In contrast, GTAP-SC has an additional nesting in the demand structure such that the firm directly decides the source regions of intermediate input into production. Specifically, the firm in GTAP-SC chooses $QIFS_{ijsr}$, the amount of foreign demand of input i from source s. This differs from the standard model in which the
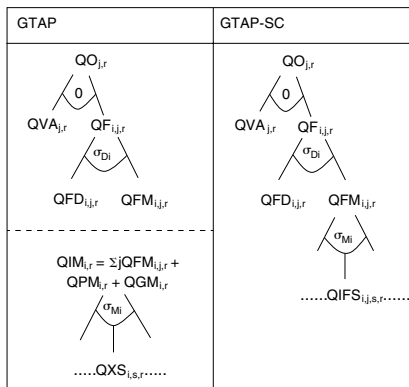
Figure 15. GTAP Model Comparison: Standard vs. Supply Chain

Source: Walmsley et al. (2014)

firm does not make region-supplier sourcing decisions, rather sourcing decisions are made at the aggregate regional level.

6. Illustrative Scenario

In this paper, I consider the illustrative scenario of a tariff removal on merchandise trade between the twelve original TPP members.[4] This is a simplified scenario to illustrate linkages in the MRIO database. I exclude changes to non-tariff barriers. Specifically, I exclude rules for services trade, investment, product standards, sanitary and phytosanitary issues (SPS), intellectual property rights (IPR), labor, environment, government procurement, small and medium enterprises (SMEs), and state-owned enterprises (SOEs).

To simulate this scenario, I implement the GTAP-SC model with an aggregate MRIO database. I specify the original twelve TPP members as well as industrial giants China, India, Brazil, Europe, and Russia (Table 2). I aggregate to twelve sectors, including ten sectors of processed goods, a sector of agricultural and natural resources, as well as a services sector (Table 3).

In analyzing simulations, I will present results in three subsections. First, I will present a consumer study. Specifically, I will examine how tariff removal on U.S. imports differentially affects consumers and firms. Second, I will present a pro-

---

[4] This paper was written prior to the change in U.S. administration and the accompanying change in U.S. trade policy. On the 23rd of January 2017, the White House issued a memorandum for the U.S. Trade Representative, ordering the withdrawal of the U.S. from the TPP (The White House 2017). Subsequently, the U.S. Trade Representative issued a letter to the other eleven signatories of the TPP to formally withdraw from the TPP agreement (USTR 2017). Since the exclusion of the U.S. from the trade talks, the other 11 signatories have continued talks with Canada taking the lead to champion labor and environmental provisions (Global Affairs Canada 2017).

Table 2. Regions

REG	Country Description
AUS	Australia
NZL	New Zealand
JPN	Japan
BRN	Brunei
MYS	Malaysia
SGP	Singapore
VNM	Viet Nam
CAN	Australia
USA	United States of America
MEX	Mexico
CHL	Chile
PER	Peru
CHN	China
IND	India
BRA	Brazil
EUR	Europe
RUS	Russia
ROW	Rest of World

Source: GTAP regions.

Table 3. Sectors

SEC	Sector Description
AGN	Agriculture and Natural Resources
FOD	Processed Foods
TEX	Textiles
WAP	Wearing Apparel
LEA	Leather Goods
LUM	Lumber
CRP	Chemicals, Rubbers, and Plastics
MVH	Motor Vehicles
ELE	Electronics
OME	Machinery and Equipment
OMF	Other Manufactured Goods
SRV	Services

Source: GTAP sectors and aggregates.

ducer study in which I will analyze how U.S. trading partners' tariff removals affect U.S. exports. I trace exports from U.S. producers to distinct changes in foreign firm and consumer import demands. Third, I present a North American study, where I consider changes in supply chains between North American trade partners. Subsequently, I discuss differences between results from the simulation in standard GTAP-SC versus GTAP as well as across MRIO versions.

7. Results

7.1 Consumer Study
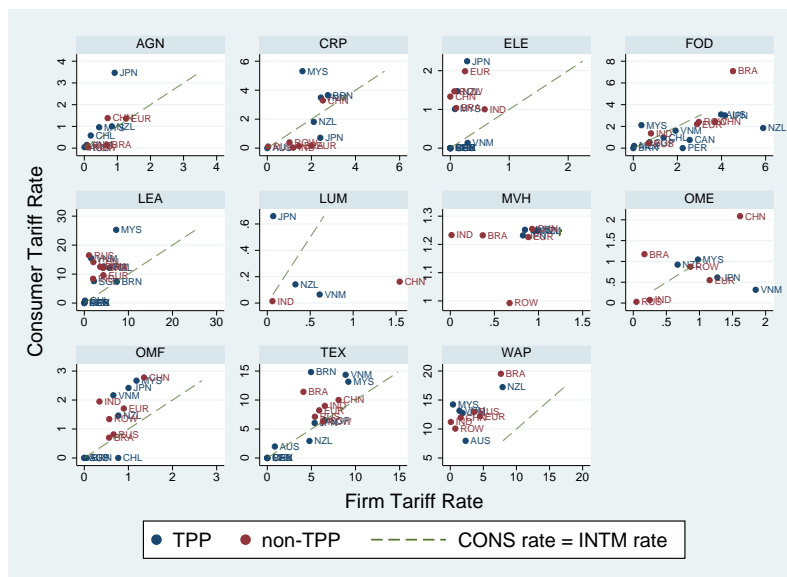
Figure 16. U.S. Composite Tariff Rates

Source: Author's calculations.

Before economic analysis of the tariff removal scenario, I will discuss the difference between composite tariff rates in the U.S. for the firm and the consumer. Figure 16 shows composite tariff rates by imported commodity and source region for consumers versus firms. Composite rates by source for each commodity are plotted such that if the markers aligned on the forty-five degree angle, then the consumer composite rate equals the firm composite rate. If markers are above the forty-five degree angle, then consumer composite rates are higher than firm composite rates. If markers are below the forty-five degree angle, firm composite rates are higher than consumer composite rates.

As shown in Figure 5, broadly, Figure 16 shows that for several sectors, such as Electronics (ELE), Leather (LEA), Motor Vehicles (MVH), Other Manufactured Goods (OMF), Textiles (TEX), and Wearing Apparel (WAP), there is clear evidence of tariff escalation with consumers facing higher tariffs on imports than firms across sources. However, tariffs of other aggregate products show different patterns. For example, firms tend to face higher tariffs on Chemicals, Rubber, and Plastics (CRP), Processed Foods (FOD), and Lumber (LUM). For Agriculture and Natural Resources (AGN) and Machinery and Equipment (OME), consumers may face higher or lower composite rates depending on the source region.

In this paper, I focus on the Wearing Apparel sector (WAP). Wearing Apparel sector (WAP) depicts an archetypal pattern of tariff escalation where consumers

face higher composite tariff rates across all source regions. Singapore (SGP) is the exception with the U.S. not imposing tariffs for consumer or firm imports of Wearing Apparel sector (WAP) from SGP.
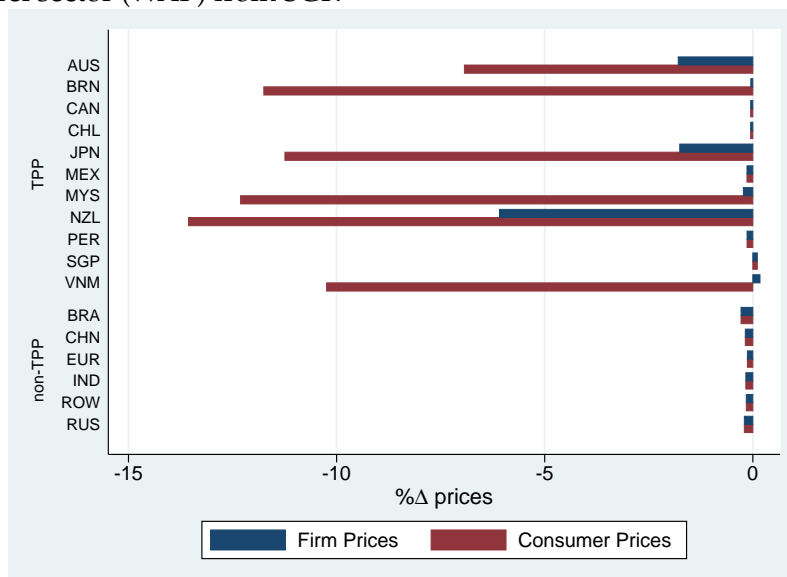
Figure 17. U.S. Composite Import Prices

Source: Author's simulations.

In Figure 17, we view post-simulation percent changes in import prices for firms and consumers across regions. We see that for TPP countries, tariff removal results in lowered import prices, with the exception of negligible positive changes of imports from Singapore. Specifically, the import prices are lower for consumers because they initially faced higher tariff rates relative to firms. Hence, the tariff removal favorably decreases consumer prices more than firm prices.

As a result of the decreased import prices, U.S. imports increase, in terms of percent changes in quantity (Figure 18). Consumer imports increase relatively more than firm imports because of the higher tariffs originally facing consumers. Imports from non-TPP regions decrease as trade is now preferentially sourced from the newly sans-tariff TPP regions.

Figure 19 shows the pre- and post-simulation trade values of wearing apparel by source region for consumers and firms. From this figure, we can see that there are significant differences, particularly for the consumers. After tariff removal, U.S. consumer imports from Vietnam surpass ten billion USD while trade from China markedly decreases.

From the consumer study, we see how incorporating tariff escalation causes differential effects of trade policy analysis on consumers and firms. Specifically, we see how U.S. consumers initially face higher composite tariffs than firms. Subsequently, consumers benefit relatively more than firms from tariff removal in terms
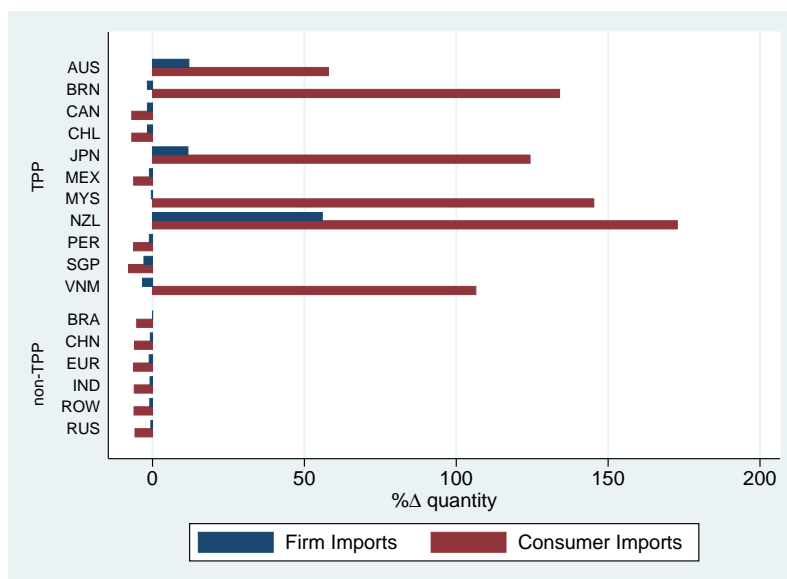
Figure 18. U.S. Import Demand

Source: Author's simulations.
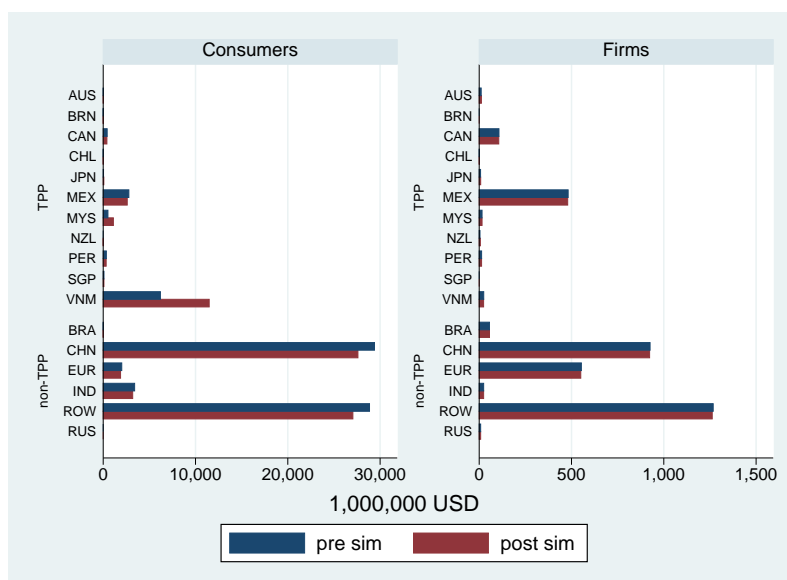
Figure 19. U.S. Trade Flows Pre- and Post-Sim

Source: Author's simulations.

of decreases in import prices on Wearing Apparel. These decreased import prices translate into increased consumer demand, corresponding to large import values.
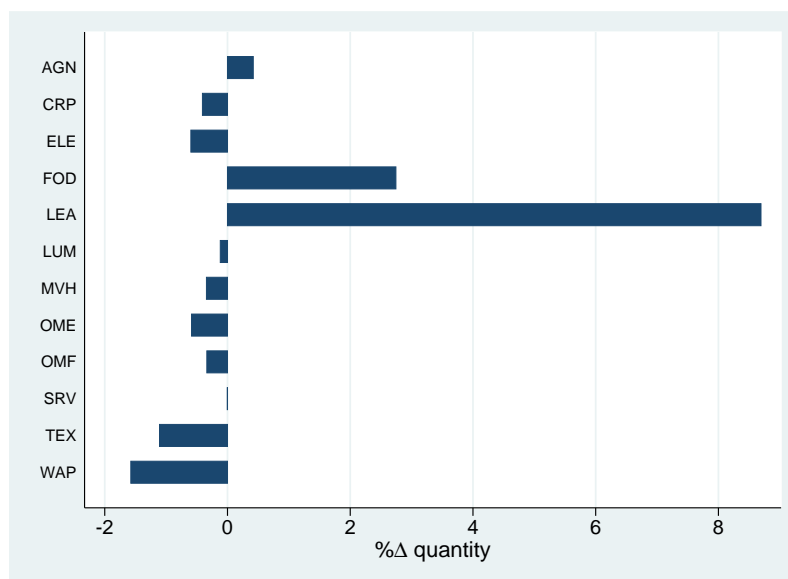
Figure 20. U.S. Production Growth

Source: Author's simulations.

7.2 Producer Study

Now, I will discuss the impact of the tariff removal on U.S. firms. From Figure 20, we can see that only three U.S. sectors gain from this scenario: Agricultural and Natural Resources (AGN), Processed Foods (FOD), and Leather Goods (LEA). By far, Leather Goods (LEA) gains the most, growing over eight percent post tariff removal.

U.S. producer expansion is fueled by export growth, as U.S. TPP trading partners remove tariffs. In Figure 21, we observe the percent change in U.S. exports of the three expanding sectors, Agricultural and Natural Resources (AGN), Processed Foods (FOD), and Leather Goods (LEA). We see that generally there are increased exports to TPP partners, whereas demand from non-TPP partners falls. By far, Japanese demand for U.S. imports increases the most, with demand for Leather Goods (LEA) imports skyrocketing.

To better understand the drastic increases in Japanese demand post tariff removal, we must first consider the initial composite tariff rates facing Japanese firms and consumers (Figure 22). I will focus on imports demand for Processed Foods (FOD) and Leather Goods (LEA) products. We observe that Japanese consumers face higher rates on Leather Goods (LEA) products whereas the pattern for composite rates on Processed Foods (FOD) is less distinguishable. Nonetheless, the rates faced by both consumers and firms are quite high for both Processed Foods (FOD) and Leather Goods (LEA). In particular, for U.S. Leather Goods (LEA) imports, composite tariff rates are over fifty percent for consumers versus around eighteen percent for firms.
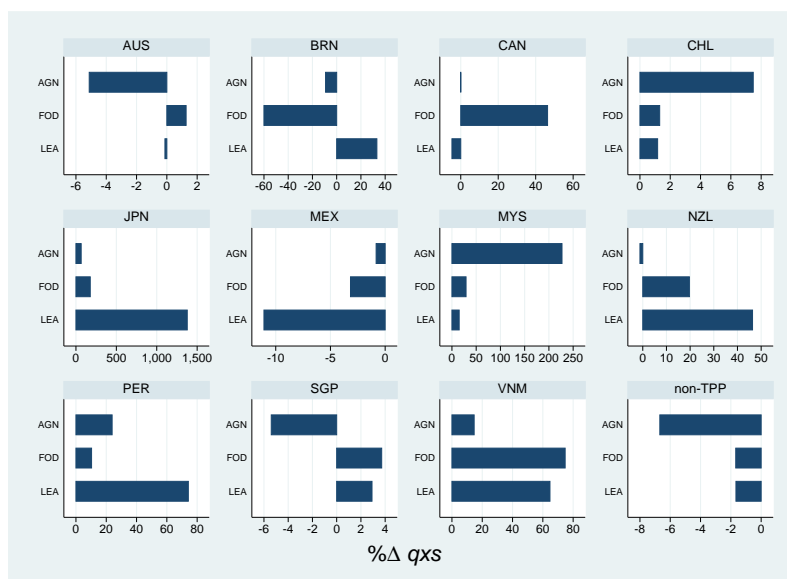
Figure 21. U.S. Exports by Partner
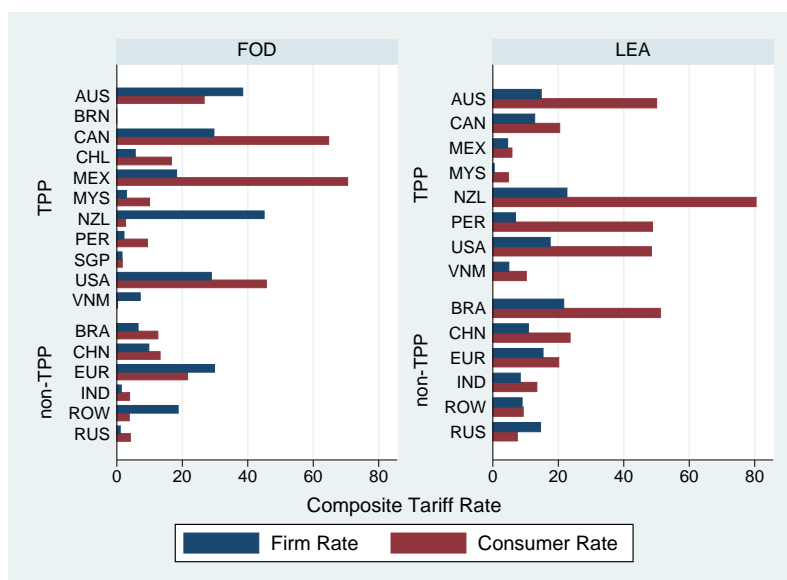
Source: Author's simulations.

Figure 22. Japanese Composite Tariff Rates

Source: Author's simulations.

In Figure 23, we observe the percent changes in composite import prices for Japanese firms. Composite prices for firm imports of Processed Foods (FOD) decline more than composite prices for firm imports of Leather Goods (LEA). This relative price decline is driven by the difference in composite tariffs for Processed
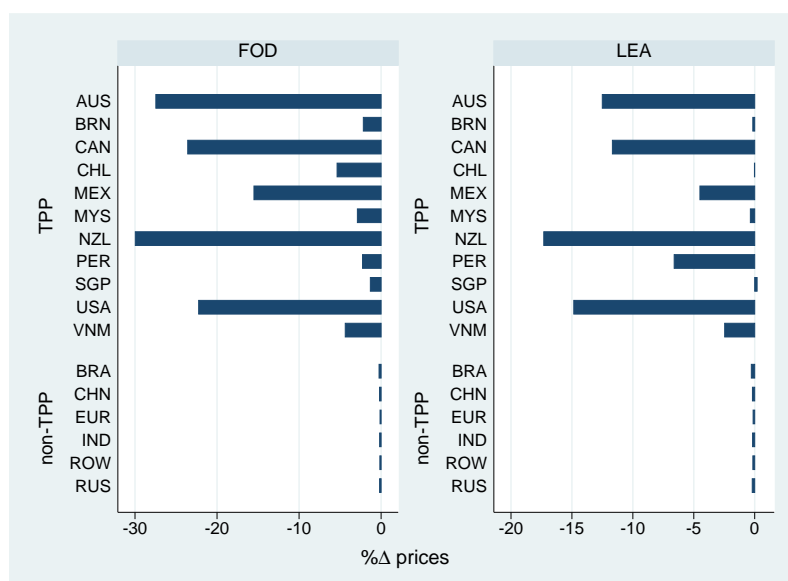
Figure 23. Japanese Firm Composite Import Prices

Source: Author's simulations.

Foods (FOD) versus Leather Goods (LEA). Consider that Japanese firms initially faced a composite tariff rate of nearly thirty percent for U.S. imports of Processed Foods (FOD) whereas Japanese firms only faced a tariff of around eighteen percent for U.S. imports of Leather Goods (LEA). Resultantly, after tariff removal, composite import prices for U.S. Processed Foods (FOD) drop by over twenty percent whereas composite import prices for U.S. Leather Goods (LEA) only drop by fifteen percent.

Japanese import growth is driven by reduced import prices from tariff removal feeding into Japanese economic expansion. In Figure 24, we observe broad economic expansion in the Japanese economy. In particular, the Leather Goods sector (LEA) expands by around one percent. To better understand this growth in the Leather Goods (LEA) sector, we need to understand the cost structure.

Figure 25 shows a breakdown of the cost structure for the Japanese Leather Goods sector. On the left panel, we see the overall cost structure of the sector, including value-added (labor and capital) as well as domestic inputs. From this panel, we see that imported inputs comprise around twenty-five percent of all inputs into production. On the right panel, we see the breakdown of the imported inputs. Specifically, we observe that Processed Foods (FOD) comprises the majority of imported demand, followed by Leather Goods (LEA). Why is Processed Foods (FOD) a major imported input into Japanese Leather Goods (LEA) production ? Processed Foods (FOD) includes animal hides, clearly a major input into leather.

As tariffs are removed, the Japanese Leather Goods sector benefits from lower import prices on Processed Foods (FOD) and Leather Goods (LEA) products, both
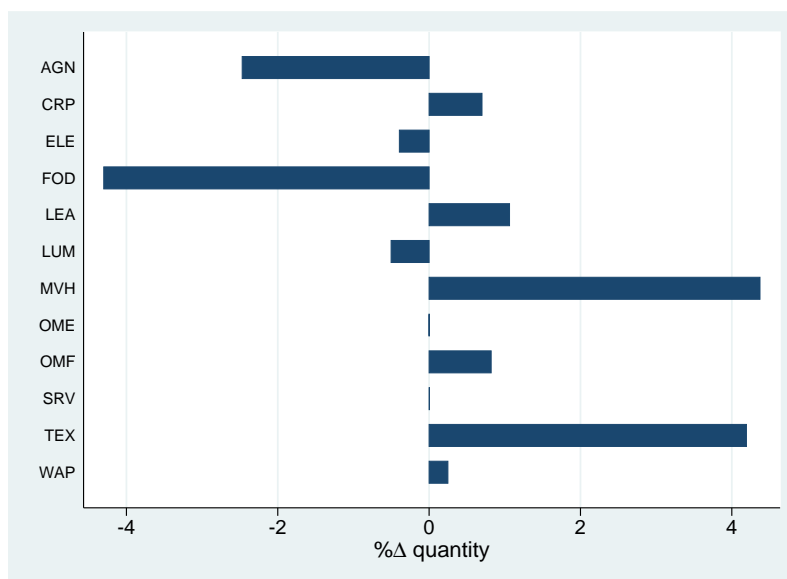
Figure 24. Japanese Production Growth

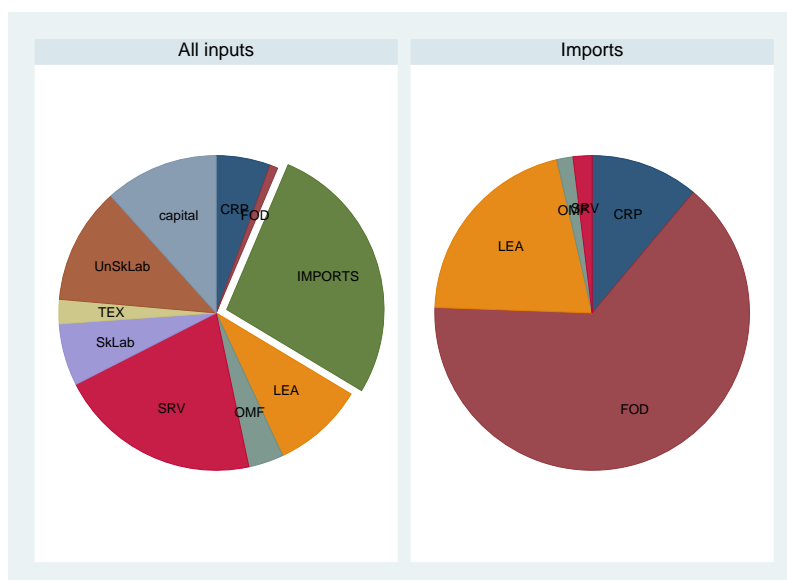*Source:* Author's simulations.

Figure 25. Japanese Leather Sector Cost Structure

Source: Author's simulations.

major inputs into production, feeding sectoral expansion. From Figure 26, we observe the percent change in the Japanese Leather Goods sector's demand for Processed Foods (FOD) and Leather Goods (LEA). We see that the Japanese Leather sector's demand for imports of U.S. Processed Foods (FOD) increases by nearly
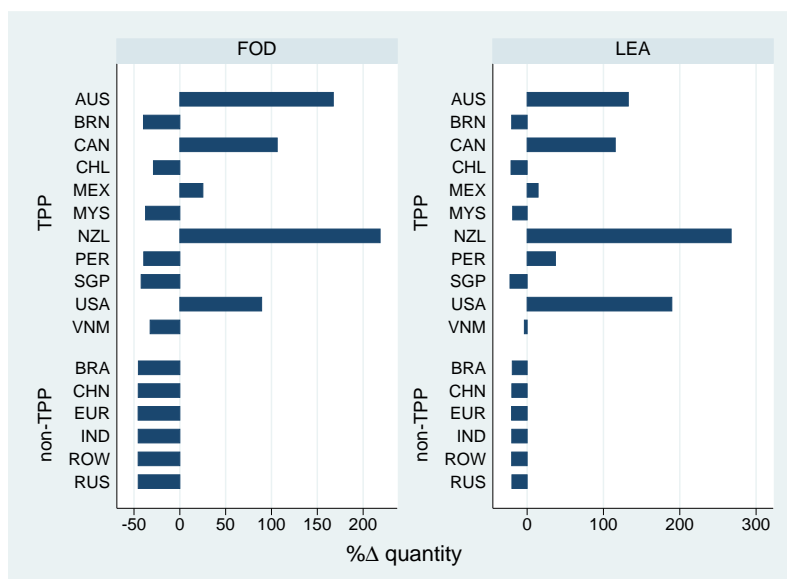
Figure 26. Japanese Leather Sector Imports

Source: Author's simulations.

one hundred percent while demand for imports of U.S. Leather Goods (LEA) increases by nearly two-hundred percent.
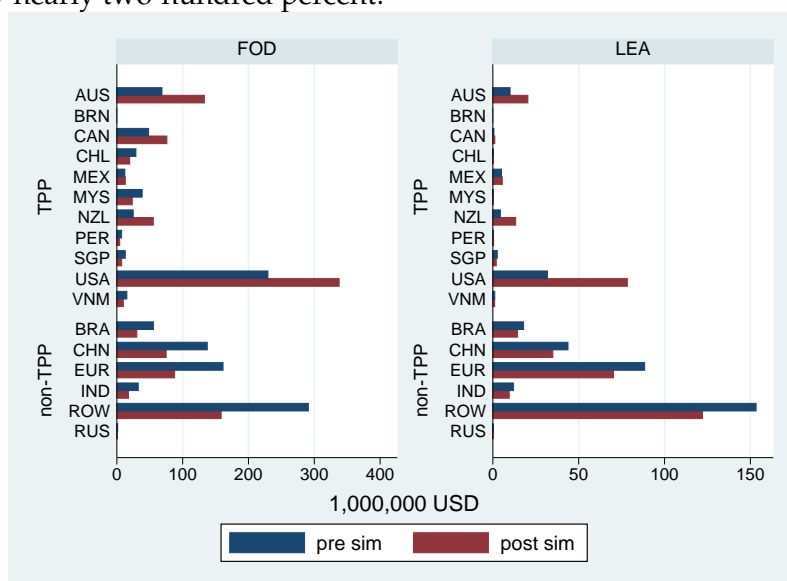
Figure 27. Japanese Leather Sector Trade Flows Pre- and Post-Sim

Source: Author's simulations.

These percent change increases translate to large trade flows in terms of value, as seen in Figure 27. In particular, for the U.S., imports of Processed Foods (FOD) increase from below two-hundred fifty million USD to above three-hundred mil-

lion USD, following tariff-removal. Processed Foods (FOD) imports from the U.S. dominate demand from the Japanese Leather sector, before and after the tariff-removal. For imports of U.S. Leather Goods (LEA), the U.S. becomes the Japanese Leather sector's largest individual supplier, with increased imports from less than fifty million USD to over seventy-five million USD.
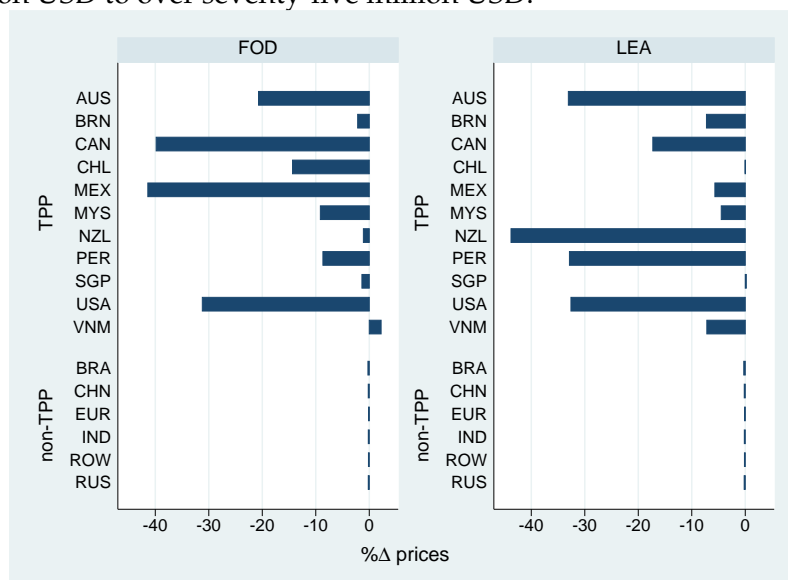
Figure 28. Japanese Consumer Composite Import Prices

Source: Author's simulations.

Now, consider the impact of decreased composite tariff rates on Japanese consumer import demand. In Figure 22, we observed that the Japanese consumer initially faced composite tariffs on U.S. imports of forty-five percent for Processed Foods (FOD) products and nearly fifty percent on Leather Goods (LEA) products. In Figure 28, we see that consumer composite import prices for both Processed Foods (FOD) and Leather Goods (LEA) decline with the tariff removal. Specifically, we see that the import prices of Processed Foods (FOD) and Leather Goods (LEA) from the U.S. both decline by over thirty percent. The similarity of changes in composite import prices reflects the similarity of the initial composite tariff rates prior to liberalization.

As Japanese consumers face lower composite import prices, they demand more imported Processed Foods (FOD) and Leather Goods (LEA) products. Figure 29 shows the increase in Japanese consumer demand for Processed Foods (FOD) and Leather Goods (LEA). Demand for U.S. Processed Foods (FOD) increases by over two-hundred percent while demand for U.S. Leather Goods (LEA) increases by nearly two-thousand percent.

These percent changes in Japanese consumer import demand for U.S. Processed Foods (FOD) and Leather Goods (LEA) products translate into large import flows
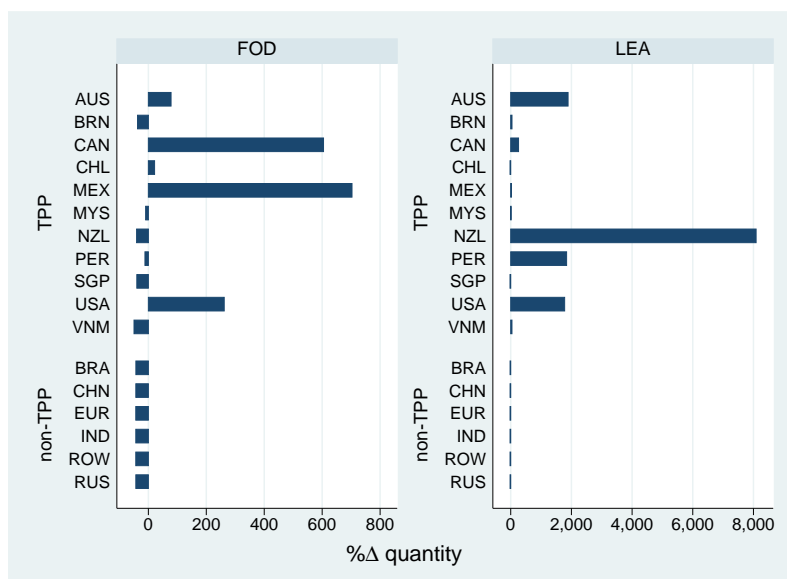
Figure 29. Japanese Consumer Composite Imports
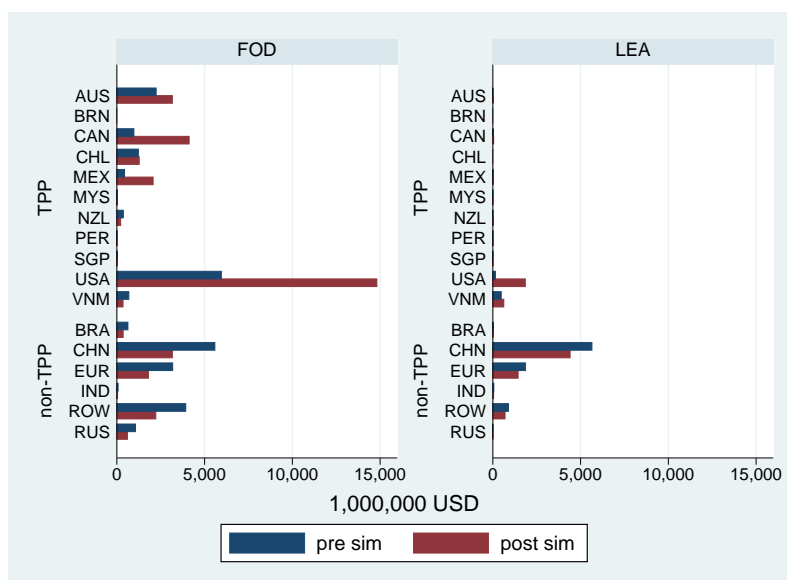
Source: Author's simulations.

Figure 30. Japanese Consumer Composite Import Value

Source: Author's simulations.

in value terms. In Figure 30, we observe that the U.S. becomes the dominant supplier of Processed Foods (FOD) imports to Japanese consumers. Japanese consumer imports of Processed Foods (FOD) increase from over five billion USD to nearly fifteen billion USD following tariff-removal. Likewise, for Leather Goods

(LEA) products, post tariff removal, imports of Leather Goods (LEA) from the U.S. increase to nearly two billion. The U.S. becomes the second-largest supplier of Leather Goods (LEA) products to Japanese consumers, taking market share from the largest supplier, China.

From the producer study, we see how U.S. producer expansion in the Processed Foods and Leather sectors develops with tariff removal by TPP partners. In particular, we observe increased demand from Japanese firms and consumers as the removal of high composite tariff rates on U.S. Processed Foods and Leather Goods translates to lowered composite import prices. Cheaper imports of Processed Foods and Leather products feed into the expansion of the Japanese Leather sector. Japanese consumers also benefit from lower prices, increasing import demand.

7.3 North American Study

In the consumer and producer studies, I analyzed U.S. trade effects across linkages with all TPP members and, specifically, with Japan. In this section, I will focus on North American supply chain linkages. Specifically, I assess how the TPP changes trade flows between the Canada, the U.S., and Mexico. I focus on two industries: the Motor Vehicles and Parts industry and the Processed Food Industry.
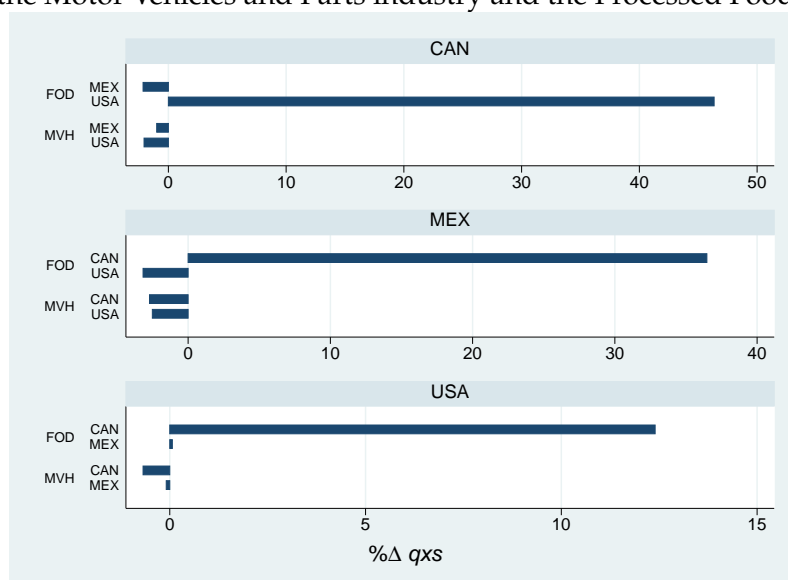

Figure 31. North American Trade of Processed Food and Motor
Vehicles and Parts

Source: Author's simulations.

Figure 31 shows overall changes in North American Supply Chains for the Processed Foods (FOD) sector and the Motor Vehicles and Parts (MVH) sector. For trade of Processed Food, Canada and Mexico trade more with each other as do the U.S. and Mexico. However, Mexico imports less Processed Food from the U.S., and changes in imports from Mexico to the U.S. are negligible. The decline in direct

Mexican imports of U.S. Processed Food appears reflective of an increase in indirect trade with Canada as an intermediary. Indeed, the largest increase in trade of Processed Food is from the U.S. to Canada (45%). Trade of Motor Vehicles declines between all three countries.
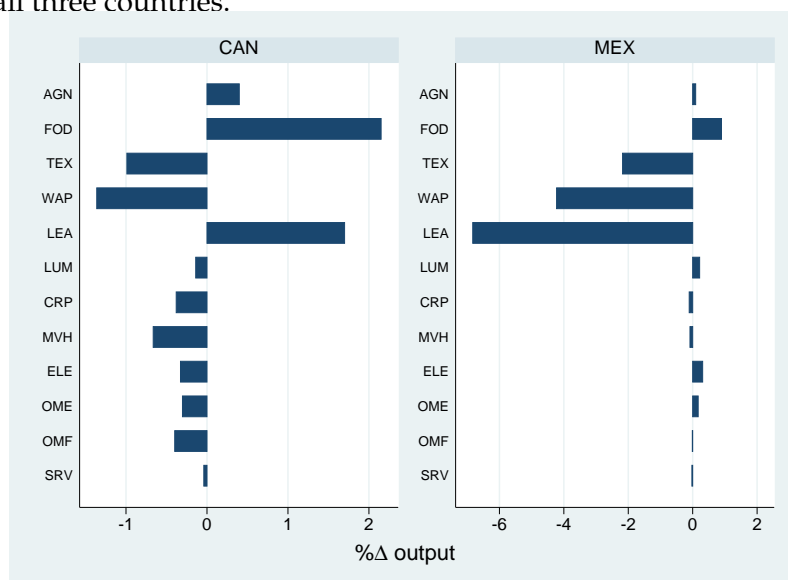

Figure 32. North American Production by Sector

Source: Author's simulations.

The sectoral production effects in Canada and Mexico (Figure 32) and in the U.S. (Figure 20) are indicative of these North American supply chain effects as observed in changes in the trilateral trade flows. In all three countries, the Processed Food sector expands, with greater relative expansion in the U.S., seconded by Canada. For the Motor Vehicles and Parts sector, Canada and the U.S. face contraction in production, while Mexican expansion is negligibly. Comparing with internal patterns of North American trade in these sectors, broad patterns emerge of sectoral expansion being linked with increased trilateral trade and contraction being linked with reduced trilateral trade.

I further decompose changes in the North American supply chain for Processed Food (FOD) into changes in consumer and producer behavior. I consider three graphs, (Figures 33-35) which depict the percent changes and accompanying changes in values for Canadian and Mexican Imports. As an overview in Figure 33, I consider the percent change in imports of Processed Food by firms and consumers. Canada imports less for consumers and firms from Mexico whereas Mexico imports more for firms from Canada. Thus, the increases in Mexican-Canadian trade of Processed Food are driven by Mexican industrial demand. From the U.S., Canada imports more for both consumers and firms, whereas Mexico imports less for both consumers and firms.
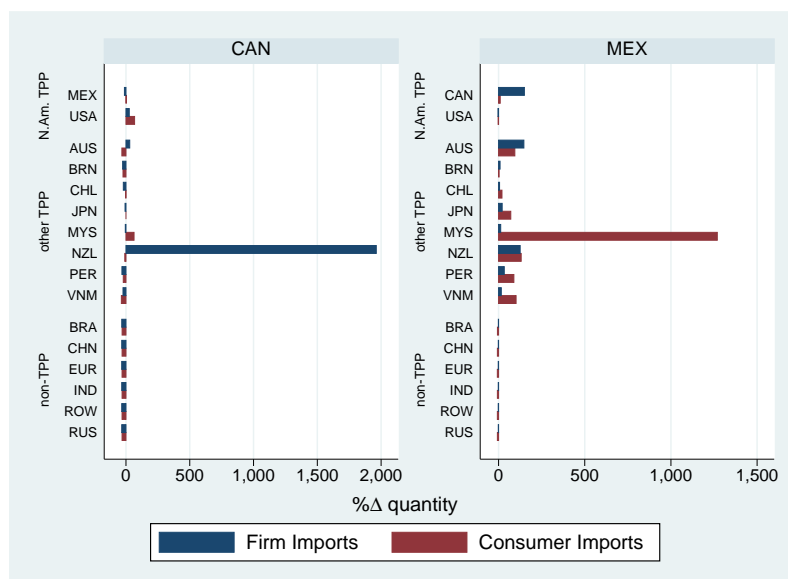
Figure 33. North American Imports of Processed Food by Source

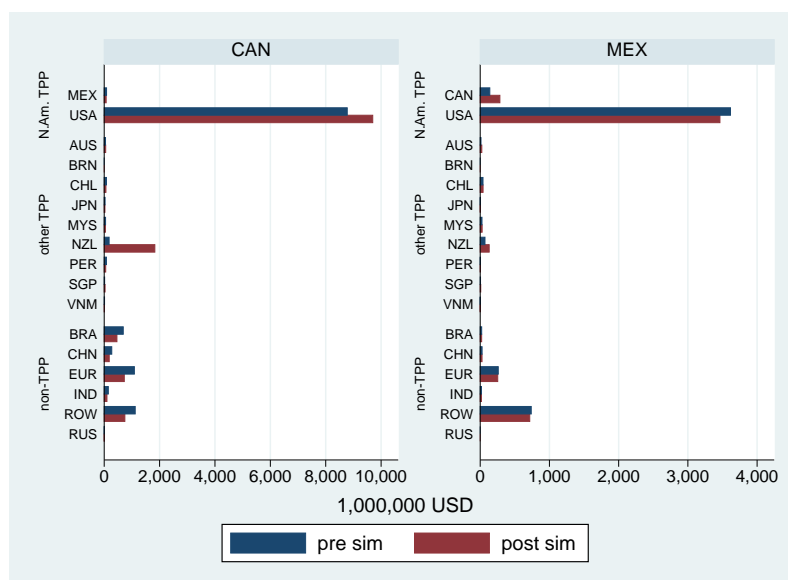*Source:* Author's simulations.

Figure 34. North American Firm Processed Food Trade Flows Pre-
and Post-Sim

Source: Author's simulations.

Figure 34 shows the values of firm imports before and after the simulation of the TPP, providing magnitudes in correspondence with the relative changes in Figure 33. The U.S. is Canada's largest source for imported Processed Food intermedi-
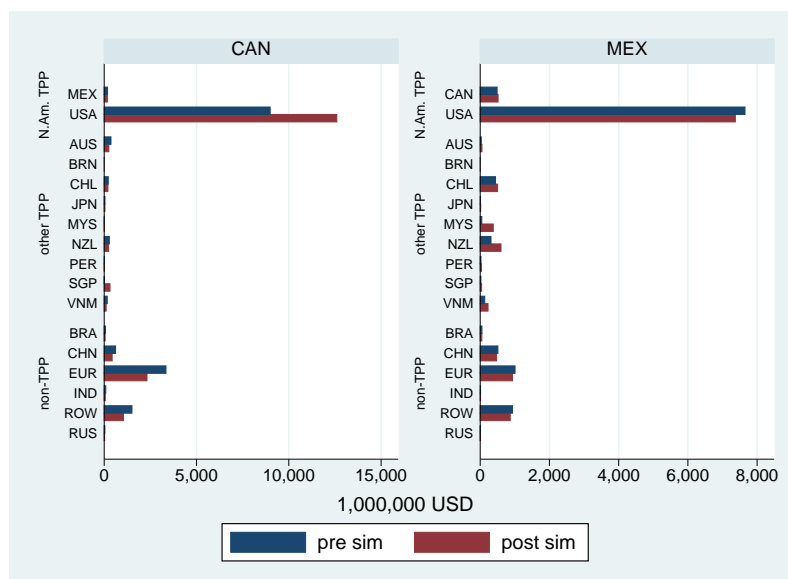
Figure 35. North American Consumer Processed Food Trade Flows
Pre- and Post-Sim

Source: Author's simulations.

ates and that Canada imports very little from Mexico. The U.S. remains the largest source after the TPP, increasing its intermediate Processed Food exports to Canada, while New Zealand takes market share from other source economies. For Mexico, Canada takes from U.S. market share. Again, I find the pattern of increased intermediate Processed Food trade from the U.S. to Canada and from Canada to Mexico with decreasing U.S. imports to Mexico. This supports the aforementioned inference that Processed Foods trade from U.S. to Mexico is now being rerouted through Canada.

Figure 35 shows changes in consumer values corresponding to Figure 33. As with firm imports, the U.S. remains Canada's primary source of Processed Food imports for consumption, continuing to gain market share following implementation of the TPP. Canada also imports relatively little Mexican Processed Food for consumption. Mexico imports less Processed Food for consumption from either Canada or the U.S., importing more from its other TPP partners, such as Malaysia, New Zealand, and Vietnam.

In Figure 36, I decompose changes in intra- North American trade of Motor Vehicles and Parts into relative investor, firm, and consumer effects. I find the same pattern across importing agents in Canada and Mexico. In both countries, imports of Motor Vehicles and Parts from North American trade partners are displaced with imports from non- North American TPP members.

Figures 37 through 39 show value changes in Canadian and Mexican imports of Motor Vehicles and Parts (MVH) for investors, firms, and consumers, respectively. Again, for both Canada and Mexico, I find trade from North American partners to
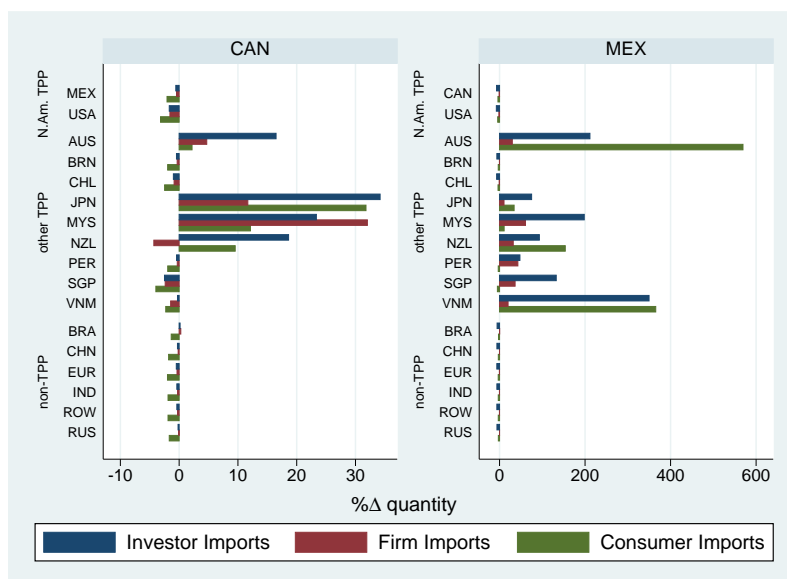
Figure 36. North American Imports of Motor Vehicles and Parts by Source

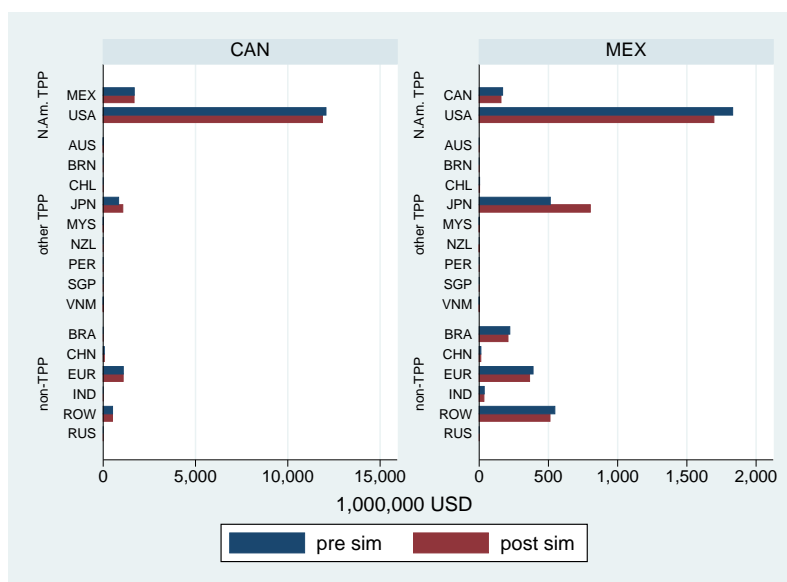*Source:* Author's simulations.

Figure 37. North American Investor Motor Vehicles and Parts Trade Flows Pre- and Post-Sim

Source: Author's simulations.

decline. However, from these graphs of value changes, Japan emerges as the apparent source taking market share of Motor Vehicles and Parts from North American
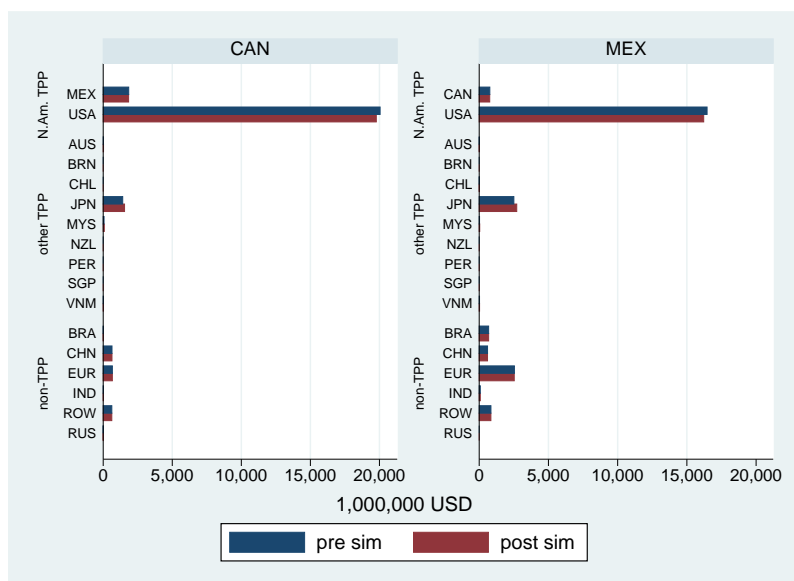
Figure 38. North American Firm Motor Vehicles and Parts Trade
Flows Pre- and Post-Sim
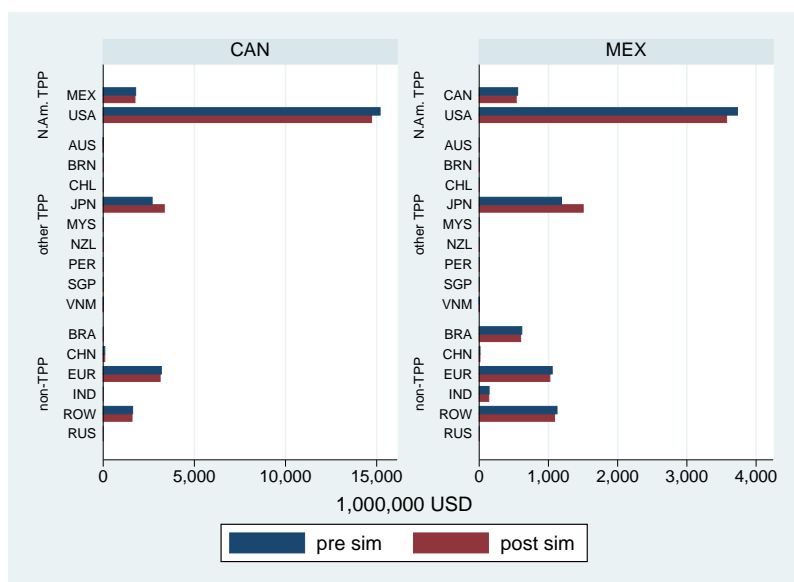
Source: Author's simulations.

Figure 39. North American Consumer Motor Vehicles and Parts
Trade Flows Pre- and Post-Sim

Source: Author's simulations.

trade partners.

   With the North American study, I show the effect of the TPP on supply chain

linkages between the Canadian, Mexican, and U.S. economies. For the Processed Food sector, Mexican-U.S. intermediates trade reroutes through Canada as the U.S. and Canadian sectors expand. For Motor Vehicles and Parts trade, intra- North American trade declines as the U.S. and Canadian sectors contract, with Japan increasing its market share in North American. Overall, the TPP strengthens North American ties as it feeds into expanding sectors while displacing intra-regional sourcing amongst contracting sectors.

8. Comparison: Standard GTAP vs GTAP-SC with Differentiated Tariffs

The incorporation of an MRIO-supportive framework into a model, such as in GTAP-SC model, entails the introduction of new cross-border linkages between exporting suppliers and importing agents. Such linkages are unobservable in the standard GTAP model. In this paper, I additionally introduce composite tariffs differentiated by agent. From the consumer and producer stories, we saw how these differences in composite tariff rates affected trade along these new linkages in GTAP-SC model. In this section, I show how these differences aggregate to the macro level.
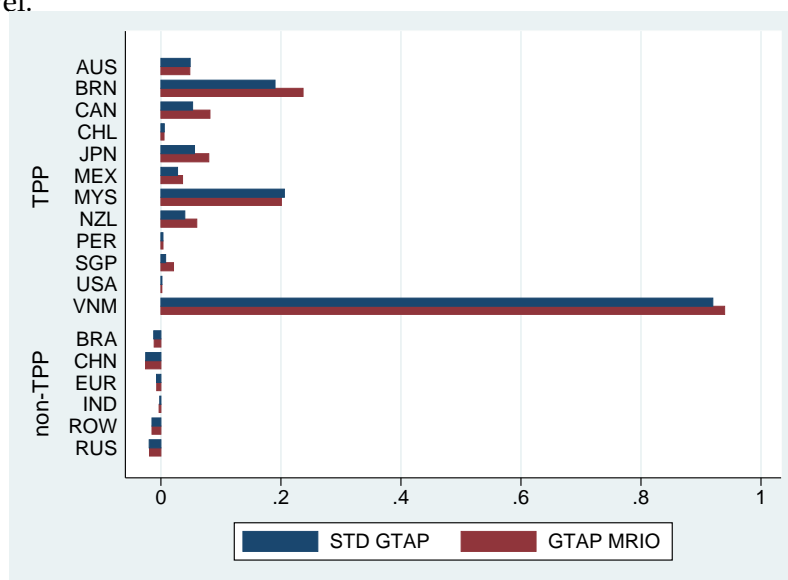

Figure 40. GTAP vs. GTAP-SC: Comparison of Real GDP

Source: Author's simulations.

In Figure 40, we observe changes in real gross domestic product (GDP) under both the standard GTAP framework and the GTAP-SC framework with differentiated composite tariffs. Overall, GDP effects are small, with Vietnam seeing the highest gains of around point nine percent. We can see that GDP gains in the GTAP-SC framework with differentiated composite tariffs tend to outpace those of the standard GTAP framework for TPP members. Predominantly, this is notice-

able for Brunei, Canada, Japan, Mexico, New Zealand, Singapore, and Vietnam. GDP of non-TPP regions declines under both scenarios.
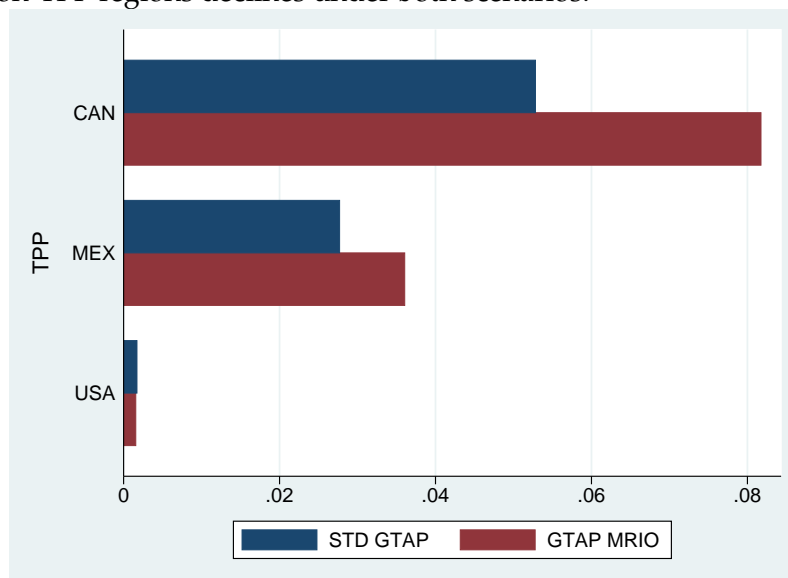

Figure 41. North America: Comparison of Real GDP

Source: Author's simulations.

In Figure 41, we observe the differences between frameworks in terms of real GDP gains for North American countries. For Canada and Mexico, we see increased gains under the GTAP-SC framework. However, for the U.S., we observe decreased gains under the GTAP-SC framework.

Focussing on the U.S., we observe in Figure 42 that the U.S. imports less uniformly across sectors under the GTAP-SC framework with differentiated tariffs, as compared with the standard GTAP framework. The exception would be imports of Leather Goods (LEA), Textiles (TEX), and Wearing Apparel (WAP), which increase slightly under the GTAP-SC framework.

Figure 43 compares production between the standard GTAP framework and the GTAP-SC framework with differentiated tariffs. We observe that for the expanding sectors of Agriculture and Natural Resources (AGN), Processed Foods (FOD), and Leather Goods (LEA), output changes differ. In particular, we see that output decreases in Agricultural and Natural Resources (AGN) and Processed Foods (FOD) in GTAP-SC compared with standard GTAP. With declines in U.S. output of Agricultural and Natural Resources (AGN) and Processed Foods (FOD), U.S. exports are lower in Agricultural and Natural Resources (AGN) and Processed Foods (FOD) under the GTAP-SC framework with differentiated tariffs as compared to the standard GTAP model (Figure 44). As the U.S. leather sector expands, U.S. Leather Goods (LEA) exports increase (Figures 43 and 44).

We can relate U.S. production expansion back to real GDP. Although the Leather
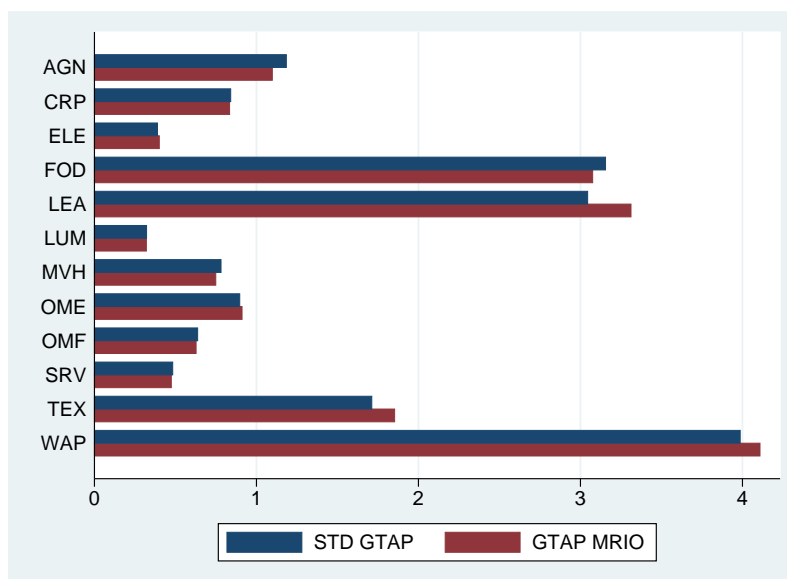
Figure 42. GTAP vs. GTAP-SC: U.S. Imports

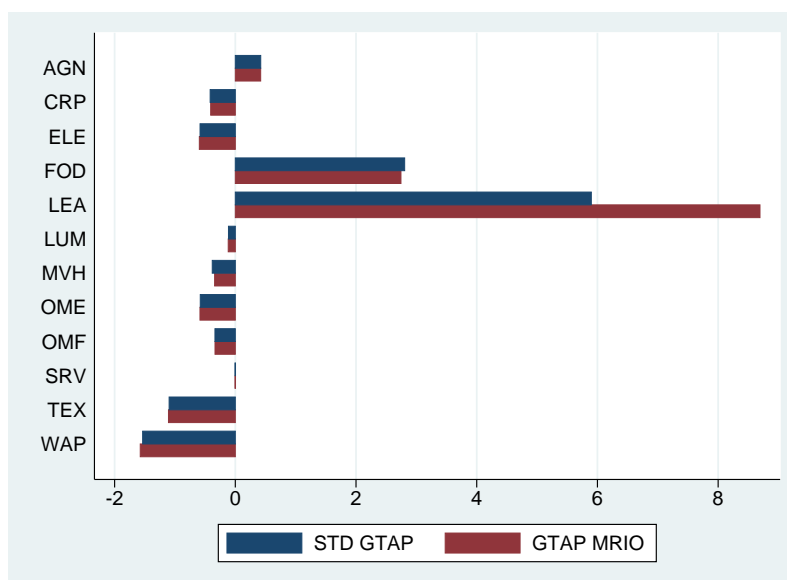*Source:* Author's simulations.

Figure 43. GTAP vs. GTAP-SC: U.S. Production

Source: Author's simulations.

sector expands, this is a relatively small sector compared to the Agriculture and Natural Resources sector or the Processed Food sector. For the U.S., the decreased gains in production in these sectors drive the overall decreased gains in U.S. real GDP.
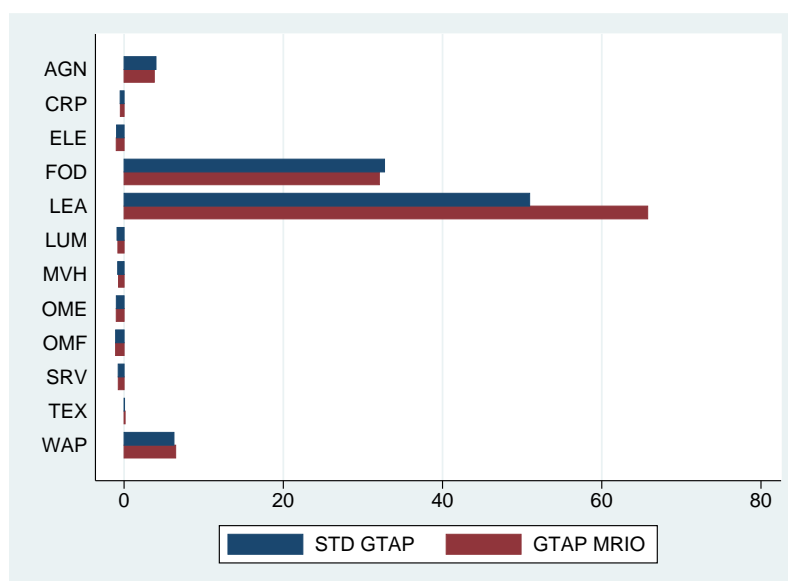
94

Figure 44. GTAP vs. GTAP-SC: U.S. Exports

Source: Author's simulations.

Overall, the differences between the standard GTAP framework and the GTAP-SC framework with differentiated tariffs can be traced back to (1) the introduction of cross-border linkages and (2) the differentiated tariffs. With the cross-border linkages in the GTAP-SC framework, sourcing flows are more established than in the standard model. The linkages from exporting supplier to importing agents are more direct and represent smaller flows in the GTAP-SC framework. In contrast, cross-border linkages only exist at the regional level in the standard GTAP framework and, accordingly, correspond to much larger trade flows. The more direct linkages with smaller flows in the GTAP-SC framework encourage trade along pre-established supply-linkages. Policies such as tariff-removal increase trade along pre-established flows, which benefits exporters such as we observed for many TPP members.

Through the incorporation of differentiated composite tariff rates into the GTAP-SC framework, I better capture tariff escalation, with firms often facing lower rates than consumers. In contrast, in the standard GTAP framework, firms and consumers face the same rate. Thus, under this new GTAP-SC framework with differentiated tariffs, firms face lower composite rates than in the standard GTAP framework. Under tariff-removal scenarios such as the one implemented in this paper, firm expansion through cheaper imported inputs is less in the GTAP-SC framework than in the standard GTAP model. This explains the relative decreases in gains for the U.S. under the GTAP-SC framework with differentiated tariffs as compared to the standard GTAP framework.

9. Comparison: Fully Proportional MRIO vs MRIO with Proportional Tariffs vs MRIO with Differentiated Tariffs

In this section, I further use the GTAP-SC framework to compare the results from simulations with three different MRIO databases: (1) an MRIO constructed proportionately (TOT PROP), (2) an MRIO constructed with trade flows differentiated by agent but with proportional tariffs across agents (PROP TARS), and (3) the new GTAP MRIO constructed with both trade flows and tariffs differentiated by agent (DIFF TAR). From these simulation comparisons, I demonstrate how the trade and tariff differentiation of the new GTAP MRIO database affect changes in macro results and trade flows after tariff removal. I compare broadly GDP across countries, and, subsequently, I focus on comparisons for the U.S. economy.
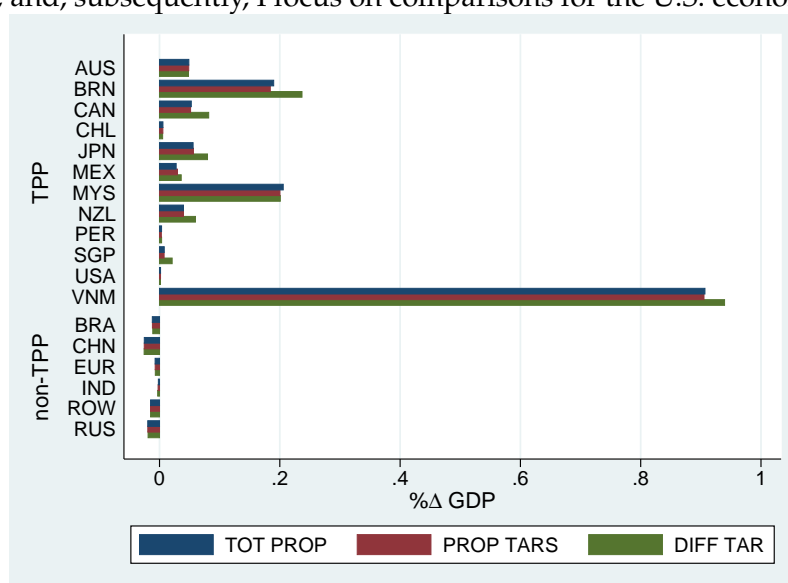

Figure 45. MRIO Comparison: GDP

Source: Author's simulations.

First, I consider changes in GDP across each simulation from each distinct database. In Figure 45, we can see that, broadly across several countries, the gains in GDP from the simulation implemented with the new GTAP MRIO (DIFF TAR) are higher than simulations implemented with either of the other two MRIO databases. The changes in GDP from simulations implemented with the totally proportionate MRIO (TOT PROP) and with differentiated trade but proportional tariffs (PROP TARS) are close in magnitude. The proximity of these GDP changes are due to the nature of the policy change being implemented, which is in this case a tariff removal. Because tariffs are proportional in both TOT PROP and PROP TARS databases, then the removal via simulation results in the same price changes on imported goods and, hence, the same economic responses. The slight differences between these two simulations reflect the differentiated trade flows in PROP TARS, which changes

the distribution of trade flows across importing firms, consumers, and investors. While all agents will face the same relative price changes in both simulations, the underlying trade flows affected will have a different magnitude and the quantity response may differ, as we will observe below.
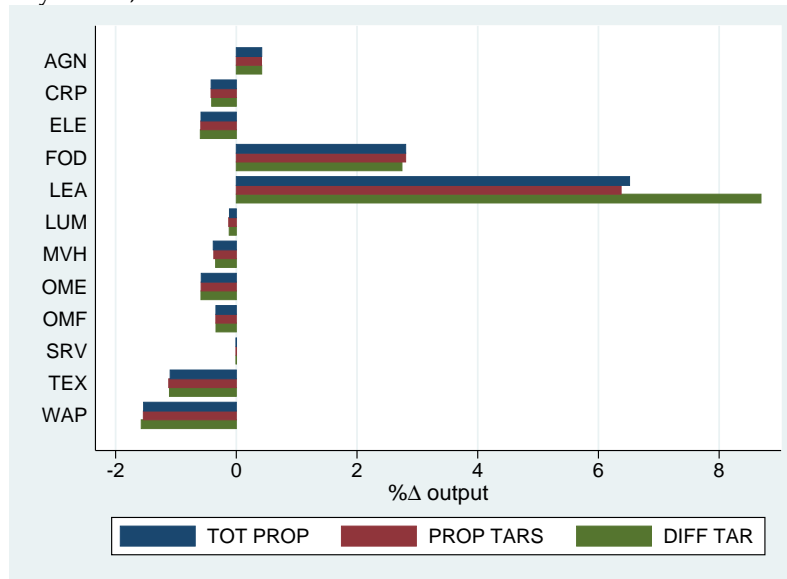

Figure 46. MRIO Comparison: U.S. Output

Source: Author's simulations.

In Figure 46, we observe differences in changes in output from production in the U.S. across sectors, between the three MRIO databases. Overall, changes in production between simulations with different databases remain close, with the exception of the Leather sector. Growth in output is relatively larger for the Leather sector in the simulation implemented with the GTAP MRIO (DIFF TAR) compared with either other MRIO database (TOT PROP or PROP TARS). This is because, with differentiated composite tariff rates in the GTAP MRIO, expansion in the U.S. Leather is driven by relatively lower import prices on intermediate inputs into production for certain source countries following a tariff removal.

Next, we compare changes in total imports of Wearing Apparel into the U.S., across all agents (Figure 47). We see that, overall, changes in U.S. imports are relatively uniform across simulations, though there are slight differences. Fore example, imports of wearing apparel to the U.S. from Japan is nearly nine percent higher in the simulation with the new GTAP MRIO as compared with either other MRIO database (TOT PROP or PROP TARS). This is explained by breakdown of consumer versus firm demands for Japanese imports of Wearing Apparel in the U.S., which are now differentially affected by the removal of tariffs. This will be further explored in the graphs below.

In Figure 48, we examine the differences in changes in U.S. imports of Wearing
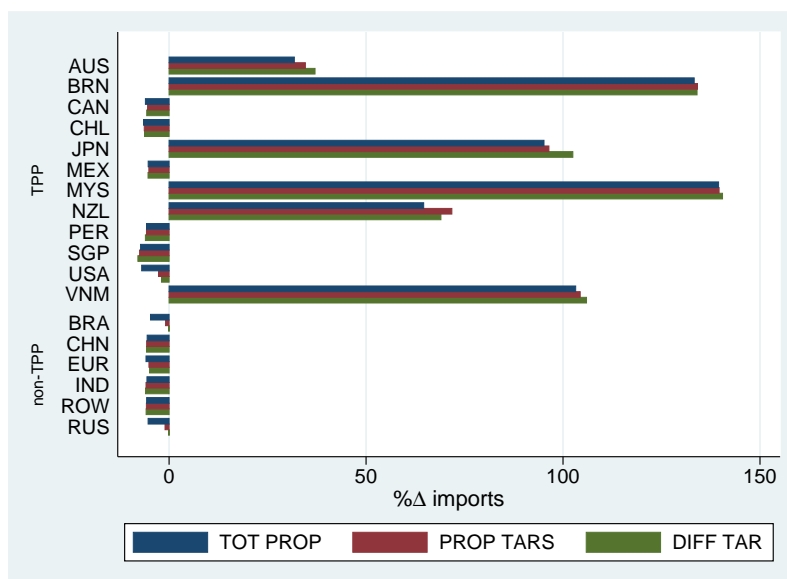
Figure 47. MRIO Comparison: U.S. Wearing Apparel Imports

Source: Author's simulations.

Figure 48. MRIO Comparison: U.S. Firm Wearing Apparel Imports

Source: Author's simulations.

Apparel by firms as intermediate inputs into production between simulations. We see the largest differences between simulations for changes in firm imports from Australia, Brunei, Japan, Malaysia, and Vietnam. For these countries, we see large import growth for simulations implemented with either MRIO with proportionate

tariffs (TOT PROP or PROP TARS), and, yet, small growth or even contraction for the simulation implemented with the new GTAP MRIO (DIFF TAR).

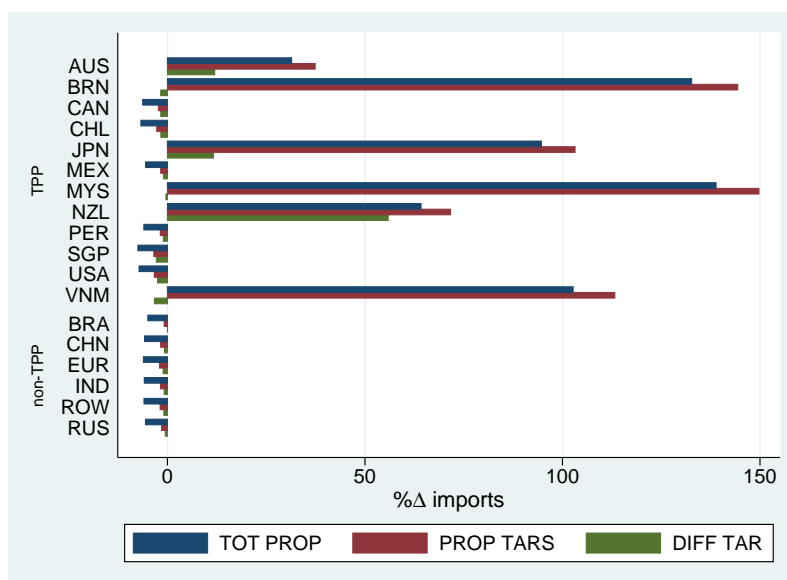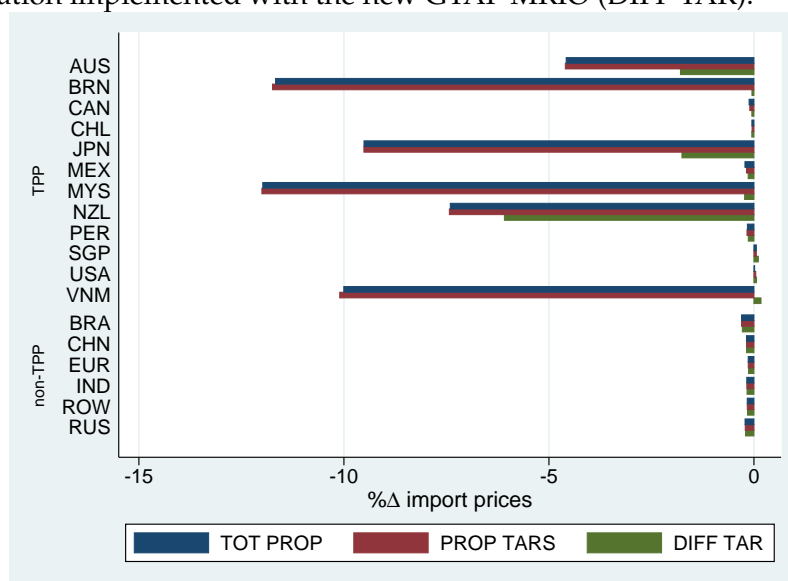**Figure 49.** MRIO Comparison: U.S. Firm Wearing Apparel Import Prices

Source: Author's simulations.

These observed differences in firm import demand among simulations can be explained by relative changes in import prices for intermediate inputs. In Figure 49, we visualize the changes in prices for intermediate inputs across simulations. We can observe that indeed, for Australia, Brunei, Japan, and Malaysia, prices decrease relatively less, whereas prices increase negligibly for Vietnam, after the tariff removal. The changes in prices from Australia, Brunei, Japan, and Malaysia are from the tariff removal, which is differentiated for the new GTAP MRIO (DIFF TAR). Specifically, firms in the GTAP MRIO now face relatively lower tariffs than consumers, and so firm tariffs are lower than under either MRIO framework which assumes that both consumers and firms face the same composite tariff rate. Resultantly, after the tariff removal, prices on imports from Australia, Brunei, Japan, and Malaysia decline less, and hence U.S. firms import relatively less, as discussed per Figure 48.

We can similarly consider changes in U.S. consumer imports of Wearing Apparel across simulations in Figure 50. Here, we see that differences in import growth for consumer goods are greatest for imports from Australia, Japan, and New Zealand. In particular, the growth in consumer demand for imports from these three countries is greatest for the simulation implementing the new GTAP MRIO (DIFF TAR) with differentiated composite tariffs, far exceeding the demand in either simulation with proportional tariffs. The increased U.S. consumer demand for imports of Japanese Wearing Apparel drives the overall increased demand for Japanese Wear-

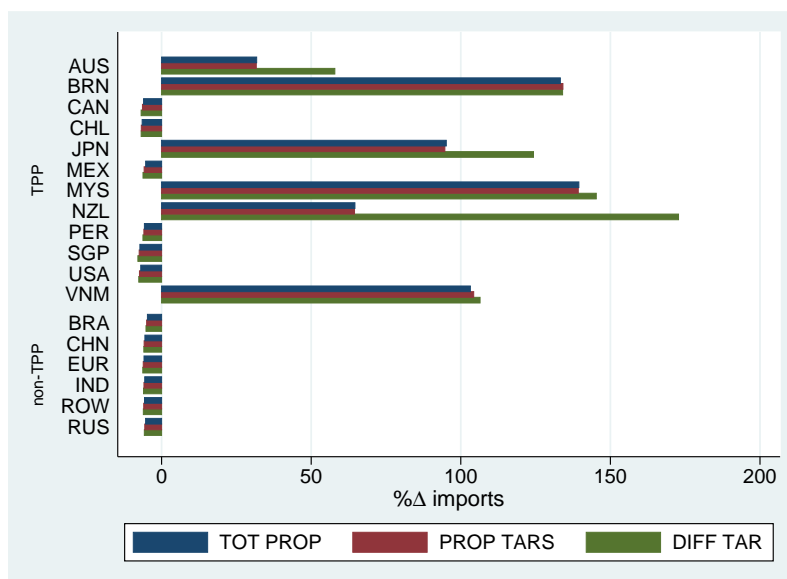**Figure 50.** MRIO Comparison: U.S. Consumer Wearing Apparel
Imports

Source: Author's simulations.

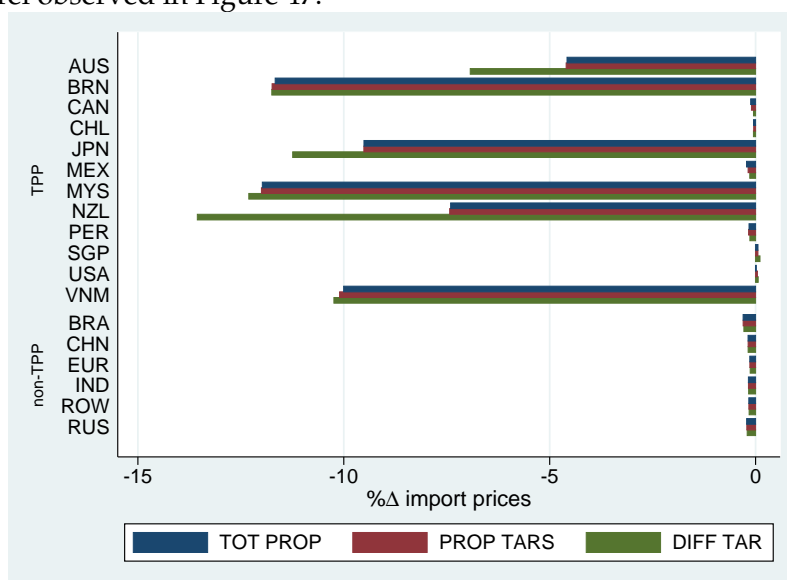ing Apparel observed in Figure 47.

Figure 51. MRIO Comparison: U.S. Consumer Wearing Apparel
Import Prices

Source: Author's simulations.

Again, the relative changes in consumer demand for imports across simulations
is linked to the relative changes in prices of consumer imports across simulations,

as seen in Figure 51. Here, we can see that the largest differences in price declines are observed for Australia, Japan, and New Zealand. Specifically, consumer import prices decline more for these three countries in the simulation implemented with the new GTAP MRIO (DIFF TAR) with differentiated composite tariffs, as compared with the simulation implemented with MRIO databases with proportional tariffs across agents (TOT PROP or PROP TARS). This is because consumer tariffs are higher than firm tariffs for Wearing Apparel in the GTAP MRIO and are, hence, higher than the composite rate faced by both firms and consumers in either other database with proportional rates.

Overall, implementing three MRIOs with successive complexity in computation and accuracy in the GTAP-SC model, we observe differences in changes of macro level indicators as well as trade flows. Only slight differences exist in simulation results with the MRIO with proportional trade and tariffs across agents (TOT PROP) and the MRIO with trade flows differentiated by agent but with proportional tariffs across agents (PROP TARS). The greatest differences are observed between the new GTAP MRIO constructed with both trade flows and tariffs differentiated by agent (DIFF TAR) and either other MRIO (TOT PROP or PROP TARS). These latter differences are greatest because of the effects of having differentiated composite rates on import price changes and, resultantly, on changes in import demands.

10. Conclusion

As global economic integration deepens, new databases are necessary to fully analyze the complexity of cross-border linkages. In this paper, I build upon prior MRIO frameworks, and I develop a new method to produce an MRIO which incorporates source- and agent-specific tariff revenues. For full replicability, I present the details and nuances of the new method. For robustness, I present in detail alternative methods, and I describe why the present method has been selected over each alternate.

Through the incorporation of source- and agent-specific tariff revenues, I not only improve MRIO the accuracy of database construction methods, but, further, I enhance the use of the MRIO for policy analysis by differentiating between composite tariff rates for firms and consumers. With graphical illustrations, I present an assessment of the resultant differentiated tariffs for five major global economies: the U.S., the E.U., Brazil, China, and India. I demonstrate the substantial diversity of composite tariff rates across commodity, by importing agent and source introduced in the GTAP MRIO. Further, I document the trend of higher composite tariff rates on imports for consumers in comparison with rates on imports for firms or investors across all economies and especially prevalent in emerging markets. Introducing tariff protection into the MRIO, I develop a more optimal framework for evaluating protectionism across economies. Future research will bring this method to full scale over the entire GTAP Database.

With the current framework presented in this paper, I develop a baseline for in-

corporating trade costs (specifically, tariff revenues) into MRIOs. Future research can build on this baseline to incorporate non-tariff trade costs through the incorporation of non-tariff measures (NTMs) as ad valorem equivalents (AVEs). Kee, Nicita, and Olarreaga (2009) estimate composite AVEs for NTMs. Through extension of the methods outlined in this paper, composite AVEs for NTMs could be estimated, allowing for the differentiation of NTMs across agents (e.g. firms versus consumers).

In this paper, I further demonstrate the novel utility of the new trade linkages and agent-specific composite tariff rates in the GTAP MRIO database for trade policy analysis in a CGE framework. I implement the GTAP MRIO within the GTAP Supply Chain model (Walmsley et al. 2014), a CGE model with direct cross-border linkages between producers and importing agents, in correspondence with the structure of the GTAP MRIO. I simulate a tariff removal in the spirit of TPP, and I examine effects on the importing consumer and exporting producer. With the new GTAP MRIO, consumers gain more from tariff removals than firms. However, firms can still gain, particularly from the expansion of foreign consumer markets.

I do two sorts of comparative analyses. First, I compare simulation results across models, implementing a TPP-style simulation in the standard GTAP model. Second, I compare simulation results across MRIO databases, running the same TPP style simulation in the GTAP Supply Chain model with an MRIO database with both trade and tariffs proportional across agents as well as an MRIO database with trade differentiated by agent but tariffs proportional across agents. These comparative analyses demonstrate the substantial differences in policy simulation obtained from the introduction of differentiated tariffs, including in macro results, aggregate, and agent-specific trade flows. Because the new GTAP MRIO differentiates composite tariff rates amongst agents, I find that consumer and firm gains (and losses) differ and aggregate to affect aggregate trade flows across importing agents.

These differential results in policy analysis from the introduction of tariff data into the MRIO underscore the relevance of this paper's contribution. I demonstrate that the incorporation of differentiated tariffs into the MRIO framework has a more substantial impact on policy analysis than the incorporation of differentiated trade flows via the HS-BEC-SNA concordance alone over the completely proportional MRIO. To be more explicit, the MRIO development which I introduce in this paper makes a more substantive contribution to expanding trade policy analysis than prior MRIO developments.

In the present paper, I only simulate the removal of tariff rates. Non-tariff trade costs could be accounted for through application of efficiency shocks in policy simulations. Baniya and Akgul (2016) examine infrastructure reforms within a CGE model of firm heterogeneity. They specifically look at the effect of improved quality of infrastructure on time costs. They implement the effects on time costs through shocks to efficiency parameters governing fixed costs of entry as well as variable costs of trade. In the GTAP-SC framework, decreases to non-tariff trade costs could

be implemented through efficiency parameters which affect effective prices of imports.

The incorporation of GVC linkages in the MRIO framework also draws attention to the need for improved elasticities. As aforementioned, in both the standard GTAP framework and the GTAP-SC framework, there are two elasticities which govern the producer's choice of supplier: σ_D and σ_M. Recall that σ_D denotes elasticity between domestic versus foreign inputs and σ_M denotes elasticity between sources. Properly modeling GVCs necessitates an update to these elasticities which were initially estimated around 2000.

While doubtless improving estimates for σ_D and σ_M should be a priority, this brings to question the necessity for two separate elasticities. The current structure of the GTAP-SC model is that the producer first chooses between domestic supply and foreign supply, as governed by σ_D, and subsequently chooses between foreign suppliers, as governed by σ_M. However, one might consider that in the globalized world of today that domestic competitors directly compete with foreign competitors. To reflect such a scenario, structural changes to the model would be necessitated such that the producer chooses simultaneously across all suppliers, both domestic and foreign, and a single elasticity would need to be estimated in a way that reflects this cross-border competition.

Indeed, Akgul et al. (2015) estimated supplier elasticities for the GTAP-HET model. The GTAP-HET model is an extension of the GTAP model which introduces firm heterogeneity for differentiated industries. For these industries, suppliers are differentiated by source-dependent variety such that domestic and foreign firms are direct competitors (Akgul et al. 2016). As such, Akgul et al. (2015) estimate a single elasticity of substitution, σ that governs producer behavior in supplier choice for differentiated industries. Indeed, they find this elasticity σ to be less than the Armington elasticity σ_M which does not account for firm-level behavior and resultantly comprise both demand-side and supply-side effects. Overall, the work by Akgul et al. (2015, 2016) is indicative of how changes in model structure and elasticities may more accurately depict the supplier choice of producers.

Further, the MRIO framework allows for agent-specific elasticities such that we could differentiate between elasticities for firms and consumers. I expect that firms are more sensitive (less flexible) to sources as they are embedded in pre-established cross-border production chains whereas households would be relatively less sensitive (more flexible) to product origins. Thus, I anticipate that such estimates of agent-specific elasticities may reveal households to have higher elasticities than firms.

Future research with the MRIO and GTAP-SC model will explore the propagation and amplification of trade costs. Cumulative effects could be studied through the elimination and reintroduction of tariffs. Similar studies could be performed for NTMs to analyze the accumulation of non-tariff trade costs. A comprehensive study would consider the elimination and reintroduction of both tariffs and NTMs.

In conclusion, the development an MRIO with differentiated tariffs serves as a point of departure for trade cost analysis in GVCs. The GTAP MRIO makes a positive step forward and importantly serves as a platform for not only GVC analysis but, further, as an integral input into the new wave of modeling frameworks which rely on direct cross-border supply-demand linkages, including the Firm Heterogeneity (Akgul et al. 2016) and Public Procurement (Aguiar et al. 2016) models.

References

Aguiar, A., C. Carrico, T. Hertel, Z. Hussein, R. McDougall, and B. Narayanan (2016). "Extending the GTAP framework for public procurement analysis." *GTAP Working Paper,* No. 82. Purdue University.

Akgul, Z., N. Villoria, and T. Hertel (2015). "Theoretically-Consistent Parameterization of a Multi-sector Global Model with Heterogeneous Firms." *GTAP Resource,* No. 4731. Purdue University.

Akgul, Z., N. Villoria, and T. Hertel (2016). "GTAP-HET: Introducing Firm Heterogeneity into the GTAP Model." *Journal of Global Economic Analysis,* 1(1): 111-180.

Baniya, S., Z. Akgul, and T. Hertel (2016). "Effects of Transportation Infrastructure Reforms on the Export Participation and Composition." *GTAP Resource,* No. 5042. Purdue University.

EORA (2017). "Eora26 MRIO Database." *http://www.worldmrio.com/.*

Francois, J., M. Manchin, and P. Tomberger (2014). "Explanatory note: Export of Value Added Database." *World Bank Open Data, Export Value Added Database.*

Global Affairs Canada (2017). "Minister Champagne Welcomes Progress on the Comprehensive and Progressive Trans-Pacific Partnership." *The Government of Canada, Global Affairs Canada, Media Relations Office*.

Hertel, T., Ed. (1997). Global Trade Analysis: Modeling and Applications. Cambridge University Press.

Johnson, R., and G. Noguera (2012). "Accounting for Intermediates: Production Sharing and Trade in Value Added." *Journal of International Economics,* 82(2): 224-36.

Kee, H., A. Nicita, and M. Olarreaga (2009). "Estimating trade restrictiveness indices." *Economic Journal,* 119: 172-199.

Koopman, R., W. Powers, Z. Wang, and S. Wei (2010). "Give Credit Where Credit Is Due: Tracing Value Added in Global Production Chains." *NBER Working Paper,* No. 16426.

Koopman, R., Z. Wang, and S. Wei (2012). "Tracing Value-Added and Double Counting in Gross Exports." *NBER Working Paper,* No. 18579.

Koopman, R., Z. Wang, and S. Wei (2014). "Tracing Value-Added and Double Counting in Gross Exports." *American Economic Review,* 104(2): 459-94.

Lenzen, M., D. Moran, K. Kanemoto, and A. Geschke (2013). "Building EORA: A Global Multi-Region Input-Output Database at High Country and Sector Resolution." *Economic Systems Research,* 25(1): 20-49.

McDougall, R. (1999). "Entropy Theory and RAS are Friends." *GTAP Working Paper,* No. 6. Purdue University.

Organisation for Economic Co-operation and Development (2015). "Trade Policy Implications of Global Value Chains." *Trade and Agriculture Directorate.*

Organisation for Economic Co-operation and Development (2016a). "Trade in Value Added (TiVA) - List of countries, economies and regions - 2016." *Directorate for Science, Technology and Innovation.*

Organisation for Economic Co-operation and Development (2016b). "Trade in Value Added (TiVA) - List of industries - 2016." *Directorate for Science, Technology and Innovation.*

Organisation for Economic Co-operation and Development (2017a). "Bilateral Trade in Goods by Industry and End-use Category." *Directorate for Science, Technology and Innovation.*

Organisation for Economic Co-operation and Development (2017b). "OECD Bilateral Trade Database by Industry and End-Use Category (BTDIXE)." *Directorate for Science, Technology and Innovation.*

Timmer, M., Ed. (2012). "The World Input-Output Database (WIOD): Contents, Sources and Methods." *WIOD Working Paper,* No. 10.

Timmer, M., E. Dietzenbacher, B. Los, R. Stehrer, and G. de Vries (2015). "An Illustrated User Guide to the World Input-Output Database: the Case of Global Automotive Production." *Review of International Economics,* 23: 575-605.

Timmer, M., B. Los, R. Stehrer, and G. de Vries (2016). "An Anatomy of the Global Trade Slowdown based on the WIOD 2016 Release." *GGDC research memorandum,* No. 162. University of Groningen.

Tsigas, M., Z. Wang, and M. Gehlhar (2012). "How a Global Inter-Country Input-Output Table with Processing Trade Account Can be constructed from GTAP Database." *GTAP Resource,* No. 3784. Purdue University.

United Nations Statistics Division (2003). "Classification by Broad Economic Categories." *Statistical Papers*, M(53)(4).

United Nations Statistics Division (2007). "BEC - HS2007 Concordance."

The U.S. Trade Representative (2017). "The United States Officially Withdraws from the Trans-Pacific Partnership." *Office of the United States Trade Representative, Press Office*.

Walmsley, T., T. Hertel, and D. Hummels (2014). "Developing a GTAP-Based MultiRegion, Input-Output Framework for Supply Chain Analysis." in Asia and Global Production Networks-Implications for Trade, Incomes and Economic Vulnerability. B. Ferrarini and D. Hummels (eds). Asian Development Bank and Edgar Elgar Publishing.

The White House (2017). "Presidential Memorandum Regarding Withdrawal of the United States from the Trans-Pacific Partnership Negotiations and Agreement." *The White House, Office of the Press Secretary, Presidential Memorandum*.

Appendix A. GAMS Code for First Optimization

Listing A.1. Optimization Procedure for $VIUMS_{iusr}$

```
1    Option Reslim=10000;
2    $oneolcom
3    $eolcom //

5    *inputting orignal data from aggregated GTAP Database Version 9.2 database

7    set USE /int, cgds, cons/;
8    alias (USE,u);
9    alias (u,uu);

11   $gdxin 'db92_TPP.gdx'
12   $LOAD
13   sets   PROD_COMM
14          REG ;
15   $load PROD_COMM REG
16   set    TRAD_COMM(PROD_COMM)
17   $load TRAD_COMM
18   alias (TRAD_COMM,i);
19   alias (PROD_COMM,j);
20   alias (REG,r)
21   alias (REG,s);
22   alias (s,ss);
23   alias (r,rx); //set to loop over countries
24   alias (i,ix); //set to loop over industries
25   set rs(r);   //subset to loop over countries
26   set is(i);   //subset to loop over industries
27   rs(r)=no;
28   is(i)=no;

30   parameter CVIMS(i,s,r); //imports of good i from country s into country r
31   $load CVIMS
32   parameter CVIGM(i,r); //imports of good i for intermediate GOV'T use in country
      r
33   $load CVIGM
34   parameter CVIPM(i,r); //imports of good i for intermediate private/HHLD use in
     country r
35   $load CVIPM
36   parameter CVIFM(i,j,r); //imports of good i for intermediate use in industry j
     in country r
37   $load CVIFM

39   *imports of good i for use u in sector j in country r
40   parameter VIM(i,u,r);
41   VIM(i,'int',r)=sum(ix,CVIFM(i,ix,r));
42   VIM(i,'cgds',r)=CVIFM(i,'cgds',r);
43   VIM(i,'cons',r)=CVIGM(i,r)+CVIPM(i,r);

45   *imports of good i from country s for intermediate use in sector j in country r

47   parameter VIMN(i,u,s,r)
48   /
49   $ondelim
50   $include 'VIMN_pre_gams_TPP.csv'
51   $offdelim
52   /;
```

```
53   VIMN(i,u,s,r)$(VIMN(i,u,s,r) eq 0)=1E-20; //set lower bound

55   *declaring new varibale where the "o" indicates that these are optimized values
     , as below
56   variables VIMO(i,u,s,r),a,z(i,r);
57   VIMO.lo(i,u,s,r) = 1E-20; //set lower bound
58   VIMO.l(i,u,s,r) = vimn(i,u,s,r); //initiate optimized values to data so as to
     give program "first" guess to work with

60   *system of equation to minimize differences between input values and optimized
     values subject to constraints
61   equations obj,cons_sect,cons_srce;

63   *objective function
64   obj..        sum((i,r)$(is(i) and rs(r)),
65                sum((u,s),
66                (VIMO(i,u,s,r)
67                *log(
68                VIMO(i,u,s,r)/VIMN(i,u,s,r)
69                )
70                )
71                ))=e=a;

73   cons_sect(i,u,r)$(rs(r) and is(i)).. sum(s,VIMO(i,u,s,r))=e=VIM(i,u,r);

75   cons_srce(i,s,r)$(rs(r) and is(i)).. sum(u,VIMO(i,u,s,r))=e=CVIMS(i,s,r);

77   model opt/obj, cons_sect, cons_srce/;

79   opt.holdfixed = 1 ;

81   parameter VIMOO(i,u,s,r);

83   *loop over each destination country rx and commodity ix
84   loop((ix,rx),

86   rs(rx)=yes;
87   is(ix)=yes;

89   VIM(ix,u,rx) = VIM(ix,u,rx)*sum(ss, CVIMS(ix,ss,rx)$(sum(uu,VIMN(ix,uu,ss,rx))
     gt 0))
90   /sum(uu,VIM(ix,uu,rx)$(sum(ss,VIMN(ix,uu,ss,rx)) gt 0)) ;

92   VIMO.fx(ix,u,s,rx)$(VIMN(ix,u,s,rx) eq 0) = 0 ;

94   Option decimals=8 ;

96   solve opt using nlp minimizing a;

98   VIMOO(ix,u,s,rx)=VIMO.l(ix,u,s,rx); //save model output

100  rs(rx)=no;
101  is(ix)=no;
102  );

104  execute_unload 'VIMO_byUSE_TPP.gdx';
105  execute 'gdx2har VIMO_byUSE_TPP.gdx VIMO_byUSE_TPP.har > VIMO_byUSE_TPP.log';
```

Appendix B. GAMS Code for Second Optimization

Listing B.1. Optimization Procedure for $VIUWS_{iusr}$

```
1   $oneolcom
2   $eolcom //
3   option dnlp=conopt;
4   option nlp=conopt;

6   set USE /int, cgds, cons/;
7   alias (USE,u);
8   alias (u,uu);

10  $gdxin 'db92_TPP.gdx'
11  $LOAD

13  sets   PROD_COMM
14         REG ;
15  $load PROD_COMM REG
16  set    TRAD_COMM(PROD_COMM) ;
17  $load TRAD_COMM
18  alias (TRAD_COMM,i);
19  alias (PROD_COMM,k);
20  alias (REG,r);
21  alias (REG,s);
22  alias (r,rx); //set to loop over destinations
23  alias (s,sx); //set to loop over sources
24  alias (i,ix); //set to loop over industries
25  set ss(s);   //subset to loop over sources
26  set rs(r);   //subset to loop over destinations
27  set is(i);   //subset to loop over industries
28  rs(r)=no;
29  is(i)=no;

31  parameter CVIWS(i,s,r);
32  $load CVIWS
33  parameter VIWS(i,s,r);
34  VIWS(i,s,r)=CVIWS(i,s,r);

36  parameter CVIMS(i,s,r);
37  $load CVIMS
38  parameter VIMS(i,s,r);
39  VIMS(i,s,r)=CVIMS(i,s,r);


42  $gdxin 'VIMO_byUSE_TPP.gdx'
43  $LOAD

45  *imports of good i from country s for use u in sector j in country r
46  parameter VIMOO(i,u,s,r);
47  $load VIMOO

49  parameter VIUMS(i,u,s,r);
50  VIUMS(i,u,s,r)=VIMOO(i,u,s,r);
51  VIUMS(i,u,s,r)$(VIUMS(i,u,s,r) lt 1E-20)=1E-20; //set lower bound

53  parameter VIMN(i,u,s,r)
54  /
55  $ondelim
```

```
56   $include 'VIMN_pre_gams_TPP.csv'
57   $offdelim
58   /;
59   VIMN(i,u,s,r)$(VIMN(i,u,s,r) lt 1E-20)=1E-20; //set lower bound

61   parameter VIWN(i,u,s,r)
62   /
63   $ondelim
64   $include 'VIWN_pre_gams_TPP.csv'
65   $offdelim
66   /;

68   *imports of good i from country s for intermediate use in sector j in country r
69   parameter VIUWS(i,u,s,r);
70   VIUWS(i,u,s,r)=VIUMS(i,u,s,r)*(VIWN(i,u,s,r)/VIMN(i,u,s,r));
71   VIUWS(i,u,s,r)$(VIUWS(i,u,s,r) lt 1E-20)=1E-20; //set lower bound


74   *declaring new varibales where the "o" indicates that these are optimized
     values, as below
75   variables VIUWSO(i,u,s,r),a;
76   VIUWSO.lo(i,u,s,r) = 1E-20; //set lower bound
77   VIUWSO.l(i,u,s,r) = VIUWS(i,u,s,r); //initiate optimized values to data so as
     to give program "first" guess to work with

79   *system of equation to minimize differences between input values and optimized
     values subject to constraints
80   equations obj,cons_tar,cons_srce;

82   obj..        sum((i,r,s)$(is(i) and rs(r) and s(s)),
83                sum((u),
84                abs(
85                (VIUWSO(i,u,s,r)
86                *log(
87                VIUWSO(i,u,s,r)/VIUWS(i,u,s,r)
88                )))))=e=a;

90   *tariff constraint
91   cons_tar(i,u,s,r)$(rs(r) and is(i) and s(s)).. VIUWSO(i,u,s,r)=l=VIUMS(i,u,s,r)
     ;

93   *sourcing constraint
94   cons_srce(i,s,r)$(rs(r) and is(i) and s(s)).. sum(u,VIUWSO(i,u,s,r))=e=VIWS(i,s
     ,r);

96   model opt/obj, cons_tar, cons_srce/;

98   opt.holdfixed = 1 ; //don't need superflous equations in model

100  parameter    VIUWSf(i,u,s,r);

102  *loop over each source country sx, destination country rx, and commodity ix
103  loop((sx,ix,rx),

105  ss(sx)=yes;
106  rs(rx)=yes;
107  is(ix)=yes;

109  Option decimals=8 ;
```

```
111   solve opt using dnlp minimizing a;

113   VIUWSf(ix,u,sx,rx)=VIUWSO.l(ix,u,sx,rx);

115   ss(sx)=no;
116   rs(rx)=no;
117   is(ix)=no;
118   );

120   execute_unload 'VIUWSf_TPP.gdx';
121   execute 'gdx2har VIUWSf_TPP.gdx VIUWSf_TPP.har > VIUWSf_TPP.log';
```