Journal of Global Economic Analysis, Volume 6 (2021), No. 1, pp. 82-127.

Disaggregating the Vegetables, Fruits and Nuts Sector to the Tariff Line in the GTAP-HS Framework

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Computable general equilibrium (CGE) models provide valuable insights into economy-wide and aggregate sectoral impacts of trade policies. However, when it comes to the assessment of specific interventions, the level of aggregation in these models is often deemed too coarse to inform negotiations. For example, in the Global Trade Analysis Project (GTAP) Data Base, all vegetables, fruits and nuts – over hundred individual commodities – are represented under one sector. Analysis at the tariff line level is typically provided by partial equilibrium (PE) models, which cannot, however, capture economy-wide effects. In this paper, we contribute to the development of the GTAP-HS framework, which comprises disaggregated values of output, trade flows and domestic absorption with supporting model components nested within the standard GTAP GE model. We construct the GTAP-HS database with GTAP vegetables, fruits and nuts sector disaggregated into 79 commodities. We apply this modelling framework to the assessment of the ongoing trade frictions between the United States and its trading partners. We find that there are significant advantages to using this nested approach to trade policy analysis, including possibilities of the trade policies assessment at the tariff line, representation of the commodity-specific substitution and avoidance of the 'false competition' critique.

JEL codes: C68, D58, F17, Q17.

Keywords: GTAP data base; Vegetables, fruits and nuts disaggregation; Tariff line; Computable general equilibrium modelling; Trade retaliation.

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1. Introduction

Computable general equilibrium (CGE) models have become a widespread method to capture the economy-wide and sectoral impacts of agricultural trade policies (Fontagné et al., 2013; Francois et al., 2013; Egger et al., 2015; Beckman and Arita, 2016; Taheripour and Tyner, 2018; Chepeliev et al., 2018). However, when it comes to the assessment of specific interventions, the level of aggregation in these models is often deemed too coarse to inform negotiations. This is particularly true in the case of sectors where protection levels and characteristics vary dramatically across commodities (Narayanan et al., 2010). For example, in the Global Trade Analysis Project (GTAP) database used with many CGE models (Aguiar et al., 2019b), all vegetables, fruits and nuts are represented under one sector. However, in reality, this sector covers more than one hundred tariff lines, each with potentially different changes in trade policies. Another problem with aggregation stems from the fact that there exist huge variations in tariff rates across different tariff lines for many commodities, along with variations in 'tariff rate quotas' (TRQs) (Grant et al., 2007), differences that are averaged out within an aggregated sector.

In addition to the tariff variation, each commodity within an aggregate sector has different level of import penetration, therefore even if all commodities within an aggregate sector face uniform tariff rates, policy impacts could differ across individual tariff lines. Heterogeneity in policy impacts at the tariff line level could be further accentuated by commodity-specific substitution possibilities. For instance, according to Fontagné et al. (2019), elasticities of substitution between different import suppliers may vary from 1.5 to 38.5 for different commodities within vegetables, fruits and nuts sector.[1] Finally, sectoral analysis in CGE models may result in 'false competition'. For example, two countries can potentially face no direct competition at the disaggregated commodity level (i.e., they ship different products to the same market – e.g., apples and oranges), but at an aggregate level, they may appear to be competitors, since they each send products within the broader sector aggregate (vegetables, fruits and nuts) to the same market.

Analysis at the individual commodity or harmonized system (HS) classification level is something that is typically provided by partial equilibrium (PE) models (e.g., Zheng et al., 2018). However, PE models deprive analysts of the benefits of an economy-wide perspective, which is required to examine the overall impacts of a broad-based trade policy, including impacts on factors of production, welfare and GDP. To overcome such limitations, a number of studies have employed a hybrid framework. In particular, Grant et al. (2007) link GTAPinGAMS

[1] Trade elasticity of 38.5 is reported by Fontagne et al. (2019) for the case of cherries.

(Rutherford, 2005) with a sub-sector PE model to conduct an analysis of trade policies in the dairy sector. Inspired by the Grant et al. work, Narayanan et al. (2010) modify the standard GTAP CGE model (Hertel, 1997) by disaggregating automotive trade and apply it to the analysis of multi-lateral tariff liberalization for the Indian automotive industry. In this paper, we refer to these hybrid models within the GTAP family as GTAP-HS where the HS stands for "Harmonized System" to denote modeling at, or close to, the individual tariff line. Aguiar et al. (2019a) further generalize the GTAP-HS modelling and data processing approach developed in Narayanan et al. (2010) and resync it with the GTAP v7 model (Corong et al., 2017). All these studies show that the GTAP-HS modelling framework, while largely relying on the theory of the standard GTAP model, is more flexible than the standalone GTAP applications in terms of providing more heterogeneous results for trade policy applications.

However, the high level of commodity detail provided by the GTAP-HS framework comes at a cost, with information needed for disaggregated input data, including bilateral trade flows, protection rates, domestic output and demand values – all identified at the tariff line level (or level of commodity disaggregation if it differs from the tariff line level).

Existing studies use different approaches to construct the databases underlying GTAP-HS. While bilateral trade flows and protection rates are readily available at the tariff line level (ITC, 2018), this is not the case for the values of domestic output and demand. To estimate these values, Grant et al. (2007) use constrained optimization to minimize deviations at the aggregate sectoral level, given disaggregated trade data. Narayanan et al. (2010) and Aguiar et al. (2019a) assume a uniform ratio of the domestic consumption to imports within the disaggregate sector.[2] Both of these approaches are inherently *ad hoc*, and therefore potentially misleading in the context of highly heterogeneous commodities as within the vegetables, fruits and nuts sector.

Introduction of the disaggregated trade, output and domestic consumption flows in the GTAP-HS framework also requires additional consumption and production structures specified via constant elasticities of substitution (CES) and constant elasticities of transformation (CET) functions. These include elasticities of transformation between disaggregated commodities supplied by an aggregate GTAP sector, substitution between different import suppliers at the disaggregate level, substitution between domestic and imported commodities at the disaggregate level, as well as substitution within domestic absorption at the disaggregate commodity level.[3] Assumptions of uniformity in elasticities across disaggregated commodities have generally been applied in the earlier studies

[2] Domestic consumption is defined as output minus exports.

[3] Domestic absorption is defined as output plus imports minus exports.

(Grant et al., (2007); Narayanan et al., (2010); Aguiar et al., (2019a)). This is clearly another important limitation.

In this paper, we contribute to the development of the GTAP-HS framework in the following ways. First, we construct the GTAP-HS database with GTAP vegetables, fruits and nuts sector disaggregated into 79 commodities. In doing so, we rely on the Food and Agricultural Organization (FAO) data (FAO, 2018), which allow us to explicitly estimate the value of output and domestic absorption at the disaggregate commodity level. This approach can be applied to the disaggregation of other food and agricultural sectors in the GTAP Data Base. Second, to capture the heterogeneity in substitution possibilities among different import supplies at the disaggregate commodity level, newly available HS6 level elasticity estimates (Fontagné et al., 2019) are introduced to the GTAP-HS modelling framework. Finally, we apply the developed modelling framework to the assessment of the ongoing trade frictions between the United States and its trading partners with a specific focus on vegetables, fruits and nuts sector. We compare simulation results between GTAP and GTAP-HS frameworks and seek to explain the sources of significant differences in the estimated impacts of trade policy changes.

The rest of the paper is organized as follows. Section 2 provides an overview of the GTAP-HS modelling framework. This section also discusses the construction of the GTAP-HS database and introduces HS6 level import elasticities to the GTAP-HS framework. Section 3 discusses policy scenarios under consideration. In Section 4, we provide an overview of U.S. trade in vegetables, fruits and nuts. In Section 5, we use the GTAP-HS framework to analyze impact of the retaliatory tariffs imposed on vegetables, fruits and nuts within the ongoing trade frictions between the United States and its trading partners. Decomposition of differences between standard GTAP and GTAP-HS modelling approaches is also discussed in this Section. Section 6 discusses assumptions and limitations of the approach. Finally, Section 7 concludes.

2. GTAP-HS model and database

We extend the GTAP-HS modelling and data processing approach developed in Narayanan et al. (2010) and further generalized for the GTAP v7 model (Corong et al. 2017) in Aguiar et al. (2019a).[4] The general idea is that each sector produces multiple products. While the production sector definition follows the CGE model aggregation, commodities are defined at the level of individual tariff lines. These commodities are consumed domestically and traded internationally, allowing for trade policies to operate differentially across tariff lines. Demands for these goods by domestic firms, government and private consumption are modeled in a two-

[4] Appendix A lists GTAP-HS sets, parameters, variables and equations introduced into the GTAP v7 model (Corong et al., 2017), as well as a mapping from GTAP-HS to Narayanan et al. (2010) model components.

stage process, with individual commodities first substituting for one another at the tariff line level. They then enter the aggregate CGE model consumption category.

For the disaggregation of GTAP fruits, vegetables and nuts sector into 79 commodities, we benefit from the FAO statistical data on quantities, prices and values of output and trade (total country exports and imports). We further develop an approach to the reconciliation of the output, trade and domestic consumption values from different datasets (GTAP, UN and FAO). The specification of substitution possibilities at the tariff line level is based on the HS6 level import substitution elasticities estimated by Fontagné et al. (2019).

2.1. GTAP-HS model

We start from key quantity and price linkages in the GTAP-HS model, using disaggregated vegetables, fruits and nuts sector for illustration. The model captures international trade, domestic consumption and output in vegetables, fruits and nuts at the HS6 level, using constant elasticity of transformation (CET) and constant elasticity of substitution (CES) structures, market clearing conditions and price linkages (Narayanan et al., 2010; Aguiar et al., 2019a).[5] The supply of the aggregated vegetables, fruit and nuts (VFN) commodity in region *s* within the GE model ($QC_{VFN,s}$) is transformed into commodities at the HS6 level ($QCK_{k,s}$), indexed by *k*, using CET function, governed by transformation parameter $\varepsilon_{VFN}<0$ (Figure 1). Part of the total quantity $QCK_{k,s}$ is allocated to the domestic market ($QDSK_{k,s}$), while the rest is supplied to the export markets and shipped to various destinations, indexed by *d* ($QXSK_{k,s,d}$). Price of commodity k, $PDSK_{k,s}$ (Figure 2), is determined by market clearing condition (Figure 1).

Each region *d* imports commodity *k* from various source regions, denoted by *s*. Specification of trade at the HS6 level is similar to the one in the standard GTAP model and employs a two-level Armington structure. First, bilateral trade quantities $QXSK_{k,s,d}$ are aggregated into imported bundle $QMSK_{k,d}$ using CES function with parameter $\sigma_{M,k}>0$. Then, imported bundle $QMSK_{k,d}$ and domestically produced $QDSK_{k,d}$ are aggregated into domestically absorbed bundle $QDMBK_{k,d}$ using CES function with parameter $\sigma_{D,k}>0$. This two-level structure at the HS6 level is the key feature of this model as it allows imports and domestic goods compete at the disaggregated level and avoid (1) false competition discussed above, and (2) mis-estimation of changes in welfare due to uneven tariff structures within the aggregated sector (Narayanan et al., 2010). Finally, $QDMBK_{k,d}$ at the HS6 level are aggregated into $QDMB_{VFN,d}$, domestically absorbed vegetables, fruits and nuts GE category, using CES function with parameter $\sigma_{VFN}>0$. For more details on the GTAP-HS model an interested reader is referred to Appendix A and Narayanan et al. (2010).

[5] Considering data limitations, a more aggregate commodity categories (relative to the HS6 level) are used for the policy analysis. A detailed discussion is provided in Section 2.2.

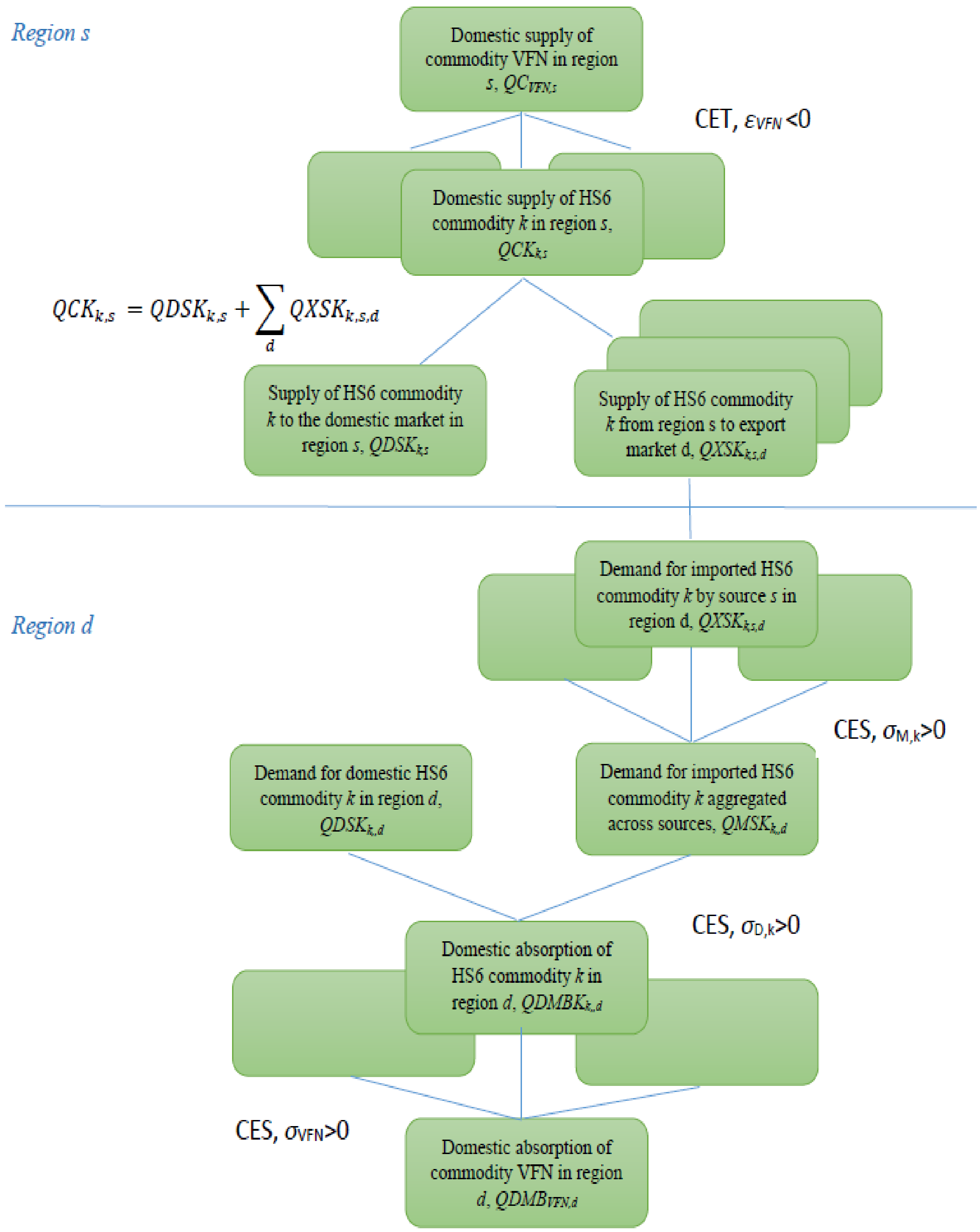

Figure 1. Quantity linkages in the GTAP-HS model.

Source: Developed by authors.

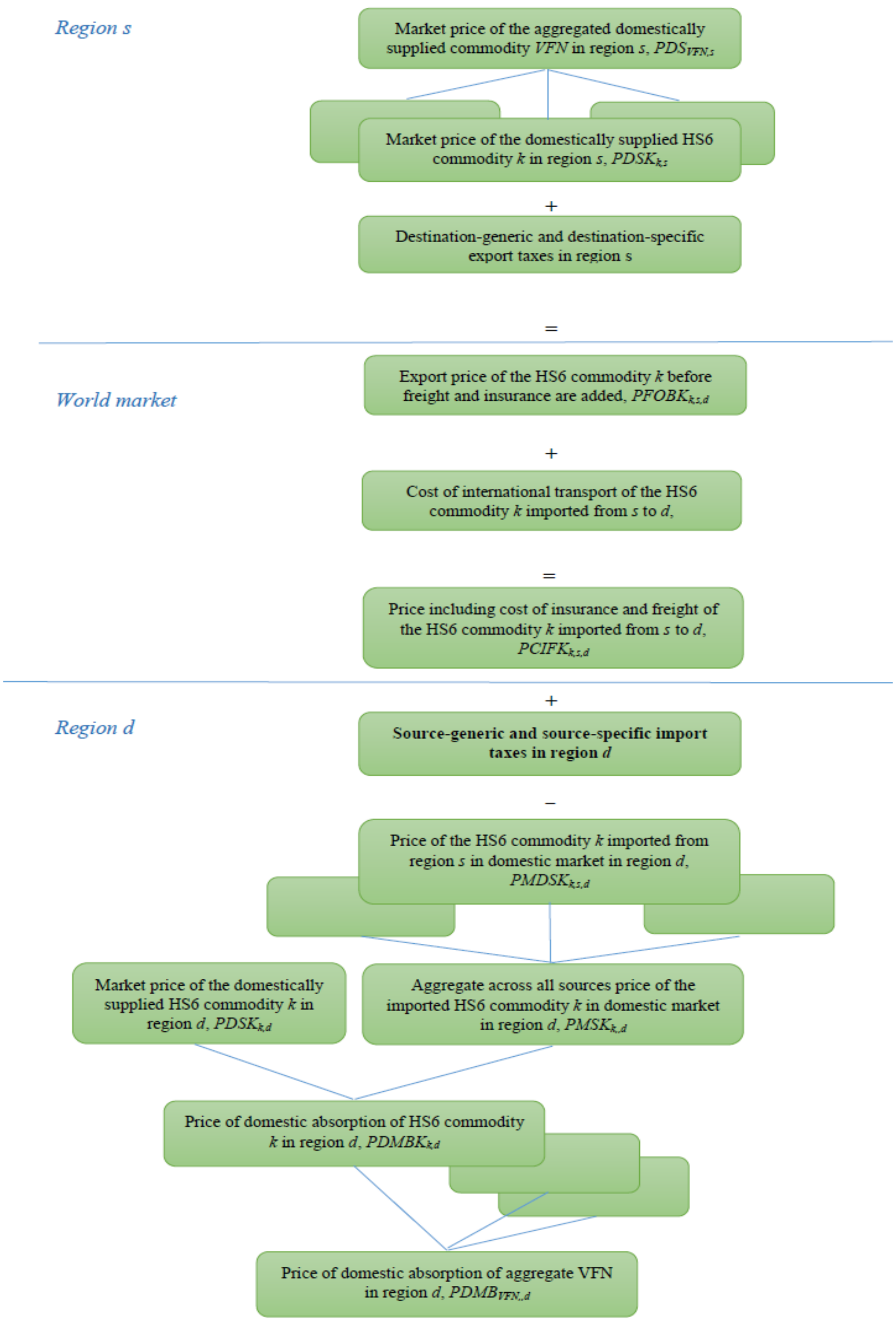

Figure 2. Price linkages in the GTAP-HS model.

Source: Developed by authors.

2.2. GTAP-HS database

Construction of the GTAP-HS database requires information on the bilateral imports, protection rates, domestic output value and domestic absorption at the detailed commodity level. Due to the lack of available data, previous studies relied on the trade data only to provide such disaggregation (Grant et al., 2007; Narayanan et al., 2010). At the same time, adequate representation of domestic output value and domestic absorption at the disaggregate commodity level is a crucial component of the GTAP-HS modelling framework. Misrepresentation of these data could potentially lead to misleading simulation outcomes.

To address this issue, we use the Food and Agricultural Organization (FAO) statistical data on the values, quantities and prices of output, and quantities and values of total country exports and imports of 93 vegetables, fruits, nuts at the country level (FAO, 2018). We further develop an approach to the reconciliation of the output, trade and domestic consumption values from different sources (GTAP, ITC and FAO). Using FAOSTAT dataset (FAO, 2018) we estimate value of exports and output for 93 vegetables, fruits and nuts. Appendix B (column 5) provides the list of the vegetables, fruits and nuts reported by the FAO. Figure 3 provides an overview of the FAO dataset processing steps.[6]

On the ***first step***, we source agricultural output values and quantities from the FAOSTAT dataset (FAO, 2018) and map them to the GTAP countries.

In some cases, FAO dataset reports quantities of output or exports, but does not report corresponding values. To estimate corresponding values, on the ***second step,*** we first estimate the commodity prices for 93 vegetables, fruits and nuts by countries. We then multiply commodity prices by quantities to estimate values of output or exports in such cases. In cases when FAO does not report commodity prices, we use different approaches discussed below to estimate them, depending on data availability.

To gap-fill prices of the agricultural commodities we additionally source the FAOSTAT trade quantities and values. FAO trade data are provided in the FCL (FAOSTAT commodity list) classification. We use correspondence tables between CPC 2.1 and FCL classifications for data mapping (FAO, 2017). Figure 4 provides and overview of the country/commodity price estimation and gap-filling steps.

For each country and commodity, we estimate prices using trade quantities and values. If both exports and imports data are available for specific country-commodity case, we estimate quantity-weighted average price. In cases, when only exports or imports data are available, price estimate is based on the corresponding trade flow. To filter the potentially unreliable price estimates we put a lower bound on the trade values and quantities of 0.1 mn USD and 0.1 tons

[6] Additional details on FAO data processing, as well as discussion with comparisons between FAO and GTAP agricultural output values can be found in Chepeliev (2020).

respectively. If either value or quantity is below this threshold, we do not use such data for price estimates.

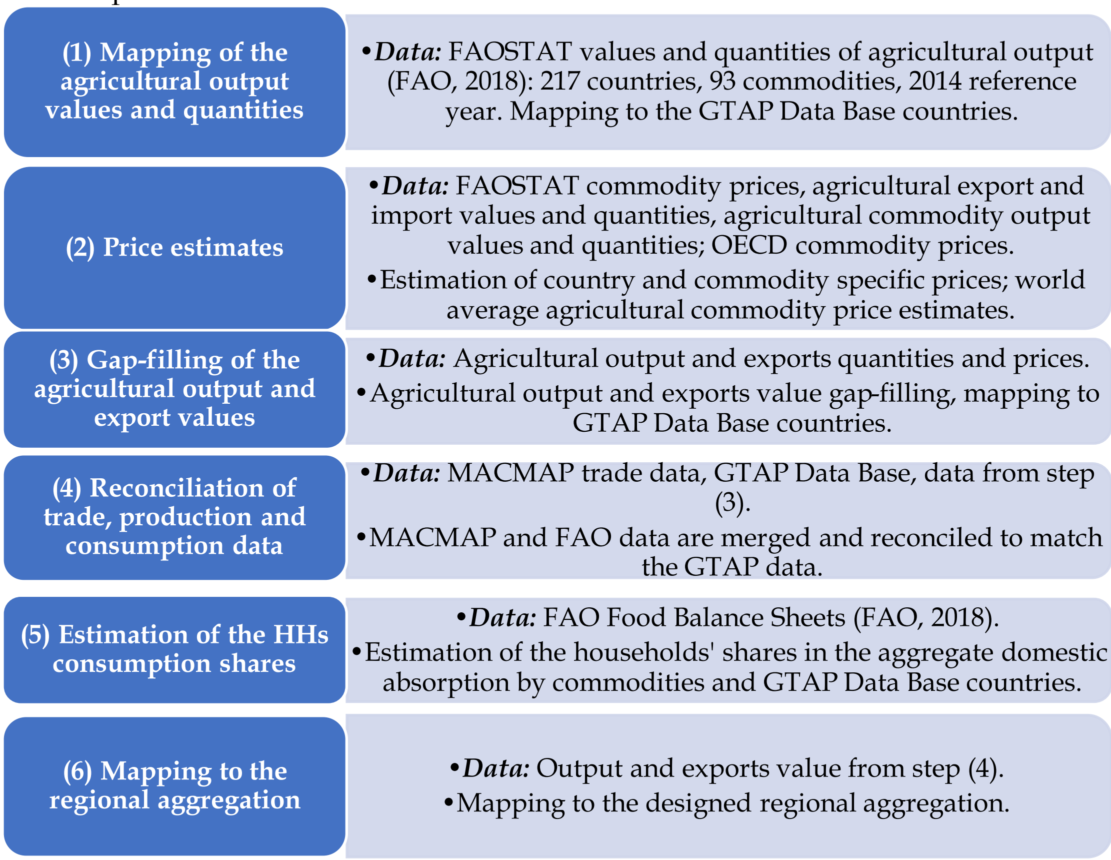

Figure 3. FAO dataset processing steps.

Source: Developed by authors.

We further gap-fill cases with unavailable prices using commodity-specific world average price estimates. First, we identify country-commodity cases with available prices and quantities to estimate quantity-weighted commodity-specific world average prices. If quantity data are not available, simple average commodity-specific price is estimated. On the next step, we gap-fill prices using commodity-specific output quantities and values. We divide world aggregate commodity output value by corresponding quantity (only country cases with available output value and quantity data are used). Finally, we use trade data to estimate commodity-specific world average prices and provide additional gap-filling. Weighted average world prices are estimated using quantities of exports and imports as weights.

After Steps 1-3 in Figure 4, there are still some cases with available output or export quantities, but unavailable prices. In such cases, we assume that commodities with unavailable prices can be mapped to specific commodities with available prices (similar commodities). Appendix C provides a mapping for such cases. We assume that commodities with unavailable prices are priced at the same level as commodities with available prices. To convert from export (FOB) and import (CIF) prices to the basic prices, we use basic/CIF and basic/FOB price ratios from the GTAP Data Base – an average for the "Vegetables, fruit and nuts" sector.

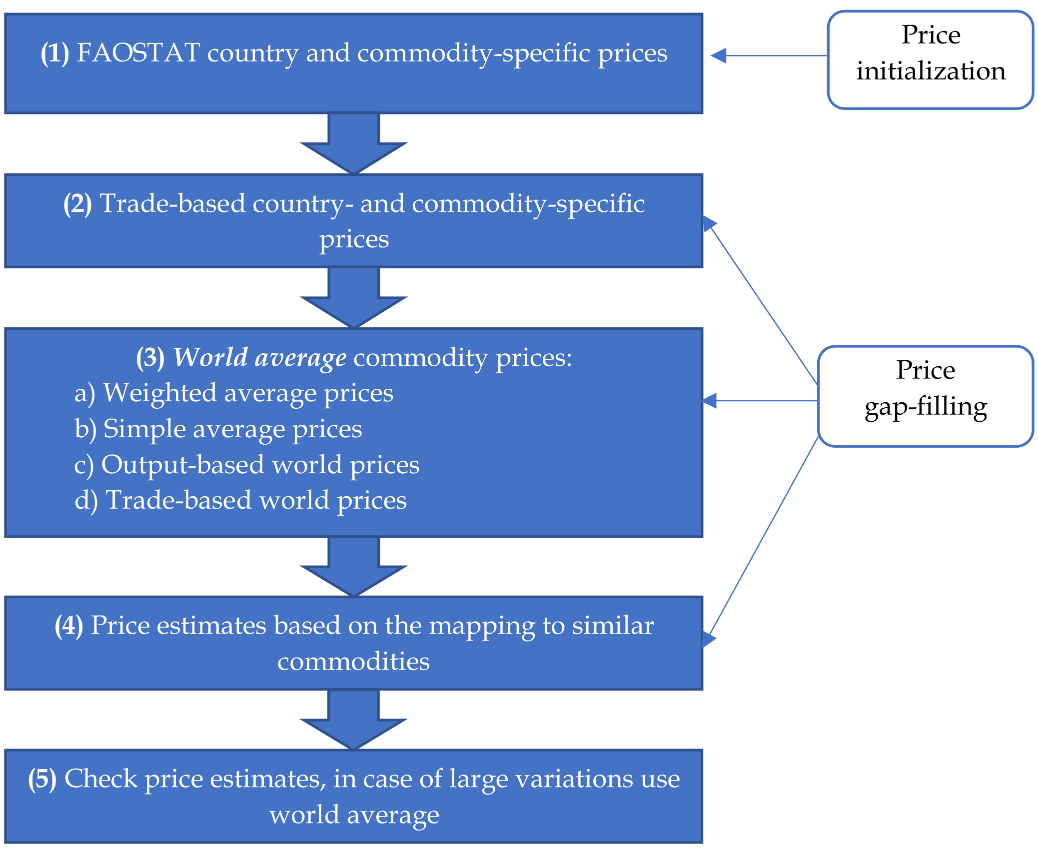

Figure 4. Steps to estimate and gap-fill agricultural commodity prices**.**

Source: Developed by authors.

We compare all estimated country-commodity prices with corresponding world average prices. If estimated prices differ from the world average price by over five times (below 20% or over 500% of the world average price), we overwrite the country-specific prices with world average estimates. This adjustment does not apply to the FAOSTAT-reported prices (Step 1, Figure 4).[7]

On the ***third step*** in Figure 3, we use quantities and prices to gap-fill values of the agricultural output and exports.

On the ***fourth step***, having constructed values of output and exports from FAO data, we source bilateral import trade values (CIF prices) and import tariff rates for the 2014 reference year from the MACMAP database (ITC, 2018).[8] MACMAP trade data and FAOSTAT dataset use different classification systems. Based on the intersection of the vegetables, fruits and nuts commodities reported by both datasets, we come up with the set of 79 aggregate (mutual) commodity categories. Appendix B reports the mapping between MACMAP, FAO and aggregate commodity categories. We then use the FAO-based value shares of output consumed domestically by households and intermediate users and MACMAP trade data to estimate exports and domestic consumption for the 79 disaggregate commodity categories. MACMAP and FAO data are reconciled to match the GTAP data at the sectoral level. The GTAP database used is version 10 with base year 2014 (Aguiar et al., 2019b).

On the ***fifth step***, we use FAO Food Balance Sheets (FAO, 2018) to estimate the households' share in the aggregate domestic absorption by commodities and regions. As of the March 2019, the latest reported data year in the Food Balance Sheets dataset is 2013, so 2013 data are used to derive these shares. To estimate these shares, we map the 93 FAO vegetables, fruits and nuts commodities to the Food Balance Sheets commodity groups and use "food" category of the Food Balance Sheets to represent the households' share in domestic absorption. This feature of the constructed dataset is not currently utilized in the GTAP-HS model, as vegetables, fruits and nuts use at the disaggregate commodity level in the GTAP-HS model is not distinguished by agents, but represented aggregately across all use categories.

Finally, on the ***sixth step***, we map values of the output and trade flows to the designed regional aggregation. In the final database, the global economy is

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[7] It should be noted that while we rely on the country- and commodity-specific price estimates to derive producer prices, the gap between producer and consumer prices for each country is commodity-generic and includes only tax component (based on the corresponding gap for the aggregate VFN sector in the GTAP Data Base). In reality, due to differences in transportation costs, retail markups and spoilage, producer-consumer price wedges can be very heterogeneous across commodities and especially high for perishable commodities (e.g. grapes). Introducing such commodity- and country-specific price wedges could improve the constructed database. Corresponding model modifications (compared to the version of the model used in this study) would need to be iplemented for the proper representation of such wedges (e.g. Peterson, 2006).

[8] MACMAP reports 3-year average data, both for values of trade and tariff rates (ITC, 2018). The 2014 reference year represents weighted average data for 2013, 2014 and 2015.

represented with 28 sectors (Appendix D) and 21 regions (Appendix E), with vegetables, fruits and nuts sector disaggregated into 79 commodities.

2.3. Substitution at the disaggregated commodity level

Specification of the GTAP-HS model requires provision of the new elasticities of substitution and transformation, in addition to the parameters used in the standard GTAP model. This includes the elasticity of transformation between disaggregated commodities (e.g. apples, pears, plums, etc.) supplied by an aggregate sector – vegetables, fruits and nuts (ε_{VFN} on Figure 1). This parameter reflects the potential for crop shifting in responses to relative price changes. In this paper we use the value of "-2" for this parameter. The elasticity of substitution among different vegetables, fruits and nuts within the domestic absorption (σ_{VFN} in Figure 1) is set at "0.5".[9]

Another set of elasticities introduced in the GTAP-HS model includes the elasticity of substitution between imports sourced from different destinations ($\sigma_{M,k}$ on Figure 1) and the elasticity of substitution between domestic and imported commodities ($\sigma_{D,k}$ on Figure 1). Both of these elasticities are defined at the disaggregated commodity level for vegetables, fruits and nuts. For the $\sigma_{M,k}$ estimates, we source data from Fontagné et al. (2019), who estimate trade elasticities at the product level (6-digit of the Harmonized System comprising 5,052 product categories) by exploiting the variation in bilateral applied tariffs for each product category for the universe of available country pairs.[10] This is done by constructing a panel of bilateral applied tariffs and bilateral trade covering the period from 2001 to 2016. A structural gravity model is used for the estimation.

From Fontagné et al. (2019), we extract the trade elasticities for 103 vegetables, fruits and nuts. We then use global average trade weights (ITC, 2018) to aggregate the HS6 level elasticity estimates to match the level of commodity detail for vegetables, fruits and nuts reported in the GTAP-HS model (Appendix B). This weighted aggregation is less than ideal as illustrated in Horridge (2018), but it is standard in the literature and fortunately most products remain fully disaggregated. In line with Horridge (2018), in the case of vegetables, fruits and nuts, substitution elasticities at the disaggregate commodity level (in most cases, individual commodities) are higher than substitution elasticity at the aggregate level (import elasticity for "v_f" sector currently used in GTAP) (Figure 5).

As can be seen from Figure 5, the GTAP 10 database reports trade elasticity of 3.7 for the aggregate VFN sector. At the same time, according to our estimates

[9] It should be noted that the supply and demand responses in the model depend on the multiple other factors, in addition to the specified values of the CET and CES parameters, including share parameters, closure assumptions, factor rigidity assumptions, specification of the functional forms, etc.

[10] In the rest of this section, we refer to $\sigma_{M,k}$ as "trade elasticity".

based on Fontagné et al. (2019), VFN trade elasticities are much higher for most commodities, with the elasticity value of around 11 having the highest frequency (Figure 5). In the modelling context, this means that under changing import prices, it would be much easier to switch between different import sources (if the direct competition exists) under the Fontagné et al. (2019) elasticity estimates than under the standard GTAP trade elasticities.

Following earlier convention, we apply the "rule of two" to derive the values of elasticity of substitution between domestic and imported commodities ($\sigma_{D,k}$ on Figure 1). In other words, we assume that $\sigma_{M,k} = 2*\sigma_{D,k}$ (Jomini et al. 1991, Hertel et al. 2009). This is another aspect of the model parameterization which requires improvement. The challenge lies in obtaining price and quantity data on consumption of domestic goods (to complement the import data).

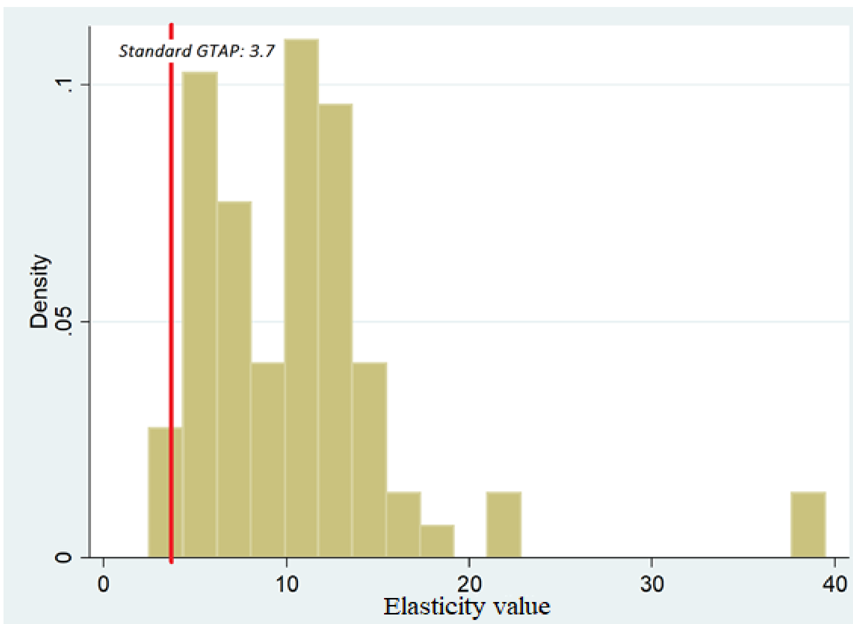

Figure 5. Frequency density of disaggregated import elasticities for vegetables, fruits and nuts at the GTAP-HS sector level.

Notes: Commodity-specific elasticities are reported. Red line corresponds to the import elasticity for "v_f" sector currently used in GTAP.

Source: Based on Fontagné et al. (2019) and Aguiar et al. (2019b).

3. Policy scenarios

In March 2018, the United States implemented tariffs of 25% on steel and 10% on aluminum imports from most countries. These tariff increases have inevitably induced retaliatory tariffs by affected trade partners. Retaliations by other countries have targeted a number of U.S. agricultural sectors, including fruits,

vegetables and nuts with wide ranging tariffs. In our analysis, we assess the cumulative impacts of these changes, focusing on U.S. agriculture as well as macro aggregates, but we also disentangle these impacts to identify separately the impacts by U.S trade partners. Our analysis considers three scenarios (Table 1).
Under the first scenario, we consider all tariffs imposed on U.S. exports of vegetables, fruits and nuts. These increases in tariffs range from 5 percentage points imposed by Turkey to 100 percentage points imposed by India on walnuts. China applied higher tariffs across almost all vegetables, fruits and nuts disaggregated categories in the model, while other trading partners increased tariffs on few U.S. products (Figure 6). Lifted tariffs between the United States, Canada and Mexico are excluded from all policy scenarios.

Table 1. Summary of scenarios used in the analysis.

No.	Scenario	Countries engaged	U.S. tariffs on foreign goods included in scenario	Foreign tariffs on U.S. goods included in scenario
1.	**VFN retaliations**	All countries that have imposed retaliatory tariffs on U.S. VFN exports, as of August 2019	None	All tariffs imposed on U.S. vegetables, fruits and nuts exports
2.	**U.S.-China trade frictions**	China	Steel & aluminum tariffs on China	China's tariffs in $3 bn round: No fruit & veg. commodities targeted in this round
			All tariffs in $200 bn Round 1: Tariff increases on 71 fruit & veg. HS6 commodities (uniform 10% increase)	First wave of $50 bn round: ➢ Tariff increases on 49 fruit & veg. HS6 commodities (uniform 15% increase) Second wave of $50 bn round: ➢ Tariff increases on 100 fruit & veg. HS6 commodities (uniform 25% increase)
			All tariffs in $200 bn Round 2: Additional 15%-point increase on VFN commodities	China's $60 bn rounds: tariffs on various other sectors
3.	**All trade frictions**	All countries affected by U.S. steel and aluminum tariffs	Steel and aluminum tariffs on all countries; U.S.-China trade frictions from Scenario 2	All tariffs from Scenario 1 and other retaliatory tariffs by EU, India, and Turkey; China's tariffs from Scenario 2

Source: Developed by authors based on Li (2019).

Under the second scenario, we consider trade frictions between the United States and China. This refers to the wide range of tariff increases that China imposed on U.S. goods, including VFN tariffs imposed by China on U.S. exports (Li, 2019). The United States targeted imports worth $200 bn, using two rounds of tariff increases. China retaliated with an equally wide range of tariffs. It first targeted $3 bn of U.S. imports, then $50 bn and $60 bn of U.S. imports over two rounds. These exchanges of tariffs affect a large number of commodities including many fruits, vegetables and nuts. In total, trade in over 100 vegetables, fruits and nuts at the HS 6-digit level, was targeted in this exchange (in addition to numerous other commodities).

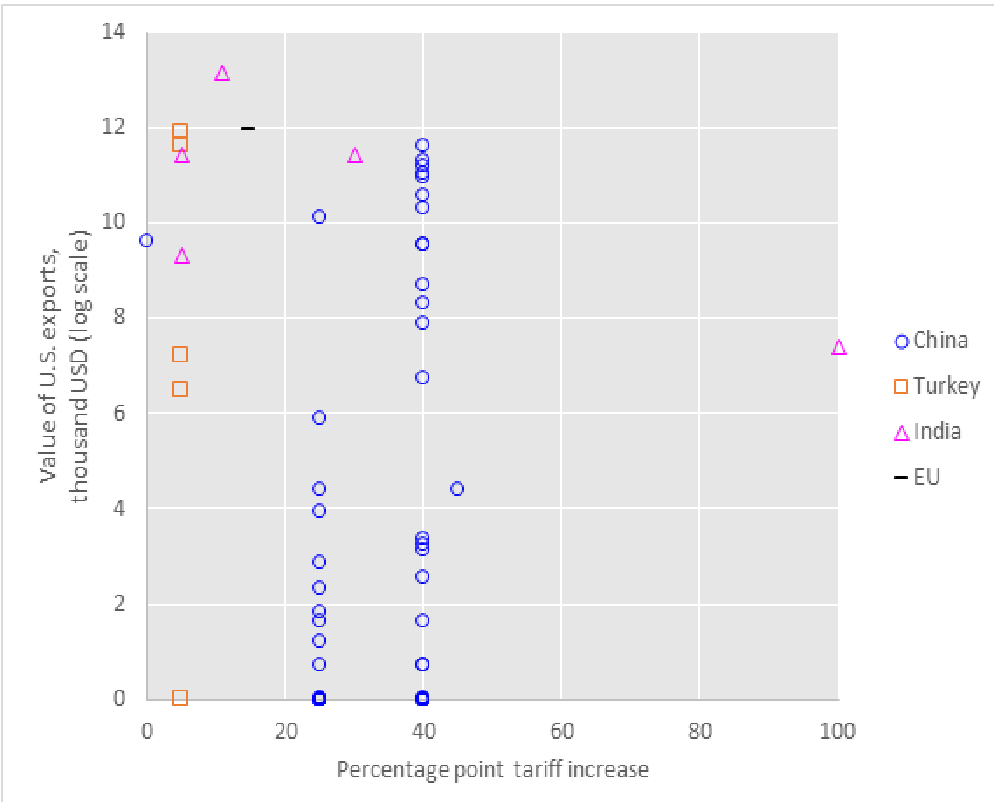

Figure 6. Export values vs. retaliatory tariffs imposed on U.S. vegetables, fruits and nuts (2014 trade values).

Notes: Each point corresponds to the commodity at the HS6 level.

Source: Developed by authors based on Li (2019), UN (2018).

In the Scenario 3, we consider trade frictions between the United States and all other countries. In addition to tariffs imposed in Scenario 2 and tariffs on vegetables, fruits and nuts in Scenario 1, Scenario 3 includes U.S. import tariffs on steel and aluminum from all other (than China) partners, and their retaliatory tariff increases on U.S. goods. These include retaliatory tariffs on U.S. exports imposed by EU, India and Turkey.

In our analysis, these tariff increases are implemented as shocks to the power of import tariffs imposed in the reference year of the analysis. The implemented shocks account for the existing tariff rates.

4. Trade in vegetables, fruits and nuts: policy environment before the trade frictions

Total value of U.S. exports of vegetables, fruits and nuts in the base year of analysis was about 16 bn USD in 2014, measured at domestic prices before export taxes, insurance and freight. Of the 79 disaggregated commodities, 17 (20%) represented 80% of these exports in value terms, with almonds, walnuts, apples, pistachios and grapes being five largest categories (Figure 7).

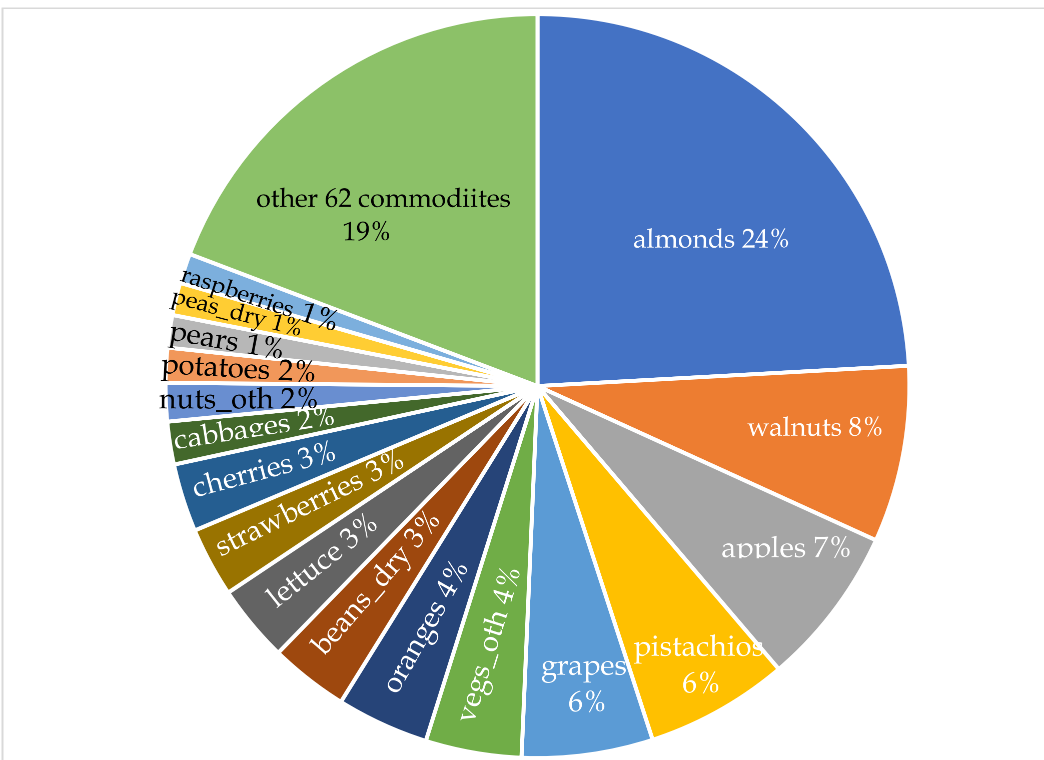

Figure 7. Structure of 2014 U.S. exports of vegetables, fruits and nuts, percent in total value of exports at domestic prices before export taxes, insurance and freight.

Source: Constructed by authors using ITC (2018).

For some of these 17 commodities (nuts, peas and beans), share of exports shipped to countries/regions that increased tariffs on U.S. vegetables, fruits and nuts was large. For example, 2275 of 3755 mn USD of almonds exported by the United States were traded with EU, China, India and Turkey (Figure 8). However, with the exception of China, these partners targeted only specific commodities. Thus, the EU targeted dry kidney beans, India targeted almonds, walnuts and apples, while Turkey targeted walnuts and almonds. It is worthwhile to note that before the trade war, India had been imposing a nearly uniform VFN tariff of 30%. Only few of the VFN commodities are subject to retaliatory tariffs in India, with the tariff on walnuts being increased by a very large amount (Figure 6). The EU and China imposed some tariffs on vegetables, fruits and nuts before the trade war. Most of these tariffs were much smaller than those imposed by India. Following the trade frictions, the EU retaliated by imposing tariffs on dry beans originating from the United States. China retaliated with a large increase in tariffs on all VFN imported from U.S. In summary, the retaliatory tariffs were expected to have noticeable impact on U.S. nuts, and all other VFN sectors that export a lot to China.

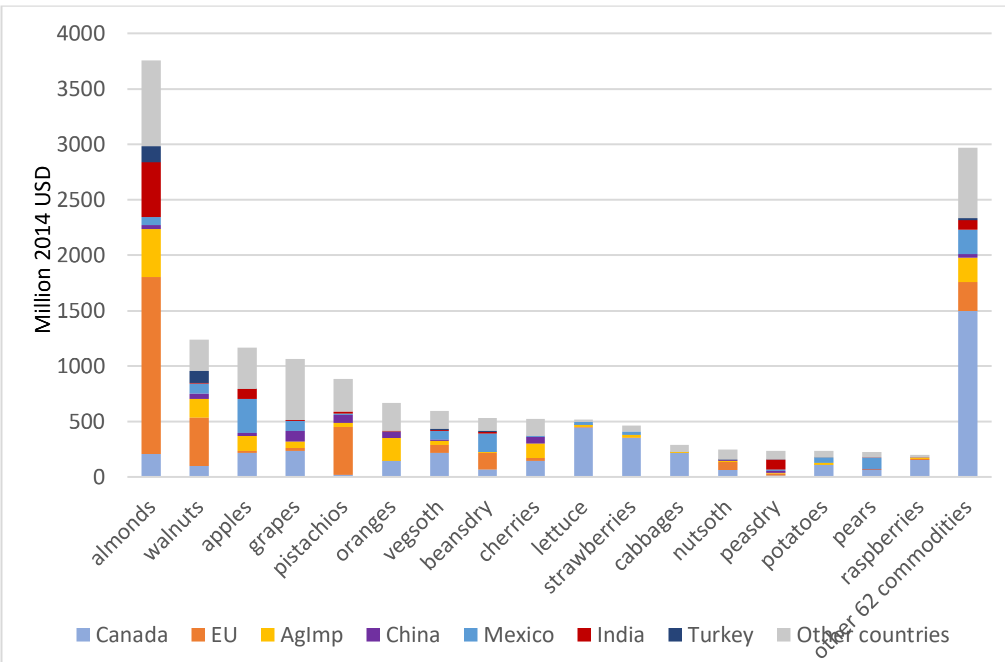

Figure 8. U.S. exports of vegetables, fruits and nuts by commodity and destination at domestic prices before export taxes, insurance and freight, mn 2014 USD.

Notes: Individual regions included in the figure are regions that have imposed retaliatory tariffs on U.S. VFN (EU, China, India and Turkey), or are the largest U.S. trading partners in our regional aggregation of the GTAP-HS data base (Canada, Mexico, AgImp).

Source: Constructed by authors using GTAP-HS database.

5. Results

5.1. Trade in Scenario 1

As U.S. vegetables, fruits and nuts commodities face increasing import tariffs within Scenario 1 (Figure 6), U.S. exports sharply decline (Figure 9). Under the CEPII trade elasticities, grapes, oranges, dry beans and dry peas experience the largest reductions in export – at least 4% reduction in quantity index.[11] In absolute terms, almonds experience the largest reduction in exports – around 90.1 mn USD, or 2.4% in relative terms. Most of these reductions are coming from U.S. exports to China. Out of the 2.5% reduction in U.S. export of vegetables, fruits and nuts, over 40% is coming from different types of nuts, including almonds, pistachios, walnuts and other nuts. The top 10 commodities represent over 92% of total U.S. vegetables, fruits and nuts export reductions (Figure 10).

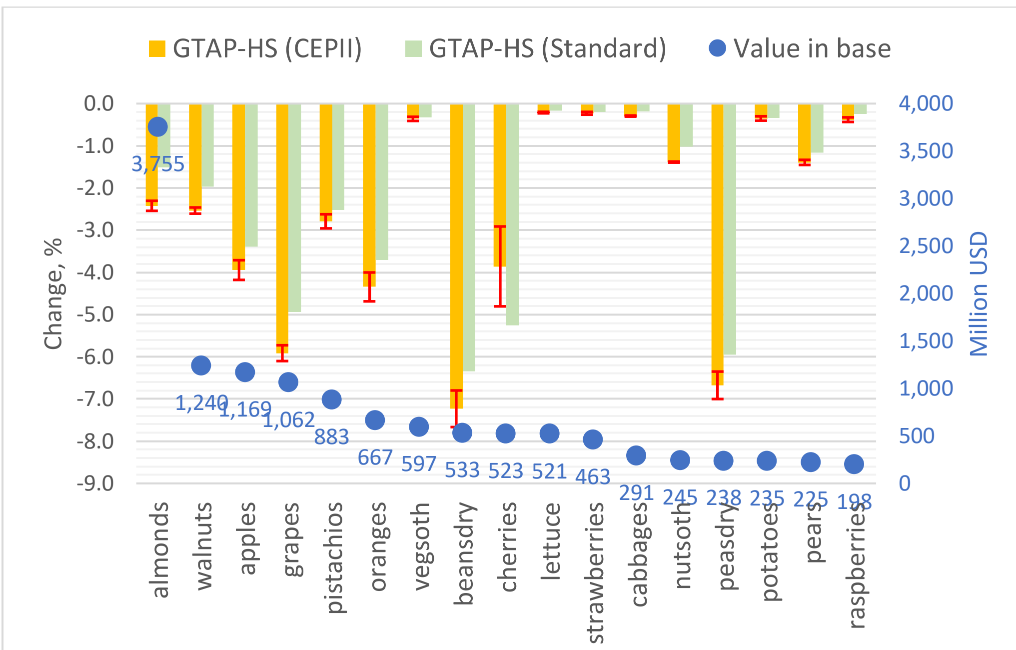

Figure 9. Change in U.S. vegetables, fruits and nuts export quantity index in Scenario 1 (top 17 commodities by value) under different elasticity assumptions, %.

Notes: On this figure and in the rest of this Section, CEPII identifier corresponds to the trade elasticities reported in Fontagné et al. (2019), while Standard identifier corresponds to the trade

[11] Change in the commodity export index for the source region is constructed using commodity and destination specific percent changes in exported quantities weighted by commodity and destination specific export value shares within total commodity export value of the source region in the reference database (initial equilibrium). Absolute changes in trade flows are calculated using prices in initial equilibrium.

elasticities used in the standard GTAP model. Error bars show uncertainty in simulated changes in exports and represent +/- two standard deviations from the mean. The uncertainty is quantified using the SSA (Arndt and Pearson, 1998). Each trade elasticity is varied independently in the range of +/- two standard errors reported in Fontagné et al. (2019), assuming a symmetric triangular distribution over that range.

Source: Estimated by authors.

While aggregate U.S. vegetables, fruits and nuts exports fall by around 399 mn USD, exports to China decline by more, 403.0 mn USD, or by 85.3%. Part of the reduction in vegetables, fruits and nuts export to China is offset by increase in U.S. exports to other destinations, such as Agricultural Importers (+50.5 mn USD), Asia (+39.8 mn USD), Other Agricultural Exporters (+24.6 mn USD) and Canada (+16.3 mn USD). Though not comparable with China in terms of the value of exports reduction, India represents the second largest market loss for the U.S. vegetables, fruits and nuts exports (-180.8 mn USD).

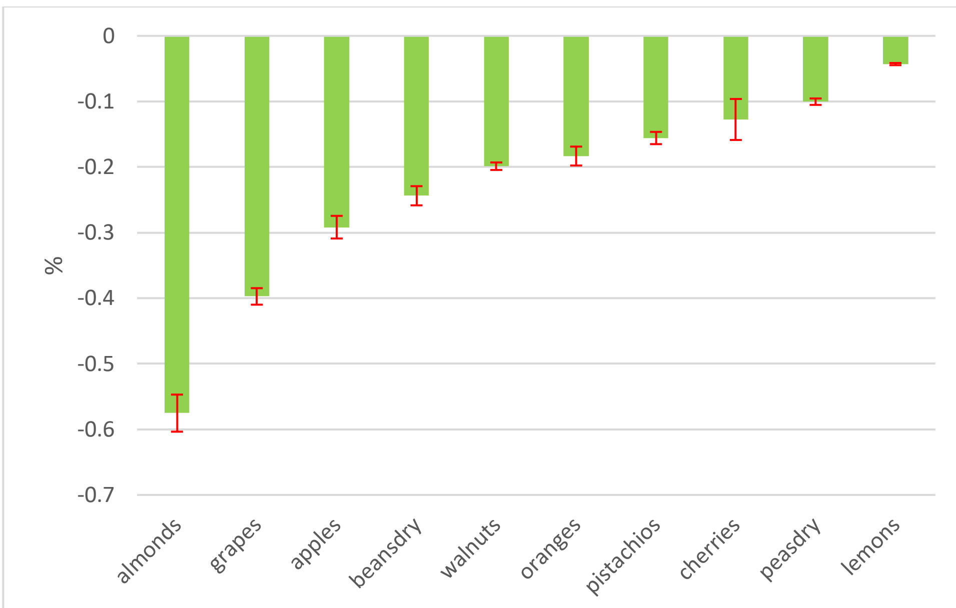

Figure 10. Contribution to change in U.S. total exports of vegetables, fruits and nuts (top 10 largest contributors) under Scenario 1, %.

Notes: Error bars show uncertainty in the simulated contributions to change in U.S. exports and represent +/- two standard deviations from the mean. The uncertainty is estimated using the SSA. Each trade elasticity is varied independently in the range of +/- two standard errors reported in Fontagné et al. (2019), assuming a symmetric triangular distribution over that range.

Source: Estimated by authors using GTAP-HS model with trade elasticities from Fontagné et al. (2019).

As discussed in Section 2.3, on average, disaggregated trade elasticities for vegetables, fruits and nuts from Fontagné et al. (2019) are significantly higher than the corresponding elasticity used in the GTAP model for the aggregate vegetables, fruits and nuts sector (Aguiar et al., 2019b). When Scenario 1 is explored under the Standard GTAP trade elasticity value 3.7 applied to all disaggregated commodities within the VFN sector, reduction in aggregate U.S. exports of vegetables, fruits and nuts is smaller (Figure 9). The decline in aggregate U.S. vegetables, fruits, and nuts exports is 2.5% using the Fontagné et al. (2019) elasticity estimates, and 2.1% using the Standard GTAP elasticity (Figure 9). This difference is because the higher trade elasticities based on Fontagné et al. (2019) imply better substitution both between import sources and domestic/imported commodities. The latter is due to the implemented "rule of two". For example, if the price of U.S. almonds imported by China increases, it is both easier for China to switch to different import suppliers, as well as substitute towards domestic production (if such product is available).

We have further explored whether an increase in the uniform trade elasticity value could result in the same aggregate U.S. VFN exports reduction in experiments with GTAP-HS, as under the Fontagné et al. (2019) elasticity estimates, i.e. 2.5%. We find that under the uniform trade elasticity of 6.2 – almost 70% higher than the Standard GTAP trade elasticity for the aggregate VFN sector – reduction in the aggregate U.S. VFN exports is the same as under the Fontagné et al. (2019) elasticity values.[12] Changes in the U.S. VFN aggregate output are also very close under these two elasticity specifications (differ by less than 0.1 percentage points). Higher differences are observed at the commodity level, as the VFN trade elasticities reported in Fontagné et al. (2019) highly vary by commodities (Figure 5). On average absolute value of difference in U.S. export quantity index change by VFN commodities is around 1.5 percentage points.[13] For 8 out of 79 commodities such difference is above 5 percentage points.

At the regional level, according to the GTAP-HS model with CEPII[14] elasticities, U.S. exports of vegetables, fruits and nuts to China experience the largest reduction (-85.3%), followed by India (-22.3%) and Turkey (-9.1%) (Figure 11). At the same time, a redirection of aggregate U.S. vegetables, fruits and nuts exports

[12] We apply the "rule of two" to derive the values of elasticity of substitution between domestic and imported commodities in both cases.

[13] For instance, if GTAP-HS (CEPII) reports change in U.S. export quantity index for walnuts to be -10% and GTAP-HS with the uniform trade elasticity of 6.2 reports corresponding change to be -12.5%, an absolute value of difference is 2.5 percentage points. We estimate such absolute value of difference for exports of each of the 79 VFN commodities and take a simple average over these absolute values of differences.

[14] We use "CEPII" notation to identify trade elasticities sourced from Fontagné et al. (2019).

is observed. Exports to Asia grow by 4.6%, followed by Europe (+4.1%), Russia (+3.9%),[15] MENA countries (+3.9%) and Brazil (+3.8%). The U.S. VFN export reduction of 611.1 mn USD (to China, India and Turkey) is partially compensated by increasing VFN exports to other destinations (+211.2 mn USD).

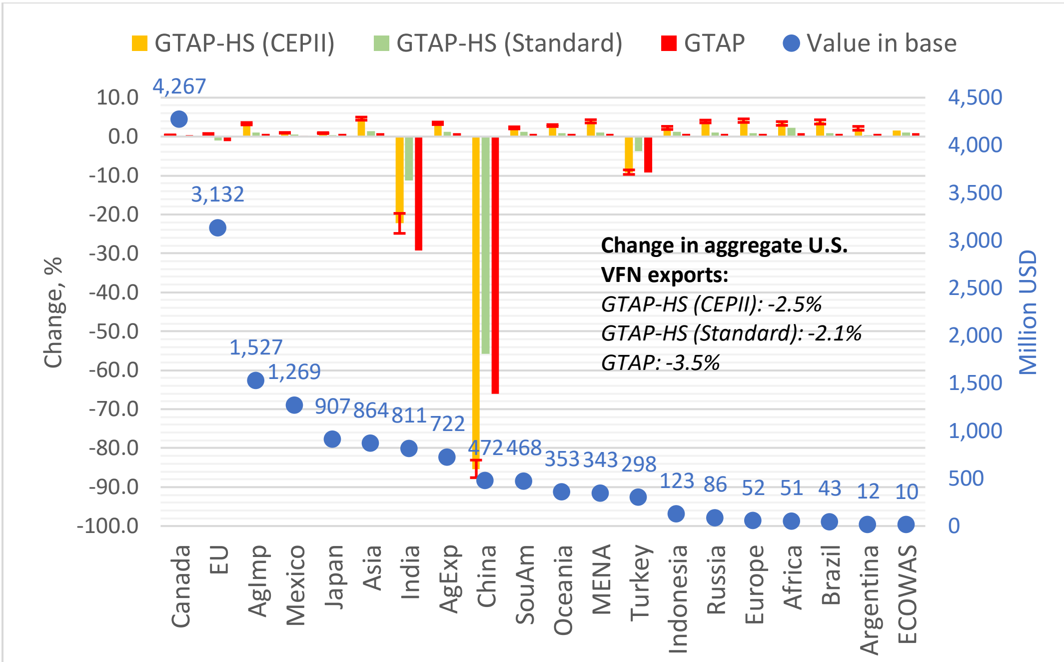

Figure 11. Change in U.S. bilateral and total exports of vegetables, fruits and nuts by region in Scenario 1: GTAP-HS vs GTAP.

Note: Error bars show uncertainty in the simulated changes in exports and represent +/- two standard deviations from the mean. The uncertainty is measured using the SSA. Each trade elasticity is varied independently in the range of +/- two standard errors reported in Fontagné et al. (2019), assuming a symmetric triangular distribution over that range.

Source: Estimated by authors.

Comparison of the Scenario 1 results with the standard GTAP model (Corong et al., 2017)[16] shows that GTAP-HS simulations, under both Standard and CEPII-based elasticities, result in smaller reduction in U.S. VFN exports (Figure 11). GTAP-HS with the Standard elasticities reports 1.4 percentage points lower U.S. VFN export reduction than the GTAP model with aggregated VFN sector (-2.1%

[15] Currently Russia bans all vegetables, fruits and nuts from the United States, as well as EU and other Western countries. Our simulation design does not take this ban into account.
[16] For the case of the standard GTAP model (with aggregate representation of the VFN sector), HS6 level import tariff shocks are aggregated to the GTAP sectoral level using trade weights from ITC (2018).

vs -3.5%). There are two key elements for such a difference. First, GTAP-HS (Standard) reports lower reductions in exports to China, India and Turkey than the GTAP model (Figure 11). Second, GTAP-HS (Standard) reports a higher increase in U.S. VFN exports to other destinations that have not imposed import tariffs on U.S. VFN commodities.

There is high heterogeneity in import penetration of different VFN commodities within specific destination. For instance, in the case of U.S. VFN exports to China, the import penetration rate reaches 21.7% (almonds), with a simple average of 0.7%. In many cases, imported VFN commodities face the same tariff rate increase (e.g. 40% in the case of almonds, hazelnuts and cashew), but have different level of import penetration (21.7%, 1.5% and 0.1% respectively), which contributes to the difference in policy impacts at the tariff line level.

5.2 Trade in Scenarios 2 and 3

Under the U.S.-China trade frictions scenario, aggregate U.S. exports of vegetables, fruits and nuts increase by 1.4% (Figure 12). While VFN exports to China fall by 85.6% – even more dramatic than under Scenario 1 – VFN exports to other destinations increase at a higher pace than in the former case and overweight the loss of the Chinese market. There are no VFN tariffs imposed by India, EU and Turkey within the Scenario 2, therefore U.S. VFN exports to these destinations increase. In the case of Scenario 3 (all trade frictions), U.S. VFN exports increase by 0.4%, as tariffs by India and Turkey are imposed in addition to Chinese tariffs. Mixed patterns are observed for VFN commodity exports within Scenario 3. Some of the most negatively impacted VFN commodities (in terms of the relative U.S. export reduction) under Scenario 3 include dry beans (-4.9%), other nuts (-3.6%), dry peas (-2.1%), grapes (-2.3%) and apples (-1.5%). For each of these commodities, values of export exceed 230 mn USD and are close to 1 bn USD in cases of apples and pistachios in 2014 (before trade frictions began). On the other hand, a number of VFN commodities experience increase in exports, these include raspberries (+3.1%), potatoes (+2.8%), other vegetables (+2.2%), cabbages (+1.7%) and strawberries (+1.3%). This leads to the net U.S. aggregate VFN exports increase under Scenario 3. In general, if import tariffs on vegetables, fruits and nuts are considered in isolation from import tariffs imposed on other commodities (Scenario 1), U.S. VFN exports experience a sizeable reduction, while in the case when VFN tariffs are considered in the context of other retaliations (Scenarios 2 and 3) VFN exports even moderately increase. The explanation behind such difference is that under Scenario 1 only VFN commodities face increasing import tariffs and producers are switching to other commodities, increasing their output and export quantities. At the same time, under Scenarios 2 and 3, other commodities (e.g. manufacturing sector), in addition to vegetables, fruits and nuts, also experience increasing import tariffs. In many cases, those tariff increases are even higher than for vegetables, fruits and nuts, therefore there is much less switching to the production and exports of other commodities. In fact, there is even some shift toward additional VFN production and exports.

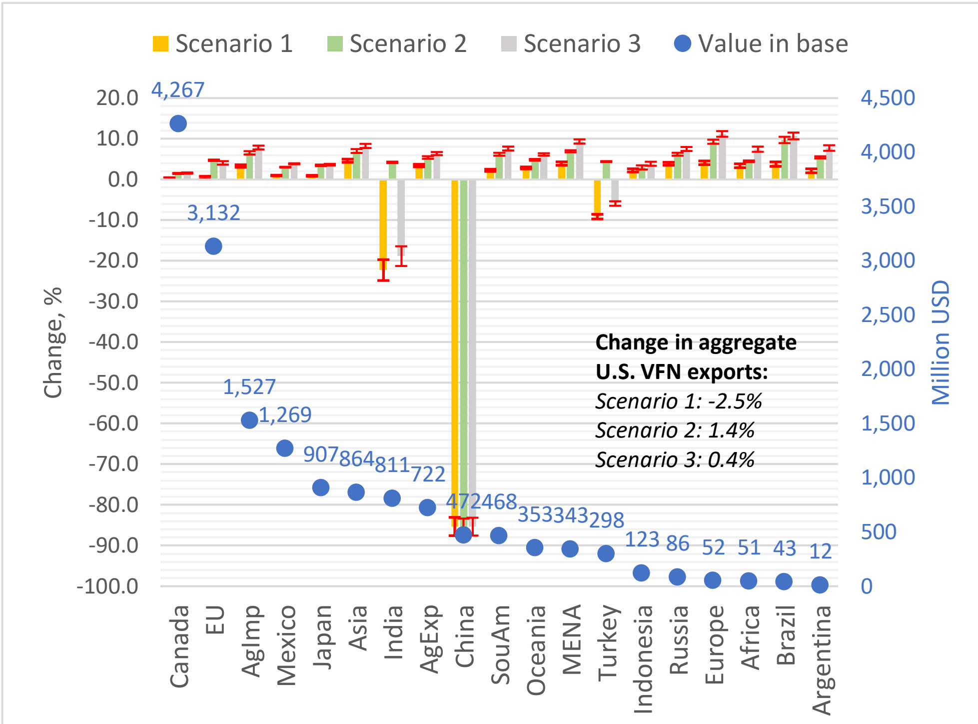

Figure 12. Change in the U.S. exports of VFN commodities by partner and scenario, %.

Note: Error bars show uncertainty in the simulated changes in exports and represent +/- two standard deviations from the mean. The uncertainty is quantified using the SSA. Each trade elasticity is varied independently in the range of +/- two standard errors reported in Fontagné et al. (2019), assuming a symmetric triangular distribution over that range.

Source: Estimated by authors using GTAP-HS model with trade elasticities from Fontagné et al. (2019).

5.3 Economy-wide impacts in the three Scenarios

In terms of aggregate welfare changes under GTAP-HS (CEPII), tariffs imposed on U.S. export of vegetables, fruits and nuts (Scenario 1) do not result in significant losses, as welfare in the United States falls by around 121.4 mn USD (less than 0.001%), while China experiences a reduction in welfare of 123.7 mn USD or around 0.0015%. While global welfare falls by around 117.9 mn USD under GTAP-HS (CEPII), GTAP-HS (Standard) reports a 23% larger global welfare reduction (Appendix F). Standard GTAP model reports 59% higher (relative to GTAP-HS (CEPII)) global welfare loss under Scenario 1 (Appendix F).

Much higher welfare losses are observed when the United States enters trade frictions with China, as the number of commodities under trade retaliation rapidly increases and both economies suffer significantly – welfare in the United States is reduced by almost 35 bn USD (0.2%), while China has an even larger loss (-68.4 bn USD or 0.8%). All other U.S. trade partners are welfare gainers, with the EU being the largest one (13.6 bn USD or 0.1%), followed by Canada (8.0 bn USD or 0.5%), Mexico (6.4 bn USD or 0.6%) and Japan (5.1 bn USD or 0.1%). U.S. trade frictions with the Rest of the World seem to have no additional significant impact on welfare (last two columns in the Appendix F table are similar). In general, in terms of welfare impacts, ongoing trade frictions between China and the United States positively contribute to the welfare of all other regions. Even India and EU who are imposing retaliatory tariffs on U.S. exports, turn to be net welfare gainers due to the U.S.-China trade war.

6. Limitations and critical assumptions of the developed approach

Any economic model by definition represents a simplified version of reality. A number of simplifying assumptions are made, while focus of the model is put on the specific features of the economic system under consideration. This is entirely true for the standard GTAP model (Hertel, 1997; Corong et al., 2017), which is the basis of our modelling approach, as well as the GTAP-HS model adopted in this study (Narayanan et al., 2010; Aguiar et al., 2019a). Critical assessment of some key assumptions and their implications is important for the correct interpretation of modelling results and identification of potential improvements to the modelling framework. In this context, there are several assumptions of the developed modelling framework that need to be highlighted and discussed.

Within our modelling approach we do not explicitly represent the production structure of the disaggregated VFN commodities. Instead, the output of the aggregate VFN sector is allocated across different commodities using the CET function. This has several implications. First, under the current approach, how output of a given VFN commodity changes due to a trade policy shock depends on a single CET parameter and revenue shares. For some of the HS6 commodities, such as fruit and nut trees, a large expansion of output may not be possible within short or medium time horizon, suggesting the CET parameter should be close to zero, while for annual crops the CET parameter may be larger. Second, with the CET function allocating VFN output across disaggregated commodities, the cost structure of the VFN production sector is independent of the composition of output. The cost structure of the aggregate VFN sector can be viewed as the aggregation of the cost structures of the 79 commodities that the aggregate VFN sector supplies. In the initial data base, the cost structure of the aggregate VFN sector is representative of the 79 sectors the aggregated VFN produces. After a trade policy or other shock, the cost structure of the aggregate VFN sector will not be perfectly reflecting output mix in the new equilibrium. However, due to the very large number of commodities supplied by VFN and the fact that there is no dominant commodity within regional VFN output, the cost structure of the aggregate VFN sector will represent relatively well the aggregation of the cost structures of the supplied commodities. For this conclusion to hold in simulations with the GTAP-HS, the CET parameter should be relatively small. The absolute magnitude of the CET parameter gives maximum own price supply elasticity for a commodity with a tiny revenue share within aggregate VFN. We use CET=-2, meaning that the own price supply elasticity for a commodity with a tiny revenue share is very close to 2. As the revenue share rises, this supply elasticity shrinks. Given these limitations, a high priority improvement of the VFN sector representation within the GTAP-HS modelling framework is to disaggregate the VFN sector into two sectors so that annuals and perennials are separated on both production (cost structure) and supply sides, with the specification of production structure separately for each of the disaggregated categories. This task, however, requires detailed input-output data, in addition to trade data, or a method to estimate missing data (Dixon et al. 2020).

Several studies have implemented splits of various GTAP Data Base sectors and implemented adjustments to the standard GTAP model to provide a better fit for the modified data inputs (e.g. Dixon et al., 2020; Taheripour and Tyner, 2018). These efforts were generally implemented for limited aggregations of the GTAP data base, with the choice of sectors and regions largely shaped by data availability. In this paper we strive to develop the GTAP-HS Data Base with disaggregated VFN sector for all 141 GTAP 10 Data Base regions. In this context, the possibility of the VFN sector being split into annuals and perennials (or even more granular disaggregation) is constrained by availability of data at global scale. In particular, the most detailed input-output or supply-use tables available for selected countries, such as the United States (BEA, 2018), Japan (MIC, 2019), Canada (Statistics Canada, 2019) or South Korea (Bank of Korea, 2019) do not explicitly distinguish between annuals and perennials.[17] Land use factor payments

[17] The U.S. supply-use table with 405 industries distinguishes four sectors that can be mapped to the GTAP Data Base VFN sector – Vegetable and melon farming; Fruit and tree nut farming; Greenhouse, nursery, and floriculture production; and Other crop farming. Perennials, for instance, are distributed between several categories in this list – mushrooms are included to the Greenhouse, nursery, and floriculture production; tree nuts are listed under the Fruit and tree nut farming; artichokes and asparaguses are reported in the Vegetable and melon farming (BEA, 2018; Wittwer, 2017). Japanese input-output table distinguishes between potatoes, sweet potatoes, vegetables and fruits, soybeans and other pulses (MIC, 2019). Other detailed input-output tables provide even less details for the VFN sector representation. Supply and use tables for Canada with 492 industries distinguishes Potatoes, Fruits and nuts, Vegetables, Other miscellaneous crop products and Imputed feed (Statistics Canada, 2019). South Korean input-output table with 165 sectors reports Grains and other edible crops, Vegetables and fruits and Other crops categories (Bank of Korea, 2019).

are also not reported by all the listed above data sources. Differing compositions of perennial and annual crops by countries might also complicate application of factor and intermediate input shares derived from the specific country data to other regions.

One other critical modeling assumption that we would like to highlight includes the specification of the substitution and transformation elasticities in the adopted modelling framework. After disaggregation of the VFN sector on the production side into annual and perennial crops, setting of the substitution and transformation parameters in these two sectors based on available econometric estimates, as well as potential revision of the supply nesting, should be a high priority in future model improvements.

7. Conclusions

Trade policies are front and center on the political agenda. And, while 'big picture' analyses are useful, it is the individual commodity groups that are being most sharply affected by the policy changes. In this paper, we present a new modeling framework to analyze changes in trade policies implemented at the tariff line in vegetables, fruits and nuts sectors. The key component of the framework is the global data base with production, trade, protection and domestic use of vegetables, fruits and nuts sector disaggregated into 79 commodities, all nested within the GTAP Data Base.

The key strength of the developed approach and constructed GTAP-HS database is the explicit representation of the value of output and domestic absorption at the disaggregate commodity level. Due to the lack of available data, previous studies have relied solely on the trade data to provide such disaggregation. In particular, Grant et al. (2007) use constrained optimization to minimize deviations at the aggregate sectoral level, given disaggregated trade data. Narayanan et al. (2010) and Aguiar et al. (2019a) assume a uniform ratio of the domestic consumption to imports within the disaggregate sector. Both of these approaches are inherently *ad hoc*, and therefore potentially misleading in the context of highly heterogeneous commodities. In this paper, we use the FAO statistical data on values, quantities and prices of output, total country exports and imports. We further develop an approach to the reconciliation of the values of output, trade and domestic consumption from different datasets (GTAP, ITC and FAO) to develop the GTAP-HS database with 79 VFN commodities.

We complement the GTAP-HS database with detailed trade elasticities estimated at the HS6 level, based on recent estimates by Fontagné et al. (2019). The disaggregated data and substitution/transformation possibilities at the tariff line level provide a much richer framework for analysis of tariff policies. We illustrate the benefits of the newly developed dataset and modelling framework by applying it to the assessment of ongoing trade frictions between the United States and its trading partners, focusing on impacts for vegetables, fruits and nuts sector. We highlight the differences between GTAP and GTAP-HS. With multiple contributing factors, understanding of the key driving forces of such differences in results is a major point of the GTAP-HS analysis reported in this paper.

Comparisons between GTAP-HS and the standard GTAP model show that GTAP-HS model reports lesser reduction in U.S. VFN exports under the tariff frictions scenario than predicted by the standard GTAP model. At the same time, the magnitude of these differences depends critically on the specification of trade elasticities. If only tariffs on U.S. VFN exports (Scenario 1 in this paper) are considered, U.S. VFN exports fall by 3.5% under the standard GTAP model. GTAP-HS with trade elasticities adopted from the standard GTAP model reports U.S. VFN export reduction of 2.1%, while GTAP-HS with trade elasticities sourced from Fontagné et al. (2019) (on average much higher than in the standard GTAP) shows U.S. VFN exports reduction of 2.5%.

Higher trade elasticities mean that U.S. trading partners that imposed import tariffs have better opportunities for switching to other import sources and substituting VFN imports by domestic production. Therefore, U.S. VFN exports reduction to China, India and Turkey under Fontagné et al. (2019) trade elasticities are much higher than under the Standard elasticities. Although there is a higher increase in U.S. VFN exports to other destinations, this expansion does not fully outweigh additional export losses (under the Fontagné et al. (2019) trade elasticities relative to the Standard elasticities).

Because it is based on a GE framework, the GTAP-HS model allows us to analyze impacts of policies implemented in other sectors on disaggregated sectors of interest and vice-versa. Our simulations suggest that if import tariffs on vegetables, fruits and nuts are considered in isolation from import tariffs imposed on other commodities (Scenario 1), U.S. VFN exports experience a substantial reduction. However, when VFN tariffs are considered in the context of other retaliations, U.S. VFN exports even moderately increase (Scenarios 2 and 3). The explanation behind this difference is that under Scenario 1 only VFN commodities face increasing import tariffs and producers are switching to other commodities, increasing their output and exports. At the same time, under Scenarios 2 and 3, other commodities, in addition to vegetables, fruits and nuts, also experience increasing import tariffs. In many cases, those tariff increases are even higher than for vegetables, fruits and nuts, therefore there is much less switching to the production and exports of other commodities, in fact there is even some shift toward additional VFN production and exports.

There are a number of potential extensions to our approach from both methodological and policy perspectives. First, use of the CET functional form to represent supply of the disaggregated commodities by the aggregate VFN sector relies just on a single transformation parameter and revenue shares. Yet, these commodities, such as annual and perennial crops, differ in their cost structures, types of capital employed, and time required to adjust to changes in trade policies. Second, the CET implies that the cost structure of the aggregate VFN sector is independent from the composition of the VFN sector output -- a limitation that we believe of a lesser importance given the large number of the disaggregated VFN commodities. One important direction for future work that addresses both limitations involves splitting the VFN sector into annuals and perennials with the specification of distinct production structures for each of these sectors. Once this has been accomplished, it will open the door to some very interesting modeling activities. Specifically, distinguishing between general purpose (tractors and other farm equipment) and sector-specific capital (orchards) will be important for such an extension (Dixon et al. 2011). The responsiveness of perennial crops to changes in trade policy will differ dramatically from that of annual crops in the near term. Capturing these differentials is an important area for future research (see e.g. Dixon et al., 2011).

Third, as the values of substitution and transformation elasticities play an important role in determining trade policy results, it would be relevant to further refine values of these parameters. While trade elasticities used in this paper are based on the available econometric estimates (Fontagné et al., 2019), this is not the case for elasticity of substitution within domestic absorption and elasticity of transformation among disaggregated commodities supplied by the aggregate VFN sector. Fourth, our disaggregation procedure can be applied to other agricultural and food sectors, adding more commodity-level details to the GTAP-HS database. Fifth, while in this paper we have been focusing on changes in trade and aggregate welfare, it could be relevant to explore in more detail impacts on the domestic markets. This detailed representation of vegetables, fruits and nuts could allow users to associate disaggregated commodity supply changes with the specific U.S. states and explore the results at the regional level. Finally, this newly developed modelling framework can be further validated by an assessment of short-term impacts of trade policies under consideration and their comparison with actual changes in trade patterns.

Data availability

The underlying GTAP-HS database at a fully disaggregated level (141 regions and 65 sectors, with vegetables, fruit and nuts sector disaggregated into 79 commodities) is available upon request to all GTAP 10 Data Base subscribers, data contributors and GTAP Board Members.

Acknowledgments

We thank to three anonymous referees for the valuable comments and suggestions. We are grateful for financial support provided by the Economic

Research Service and Foreign Agricultural Service, United States Department of Agriculture.

The findings and conclusions in this publication are those of the authors and should not be construed to represent any official USDA or U.S. Government determination or policy.

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Appendix A. Overview of the GTAP-HS model

Tables A.1-A.3 list new sets, variables and parameters introduced into the standard GTAP v7 model (Corong et al., 2017) to support structure of the GTAP-HS model. Upper case letters are used for set names, parameters, coefficients, and to denote levels of prices, quantities and values. Lowercase letters are used to denote percent change variables.[18] For complete representation of the model structure, a reader is referred to Narayana et al. (2010).

Table A.1 lists GTAP-HS sets and subsets incorporated into the standard GTAP v7 model. Set COMM in both the standard GTAP v7 and GTAP-HS models contains supplied commodities *c*. The set SPLT_COMM is a subset of COMM and contains those of the *c* commodities that are being split. Set ASECT_COMM is a subset of set COMM and contains commodities *c* that are not disaggregated. Set SSECT_COMM contains commodities *k* disaggregated at the HS6 (or close to HS6) level. Set DAGG_COMM represents the union of non-disaggregated commodities *c* and the HS6 disaggregated commodities *k*. The mapping set, MPSP_COMM, maps the HS6 commodities *k* to one and only one commodity *c* in SPLT_COMM (Aguiar et al. 2019).

Table A.1. New sets introduced into the standard GTAP v7 model to support GTAP-HS structure, and correspondence to sets in Narayanan et al. (2010).

Set name in GTAP-HS	Description	Corresponding set name in Narayanan et al. (2010)
SPLT_COMM	Sectors of the model with output disaggregated into HS6 (or close to HS6) commodities (v_f, mil)	SPLT_COMM
SSECT_COMM	Set of disaggregated commodities (almonds, cherries…)	SSECT_COMM
ASECT_COMM	Non-disaggregated sectors in the model ASECT_COMM = COMM - SPLT_COMM	ASECT_COMM
DAGG_COMM	Set of non-disaggregated and disaggregated commodities DAGG_COMM = ASECT_COMM + SSECT_COMM	DAGG_COMM
MPSP_COMM	Mapping from SSECT_COMM to SPLT_COMM	MPSP_COMM

Source: Developed by authors.

[18] Variables in welfare decomposition CNT* in Table A2 are absolute change variables.

Table A.2. Variables that have been added in the standard GTAP v7 model and correspondence to the variables in Narayanan et al. (2010).

Variable in GTAP-HS	Description	Corresponding variable in Narayanan et al. (2010)
qck(k,r)	Total supply of commodity k in region r	qok
pdsk(k,r)	Price of domestically supplied HS6 commodity k in region r	pmk
qdsk(k,s,d)	Domestic usage of HS6 commodity k in region r	qdmk
qxsk(k,s,d)	Export quantity of HS6 commodity k from s to destination d	qxsk
pfobk(k,s,d)	FOB world price of HS6 commodity k from source s to destination d	pfobk
pcifk(k,s,d)	CIF price of imported HS6 com. k from source s to destination d	pcifk
pmdsk(k,s,d)	Basic price of imported HS6 com. k from source s to destination d	pmsk
qmsk(k,d)	Aggregate imports of HS6 com k in d, basic price weights	qimk
pmsk(k,d)	Price of aggregate HS6 commodity import bundle k in region d	pimk
qms(c,r)	Aggregate imports of c in region r, basic price weights	qim
qdmbk(k,r)	Domestic absorption of HS6 commodity k at basic prices	qdk
pdmbk(k,r)	Composite (dom-imp) price of com. k in region r	pdk
qdmb(c,r)	Aggregate demand for composite c in region r	qd
pdmb(c,r)	Price of composite commodity c in r	pd
amsk(k,s,d)	Import augmenting tech change in reg d for com k from reg s	amsk
tmk(k,r)	Source-generic change in tax on imports of k in s	tmk
tmsk(k,s,d)	Source-specific change in tax on imports of k from s to d	tmsk
txk(k,r)	Destination-generic change in subsidy on exports of k from r	txk
txsk(k,s,d)	Destination-spec. change in subsidy on exports of k from s to d	txsk
tradslackk(k,r)	Slack variable in comm. k's market clearing condition	tradslackk
atallk(m,k,s,d)	Tech. change in m's shipping of k from region s to d	atallk
atfk(k)	Tech. change shipping of k, worldwide	atfk
ptransk(k,s,d)	Cost index for international transport of k from s to d	ptransk
atmfsdk(m,k,s,d)	Tech change in m's shipping of k from region s to d	atmfsdk
qtmfsdk(m,k,s,d)	International margin m on k from s to d	qtmfsdk
CNTqxks(k,s,d)	Contribution to EV of changes in exports of k from s to d	CNTqxskrs

(Continued)

Table A.2. Variables that have been added in the standard GTAP v7 model and correspondence to the variables in Narayanan et al. (2010) (Continued).

Variable in GTAP-HS	Description	Corresponding variable in Narayanan et al. (2010)
CNTqxs(c,s,d)	Contribution to EV of changes in exports of c from s to d	CNTqxsirs
CNTqxsslack(c,s,d)	Slack variable for CNTqxs in GTAP-HS module	CNTqxsslack
CNTqmsk(k,s,d)	Contribution to EV of changes in imports of k from s to d	CNTqimksr
CNTqmsslack(c,s,d)	Slack variable for CNTqms in GTAP-HS module	CNTqimslack
qxsslack(c,s,d)	Slack variable for qxs variable in equation E_qxs	qxsslack
qmsslack(c,s,d)	Slack variable for qms variable in equation E_qms	qmsslack
pmsslack(c,s,d)	Slack variable for pms variable in equation E_pms	pimslack
pmdsslack(c,s,d)	Slack variable for pmds variable in equation E_pmds	pmslack
pfobslack(c,s,d)	Slack variable for pfob variable in equation E_pfob	pfobslack
pcifslack(c,s,d)	Slack variable for pcif variable in equation E_pcif	pcifslack
ptransslack(c,s,d)	Slack variable for ptrans in equation E_ptrans	ptranslack
Exogenous variables, defined over subset of COMM set ASECT_COMM, introduced for convenience to facilitate automatic closure in Aguiar et al. (2019)		
tmsf(c,s,d)	Source-specific change in tax on imports of c from s to d	n.a.
tmf(c,s,d)	Source-generic change in tax on imports of c to r	n.a.
txsf(c,s,d)	Destination-specific change in subsidy on exports of c from s to d	n.a.
txf(c,r)	Destination-generic change in subsidy on exports of c from r	n.a.
amsf(c,a,d)	Commodity c augmenting tech change from s to d	n.a.
pcifslackf(c,s,d)	Exogenous pcifslack	n.a.
pfobslackf(c,s,d)	Exogenous pfobslack	n.a.
pmdsslackf(c,s,d)	Exogenous pmdsslack	n.a.
ptransslackf(c,s,d)	Exogenous ptransslack	n.a.
qxsslackf(c,s,d)	Exogenous qxsslack	n.a.
pmsslackf(c,s,d)	Exogenous pmsslack	n.a.
qmsslackf(c,s,d)	Exogenous qmsslack	n.a.
CNTqmsslackf(c,s,d)	Exogenous CNTqmsslack	n.a.
CNTqxsslackf(c,s,d)	Exogenous CNTqxsslack	n.a.

Notes: k is element of set SSECT_COMM; *r*, *s* (source) and *d* (destination) are elements of set REG, and *c* is element of set COMM

Source: Developed by authors.

Table A.3. New parameters introduced into the standard GTAP v7 model to support GTAP-HS structure, and correspondence to parameters in Narayanan et al. (2010).

Parameter in GTAP-HS	Description	Corresponding parameter in Narayanan et al. (2010)
ETRAHS6(c,r)	Elasticity of transformation in the CET function that allocates supply of aggregated commodity *c* across disaggregated commodities	ETRAHS6
ESUBMK(k)	Elasticity of substitution among imports from various sources within imported bundle of disaggregated commodity *k*	ESUBMK
ESUBDK(k)	Elasticity of substitution between imported bundle and domestic disaggregated commodity *k*	ESUBDK
ESUBK(MPSP_COMM(k), r)	Elasticity of substitution among disaggregated commodities *k* within domestic absorption of aggregated commodity *c*	ESUBK

Source: Developed by authors.

Key equations that support structure presented in Figures 1 and 2 in the main text

Linearized equations are shown in lowercase, as they appear in the code of the GTAP model. The supply of the aggregated commodity c (VFN in our analysis) in region s, $QC_{c,s}$, is transformed into commodities at the HS6 level, $QCK_{k,s}$, indexed by k (apples, tomatoes, almonds, etc.) using CET function (Figure 1). In linearized form, supply of HS6 level commodity k is determined by equation E_qck in the model code:

$$qck_{k,s} = qc_{c,s} + ETRAHS6_{c,s}(pds_{c,s} - pdsk_{k,s}),\ c \in MPSP\_COMM(k) \quad \text{(A.1)}$$

where $ETRAHS6_{c,s}$ is (negative) CET parameter, represented by ε elasticity in Figure 1 in the main text. The percent change in supply of HS6 commodity $qck_{k,s}$, e.g. almonds in the United States, depends on percent change in price of almonds $pdsk_{k,s}$ relative to percent change in price of aggregate VFN, $pds_{c,s}$, as well change in aggregate supply of VFN in the United States $qc_{c,s}$.

Value of VFN sector output is product of supply price, $PDS_{c,s}$, and quantity of aggregated VFN output, $QC_{c,s}$. Value of VFN sector output is equal to the sum of the values of disaggregated commodities:

$$PDS_{c,s}\,QC_{c,s} = \sum_{k:MPSP\_COMM(k)=c} PDSK_{k,s}\,QCK_{k,s} \quad \text{(A.2)}$$

Let's denote value of the aggregate sector output $VCB_{c,s} = PDS_{c,s}\,QC_{c,s}$, and value of the disaggregated commodity output $VCBK_{k,s} = PDSK_{k,s}QCK_{k,s}$. Then, changes in aggregate sector price, $pds_{c,s}$, is revenue share weighted sum of price changes of the disaggregated commodities (equation *E_pds2* in the model code):

$$VCB_{c,s}pds_{c,s} = \sum_{k:MPSP\_COMM(k)=c} VCBK_{k,s}\ pdsk_{k,s} \quad \text{(A.3)}$$

Part of the total quantity $QCK_{k,s}$ is allocated to the domestic market ($QDSK_{k,s}$) , while the rest is supplied to the export markets and shipped to various destinations, indexed by d, ($QXSK_{k,s,d}$). We assume that commodity k supplied to different markets is homogenous, meaning that $QCK_{k,s}$, $QDSK_{k,s}$ and $QXSK_{k,s,d}$ are supplied at the same price, $PDSK_{k,s}$. The assumption allows to write market clearing condition for each disaggregated VFN commodity:

$$QCK_{k,s} = QDSK_{k,s} + \sum_d QXSK_{k,s,d} \quad \text{(A.4)}$$

In the model code, the market clearing is represented by equation *E_pdsk*.

Imported quantities of HS6 commodity k from various sources s, $QXSK_{k,s,d}$, are aggregated into imported composite of k in destination region d, $QMSK_{k,d}$, using CES function (Figure 1). In the model code, the demand for imported commodity k from region s in destination d is represented by equation *E_qxsk*:

$$qxsk_{k,s,d} = -amsk_{k,s,d} + qmsk_{k,d} - ESUBMK_{k,d}(pmdsk_{k,s,d} - amsk_{k,s,d} - pmsk_{k,d}) \quad \text{(A.5)}$$

where $ESUBMK_{k,d}$ is (positive) CES parameter, represented by $\delta_{M,k}$ in Figure 1, $amsk$ are preference shifters. The percent change in imports of HS6 commodity k by region d from any other region s is determined by three factors: (i) change in demand for composite import of commodity k $qmsk_{k,d}$, (ii) import-augmenting technical change, $amsk_{k,s,d}$, that lowers the effective price of a good in the destination market, (iii) and substitution among different sources that depends on the difference between import prices from specific sources $pmdsk_{k,s,d}$ and the sum of import-augmented technical change $amsk_{k,s,d}$ and aggregate import price $pmsk_{k,d}$, multiplied by $ESUBMK_{k,d}$ (Narayanan et al. 2010). Value of aggregate imports of k in d is equal to sum of values of imports of k to d from various sources s. This zero profits condition for aggregate imports $QMSK_{k,d}$ defines the aggregated across sources price of imported good k, $PMSK_{k,d}$ (Aguiar et al. 2019):

$$PMSK_{k,d}QMSK_{k,d} = \sum_s PMDSK_{k,s,d}\,QXSK_{k,s,d} \quad \text{(A.6)}$$

In the model code, this condition in linearized form is represented by equation *E_pmsk*.

Moving down in Figure 1 to the next CES nest, imported bundle $QMSK_{k,d}$ and domestically produced $QDSK_{k,d}$ are aggregated into domestically absorbed bundle $QDMBK_{k,d}$ using CES function. In the model code, these relationships are represented with equations *E_qmsk* (A.7) and *E_qdsk* (A.8):

$$qmsk_{k,d} = qdmbk_{k,d} - ESUBD_{k,d}(pmsk_{k,d} - pdmbk_{k,d}) \text{ (A.7)}$$

$$qdsk_{k,d} = qdmbk_{k,d} - ESUBDK_{k,d}(pdsk_{k,d} - pdmbk_{k,d}) \text{ (A.8)}$$

where $ESUBD_{k,d}$ is (positive) CES parameter, represented by $\sigma_{D,k}$ in Figure 1. Equations (A.7) and (A.8) determine changes in region d demand for HS6 commodity k aggregate imports and region d demand for HS6 commodity k produced domestically, $qmsk_{k,d}$ and $qdsk_{k,d}$. These demands depend on changes in domestic absorption of the HS6 commodity k, $qdmbk_{k,d}$, and difference between changes in prices, multiplied by $ESUBD_{k,d}$. Value of domestic absorption of HS6 commodity k in a region is equal to the sum of values of aggregate imports and domestic use of domestically produced commodity k. This zero profit condition determines the absorption price $PDMBK_{k,d}$:

$$PDMBK_{k,d}\, QDMBK_{k,d} = PMSK_{k,d} QMSK_{k,d} + PDSK_{k,d} QDSK_{k,d} \text{ (A.9)}$$

In the model code, this condition in linearized form is represented by equation *E_pdmbk*.

Finally, domestic absorptions of HS6 commodities k $QDMBK_{k,d}$ are aggregated into domestic absorption of aggregate commodity c (VFN in this analysis), $QDMB_{c,d}$, using CES function. The aggregate commodity c is the one that HS6 commodities k are mapped to, as defined by the mapping MPSP_COMM in Table 1. In the model code, equation *E_qdmbk* defines regional demand for commodity k:

$$qdmbk_{k,d} = qdmb_{c,d} - ESUBK_{k,d}\left(pdmbk_{k,d} - pdmb_{c,d}\right),\ k{:}\, MPSP\_COMM(k) = c \text{ (A.10)}$$

Value of domestic absorption of aggregate commodity c is equal to sum of values of domestic absorption of disaggregated HS6 commodities k mapped to that c. This zero profit condition determines price of the aggregate commodity $PDMB_{c,d}$:

$$PDMB_{c,d} QDMB_{c,d} = \sum_{k:MPSP\_COMM(k)=c} PDMBK_{k,d}\, QDMBK_{k,d} \text{ (A.11)}$$

In the model code, this condition in linearized form is represented by equation *E_pdmb*.

Now let's introduce equations in the GTAP-HS model that support price linkages in Figure 2. Starting from the very top in Figure 2, percent change in price of domestically supplied aggregate commodity c in region s, $pds_{c,s}$, is determined by equation (A.3). At the next level, percent change in the supply price of disaggregate HS6 commodity k, $pdsk_{k,s}$, is defined by market clearing condition (A.4).

Other equations mirror those in the standard model, except for the fact that they are all defined at disaggregate commodity k level (Narayanan et al. 2010). The border export price, or FOB price, of disaggregate commodity k, $PFOB_{k,s,d}$, depends on supply price $PDSK_{k,s}$, power of destination generic export tax $TXK_{k,s}$ and power of a bilateral export tax $TXSK_{k,s,d}$:

$$PFOB_{k,s,d} = PDSK_{k,s} TXK_{k,s} TXSK_{k,s,d} \quad \text{(A.12)}$$

In the model code, this relationship in linearized form is represented by equation *E_pfobk*.

The border import price of commodity k, $PCIFK_{k,s,d}$, equals to FOB price plus transport margin. This relationship in linearized form is depicted by equation *E_pcifk*. Price of HS6 commodity k imported from region s to region d at region d domestic prices, $PMDSK_{k,s,d}$, equals to $PCIFK_{k,s,d}$ multiplied by the power of source generic import tax $TMK_{k,d}$ and power of bilateral import tax $TMSK_{k,s,d}$ (in linearized form, equation *E_pmdsk* in the model code). The remaining price linkages shown in Figure 2 are presented in equations (A.6), (A.9) and (A.11) above.

The rest of the equations are introduced to ensure that changes in disaggregate imports $qmsk_{k,d}$, disaggregate import prices $pmsk_{k,d}$, import tariffs $tmsk_{k,s,d}$, export taxes $txsk_{k,s,d}$, export FOB prices $pfobk_{k,s,d}$, import CIF prices $pcifk_{k,s,d}$, and import domestic market price $pmdks_{k,s,d}$ are appropriately aggregated (Narayanan et al. 2010).

Appendix B. The mapping between MACMAP HS 2012 codes, FAO CPC 2.1 categories and aggregated (mutual) commodity categories

No.	HS 2012 code (MACMAP trade data)	Aggregate commodity code	Aggregate commodity name	CPC 2.1 code (FAO data)
1	**2**	**3**	**4**	**5**
1	120991, 70940, 70999	vegsoth	Other vegetables	01219.01, 01239.01, 01290.01, 01290.90
2	121292	carob	Locust beans (carobs)	01356
3	70110, 70190	potatoes	Potatoes	01510
4	70200	tomatoes	Tomatoes	01234
5	70310	onions	Onions	01253.01, 01253.02
6	70320	garlic	Green garlic	01252
7	70390	leeks	Leeks and other alliaceous vegetables	01254
8	70410	broccoli	Cauliflowers and broccoli	01213
9	70420, 70490	cabbages	Cabbages	01212
10	70511, 70519, 70521, 70529	lettuce	Lettuce and chicory	01214
11	70610	carrots	Carrots and turnips	01251
12	70690, 71490	rootsoth	Other vegetable roots	01599.10
13	70700	cucumbers	Cucumbers and gherkins	01232
14	70810	peasgreen	Peas, green	01242
15	70820	beansgreen	Beans, green	01241.01, 01241.90
16	70890	legumoth	Other beans and peas, green	01243
17	70920	asparagus	Asparagus	01211
18	70930	eggplant	Eggplants (aubergines)	01233
19	70951, 70959	mushrooms	Mushrooms and truffles	01270
20	70960	chilli	Chillies and peppers, green	01231
21	70970	spinach	Spinach	01215
22	70991	artichokes	Artichokes	01216
23	70993	pumpkins	Pumpkins, squash and gourds	01235

(Continued)

Appendix B. The mapping between MACMAP HS 2012 codes, FAO CPC 2.1 categories and aggregated (mutual) commodity categories (Continued).

No.	HS 2012 code (MACMAP trade data)	Aggregate commodity code	Aggregate commodity name	CPC 2.1 code (FAO data)
1	2	3	4	5
24	71310	peasdry	Peas, dry	01705
25	71320	chickpeas	Chick peas, dry	01703
26	71331, 71332, 71333, 71339	beansdry	Beans, dry	01701
27	71334	bambara	Bambara beans, dry	01708
28	71335	cowpeas	Cow peas, dry	01706
29	71340	lentils	Lentils, dry	01704
30	71350	broadbeans	Broad beans and horse beans, dry	01702
31	71360	pigeonbeans	Pigeon peas, dry	01707
32	71390	pulsesoth	Vegetables, leguminous; n.e.c.	01709.01, 01709.02, 01709.90
33	71410	cassava	Cassava	01520
34	71420	sweetpot	Sweet potatoes	01530
35	71430	yams	Yams	01540
36	71440	taro	Taro	01550
37	71450	yautia	Yautia	01591
38	80111, 80112, 80119	coconuts	Coconuts	01460
39	80121, 80122	brazil	Brazil nuts	01377
40	80131, 80132	cashew	Cashew nuts	01372
41	80211, 80212	almonds	Almonds	01371
42	80221, 80222	hazelnuts	Hazelnuts	01374
43	80231, 80232	walnuts	Walnuts	01376
44	80241, 80242	chesnuts	Chestnuts	01373
45	80251, 80252	pistachios	Pistachios	01375
46	80261, 80262, 80290	nutsoth	Other nuts	01379.90
47	80270	kolanuts	Kola nuts	01379.02
48	80280	arecanuts	Areca nuts	01379.01
49	80310	plantains	Plantains	01313

(Continued)

Appendix B. The mapping between MACMAP HS 2012 codes, FAO CPC 2.1 categories and aggregated (mutual) commodity categories (Continued).

No.	HS 2012 code (MACMAP trade data)	Aggregate commodity code	Aggregate commodity name	CPC 2.1 code (FAO data)
1	2	3	4	5
50	80390	bananas	Bananas	01312
51	80410	dates	Dates	01314
52	80420	figs	Figs	01315
53	80430	pineapples	Pineapples	01318
54	80440	avocados	Avocados	01311
55	80450	mangoes	Mangoes, guavas, mangosteens	01316
56	80510	oranges	Oranges	01323
57	80520	tangerines	Tangerines, mandarins, clementines	01324
58	80540	pomelos	Pomelos and grapefruits	01321
59	80550	lemons	Lemons and limes	01322
60	80590	citrusoth	Other citrus fruit, n.e.c.	01329
61	80610	grapes	Grapes	01330
62	80711	watermelons	Watermelons	01221
63	80719	cantaloupes	Cantaloupes and other melons	01229
64	80720	papayas	Papayas	01317
65	80810	apples	Apples	01341
66	80830	pears	Pears	01342.01
67	80840	quinces	Quinces	01342.02
68	80910	apricots	Apricots	01343
69	80921	cherriessour	Sour cherries (Prunus cerasus), fresh	01344.01
70	80929	cherries	Cherries, other than sour cherries (Prunus cerasus), fresh	01344.02
71	80930	peaches	Peaches and nectarines	01345
72	80940	plums	Plums and sloes	01346
73	81010	strawberries	Strawberries	01354

(Continued)

Appendix B. The mapping between MACMAP HS 2012 codes, FAO CPC 2.1 categories and aggregated (mutual) commodity categories (Continued).

No.	HS 2012 code (MACMAP trade data)	Aggregate commodity code	Aggregate commodity name	CPC 2.1 code (FAO data)
1	**2**	**3**	**4**	**5**
74	81020	raspberries	Raspberries	01353.01
75	81030	currants	Currants	01351.01, 01351.02
76	81040	cranberries	Cranberries	01355.01, 01355.02, 01355.90
77	81050	kiwi	Kiwi fruit	01352
78	81060, 81090	tropoth	Other tropical and subtropical fruits, n.e.c.	01319, 01359.02, 01359.90, 01349.10, 01349.20
79	81070	persimmons	Persimmons	01359.01

Source: Developed by authors based on FAO (2018), ITC (2018).

Appendix C. The mapping between FAO commodities with available and unavailable prices

Commodities with unavailable prices		Commodities with available prices		Number of gap-filled country-commodity cases
CPC 2.1 code	**Commodity name**	**CPC 2.1 code**	**Commodity name**	
01377	Brazil nuts, in shell	01379.90	Other nuts (excluding wild edible nuts and groundnuts), in shell, n.e.c.	17
01359.02	Cashewapple	01359.90	Other fruits, n.e.c.	16
01219.01	Cassava leaves	01215	Spinach	4

Source: Developed by authors.

Appendix D. The mapping from disaggregated to aggregated GTAP sectors

No.	Aggregated sectors		Disaggregated sectors
	Code	**Description**	
1	Rice	Paddy rice	pdr, pcr
2	Wheat	Wheat	wht
3	Corn	Corn	Corn
4	Othcoarse	Other coars grains	Othgro
5	V_F	Vegetables, fruit, nuts	v_f
6	Soy	Soy	soy
7	Rapeseed	Rape seed	rape
8	Othosd	Other oil seeds	othosd
9	Sugar	Sugar cane, sugar beet	c_b, sgr
10	Plantfibers	Plant-based fibers	pfb
11	Othercrops	Crops nec	ocr
12	Animals	Livestock and Meat Products	ctl, oap, rmk, wol
13	NatResources	Natural resources	frs, fsh, omn
14	Coal	Coal	coa
15	Oil	Oil	oil
16	Gas	Gas	gas, gdt
17	Beef	Bovine meat products	cmt
18	Pork	Pork	Pork
19	Othermeat	Other meat	OthMeat
20	VegOil	Vegetable oils and fats	vol
21	Milk	Dairy products	mil
22	Ofd	Food products nec	ofd
23	B_t	Beverages and tobacco products	b_t
24	L_Mfg	Light Manufacturing	tex, wap, lea, lum, ppp, fmp, mvh, otn, omf
25	p_c	Petroleum, coal products	p_c
26	H_Mfg	Heavy Manufacturing	crp, nmm, i_s, nfm, ele, ome
27	Ely	Electricity	ely
28	OthServices	Other services	wtr, cns, trd, otp, wtp, atp, cmn, ofi, isr, obs, ros, osg, dwe

Notes: The standard GTAP 10p2 Data Base (Aguiar et al., 2019b) distinguishes 57 sectors. In this paper, we use a disaggregated version of the GTAP Data Base with 61 sectors. In particular, "Cereal grains nec" is disaggregated into "Corn" and "Other coarse grains"; "Oil seeds" is split into “Soy”, “Rape seed” and “Other oil seeds”; and “Other animal products” is disaggregated into “Pork” and “Other meat”. This split was implemented using the MSplitCom utility (https://www.copsmodels.com/msplitcom.htm).

Source: Developed by authors.

Appendix E. The mapping from disaggregated to aggregated GTAP regions

No.	Aggregate region	Description	GTAP region
1	Oceania	Oceania	aus nzl xoc
2	China	China	chn
3	Japan	Japan	jpn
4	AgImp	Agricultural Importers	kor twn sgp che irn sau are egy
5	Asia	Asia	mng xea brn khm lao phl xse bgd npl pak lka xsa hkg
6	Indonesia	Indonesia	idn
7	Turkey	Turkey	tur
8	AgExp	Other Agricultural Exporters	mys tha vnm chl ukr zaf
9	India	India	ind
10	Canada	Canada	can
11	USA	USA	usa
12	Mexico	Mexico	mex
13	SouAm	South America	xna bol col ecu pry per ury ven xsm cri gtm hnd nic pan slv xca dom jam pri tto xcb
14	Argentina	Argentina	arg
15	Brazil	Brazil	bra
16	EU	European Union	aut bel cyp cze dnk est fin fra deu grc hun irl ita lva ltu lux mlt nld pol prt svk svn esp swe gbr bgr hrv rou
17	Europe	Europe	nor xef alb blr xee xer kaz kgz tjk xsu arm aze geo
18	Russia	Russia	rus
19	MENA	Middle East and North Africa	bhr isr jor kwt omn qat xws mar tun xnf
20	ECOWAS	Economic Community of West African States	ben bfa civ gha gin nga sen tgo xwf
21	Africa	Africa	cmr xcf xac eth ken mdg mwi mus moz rwa tza uga zmb zwe xec bwa nam xsc xtw

Source: Developed by authors.

Appendix F. Change in regional welfare by scenario, mn 2014 USD

Model->	GTAP	GTAP-HS (Standard)	GTAP-HS (CEPII)		
Region\Scenario	Scenario 1: Retaliatory tariffs on US VFN only			Scenario 2: US-China trade frictions	Scenario 3: All trade frictions
Oceania	6.4	9.0	16.5	1124.9	1210.5
China	-137.7	-143.9	-123.7	-68407.2	-67279.6
Japan	11.5	7.3	9.8	5135.9	5173.4
AgImp	0.9	2.0	13.1	4599.6	4313.3
Asia	9.0	-0.1	2.5	2299.2	2254.1
Indonesia	2.1	1.2	1.4	536.0	507.7
Turkey	0.2	-3.0	-10.6	350.3	-92.2
AgExp	38.8	24.3	22.3	3810.0	3628.8
India	-20.9	17.6	11.9	1464.3	1600.7
Canada	34.1	17.4	18.7	7969.2	8726.2
USA	-161.8	-102.6	-121.4	-34880.8	-36463.2
Mexico	5.6	14.2	14.9	6411.8	6953.8
SouAm	7.2	7.0	8.3	2012.9	1836.8
Argentina	0.4	1.0	0.6	652.1	668.6
Brazil	-1.1	-0.8	-1.4	3410.8	3559.5
EU	30.3	18.4	27.5	13615.9	13571.7
Europe	-1.8	-1.5	-0.5	392.5	340.4
Russia	-6.9	-5.5	-3.5	560.5	559.4
MENA	-4.9	-4.5	-2.4	817.6	640.0
ECOWAS	1.3	-2.1	-1.4	616.9	575.1
Africa	-0.2	-1.1	-0.2	636.2	602.5
World	-187.4	-145.5	-117.9	-46871.4	-47112.3

Notes: For the GTAP-HS (CEPII) model, mean EV estimates of the SSA runs are reported.

Source: Estimated by authors.