An integrated tool for GVCs analysis through the GTAP model

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GCVs have become a key future of today's global economy and are the heart of international trade and investment policy. As over 50% of trade in goods takes place in intermediaries, planning a trade policy couldn't rely upon gross trade statistics. New trade figures are required in order perform a more accurate analysis of trade via the deconstruction of traded products in terms of value-added content, distinguished by sector/region of origin/destination. Scientific efforts have been made in this direction, however, decompositions of gross trade are limited to descriptive statistics while many trade policy analysis are made by CGE models. The objective of this paper is to fill this gap, specifically for the GTAP model. In order to reckon with the structure in values in gross flows, we introduce in the model value-added multipliers, which combine the sectoral value-added shares in each country with the direct and indirect intermediate usage in the productive process. The condition that the sum over all sector/country sources in the value-added multipliers must give unity, assures that consistency is maintained. As a result, we obtain new variables –defined in terms of value added embedded in trade- to be analyzed in assessing the impact of counterfactual simulations using the GTAP model. Clearly, even without a simulation, the new code and routine introduced in the model also allow the analyst to use RunGTAP interface as tool to decompose gross trade flows.

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1. Introduction

The increased complexity and the speed of expansion of global interactions have lead to a renewed interest on the topic of Global Value Chains (GVCs) among scholars and policy makers. New trade numbers replacing gross statistics are required in order perform a more accurate analysis of trade via the deconstruction of traded products in terms of value-added content, distinguished by sector/region of origin/destination. A body of active an expanding research has been concerned with the correct measurement of the structure of value added which underlies gross trade.

Mainly due to its consistency, full global coverage, and the large country and sectoral details it provides, the GTAP database has been extensively used in performing economic analysis of GVCs. Trade metrics on a value-added basis are based on the input-output (IO) economics (Leontief, 1936), where micro- and macro-economics are linked through the interaction of the constituents parts of the economy. The IO tables represent the delivery of output among sectors as well as the cost structure of producing in each sector. GTAP database harmonizes individual country IO data with bilateral trade flows, and provides information on total purchases of intermediate inputs by firm (domestic and imported) and total purchases of final goods by households, government and for investment (domestic and imported). However, it does not attribute bilateral trade to the consuming agent (e.g., firms or final consumption), instead aggregating these flows at the border (Narayanan et al., 2012). One common approach to overcome this limitation is to assume that all uses of a good are sourced in the same way (Walmsley et al., 2014). Daudin, Rifflart and Schweisguth (2011), Jonson and Noguera (2012) and Lejour, Rojas-Romagosa and Veenendaal (2012) use the GTAP data and a proportionality assumption in order to estimate value-added trade flows and define indicators for GVCs (e.g., re-imported and redirected value added, the value-added exports).

A more informed procedure is obtained when applying the UN Broad Economic Categories (BEC) classification scheme to the 6 digit harmonized system (HS) level bilateral trade data in COMTRADE. The BEC-influenced sourcing shares for intermediate and final demand are applied to the original GTAP data (Koopman et al., 2010; Walmsley et al., 2014; Aguiar et al., 2016). In the rebalancing procedure, trade data are kept intact while allowing the sourcing shares to adjust. The discrepancies between the two methods are considered in Koopman, Powers, Wang and Wei (2010), they find that the application of end-use categories produces lower intermediate share in exports for most developing countries (with the exception of natural-resource exporting countries such as Brazil and Russia). The BEC-informed method allows to obtain a less distorted estimate of intermediate shares to be used in decomposing gross flows; however, it is worth noticing that there is scope in improving the quality of data underlying macro GVC analysis, as BEC concordance has limited information about sourcing (i.e. proportionality is still required in order to estimate, within intermediate flows from a certain source country/sector, the purchasing sectors within all countries of destination). This adds to the inability of the BEC classification to properly identify dual-use products (Sturgeon and Memedovic, 2010).

Despite value-added measures of trade are based on estimates rather than directly observed, and there is no internationally agreed methodological framework for their measurement as international guidelines on measuring trade focus on gross values (IMF, 2013), the active research on the topic has greatly increased our knowledge of the origin of value within gross trade numbers (Johnson and Noguera, 2012; Foster-McGregor and Stehrer, 2013; Wang et al., 2013; Koopman et al. 2014; Borin and Mancini, 2015), the position and participation of a country or sector within international production networks (Koopman et al., 2010; Antràs et al., 2012; Fally, 2012; Wang and Wei., 2016), the links through which foreign demand activates the domestic production (Cappariello and Felettigh, 2015; Borin and Mancini, 2015).

IO-based analysis on GVCs use value-added multipliers that take into account the interdependence among sectors in the production processes and allow to catch a range of effects due to an increase of final output, but are not able to account for changes in GVCs in response to a significant shock to an economy. A unitary increase in the demand for a final good has an initial output effect on the production and value added of the sector that supplies that good. This in turn implies changes in the production and value added of sectors supplying intermediate inputs to the sector concerned (direct, or first round effect) and indirect effects on the outputs of all other sectors producing in all the stages of the production chain (Gretton, 2013). These effects are traditionally assessed under simplifying assumptions, e.g., fixed technological coefficients[1] and infinitely elastic supply of factors available to the economy, so that output can instantaneously and costlessly adjust to any variation in the level of final demand[2]. However, GVCs are better analyzed as "a complex set of general equilibrium interdependencies between countries that reflect a combination of preferences, technology, endowments, and policy. Shocks to income or changes in trade policy, for example, may result in subtle ripple effects throughout supply chains that are difficult to

[1] The fixed coefficient requirement pertains to intermediate component of the production, while is not necessarily required of primary factors since the latter are not included in the Leontief inverse. Thus, IO tables expressed in value terms require only fixed value shares, then they are equivalent to Cobb-Douglas formulation (see, i.e., Rose, 1995).

[2] In GTAP, this can be obtained by fixing real factor prices in all regions and endogenizing their aggregate supplies. For details, refer to Walmsley et al. (2014).

understand by considering only retrospective patterns of output and trade, or by fixing relative prices in prospective analyses" (Walmsley et al., 2014:17). Computable general equilibrium (CGE) modeling incorporates factor constraints and allows relative prices to adjust and factors to be reallocated across sectors, while admitting substitution effects in production and consumption, both within and across countries (Ferrarini and Hummels, 2014). CGE models can address a broader set of issues than the IO analysis alone, while the latter can provides CGE models with a detailed information about the value-added structure of trade flows.

The aim in this work is to include GVCs analysis in a CGE context, i.e. GTAP model. Our work is related to that of Walmesley, Hertel and Hummels (2014). They replicate IO model in a CGE framework, then sequentially relax the model's closure assumptions and introduce a full CGE model, GTAP-SC ("Supply Chain"), which allows for import sourcing by agent. Specifically, GTAP-SC model applies the Armington assumption at the agent level, and incorporates econometrically estimated parameters describing how economic agents respond to changing relative prices of alternative suppliers of intermediate inputs (Hertel et al., 2014)[3]. Increasingly imports are being purchased by firms for intermediate use. Whether imports are purchased for intermediate or final use affects the extent to which domestic or international trade policies impact competitiveness, domestic production and employment. An example of this is the removal of tariffs on imports. When imports are sold to final consumers, the fall in tariffs causes substitution away from domestic production, lowering employment; while removal of tariffs on imports sold as intermediate goods raise competitiveness, production and employment. The repercussions of policies on intermediate and final imports is best examined in a model that includes supply chains.

Since the GTAP commodities are aggregates over numerous HS-6 categories, the GTAP commodity (e.g., motor vehicles, MVH) sold to sectors for intermediate demand (MVH-semi trailers) may fundamentally differ from the same aggregate commodity sold to households (MVH-small passenger cars). As such, tariff and non-tariff measures differ by the agent purchasing the commodity, as well as by the source and destination of the commodity. More detailed information on the source of imported investment goods, and the tariff rates applied on these imports, improves our ability to analyze the impact of economic policies and other environmental factors on investment. Additionally, many countries are interested in which policies they can implement to help them participate in global supply chains; and recognize

[3] This treatment in the GTAP-SC model allows import prices to differ by agent, as would be the case if there are differential import taxes applied to intermediate vs. final goods (Walmsley et al., 2014:33).

how GVCs affect their economic growth, future development, structural change, and vulnerability to external shocks.

While mapping trade in intermediate inputs brings advancements in understanding the topology of the production process, a value-added approach enables one to assess the net economic contribution of each sector/country participating in GVCs (Escaith, 2014). In this work, we propose an extension to the standard GTAP model which allows to compute the value-added content of gross flows from a source-based perspective, according to the country/sector of its origin. Specifically, the original variable for bilateral flows is split in three sub-components: i) the (direct) foreign value added originated in the exporting country, ii) the domestic value added which is first exported and successively imported back after being processed abroad, and iii) the (indirect) foreign value added of each third country which is indirectly imported. In order to obtain this decomposition, we introduce in the model the value-added multipliers, which combines the sectoral value-added shares in each country with the direct and indirect intermediate usage in the productive process. The condition that the sum over all sector/country sources in the value-added multipliers must give unity, assures that consistency with the GTAP database is maintained. We integrate this decomposition in the RUNGTAP suite, thus enlarging the set of variables available to describe both the baseline and the simulations results. With respect to other databases, OECD/TiVA or WIOD for example, this development are model integrated and allow not only to have a descriptive picture of world trade but also to include the value chains analysis in assessing the impact of counterfactual simulations using the GTAP model.

The paper is articulated as follows. In the next section, we give some preliminary insights on value-added trade and we develop the GTAP module for GVC analysis, which introduces the value-added decomposition of gross bilateral flows. In section 3 an exemplificative simulation to illustrate the different dimensions which can be analyzed in performing a trade policy shock. We consider a Free Trade Agreement between European Union and Japan and show the structural changes in trade flows related to global networks of production.

2. The extended GTAP model for value-added analysis

GVCs are defined as an inter-country, inter-sector system of value-added sources and destinations (Koopman et al., 2014). The value is added at each successive stage of the productive process, where the value added equals the value of payments to the primary factors of production in the country-sector where the particular stage of production happens. The back and forth of intermediates -i.e., parts and components or any other item used as an input for further processing- causes a double counting problem as long as gross values rather than net value added between border crossing are recorded. Moreover traditional trade statistics do not account for indirect trade which occurs indirectly via a third country. Figure 1 illustrates the point where the bilateral flow from country s to country r is considered. Country r is the final market for the good worth 10 $ (F = 10).

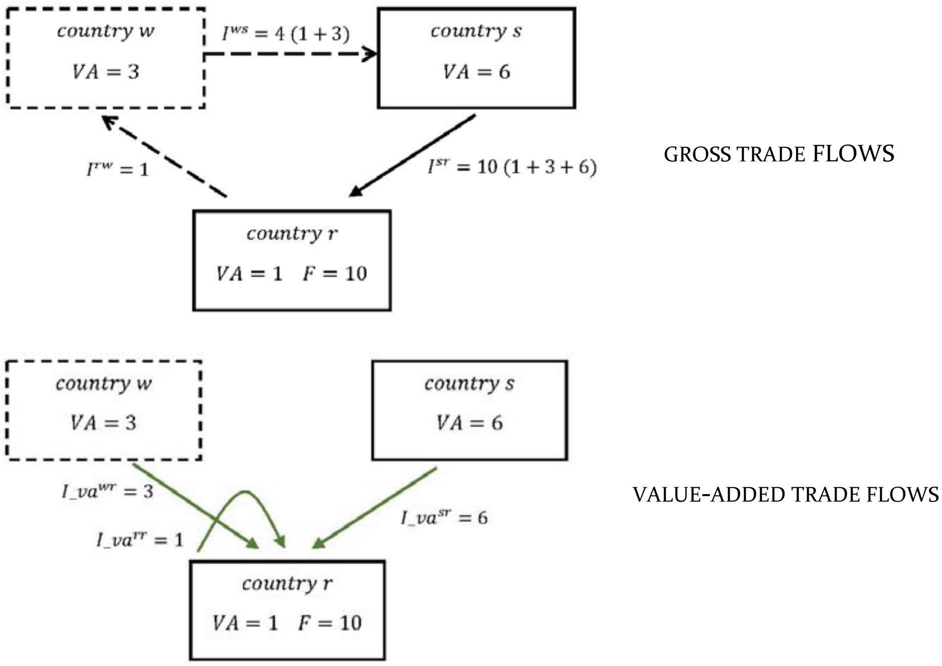

Figure 1. Gross and value-added trade flows.

A basic GVC is described: country r produces 1$ of intermediate inputs, using only its primary factors, which is exported to country w. In turn, country w adds to 1$ of imported inputs, 3$ of domestic value added. The 4$ intermediate inputs are sent to country s which performs the last stage of production adding 6$ of value to satisfy the final demand in country r. In gross trade statistics (upper panel of Figure 1), it would appears 10$ exchanges from country s to r, 4$ from w to s, and 1$ from r to w. It is shown that the first 1$ originated in r is counted three times and 3$ originated in w is counted twice. Total accounting is clearly over-counted due to these pure double-counted terms which cannot be traced back to whatever country's GDP (Koopman et al., 2014). From a value-added trade perspective (lower panel of Figure 1), country r is satisfying its 10$ final consumption by importing 6$ from s, 3$ indirectly from w, and 1$ from r itself (reflected value added). From the exporter's point of view, country s' value-added exports to country r amount to 6$, while its gross exports are 10$, so that foreign content of its bilateral exports amount to 4$.

In order to reckon with the structure in values which is embedded in gross flows, we use the insights of the IO economics and obtain the value-added multipliers to be used in the decomposition. We start with the standard GTAP model of global trade with perfect competition and constant returns to scale technology. It is built on a complete set of economic accounting and detailed inter-sector linkages for each of the economies represented. Across regions, a symmetric treatment of production and utility functions is given, so that the only differences in regional behavior in the model are those arising from differences in the relative importance of economic flows, and differences in model parameters related to the consumer demand (Hertel, 2013). The expenditures by the regional household, which receives the factor rewards, are governed by a utility function which aggregates private consumption, government spending and savings. The utility function is nested as in the standard GTAP model, with a first aggregation made over distinct goods or sectors, and between the latter a choice is made over domestic or imported quantities[4]. The firm behavior is represented in Figure 2.

```
                    --------------------
                          qo(j,r)
                            /\
                           /  \  <----- CES(ESUBT=0)
                          /    \
                         /      \
                        /        \
              qva(j,r)        qf(i,j,r)
                /|\                /\
CES(ESUBVA)--->/ | \              /  \  <------
CES(ESUBD)    /  |  \            /    \
             /   |   \          /      \
            /    |    \        /        \
      Land   Labor  Capital  Domestic     Foreign
         qfe(i,j,r)        qfd(i,j,r)    qfm(i,j,r)
                                          |
                                          |
                                          | <------ CES(ESUBM)
                                          |
                                       qifs(i,j,s,r)
```

Figure 2. Production structure in the GTAP model (Version 6.2-SC with sourcing of imports by agent).

Source: Based on figure 2.2 in Walmsley et al. (2014).

In the technology tree assumed by the model, composite value-added (qva) and intermediates (qf) enter with fixed proportions (Leontief technology) in

[4] Non-homotheticity (that is, the dependency of consumer's demand on the income level) is assumed for private household demands whose preferences are modeled through a constant difference of elasticities (CDE) functional form (Hanoch, 1975).

the production of output (qo)[5], that is the optimal mix of intermediate inputs is chosen independently of the prices of primary factors and vice versa. The firms' conditional demand for components of value added (land, labor and capital) depend on their relative prices only. As for the intermediate input side, imported intermediates are assumed to be separable from domestically produced intermediate inputs (Hertel and Tsigas, 1997).

The import demand is modeled following the Armington aggregation structure, with an exogenously differentiation scheme given by the geographical origin of homogeneous products. In the standard GTAP model the sourcing of imports occurs at the border. We follow Walmsley et al. (2014) in incorporating the sourcing of imports at the agent level, which applies the Armington assumption on demand for imports of the specific agent (government, private households, and firms). For firms, this is done by adding a new nest level linking the imported intermediates (qfm) and the imports indexed by the country of origin (qifs). ESUBM is the Armington CES for domestic/imported allocation where the elasticity of substitution between imports by source is the same for each agent.

The balancing constraint imposes the value of imports demanded from each source by each agent to equal the value of exports. Let i and $j = 1, \dots, N$ index sectors, and $s, r = 1, \dots, C$ index countries, and as for the standard GTAP notation define:

$vxmd_i^{sr}$: export of i from region s to region r (valued in market prices),

$vifms_{ij}^{sr}$: purchases of imports i from s for use by j in region r,

$vipms_i^{sr}$: demand for imports of i from region s to region r for private consumption, and

$vigms_i^{sr}$: demand for imports of i from region s to region r for government consumption.

Then:

$$vxmd_i^{sr} = \sum_j vifms_{ij}^{sr} + vipms_i^{sr} + vigms_i^{sr} \quad (1)$$

With sourcing of imports by agent, the market clearing condition for tradable supplies can be expressed in terms of values as:

[5] The parameters for the elasticity of substitution among composite intermediate inputs in production (ESUBT) are set to 0.

$$
\begin{aligned}
vom_i^s = \sum_j vdfm_{ij}^s \\
&+ \sum_j \sum_r vifms_{ij}^{sr} + vdpm_i^s \\
&+ \sum_r vipms_i^{sr} + vdgm_i^s \\
&+ \sum_r vigms_i^{sr} + vdfm_{i,cgds}^s + \sum_r vifms_{i,cgds}^{sr} \\
&+ vst_i^s
\end{aligned} \tag{2}
$$

where:

vom_i^s: value of output of commodity i in region s,

$vdfm_{ij}^s$, $vdpm_i^s$, $vdgm_i^s$: domestic good i demanded in region s by sector j, private households and government, respectively,

$vdfm_{i,cgds}^s$ and $vifms_{i,cgds}^{sr}$: domestic and imported i for investment, and

vst_i^s: exports of region s to the international transport sector i.

The first two terms in (1) are the intermediate delivery of i in region s, while terms 3 to 8 refer to final consumption. The last term, vst_i^s, is the global transport sector to which regional economy s export transport services. Due to lack of information, regional transport services exports are not associated with particular commodities and routes (Hertel and Tsigas, 1997). Following Peters et al. (2011), we assume that for each use of the international transport pool is proportionally distributed over each supplier. We apply the regional shares of exports on the transport pool to the international transportation margin ($vtwr_{ij}^{rs}$) which are defined over commodities (j) and routes (from r to s):

$$
vste_{ij}^{sr} = \frac{vst_i^s}{\sum_s vst_i^s} \sum_r vtwr_{ij}^{rs} \tag{3}
$$

By construction, and given the zero profit condition for the international transport sector, it holds:

$$
\sum_j \sum_r vste_{ij}^{sr} = vst_i^s \tag{4}
$$

For the ease of exposition, we define total intermediate demand (int_{ij}^{sr}), total final demand (fin_i^{sr}) and the total value of imports agent generic ($vims_i^{sr}$):

$$
int_{ij}^{sr} = vdfm_{ij}^s + vifms_{ij}^{sr} + vste_{ij}^{sr} \quad , \tag{5}
$$

$$fin_i^{sr} = vdpm_i^s + vdgm_i^s + vipms_i^{sr} + vigms_i^{sr} + vigms_i^{sr} + vdfm_{i,cgds}^s + vifms_{i,cgds}^{sr} \;, \tag{6}$$

$$vims_i^{sr} = \sum_j \sum_r vifms_{ij}^{sr} + \sum_r vipms_i^{sr} + \sum_r vigms_i^{sr} + vst_i^s \tag{7}$$

By substituting (5) and (6) into (2):

$$vom_i^s = \sum_j \sum_r int_{ij}^{sr} + \sum_r fin_i^{sr} \tag{8}$$

The right-hand side of (8) is equivalent to the row balance condition in the IO analysis, that is production is completely used as intermediate or final consumption, either at home or abroad[6]. The delivery of intermediates is used in the production of the receiving countries. As a share of destination country r's sectoral output, we get:

$$a_{ij}^{sr} = \frac{int_{ij}^{sr}}{vom_j^r} \tag{9}$$

where a_{ij}^{sr} is an element of the A matrix of technical (or structural) coefficients with dimension $NCxNC$, giving the share of intermediate i originated in region s which is used by sector j in country r on of j's output in r. By substituting, equation (8) can be written as:

$$vom_i^s = \sum_j \sum_r a_{ij}^{sr} vom_j^r + \sum_r fin_i^{sr} \tag{10}$$

Considering all countries and introducing a block matrix notation (a block for each country/country pair), output identity can be expressed as:

$$\begin{bmatrix} VOM^1 \\ VOM^2 \\ \vdots \\ VOM^c \end{bmatrix} = \begin{bmatrix} A^{11} & A^{12} & \cdots & A^{1c} \\ A^{21} & A^{22} & \cdots & A^{2c} \\ \vdots & \vdots & \ddots & \vdots \\ A^{c1} & A^{c2} & \cdots & A^{cc} \end{bmatrix} \begin{bmatrix} VOM^1 \\ VOM^2 \\ \vdots \\ VOM^c \end{bmatrix} + \begin{bmatrix} FIN^{11} & FIN^{12} & \cdots & FIN^{1c} \\ FIN^{21} & FIN^{22} & \cdots & FIN^{2c} \\ \vdots & \vdots & \ddots & \vdots \\ FIN^{c1} & FIN^{c2} & \cdots & FIN^{cc} \end{bmatrix} \tag{11}$$

[6] Recall that the diagonal elements of the intermediate matrix include both domestic and imported goods, cfr. eq. (5), and the final demand matrix include both domestic consumption and imports, cfr. eq. (6). The domestic consumption is added in both equations whenever $s = r$.

For given levels of final demand, the system in (11) can be solved for VOM, which gives:

$$\begin{bmatrix} VOM^1 \\ VOM^2 \\ \vdots \\ VOM^c \end{bmatrix} = \begin{bmatrix} I - A^{11} & -A^{12} & \cdots & -A^{1c} \\ -A^{21} & I - A^{22} & \cdots & -A^{2c} \\ \vdots & \vdots & \ddots & \vdots \\ -A^{c1} & -A^{c2} & \cdots & I - A^{cc} \end{bmatrix}^{-1} \begin{bmatrix} FIN^{11} & FIN^{12} & \cdots & FIN^{1c} \\ FIN^{21} & FIN^{22} & \cdots & FIN^{2c} \\ \vdots & \vdots & \ddots & \vdots \\ FIN^{c1} & FIN^{c2} & \cdots & FIN^{cc} \end{bmatrix} = \begin{bmatrix} L^{11} & L^{12} & \cdots & L^{1c} \\ L^{21} & L^{22} & \cdots & L^{2c} \\ \vdots & \vdots & \ddots & \vdots \\ L^{c1} & L^{c2} & \cdots & L^{cc} \end{bmatrix} \begin{bmatrix} FIN^{11} & FIN^{12} & \cdots & FIN^{1c} \\ FIN^{21} & FIN^{22} & \cdots & FIN^{2c} \\ \vdots & \vdots & \ddots & \vdots \\ FIN^{c1} & FIN^{c2} & \cdots & FIN^{cc} \end{bmatrix} \quad (12)$$

where I is the $NCxNC$ identity matrix, and $L = (I - A)^{-1}$ is the global Leontief inverse (or multiplier) matrix, giving total requirement of output directly *and* indirectly required worldwide to produce one unit of consumption.

Next, we turn to the value-added component. Output net of intermediate usage gives the composite value added originated in each producing sector for each economy. Then, sectoral value-added shares for country s is given by:

$$vsh_j^s = \frac{(vom_j^s - \sum_i \sum_r int_{ij}^{rs})}{vom_j^s} \quad (13)$$

Define a diagonal matrix $\widehat{VSH}$ with value-added shares in the main diagonal and zero in the off-diagonals. Multiplying $\widehat{VSH}$ with the Leontief inverse generates the value-added multiplier matrix, which provides a breakdown of the flows of value added across sectors:

$$\widehat{VSH}L = \begin{bmatrix} VSH^1L^{11} & VSH^1L^{12} & \cdots & VSH^1L^{1c} \\ VSH^2L^{21} & VSH^2L^{22} & \cdots & VSH^2L^{2c} \\ \vdots & \vdots & \ddots & \vdots \\ VSH^cL^{c1} & VSHL^{c2} & \cdots & VSH^cL^{cc} \end{bmatrix} \quad (14)$$

The $\widehat{VSH}L$ is the key matrix in the value-added trade literature (alternatively referred to as VB or VAS matrix). It contains all the information about the partition of value added by country/sector sources in the production process. Specifically, a typical sub-matrix in the main diagonal represents the domestic value-added share in domestic production per sector. For country s it is given by:

$$\widehat{VSH}^s L^{ss} = \begin{bmatrix} vsh_1^s l_{11}^{ss} & vsh_1^s l_{12}^{ss} & \cdots & vsh_1^s l_{1n}^{ss} \\ vsh_2^s l_{21}^{ss} & vsh_2^s l_{22}^{ss} & \cdots & vsh_2^s l_{2n}^{ss} \\ \vdots & \vdots & \ddots & \vdots \\ vsh_n^s l_{n1}^{ss} & vsh_n^s l_{n2}^{ss} & \cdots & vsh_n^s l_{nn}^{ss} \end{bmatrix} \tag{15}$$

where the element $vsh_n^s l_{n1}^{ss}$ gives the share of value added originated in the domestic n-th sector used by domestic sector 1 related to a unit of final demand. The off-diagonal sub-matrices denote foreign value-added shares in domestic production, disentangled along country-sector. The shares value added of country 1 embedded in country s' domestic production are represented by:

$$\widehat{VSH}^1 L^{1s} = \begin{bmatrix} vsh_1^1 l_{11}^{1s} & vsh_1^1 l_{12}^{1s} & \cdots & vsh_1^1 l_{1n}^{1s} \\ vsh_2^1 l_{21}^{1s} & vsh_2^1 l_{22}^{1s} & \cdots & vsh_2^1 l_{2n}^{1s} \\ \vdots & \vdots & \ddots & \vdots \\ vsh_n^1 l_{n1}^{1s} & vsh_n^1 l_{n2}^{1s} & \cdots & vsh_n^1 l_{nn}^{1s} \end{bmatrix} \tag{16}$$

Since all value embedded in the production of a unit of output must be either domestic or foreign, the sum over all sector/country sources in the value-added multipliers (sum by column of the $\widehat{VSH}L$ matrix), must give unity. For the generic column referred to the production of j in country s it is true the following:

$$\sum_i \sum_r vsh_i^r l_{ij}^{rs} = 1 \tag{17}$$

The condition in (17) assures that consistency is maintained while post-multiplying by the bilateral import vectors. This allows to recover the value-added content of bilateral trade, both direct and indirect. Specifically, the value added which originates in (all i upstream sectors of) country t and is embedded in country s' exports (in sector j) to country r is given by:

$$\begin{aligned} VAIT_{tsr}^j &= \sum_i vshl_{ij}^{ts} * vims_j^{sr} \\ &= \sum_i vshl_{ij}^{ss} * vims_j^{sr} + \sum_i vshl_{ij}^{rs} * vims_j^{sr} \\ &+ \sum_i \sum_{t \neq s,r} vshl_{ij}^{ts} * vims_j^{sr} \end{aligned} \tag{18}$$

Equation (18) splits the original variable for bilateral flows ($vims$) into three sub-components accordingly to the origin of traded value added. Namely, from the point of view of country r importing from s:

i) the foreign value added originated in all sectors of the direct exporting country s embodied in its exports of sector j to r (first term RHS),

ii) the domestic value added originated in all sectors of r which is imported back from the sector j of country s (second term RHS), and

iii) the indirect foreign value added of third countries which is indirectly imported by r from sector j of s (last term RHS).

Each of these components can be analyzed in assessing the impact of counterfactual simulations. As an example, consider a trade policy shock. As in the standard model, a reduction of the bilateral import tariff on i from r to s would imply a reduction in the price of s' imports of i from country r and will cause a substitution away from competing imports. Lower prices cause demand to increase for that imports which induces an expansion effect (both in liberalizing country and in the exporting country), due to the zero profit condition and the constant return to scale assumption. Under standard closure, the supply of factors is fixed, so that the increasing demand for primary factors implies prices to adjust and factors to be reallocated across sectors. The shock is then transmitted to other sectors of the economy. The increased demand in country r for intermediate inputs used in the production of commodity i has an effect on the traded value added for countries which supply that intermediates. The GTAP-VA ("Value added") module allows to assess the impact on the output which is activated through the production chain for the traded GTAP commodity i. The value-added multipliers are endogenous to the model so they are responsive to substitution and reallocation effects due to the policy shock.

In the next section we give an illustrative application of the extended model by considering the effects of a trade agreement between European Union and Japan on the value-added composition of gross bilateral trade.

3. **Illustrative application**

The global economy is aggregated into 10 economies (European Union, Canada, United States of America, China, Japan, Korea, India, Brazil, Russia and Turkey) plus the rest of the world and 13 sectors (agriculture, extraction, food, textiles, wood, petroleum, chemicals, metals, motor vehicles, electronic equipment, machinery, manufactures, and services). The correspondence with GTAP regions and sectors is given in Table 1.

Table 1. GTAP database aggregation

Commodities and Activities*
Agriculture
Extraction
Food
Textiles
Wood
Petroleum
Chemicals
Metals
Motor vehicles
Electronic equipment
Machinery
Manufacturing
Services
Country/Region
European Union**
Canada
United States of America
China
Japan
Korea
India
Brazil
Russia
Turkey
Rest of the world

* Agriculture: paddy rice; wheat, cereal grains nec; vegetables, fruit, nuts; oil seeds; sugar cane, sugar beet; plant-based fibers; crops nec; bovine cattle, sheep and goats, horses; animal products nec; raw milk; wool, silk-worm cocoons. Extraction: forestry; fishing; coal; oil; gas; minerals nec. Food: bovine cattle, sheep and goat meat products; meat products; vegetable oils and fats; dairy products; processed rice; sugar; food products nec; beverages and tobacco products. Textiles: textiles; wearing apparel; leather products. Wood: wood products; paper products, publishing. Petroleum: petroleum, coal products. Chemicals: chemical, rubber, plastic products. Metals: mineral products nec; ferrous metals; metals nec; metal products. MotorVehi: motor vehicles and parts; transport equipment nec. ElecEquip: electronic equipment. Machinery: machinery and equipment nec. Manufacturing: manufactures nec. Services: electricity; gas manufacture, distribution; water; construction; trade; transport nec; water transport; air transport; communication; financial services nec; insurance; business services nec; recreational and other services; Public Administration and defense, education, health; ownership of dwellings.

** European Union: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom.

3.1 Descriptive analysis

First we report the origin of value added for the total imports and exports of an economy. As for the imports side, we can recover the domestic (reflected) value-added content and the foreign value-added, both direct (originated in the exporting country) and indirect (originated in third countries). Looking at the exports, we obtain the exported value originated in the exporting country, the value which is reflected back to the importing economy, the and the foreign value added which is redirected by the exporting country[7].

Table 2 shows a breakdown of total imports and exports for European Union. Its imports mainly contain foreign value added originated in the exporting country, where the highest shares are found in sectors like extraction, agriculture, food and services, which require very few imported intermediates in their production. The share for indirect trade is a no negligible portion (17.4%), of which 3.8% represents value added that has been created domestically in upstream stages of the chain. Imports in motor vehicles and chemicals reflect the highest shares of European value added. In manufacturing sectors like electronic equipment and motor vehicles, and in the extractive industry (e.g. coke, petroleum products, processing of nuclear fuel) is redirected the highest share of foreign value added which is originated in 'third' countries, reflecting the fact that it supplies inputs at key sectors involved in GVC trade. The majority of the European Union exports is represented by European value added (85.2%), as large economies typically source only a small share of their intermediate inputs from abroad. When considering both the reflected and the foreign value added which is redirected by European Union, we get a measure of its backward participation to GVCs (see, i.e., TiVA indicator), that is the use of imports of intermediates to produce exports (14.7%), more pronounced for the extractive industry (53.1%). Table 3 shows the same decomposition for Japanese trade. The two economies are quite similar in terms of the composition of trade. A few differences may be noted. Only 1.6% is the domestic value which is imported back in Japan, with the electronics sector showing a higher share (5.5%) on total sectoral imports. Japan has a higher backward participation share (18.6). More than 60% of the exports in petroleum is foreign sourced and more than 30% in textiles.

A country's involvement in GVCs can be assessed also in terms domestic value added sent indirectly to third economies. The forward participation expresses the domestic value added content in inputs which is exported to third economies for further processing and export through the value chain.

[7] The attribution of domestic/foreign label through the paper is always made with reference to the importing country. Whenever the importing country is the same country where the value originates, we have "domestic" value.

Table 2. Breakdown in total imports and exports, European Union.

Value of total imports		**Value of total exports**	
(excluding intra-EU trade)	3.055.748	(excluding intra-EU trade)	2.709.402
Foreign value added, direct	2.523.518	**Exported domestic value added,**	2.309.071
(% share, total gross imports)	**82,6%**	*(% share, total gross exports)*	**85,2%**
Main partner:		Main partner:	
(% total foreign value added, direct)		*(% total foreign value added, direct)*	
United States	16,4%	United States	19,3%
China	13,4%	China	8,6%
Russia	11,6%	Russia	6,7%
Japan	4,1%	Japan	4,2%
Main sector:		Main sector:	
(% total sectoral imports)		*(% total sectoral exports)*	
Extraction	93,6%	Services	91,4%
Agriculture	91,2%	Extraction	91,3%
Services	89,2%	Agriculture	90,5%
Food	85,4%	Wood	90,2%
Domestic value added, reflected	117.254	**Reflected value added**	55.345
(% share, total gross imports)	**3,8%**	*(% share, total gross exports)*	**2,0%**
Main partner:		Main partner:	
(% total domestic value added)		*(% total domestic value added)*	
United States	10,9%	United States	21,4%
China	9,9%	China	7,9%
Turkey	7,5%	Russia	5,3%
Russia	6,6%	Japan	1,3%
Main sector:		Main sector:	
(% total sectoral imports)		*(% total sectoral exports)*	
MotorVehi	6,5%	Petroleum	10,1%
Chemicals	6,1%	ElecEquip	2,6%
Machinery	5,3%	Chemicals	2,5%
Metals	5,0%	Metals	2,2%
Foreign value added, indirect	414.976	**Foreign value added, indirect**	344.986
(% share, total gross imports)	**13,6%**	*(% share, total gross exports)*	**12,7%**
Main partner:		Main partner:	
(% total foreign value added, indirect)		*(% total foreign value added, indirect)*	
United States	13,6%	United States	19,1%
China	12,2%	China	8,8%
Russia	4,8%	Russia	6,7%
Japan	9,1%	Turkey	4,8%
Main sector:		Main sector:	
(% total sectoral imports)		*(% total sectoral exports)*	
ElecEquip	27,4%	Petroleum	43,0%
Petroleum	26,8%	ElecEquip	19,0%
MotorVehi	20,1%	MotorVehi	14,9%
Metals	18,2%	Chemicals	14,9%

Notes: Absolute values are expressed in mio, US $.

Source: Authors' calculations based on GTAP database.

Table 3. Breakdown in total imports and exports, Japan.

Value of total imports	956.998	**Value of total exports**	902.546
Foreign value added, direct	790.484	**Exported domestic value added, dire**	734.780
(% share, total gross exports)	**82,6%**	*(% share, total gross exports)*	**81,4%**
Main partner:		Main partner:	
(% total foreign value added, direct)		*(% total foreign value added, direct)*	
China	17,6%	China	20,5%
United States	13,4%	United States	16,5%
European Union	11,6%	European Union	14,0%
Korea	3,1%	Korea	7,6%
Main sector:		Main sector:	
(% total sectoral imports)		*(% total sectoral exports)*	
Extraction	92,8%	Services	92,3%
Agriculture	89,8%	Agriculture	88,8%
Services	89,7%	Extraction	87,2%
Food	85,8%	Manufacture	85,2%
Domestic value added, reflected	15.224	**Reflected value added**	22.470
(% share, total gross exports)	**1,6%**	*(% share, total gross exports)*	**2,5%**
Main partner:		Main partner:	
(% total domestic value added)		*(% total domestic value added)*	
China	27,7%	China	23,4%
Korea	11,4%	United States	13,8%
United States	5,8%	European Union	9,9%
European Union	4,6%	Korea	2,2%
Main sector:		Main sector:	
(% total sectoral imports)		*(% total sectoral exports)*	
ElecEquip	5,5%	Petroleum	14,1%
Machinery	3,4%	Textiles	6,8%
MotorVehi	3,0%	Chemicals	3,0%
Metals	2,4%	ElecEquip	3,0%
Foreign value added, indirect	151.290	**Foreign value added, indirect**	145.296
(% share, total gross exports)	**15,8%**	*(% share, total gross exports)*	**16,1%**
Main partner:		Main partner:	
(% total foreign value added, indirect)		*(% total foreign value added, indirect)*	
China	22,2%	China	21,6%
Korea	12,1%	United States	15,1%
United States	9,9%	European Union	12,8%
European Union	9,3%	Korea	10,0%
Main sector:		Main sector:	
(% total sectoral imports)		*(% total sectoral exports)*	
Petroleum	35,7%	Petroleum	46,8%
ElecEquip	28,1%	Textiles	23,6%
Metals	24,0%	Chemicals	23,5%
Chemicals	22,6%	Metals	22,0%

Notes: Absolute values are expressed in mio, US $.

Source: Authors' calculations based on GTAP database.

When considering only extra-EU trade, European Union shows a low level of forward participation. As shown in Table 4, machinery and chemicals are the sectors with a highest shares on the total of the component (more than 14%). The indirect exports happen mainly through China, United States, Korea and Japan.

Table 4. Indirect exported value added, European Union.

GVC participation_forward	**12,2**
(% share, total gross exports)	
Main partner:	
(% share, total indirect exports of value added)	
China	13,2
United States	12,4
Korea	6,5
Japan	4,6
Main sector:	
(% share, total indirect exports of value added)	
Machinery	14,5
Chemicals	14,2
Extraction	12,5
ElecEquip	11,0

Source: Authors' calculations based on GTAP database.

The participation of Japan in GVCs is mainly driven by its forward linkages (Table 5). On total gross exports, more than 21% represents indirect exports. The main trade partners in redirecting domestic intermediates are China, Korea and European Union. Japanese intermediates are mainly used for exports in electronic equipment and machinery.

Table 5. Indirect exported value added, Japan.

GVC participation_forward	**21,2**
(% share, total gross exports)	
Main partner:	
(% share, total indirect exports of value added)	
China	23,7
Korea	14,0
European Union	9,5
United States	8,1
Main sector:	
(% share, total indirect exports of value added)	
ElecEquip	26,0
Machinery	20,4
MotorVehi	13,6
Chemicals	11,5

Source: Authors' calculations based on GTAP database.

3.2 Simulation and results

For our simulation, we fully remove tariffs between the European Union and Japan. The baseline refers to 2011. First we discuss the impact on bilateral trade. Table 6 shows the effects on the European Union's imports from Japan considering gross trade and value-added trade. The first column shows baseline trade volumes, and the second column gives the percent change due to the European Union-Japan free-trade agreement (FTA). The third to fifth columns regard the domestic value added which is re-imported in European Union, and give, respectively, the baseline volumes, the shares on gross imports and the percent change deriving from tariff removal. Columns six to eight show the same information for the Japanese value added directly exported to European Union. Finally, columns nine to eleven concern the value added originated in third countries. European imports from Japan would increase by 18%. The largest trade gains from liberalization would occur in the motor vehicles, machinery and chemicals sectors. Japan would export more in European Union also in food (+58,9%) and textiles (+55,7%), however in absolute terms the increase is quite low.

Looking at the value-added components, we find that the gains are redistributed among all the countries backward involved in the production of the imported goods. Even if the composition of imports would change only marginally due to the bilateral elimination of tariffs, in terms of value-added trade we find some interesting effects. First, dismantling tariff bilaterally implies the domestic value added (reflected) to increase more than the increase recorded on gross values. That is, domestic firms producing in upstream stages intermediates further processed and imported back would take relatively more advantage from the liberalization. This can be seen from the fact that the percentage increase referred to the domestic component of imports is always higher as compared to gross trade, while foreign value added (both direct and indirect) moves around the same percentages as gross imports' changes. This "amplified" effect is explained by the fact that the domestic component of imports concerns goods that double-cross exactly the borders which are liberalized. This effect is more pronounced in textiles and food sectors. Second, the increase in the exporter's direct value added (foreign value added, direct) is lower than the increase we obtain for exports on a gross metric, since the gains are now redistributed among all the countries backward involved in GVCs. Third, third countries value added redirected by Japan to European Union also increase. We will come back to these indirect effects later in this paper.

Table 7 gives a similar picture for Japanese imports from European Union. Japan would import 19,2% more from European Union. Here the gains are mostly generated in the food sector (+186,3%), followed by textiles (+136%),

Table 6. Breakdown in the impact on European Union's imports from Japan, by value-added component.

	Gross imports		Domestic value added			Foreign value added, direct			Foreign value added, indirect		
Sector	Baseline	FTA scenario	Baseline		FTA scenario	Baseline		FTA scenario	Baseline		FTA scenario
	(mio, US $)	*% change**	*(mio, US $)*	*(% share)***	*% change**	*(mio, US $)*	*(% share)***	*% change**	*(mio, US $)*	*(% share)***	*% change**
Agricultur	58	20,2	1	(1,2)	37,8	52	(88,8)	20,0	6	(10,0)	19,0
Extraction	95	8,5	1	(1,0)	27,7	83	(87,2)	8,6	11	(11,8)	7,1
Food	246	58,9	4	(1,4)	147,5	207	(84,1)	58,0	36	(14,5)	53,8
Textiles	1.053	55,7	33	(3,1)	137,3	732	(69,6)	54,9	288	(27,4)	48,3
Wood	459	3,7	9	(1,9)	10,7	393	(85,7)	3,6	57	(12,4)	3,2
Petroleum	1.801	8,2	32	(1,8)	8,5	705	(39,1)	8,1	1.065	(59,1)	8,1
Chemicals	14.465	24,6	457	(3,2)	31,7	10.640	(73,6)	24,5	3.368	(23,3)	24,0
Metals	7.990	9,8	120	(1,5)	14,2	6.055	(75,8)	9,7	1.815	(22,7)	9,6
MotorVehi	23.630	45,2	488	(2,1)	51,2	19.847	(84,0)	45,1	3.295	(13,9)	44,8
ElecEquip	10.602	15,6	196	(1,8)	20,4	8.562	(80,8)	15,5	1.843	(17,4)	15,7
Machinery	34.718	13,7	598	(1,7)	17,2	29.318	(84,4)	13,7	4.803	(13,8)	13,8
Manufactu	1.619	11,7	27	(1,6)	20,8	1.380	(85,2)	11,5	213	(13,2)	10,8
Services	27.083	-0,9	251	(0,9)	7,6	25.005	(92,3)	-0,9	1.828	(6,7)	-1,6
Total	123.819	18,0	2.214	(1,8)	28,7	102.977	(83,2)	17,5	18.627	(15,0)	19,6

* Percent change resulting from tariff removal scenario.

** Percent gross imports, by sector

Source: GTAP-VA model simulation.

Table 7. Breakdown in the impact on Japan's imports from European Union, by value-added component.

	Gross imports		Domestic value added			Foreign value added, direct			Foreign value added, indirect		
Sector	Baseline	FTA scenario	Baseline		FTA scenario	Baseline		FTA scenario	Baseline		FTA scenario
	(mio, US $)	*% change **	*(mio, US $)*	*(% share) ***	*% change **	*(mio, US $)*	*(% share) ***	*% change **	*(mio, US $)*	*(% share) ***	*% change **
Agriculture	558	23,3	2	(0,3)	37,3	505	(90,6)	23,2	52	(9,3)	23,4
Extraction	220	9,1	1	(0,3)	20,1	201	(91,4)	9,0	19	(8,4)	9,2
Food	7.011	186,3	21	(0,3)	215,9	6.236	(88,9)	186,2	754	(10,8)	186,3
Textiles	3.938	136,0	20	(0,5)	177,0	3.380	(85,8)	135,8	538	(13,7)	136,1
Wood	3.412	6,5	12	(0,3)	17,2	3.079	(90,2)	6,5	321	(9,4)	6,5
Petroleum	335	5,7	1	(0,2)	8,8	157	(46,9)	5,7	177	(52,8)	5,6
Chemicals	22.311	6,4	151	(0,7)	20,5	18.421	(82,6)	6,3	3.739	(16,8)	6,4
Metals	4.896	5,6	28	(0,6)	15,3	4.097	(83,7)	5,6	771	(15,7)	5,8
MotorVehi	11.633	1,4	152	(1,3)	22,4	9.645	(82,9)	1,1	1.837	(15,8)	1,3
ElecEquip	2.016	0,9	34	(1,7)	8,4	1.581	(78,4)	0,8	402	(19,9)	0,7
Machinery	14.440	1,2	149	(1,0)	11,4	12.238	(84,8)	1,1	2.052	(14,2)	1,2
Manufacture	1.561	20,1	8	(0,5)	32,7	1.347	(86,3)	20,1	205	(13,1)	20,5
Services	39.337	0,5	120	(0,3)	10,0	35.964	(91,4)	0,5	3.252	(8,3)	0,6
Total	111.668	19,2	696	(0,9)	26,7	96.852	(86,8)	19,2	14.120	(12,6)	18,2

* Percent change resulting from tariff removal scenario.

** Percent gross imports, by sector

Source: GTAP-VA model simulation

sectors facing a high protection in the baseline. This would imply a major diversification, whereas the baseline shows a concentration in a few sectors (services, chemicals, motor vehicles and machinery, which account for almost 80% of total bilateral imports). Also in this case, the domestic value added is the most affected among the value-added components. The European Union value added directly exported to Japan would increase mainly in food and textiles sectors. Indirect trade to Japan via European Union would also increase.

Next, we consider the effects on third economies due to their backward linkages in the production of European exports. The "systemic" effect can be analyzed by disentangle the country of origin in each trade link. Table 8 reports the absolute change in the value each country adds to European exports, deriving from tariff removal between European Union and Japan.

Table 8. Changes in the composition of European Union exports deriving from the FTA with Japan.

Exporter: European Union											
	Importing country										
	Japan	USA	Russia	India	Turkey	Canada	Brazil	Korea	China	RoW	Total VA
EU	18.629	-1.134	-345	-205	-249	-186	-191	-48	-272	-2.318	13.681
Country of origin of value											
Japan	186	458	170	58	112	56	63	58	272	1.060	2.493
USA	368	-22	-6	-3	-5	-4	-4	0	-3	-38	283
Russia	245	-19	-5	-3	-3	-3	-3	-1	-3	-35	170
India	92	-4	-1	0	-1	-1	-1	0	-1	-6	77
Turkey	70	-5	-1	0	-2	-1	-1	-1	-2	-12	45
Canada	57	-2	0	0	0	-1	0	0	0	-2	52
Brazil	144	0	0	0	0	0	0	0	2	4	150
Korea	38	-3	-1	0	0	-1	0	-1	-1	-5	26
China	304	-9	-3	-2	-3	-2	-2	1	2	-15	271
RoW	1.258	-37	-8	-8	-9	-7	-8	3	7	-57	1.134
Total exports	21.391	-777	-200	-163	-160	-150	-147	11	1	-1.424	18.382

Note: Absolute changes deriving from tariff removal.

Source: GTAP-VA model simulation.

By row, is represented the country of origin of value, so that the sum by row gives the total exported value through European exports to the world. Columns distinguish the importing country; sum by column gives the total bilateral imports from European Union. Except for the first row (which records total exports) and the second row (which is European Union's value added directly exported), the diagonal elements give the value added that European Union reflects to each country. Extra-diagonals refer to the indirect value added redirected by European Union to each country of destination. As expected, European Union's total exports would expand due to the FTA. As already seen, its trade with Japan increases, while trade diversion occurs for all other countries, particularly for United States (last row). Within the decrease in European exports to Unites States, we can account for which country is losing/gaining more by the bilateral liberalization (second column). The domestic content of United States reflected by European Union would decrease. Japan increase its indirect exports to Unites States diverted by European Union, while all other countries will decrease their value exported indirectly to United States (via European Union).

Then, we may ask what happens to the indirect value which is exported to United States through different trade links. As Table 9 shows, European Union, Brazil, China and Japan slightly increase their indirect exports to United States, while for the other countries indirect exports decrease, particularly for Russia. The reflected component (first row) increases meaning that United States is importing more of its domestic value added.

Table 9. United States' indirect imports of value added, by country of origin of value.

Indirect imports, United States

Exporter: World

USA	EU	Japan	Russia	India	Turkey	Canada	Brazil	Korea	China	RoW	Total
126	54	2	-24	-2	-3	-1	11	4	3	-164	5

Note: Absolute changes deriving from tariff removal.

Source: GTAP-VA model simulation.

Further, we can check for the countries which are reflecting more/less United States' value. United States would import back more domestic value added from Canada and China which overset its losses from European Union and Japan (Table 10).

Table 9. United States' indirect imports of domestic value added, by country of reflection.

United States' imports of domestic value added

EU	Japan	Russia	India	Turkey	Canada	Brazil	Korea	China	RoW	Total
-22	-56	1	2	0	68	2	7	29	95	126

Note: Absolute changes deriving from tariff removal.

Source: GTAP-VA model simulation.

The breakdown can be done for each economy in the global trade system, and can be extended to analyze each exporting sector. The developments presented in this paper allow to obtain a more detailed framework in analyzing the global effects of trade policy on production networks.

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