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GTAP-VA: an Integrated Tool for Global Value Chain Analysis

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Global Value Chains (GVCs) have transformed production across a broad range of goods and services worldwide. New trade statistics are required in order to perform a more accurate analysis of trade flows through their decomposition in terms of value-added content, distinguished according to the sector/region of origin/destination. Our approach traces value added embedded in trade flows back to its origin or forward to its destination in a Computable General Equilibrium (CGE) model. A new module (available as a download with this paper) is introduced to the Global Trade Analysis Project (GTAP) model and used in a stylized scenario with 3 regions (the United States, the European Union and the Rest of the World) and 3 sectors (Manufactures, Agrifood and Services) where a free trade area between the European Union and the United States is simulated. Results show that the new version of the model (GTAP-VA) makes a useful contribution to trade policy analysis.

JEL codes: C68, F13, F17.

Keywords: Trade in value added; Global value chains; Computable general equilibrium model; Global Trade Analysis Project; Trade policy.

1. Introduction

In recent decades, the increased complexity and speed of expansion of global interactions have led to renewed interest in Global Value Chains (GVCs) among scholars and policy makers. As a result, the conceptual framework used to analyze trade and the empirical measurements of international commercial flows are changing. Over 50% of trade in goods takes place in intermediates,

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reflecting the fact that countries use foreign intermediate inputs to produce exports so that the destinations of exports do not always coincide with the final markets of consumption.

Traditional trade statistics do not provide information on the actual patterns of production behind world trade since the value added exported by a country does not coincide with the value of that country's exports because exports contain value added from other countries. Moreover, imports have a *domestic* content given by the contribution of domestic firms exporting intermediate inputs which are processed abroad and then imported back. Finally, gross recording of trade flows does not account for backward/forward trade, i.e., trade in value added between two countries occurring via a *third* country.

Given that official trade statistics based on gross flows hide the extent of GVCs, there is also widespread recognition that fragmentation of global production requires measurement of trade in Value Added (VA). Traditional approaches assigned the total commercial value of an import to a single country of origin. This was an accurate formula when trade simply involved final goods produced from domestic inputs. It also works when imported raw materials are used to produce goods consumed in the importing country. However, when applied to 'made in the world' products, the methodology can exaggerate bilateral trade imbalances and misrepresent where value addition occurs. This incongruence can generate policies that do not reflect the pace, direction, and reality of world production and trade.

The current standard for GVC analysis relies on an Inter-Country Input-Output (ICIO) table. An ICIO table harmonizes national input-output (IO) tables for multiple regions and links trade flows directly from producers in each region to importing firms and consumers in all other regions. Various research initiatives have undertaken the development of different versions of an ICIO table. Among the most well-known there are the World Input Output Database (WIOD: http://www.wiod.org/home), Trade in Value Added (TiVA: http://www.oecd.org/sti/ind/measuringtradeinvalue-addedanoecd-wtojointinitiative.htm) as well as the Global Trade Analysis Project (GTAP) Data Base.

Thanks to the diffusion of new software routines, e.g., "decompr" in R (Quast and Kummritz, 2015) and the new "icio" STATA command (Belotti et al., 2018), it is relatively easy to get new trade metrics which deconstruct gross trade into different value-added components. Building on an earlier attempt by Antimiani et al. (2018) to use the GTAP Model to account for the value-added impact of trade restrictions, the main contribution of this paper is that we introduce the trade in VA decomposition directly into the GEMPACK model code for the GTAP model. Although we are not the first to exploit the GTAP Data Base to construct an ICIO table for computing trade in VA flows (for example, Koopman et al., 2010; Johnson and Noguera, 2012; Peters et al., 2011; Francois et al., 2015; Greenville et al., 2017), we propose an extension to the standard GTAP Model which allows the value-added content of gross flows to be computed from a source-based perspective, i.e., according to the country/sector of origin. On the one hand, we follow the domestic value-added content of exports across borders by computing the backward/forward trade linkages. On the other hand, we follow the value added from the sector of origin to the sector of trade and highlight the upstream/downstream position of different industries.

The GTAP Data Base has been extensively used to perform economic analysis of trade in VA, mainly due to the internal consistency, full global coverage, and the large country and sectoral details provided (Aguiar et al., 2016a). The advantage of using the GTAP Data Base for GVC analysis is that it reconciles data from different sources and puts them into one consistent database with a broad sectoral and regional coverage. However, the database itself does not account for how imported intermediate products are used. Within the GTAP framework, imports of intermediates from all countries are aggregated at the product level at the border into a composite imported good. This composite good is then allocated across sectors and uses based on relative demands and shares. In this way, we cannot trace exports of intermediates from one country into the production processes of another, and following on from that, into their contributions to the other countries' exports. That is to say, we cannot directly identify the industry to industry trade required for the construction of an ICIO table.

There are different methods in which supplementary information is used to distinguish between countries of origin on an industry-use basis. The approach used in this study as well as in many others applies the proportionality assumption to allocate the imports of products from any given country between final demand and intermediates, and then within intermediates, between the intermediate usage by individual production commodities. The key problem with this method is that it ignores differences in the types and quality of imports from different regions. For a given product, some country exports may target final demand, while others may target intermediate demand. A more refined method uses concordances that map between products and end uses to differentiate between sourcing of imports across agents (Liapis and Tsigas, 2014; Walmsley et al., 2014).

It is worth emphasizing that our application chooses to use the simplest methodology, i.e., proportionality, in order to focus on the novelty of the results relating to trade in value added. However, the decomposition module could be used with any ICIO tables and more information on the sourcing of foreign inputs by different sectors would improve the accuracy of the results in terms of value added.[1]

The recent literature 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

[1] A recent paper by de Gortari (2018) develops a new measurement framework that leverages both input-output data and other sources of information to better measure GVC integration.

within international production networks (Koopman et al., 2010; Antràs et al., 2012; Wang and Wei, 2016); the links through which foreign demand activates domestic production (Cappariello and Felettigh, 2015; Borin and Mancini, 2015). GVC analyses at the macro level use different approaches to measuring trade on a value-added basis. According to the categorization proposed in a recent paper by Johnson (2017), trade in VA can be assessed by decomposing the value-added content either of final goods or of gross exports. In this work, we focus on the decomposition of gross trade flows which represent a crucial outcome of trade policy simulations carried out with a global computable general equilibrium model such as GTAP.

IO analysis of GVCs uses value-added multipliers which combine the sectoral value-added shares in each country with the direct and indirect intermediate usage in the production process. 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 stages of the production chain (Gretton, 2013). These effects are traditionally assessed under simplifying assumptions, e.g., fixed technological coefficients 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.

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 (Walmsley et al., 2014, p.17). This type of analysis can be performed using Computable General Equilibrium (CGE) models since they take interdependence between sectors into account allowing relative prices to adjust and factors to be reallocated across sectors, admitting substitution effects in production and consumption both within and across countries (Ferrarini and Hummels, 2014).

Given the importance of GVCs in both theory and empirical analysis, quantitative models that are able to trace value added embedded in gross trade flows are needed in international trade policy analysis. Such a decomposition will be a useful tool for making informed decisions regarding trade and economic policy. It is worth emphasizing that the value-added computation is carried out ex post, that is, after the policy-perturbed CGE model has endogenously converged to a solution. For this reason, this should be viewed as a new tool that allows a better understanding of simulation results irrespective of the structure/assumptions of the model itself.

Since traditional CGE models assess changes of trade flows in gross terms, incorporating trade in VA into CGE models can improve the ability of these models to trace out trade and allocative implications of trade policies which were previously unexplored in traditional models. An accurate, evidence-based measure of the true value-added embodied in trade is necessary if policy makers are to make informed decisions on trade and economic policy.

There have recently been some important extensions of the GTAP Model to allow for supply chain cross-border linkages corresponding to the ICIO table, including the GTAP-SC model (Walmsley et al., 2014), the GTAP HET model (Akgul et al., 2016), and the GTAP Public Procurement Model (Aguiar et al., 2016b).[2] In particular, the 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). This treatment allows import prices to differ by agent and this makes possible a better representation of the trade policy impact on firms' import choices (Walmsley et al., 2014; Carrico, 2017).

Parallel to the evolution of the GTAP model, some other CGE models have sought to include global value chain analysis. Specifically, in 2017, Minor and Walmsley published a working paper on the possible impact in reversing NAFTA agreement. They used the Impact ECON Global Supply Chain (IESC) model, based on the GTAP Data Base. Similarly to GTAP-SC, the IESC model uses a nested Armington demand structure to distinguish imports from different source regions (Minor and Walmsley, 2017). In the same vein, the OCED recently updated its own CGE model, METRO, and introduced an ICIO-TiVA module. The module output produces GVC indicators similar to the approach used in the OECD-WTO TiVA database plus a value-added decomposition of final demand (OECD, 2018).

While there are papers using input output data in the context of trade policy (Rouzet and Miroudot, 2013; Muradov, 2015; Ghodsi and Stehrer, 2016), a readily accessible GTAP implementation with value added trade is not yet available: the aim of this paper is to fill this gap.[3] In contrast to other databases, WIOD or TiVA, for example, this development is model integrated and not only provides a descriptive picture of world trade, but also includes the trade in VA results when assessing the impact of counterfactual simulations using the GTAP Model.

In our illustrative simulations, we incorporate the trade in VA decomposition into the standard GTAP Model, using the pre-released Version 10 of the GTAP Data Base and illustrating this framework with a stylized scenario. While we use the standard model in this illustrative application, it is worth recalling that the proposed decomposition works with any ICIO tables

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[2] In addition to the introduction of these more specific inter-country linkages, the GTAP HET model and the GTAP Public Procurement Model introduce theoretical innovations, namely firm heterogeneity and procurement preferences, respectively.

[3] Ferraz et al. (2015) carry out a set of dynamic CGE simulations where the results are evaluated according to the logic of integration to international supply chains as well as trade in value added, instead of the usual ‘gross” trade analysis. However, their decomposition is not embedded within the GTAP Model code. More recently, Vandenbussche et al. (2018) used World Input Output Data (WIOD) to simulate the effects of TTIP in terms of value added and employment with a multi-sector model.

and GTAP Model versions. Accordingly, we believe that this trade in VA decomposition is going to be of paramount interest for CGE analysis.

The paper is structured as follows. In the following section, we provide some preliminary insights into value-added trade and 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 that can be analyzed when performing a trade policy shock is given. We consider a Free Trade Agreement between the European Union and the United States and explore the ensuing structural changes in trade flows related to global networks of production. Section 4 concludes.

2. The extended GTAP Model for value-added analysis

2.1 Concepts

GVCs are defined as an inter-country, inter-sector system of value-added sources and destinations (Koopman et al., 2014, p. 459). The value is added at each successive stage of the production process, where the value added equals the value of payments to the primary factors of production in the country/sector in which the particular stage of production occurs. The trade in VA decomposition allows the segments of value created in different countries to be disentangled within gross trade flows.

When intermediate goods (e.g., parts and components or any other item used as an input for further processing) cross more than one border, traditional trade statistics are not representative of the production patterns underlying global trade.

To deal with the increased complexity in global trade, a number of indicators within the trade in VA analytical framework have been developed based on ICIO tables. Some of them refer to the decomposition of final goods as in Johnson and Noguera (2012) who measure inter-country production sharing as the ratio of value added to gross exports (VAX), where value-added exports are defined as the value added produced in one country, but absorbed in final demand by another. A complementary perspective in decomposing final goods looks at the production side and consists of allocating the value added generated in the production of final goods back to the countries in which that income is generated. This "GVC Income" approach traces the value added by all labor and capital that is directly and indirectly needed for the production of final manufacturing goods (Timmer et al., 2013; Timmer et al., 2014; Los et al., 2016).

The literature aimed at decomposing gross trade flows is more relevant in our case. This line of research starts from the pioneering work of Hummels et al. (2001) who provide the first metric of vertically integrated trade which took into account the role of foreign inputs used in a country's exports. Accordingly, this vertical specialization measure reports the value of imported inputs embodied in goods that are exported. As a share of total exports, it provides an index of backward participation in GVCs.

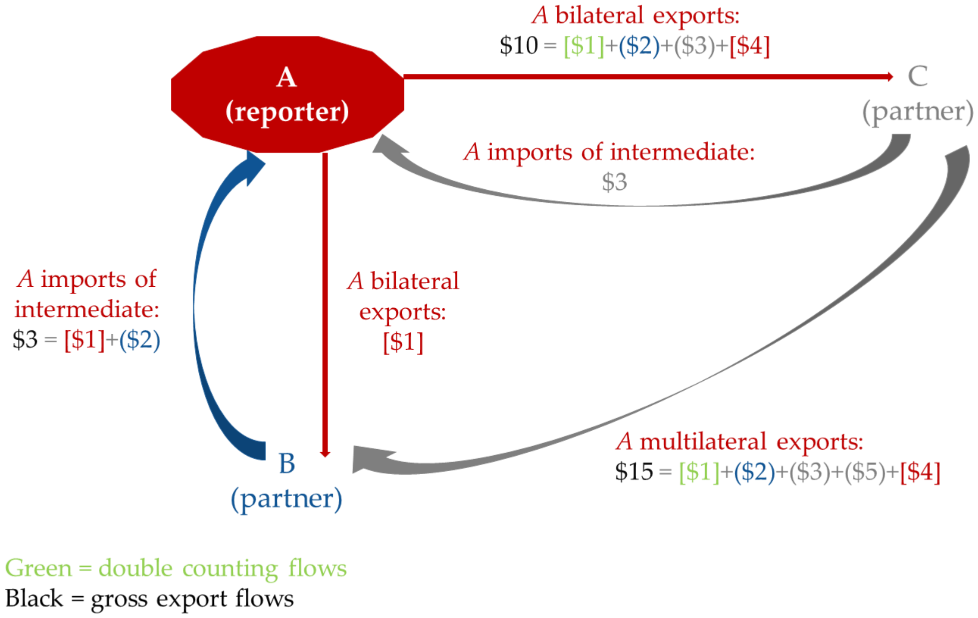
A second indicator refers to a different channel through which a country is involved in GVC, i.e., by producing intermediate exports which are used by the receiving country to produce its exports. This indicator, proposed by Hummels et al. (2001), provides a measure of the forward linkages a country has in selling in GVCs. Although the degree to which exports are used by other countries for further export generation may appear less relevant for policymakers because it does not change the domestic value-added contribution of trade, the participation rate is a useful indicator of the extent to which a country's exports are integrated in international production networks (UNCTAD, 2013).

A third measure captures reflected, or circular, trade; it accounts for a subset of the previous indicator and refers to the portion of trade that is imported back into the country of origin of value (Daudin et al., 2011). This indicator provides interesting insights for policy makers since one implication of the reflected trade is that restrictive measures a country imposes on its imports have an impact on domestic firms exporting intermediate inputs processed abroad and then imported back. This may alter that country's incentive to impose import protection (Blanchard et al., 2016) as long as restrictive measures assume a 'beggar thyself' connotation (IMF, 2013; Miroudot and Yamano, 2013; Antimiani et al., 2018; Balié et al., 2017).

A complete decomposition of gross trade is found in Koopman et al. (2014). They provide a unified mathematical framework for the decomposition of total gross exports into three main components: the domestic value-added, the foreign value-added, and the 'reflected' value-added., i.e. the domestic content in intermediate exports that finally returns home. Each of these components can be further split by taking into account the intermediate or final use of the exported goods. Furthermore, they quantify double counted items from standard trade statistics.

Wang et al. (2013) and Borin and Mancini (2015) extend the Koopman et al. (2014) framework to provide a breakdown of bilateral exports at the sector level. The analysis of trade in VA on a specific bilateral flow can be performed from two different perspectives: a) from the country where the value added originates (source-based), or b) from the last country that absorbs the value added (sink-based). This distinction is relevant whenever a certain portion of value added crosses the same border more than once (Nagengast and Stehrer, 2014; Borin and Mancini, 2015).

Figure 1 provides a numerical example and shows traditional trade flows as well as source and sink trade in VA decompositions. Let's suppose that country A exports in a first round an intermediate input worth \$1 to country B. The receiving country B then processes that input, adds \$2 in value added, and then exports the good back to country A as an intermediate with value \$3. In country A, this intermediate good is combined with other intermediate inputs imported from country C worth \$3, and \$4 of country A's domestic value added. The \$10 intermediate input is sent to country C which performs the last stage of production adding $5 of value to satisfy the demand for imports in country B. To provide an example, we focus here on country A's exports.



Traditional

		Importer A	Importer B	Importer C
Exporter	A		1	10
Exporter	B	3		
Exporter	C	3	15	

Source

		Importer A	Importer B	Importer C
Exporter	A		1	4
Exporter	B	2		
Exporter	C	3	5	

Sink

		Importer A	Importer B	Importer C
Exporter	A		5	
Exporter	B		2	
Exporter	C		8	

Figure 1. Trade and value-added flows under different accounting approaches

Source: Authors' calculations.

Traditional trade statistics tally the gross value of goods at each border crossing. Then, in a gross accounting, country A exports total $11 ($1 to country B and $10 to C). However, the value which has been effectively produced in A only accounts for $5 of exports. The difference between gross and value-added exports arises from two sources. First, in order to export, A needs some intermediate inputs from abroad ($2 from B and $3 from C), representing the foreign value added in its exports. Second, A's intermediate export to B returns home as an intermediate import and is used for the production of its exports to C, meaning that there is a repeated counting of $1 in A's domestic value added in exports. The foreign content of exports and the double-counting implies that gross statistics overstate the domestic value added in a country's exports.[4] The source and sink methods both provide trade in VA accounting that distinguishes between domestic and foreign content of trade and removes the double-counting inflating traditional accounts. However, the two approaches provide two different reallocations of value-added flows to specific bilateral trade links.

The source-based approach follows the value added at the first border crossing. In this case, country A exports $1 of domestic value added to country B. Since, by assumption, it uses only domestic inputs which have never left the country, gross and value-added exports coincide. Conversely, country A's gross exports to country C do not reflect the value added created in country A. The composition of country A's exports to country C would be the following: $4 of domestic value added + $5 of foreign value added ($2 from country B and $3 from country C which are reflected to the source country) + $1 of double-counting (country A's domestic value added already accounted for in its exports to country B). That is to say, under the source method, the value added of country A is allocated to the first country that imports the value added to, in this case, both countries B and C.

Conversely, the sink-based approach would attribute $5 to the domestic value added in the exporting country A to the final importer (C): the original $1 it exported to country B plus the additional $4 added before exporting the good to country C. That is, under the sink method, the value added of country A is allocated to the last country that absorbs the value added, in this case, country C.

In this work, we adopt a source-based approach and we assign the value-added exports to the gross trade flow in which it leaves the producing country for the very first time; if the value-added crosses the international border a second or third time, it is considered double-counting. Besides properly allocating the domestic value-added exports within bilateral links, our framework also takes into account the multilateral production sharing relationships. In our example, country A's domestic value added reaches country B through bilateral exports ($1 of intermediate exports) as well as through the value embedded in the exports of country C to that market ($4 exported through the multilateral link).

2.2 The value-added module

In order to reckon with the structure in values that are embedded in gross flows, we use the insights of IO analysis and obtain the value-added multipliers to be used in the decomposition of trade. The IO model (Leontief, 1936) provides a technique that represents the interdependencies between

[4] It is useful to note that since country B exports only once, its domestic value added is not double counted and the difference between gross and trade in VA accounting ($3 versus $2) is explained completely by the foreign content ($1 from A which is reflected back by C to the source/importing country A). Country C instead, shows trade patterns similar to those of country A: it has double-counting ($3) and uses foreign inputs ($7 of which $5 originating in country A and $2 produced in B).

different branches of a national economy or different regional economies. The linkages across industries and countries are used to quantify the gross output in all stages of production that is needed to produce one unit of final goods. The GTAP Model is based on a complete IO accounting framework which takes into account all sources and uses of each good. However, it requires some manipulations in order to perform GVC analysis which is addressed in this section. The approach followed to track the movement of intermediate inputs across each border is based on the work by Peters et al. (2011) which converts the GTAP Data Base into an ICIO Table. We use their procedure to attribute the sourcing of imports for intermediate use and to reallocate the supply of international transport margins within the intermediate and final demand matrices.

In the standard GTAP Model, the sourcing of imports occurs at the border, providing information on total purchases of intermediate inputs by firms (domestic and imported), and total purchases of final goods by households, government and for investment (domestic and imported), but not attributing bilateral trade to the consuming agent (e.g., firms or final consumption). One common approach to overcoming this limitation is to assume that all uses of a good are sourced in the same way (proportionality assumption). Daudin et al. (2011), Jonson and Noguera (2012) and Lejour et al. (2014) use the GTAP Data Base and the proportionality assumption in order to estimate value-added trade flows and define indicators for GVCs.

A more nuanced procedure applies 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 then applied to the original GTAP Data Base (Koopman et al., 2010; Walmsley et al., 2014; Aguiar et al., 2016b). However, the BEC classification is far from perfect and has been criticized because of its subjective allocation of products which is based on expert judgment concerning descriptive characteristics, particularly with regard to the fact that some goods may be used both as intermediates and final products which may not align with the equivalent allocations used in national data.

The ability of merchandise trade data to differentiate between products on the basis of their likely end-use (for example, whether the goods are intermediate, consumption or capital in nature) and better information on the tariff rates applied on intermediate goods, would improve the ability to analyze the impact of trade policies. Moreover, it is ultimately desirable to obtain information at the firm level to relax the assumption that all firms in a given industry have the same import content relative to their output and the same export propensity relative to their output.

In the following, we implement the proportionality assumption on the standard version of the GTAP Data Base though our decomposition works with any ICIO, regardless of the procedure used to build it. Moreover, we introduce the value-added decomposition of trade into the standard static GTAP Model with perfect competition and constant returns to scale technology

(Hertel and Tsigas, 1997). For the sake of convenience and efficiency, the equations needed to perform the decomposition represent an "add-on" module which may be appended to the bottom of the TABLO code of any version (e.g., GTAP-MRIO, or GTAP-HET) of the GTAP Model.

Let i and $j = 1, \ldots, N$ index sectors, and $s, r = 1, \ldots, C$ index countries, and as for standard GTAP notation, we define VXMD_i^{sr} as exports of i from s to r valued at market prices. In order to recover the bilateral delivery of intermediates used by firms, we use the shares of imports used by firms on the total country's imports and apply them to bilateral trade:

$$VXIMS_{ij}^{sr} = SHRIFM_{ij}^{r} * VXMD_{i}^{sr} \tag{1}$$

where SHRIFM_{ij}^{r} is the share of import i used by sector j in r. Hence, VXIMS_{ij}^{sr} is the value of the intermediate input i from region s for use by sector j in country r, evaluated at market prices in s.[5]

In the GTAP Model, regional transport services exports are not associated with particular commodities and routes and it is assumed that all demand is met from the same pool of services (Hertel and Tsigas, 1997). This implies that there is a disconnect between the sector output and the sector users of margins as an intermediate product. In order to include international transportation margins in the value-added multipliers, transportation margins related to the shipment of intermediate goods need to be allocated to the providing countries. Thus, we proportionally distribute the transport margins among users (firms and final consumers). Furthermore, we assume that the use of international transportation services by each route is in proportion to the transport services supply source structures. Specifically, the country shares of exports to the global transport pool (VTS_i^{s}) are applied to the international margin for intermediate usage in country r (VTWRI_{ij}^{r}):[6]

$$VSTP_{mj}^{sr} = \frac{VST_m^s}{\sum_s VST_m^s} \sum_i VTWRI_{mij}^{r} \tag{2}$$

Equation (2) provides the direct relation between use and supply of international transportation services. VSTP_{mj}^{sr} represents the international margin m supplied by s for j's intermediate usage in country r. The distribution

[5] GTAP *market* prices are the closest approximation to the *basic* prices used in the standard IO analysis (European Communities, 2008). However, GTAP market prices are net of taxes but include domestic transport margins (as inputs into the production process) whereas basic prices are defined as net of taxes *and* transport margins (see also, Peters et al., 2011, and Greenville et al., 2017).

[6] The distribution of transport margins over intermediate usage - as distinct from final usage included in Equation (9) - is obtained by applying the import share for firms to the original international margin usage (VTWR_{mi}^{sr}) as in Equation (1):
$VTWRI_{mij}^{r} = SHRIFM_{ij}^{r} * \sum_{\mathrm{s,reg}} VTWR_{mi}^{sr}$.
VTWRI_{mij}^{r} gives the international margin m for j's intermediate usage of imported i in region r. We drop the information on the source region s producing the product i in VTWR, since it is not necessarily the region that supplies the transport margin.

of the use of transport services over suppliers is then added to the corresponding row for the margin producing sector in the supply country:

$$VTMTXI_{ij}^{sr} = \begin{Bmatrix} VSTP_{mj}^{sr} & if\ i \in MARG\_COMM \\ 0 & if\ i \notin MARG\_COMM \end{Bmatrix} \quad (3)$$

VTMTX represents the matrix of international transport margins for intermediate goods which is non-zero only in the margin commodities sectors.

In country r, the total firms' purchases of intermediate inputs (Z_{ij}^{sr})is obtained by adding the domestic component to imports, that is, the value of purchases of domestic i for use by j in country r ($VDFM_{ij}^{r}$) and the intermediate margin matrix:

$$Z_{ij}^{sr} = \begin{Bmatrix} VXIMS_{ij}^{sr} + VDFM_{ij}^{r} + VTMTXI_{ij}^{sr} & if\ \ r = s \\ VXIMS_{ij}^{sr} + VTMTXI_{ij}^{sr} & if\ \ r \neq s \end{Bmatrix} \quad (4)$$

Equation (4) generates a matrix of dimension NCxNC where N represents the number of sectors and C the number of countries. More specifically, each entry contains the value of the intermediate inputs purchased by sector j of country r from sector i of country s. This gives information on, for instance, the United States chemicals requirement to produce light manufacturing in the European Union.

$$VOM_j^r = \sum_i \sum_s Z_{ij}^{sr} + VA_j^r \quad (5)$$

Eq (5) defines the value of j's output in region r (at domestic market prices) as the sum of the total use of intermediate inputs i (Z_{ij}^{sr}) for each producing sector and the value added (VA_j^r).The latter includes the payment to primary factors plus a composite tax value, including taxes on production and output, and trade-related taxes incurred by firms.[7]

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[7] Specifically, the vector for the value added (VA) can be defined as:
$VA_{ij}^s = VFM_{ij}^s + TTAX_j^s$,
where VFM_{ij}^s is the producer expenditure on endowment i by sector j in country s valued at market prices. The sum of all payments for primary factors gives the total remuneration of primary factors in each producing sector for each economy. The composite tax term, $TTAX_j^r$, is given by:
$TTAX_j^r = \sum_i DFTAX_{ij}^r + \sum_i IFTAX_{ij}^r + \sum_i ETAX_{ij}^r + PTAX_j^r + \sum_i \sum_s TXMTAX_{ij}^{sr}$,
where $DFTAX_{ij}^r$ and $IFTAX_{ij}^r$are taxes on use of domestic and imported intermediate good i by j in r, respectively, $ETAX_{ij}^r$ are taxes on use of endowment i by j in r, $PTAX_j^r$ are output taxes on j in r, and $TXMTAX_{ij}^{sr}$includes export/import taxes incurred by firms. The latter term can be calculated by applying the import structure of firms to taxes on exports ($XTAX_j^{sr}$) and taxes on imports ($MTAX_j^{sr}$).
This definition of value added corresponds to value added in the National Accounts sense (OECD-WTO, 2012; IMF, 2013; Aslam et al., 2017) and is coherent with the one used in standard IO analysis.

The delivery of intermediates used in the production of the receiving country can be expressed as a share of destination country r's sectoral output, thus:

$$A_{ij}^{sr} = \frac{Z_{ij}^{sr}}{VOM_j^r} \tag{6}$$

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 j's output inr.

The sectoral value-added shares for country r is given by:

$$VSH_j^r = \frac{VA_j^r}{VOM_j^r} \tag{7}$$

In order to obtain the same dimension of the technical coefficients matrix to be used later on, we diagonalize the vector of value-added shares and defined a diagonal matrix $\widehat{VSH}$ with value-added shares in the main diagonal and zero in the off-diagonals:

$$\widehat{VSH}_{ij}^{sr} = \begin{Bmatrix} VSH_j^r & if\ r = s, and\ i = j \\ 0 & if\ r \neq s, and\ i \neq j \end{Bmatrix} \tag{8}$$

Next, we define the demand for final consumption in country r of commodity j from s as:

$$FIN_j^{sr} = \begin{Bmatrix} VXCMS_j^{sr} + VDPM_j^r + VDGM_j^r + \sum_{k,cgds} VDFM_{jk}^r + VTMTXC_j^{sr} & if\ r = s \\ VXCMS_j^{sr} + TMTXC_j^{sr} & if\ r \neq s \end{Bmatrix} \tag{9}$$

where $VDPM_j^r$ and $VDGM_j^r$ are domestic goods j demanded in region r by private households and government, respectively, and $VDFM_{jk}^r$ are domestic investment purchases in r. The term $VTMTXC_j^{sr}$ represents the margin matrix for final demand and is constructed in analogy with the margin matrix for intermediates (cf. eq. 3). $VXCMS_j^{sr}$ is the value of imports of commodity j from s for final consumption in r at market prices, obtained by applying the proportionality assumption.[8]

We do not exploit the information on the different components of the value added, but consider the composite value-added vector as a whole. This is why this specification is not included in the code. However, since GTAP gives all the information on the payment for each factor (8 in the current version), it is worth noting that our framework could be easily extended to analyze the value added by specific production factors. This latter approach is developed in an ex-post accounting framework in Foster-McGregor and Stehrer (2013) and Timmer et al. (2013).

[8] That is, $VXCMS_j^{sr} = (SHRIGM_j^r + SHRIPM_j^r + \sum_{k,cgds} SHRIFM_{jk}^r) * VXMD_j^{sr}$, where $SHRIGM_j^r$, $SHRIPM_j^r$and$SHRIFM_{jk}^r$ are shares of imports of j used by government, household and investment in region r.

Then, the accounting identity for tradable supplies can be expressed as:

$$VOM_j^r = \sum_i \sum_s Z_{ji}^{rs} + \sum_s FIN_j^{rs} \tag{10}$$

The right-hand side 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. By rearranging Equation (6) and substituting it in Equation (10), the row balance condition can be written as:

$$VOM_j^r = \sum_i \sum_s A_{ji}^{rs} \, VOM_i^s + \sum_s FIN_j^{rs} \tag{11}$$

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

$$\begin{bmatrix} VOM^1 \\ VOM^2 \\ \vdots \\ VOM^C \end{bmatrix} = \begin{bmatrix} A^{11} & A^{12} & \cdots & A^{1C} \\ A^{21} & A^{22} & \cdots & A^{2C} \\ \vdots & \vdots & \ddots & \vdots \\ A^{C1} & A^{C2} & \cdots & A^{CC} \end{bmatrix} \begin{bmatrix} VOM^1 \\ VOM^2 \\ \vdots \\ VOM^C \end{bmatrix} + \begin{bmatrix} FIN^{11} + FIN^{12} + \cdots + FIN^{1C} \\ FIN^{21} + FIN^{22} + \cdots + FIN^{2C} \\ \vdots \\ FIN^{C1} + FIN^{C2} + \cdots + FIN^{CC} \end{bmatrix} \tag{12}$$

For given levels of final demand, the system in (12) can be solved for VOM, which gives:

$$\begin{bmatrix} VOM^1 \\ VOM^2 \\ \vdots \\ VOM^C \end{bmatrix} = \begin{bmatrix} I - A^{11} & -A^{12} & \cdots & -A^{1C} \\ -A^{21} & I - A^{22} & \cdots & -A^{2C} \\ \vdots & \vdots & \ddots & \vdots \\ -A^{C1} & -A^{C2} & \cdots & I - A^{CC} \end{bmatrix}^{-1} \begin{bmatrix} FIN^{11} + FIN^{12} + \cdots + FIN^{1C} \\ FIN^{21} + FIN^{22} + \cdots + FIN^{2C} \\ \vdots \\ FIN^{C1} + FIN^{C2} + \cdots + FIN^{CC} \end{bmatrix}$$
$$= \begin{bmatrix} L^{11} & L^{12} & \cdots & L^{1C} \\ L^{21} & L^{22} & \cdots & L^{2C} \\ \vdots & \vdots & \ddots & \vdots \\ L^{C1} & L^{C2} & \cdots & L^{CC} \end{bmatrix} \begin{bmatrix} FIN^{11} + FIN^{12} + \cdots + FIN^{1C} \\ FIN^{21} + FIN^{22} + \cdots + FIN^{2C} \\ \vdots \\ FIN^{C1} + FIN^{C2} + \cdots + FIN^{CC} \end{bmatrix} \tag{13}$$

where I is the NCxNC identity matrix and $L = (I - A)^{-1}$ is the global Leontief inverse (or multiplier) matrix, giving the total requirement of output directly *and* indirectly required worldwide to produce one unit of consumption.[9] This

[9] The GEMPACK software does not include matrix operators. Consequently, the matrix inversion in Equation (13) is found as the solution of the linear equation system (https://www.copsmodels.com/gp-inv2.htm). The matrix inversion is computed by equation E_b which is activated by a shock variable (*dummy*) set equal to 1:

matrix is a compact representation of the ripple effects in an economy where industries are interconnected.

Let's assume a unitary increase in the demand for a final good (for example, a car). This would imply an increase in the demand for the input required directly for its production (first round of intermediates, for example, steel). In turn, the increase in the output of the direct input will correspond to an increased demand for the inputs needed to produce the direct input (second round of intermediates, for example, iron), and so on for all successive rounds of production. Each matrix coefficient then conveys all direct and indirect effects on output in one sector required by a unit of output from another sector.

Finally, the value-added contributions associated with each unit of final demand are obtained by post-multiplying the diagonal matrix of value-added shares $\widehat{VSH}$, introduced in Equation (8), with the Leontief inverse. This generates the value-added multiplier matrix, providing a breakdown of the flows of value-added across sectors:

$$\widehat{VSH}L = \begin{bmatrix} \widehat{VSH}^1 L^{11} & \widehat{VSH}^1 L^{12} & \cdots & \widehat{VSH}^1 L^{1C} \\ \widehat{VSH}^2 L^{21} & \widehat{VSH}^2 L^{22} & \cdots & \widehat{VSH}^2 L^{2C} \\ \vdots & \vdots & \ddots & \vdots \\ \widehat{VSH}^C L^{C1} & \widehat{VSH}^C L^{C2} & \cdots & \widehat{VSH}^C L^{CC} \end{bmatrix} \tag{14}$$

The $\widehat{VSH}L$ is the key matrix in the value-added trade literature. It contains all the information on 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 for each of the 1, 2, ..., N sectors. For country r it is given by:

$$\widehat{VSH}^r L^{rr} = \begin{bmatrix} vsh_1^r l_{11}^{rr} & vsh_1^r l_{12}^{rr} & \cdots & vsh_1^r l_{1N}^{rr} \\ vsh_2^r l_{21}^{rr} & vsh_2^r l_{22}^{rr} & \cdots & vsh_2^r l_{2N}^{rr} \\ \vdots & \vdots & \ddots & \vdots \\ vsh_N^r l_{N1}^{rr} & vsh_N^r l_{N2}^{rr} & \cdots & vsh_N^r l_{NN}^{rr} \end{bmatrix} \tag{15}$$

where the element $\mathrm{vsh_N^r l_{N1}^{rr}}$ gives the share of value-added originated in the domestic N 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 the country/sector. The value-added shares of country 1 embedded in country r's domestic production are represented by:

$$\widehat{VSH}^1 L^{1r} = \begin{bmatrix} vsh_1^1 l_{11}^{1r} & vsh_1^1 l_{12}^{1r} & \cdots & vsh_1^1 l_{1N}^{1r} \\ vsh_2^1 l_{21}^{1r} & vsh_2^1 l_{22}^{1r} & \cdots & vsh_2^1 l_{2N}^{1r} \\ \vdots & \vdots & \ddots & \vdots \\ vsh_N^1 l_{N1}^{1r} & vsh_N^1 l_{N2}^{1r} & \cdots & vsh_N^1 l_{NN}^{1r} \end{bmatrix} \tag{16}$$

```
Variable (change) dummy # Dummy unit shock #;
Equation E_b (all,i,TRAD_COMM)(all,j,TRAD_COMM)(all,r,REG)(all,s,REG)
sum{k,TRAD_COMM, sum[t,REG, X(i,k,r,t)*b(k,j,t,s)]} = delta(i,j,r,s)*dummy;
```

where X is the matrix to be inverted (I-A), b is the inverse of matrix X, and delta is the identity matrix.

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 r, the following is true:

$$\sum_i \sum_s \widehat{VSH}_i^s L_{ij}^{sr} = 1 \tag{17}$$

Equality (17) ensures data consistency once we post-multiply by the bilateral export vectors.[10] This allows bilateral trade flows to be decomposed according to the value-added contents.

Specifically, we introduce a further country index, $t = 1, \dots, C$, denoting the country of origin of value. Then, the value added which originates (in sector i) of country t and is embedded in country s's exports (in sector j) to country r (TVA_{ij}^{tsr}) is given by:

$$TVA_{ij}^{tsr} = \widehat{VSH}_i^t L_{ij}^{ts} * VXE_j^{sr} \tag{18}$$

where VXE_j^{sr} represents bilateral exports excluding intra-regional trade, for which the distinction between domestic and foreign value-added is not applicable.[11]

Equation (18) allows the value added embedded in each input sourced locally or imported to be unpacked within the value of a traded good. Equation (18) is implemented in the model as:

```
Formula (all,i,TRAD_COMM)(all,j,TRAD_COMM)(all,t,REG)(all,s,REG)(all,r,REG)
TVA(i,j,t,s,r) = VSHDL(i,j,t,s) * VXE(j,s,r);
```

where VSHDL(i,j,t,s) corresponds to $\widehat{VSH}_i^t L_{ij}^{ts}$ in Equation (18).

Exploiting the information on the origin of value added embedded in trade, we can decompose export values at the sector level into the domestic value added generated in their production, both directly (from the producing/exporting sector) and indirectly (embedded in other domestic sectors' exports or in other countries' exports), and the foreign value added

[10] The value-added multipliers can be pre-multiplied by other exogenous vectors, e.g., exports of final goods. This would result in value-added export measures defining the value added from one country which is absorbed by another country (see, for example, Johnson and Noguera, 2012).

[11] In equation (18), each element i in the row for the j-th column of the $\widehat{VSH}L$ matrix is multiplied by the corresponding column element of the vector VXE. Thus, for a specific bilateral link we obtain the TVA matrix of dimension NCxN, where the N sectors in the columns represent the exporting sectors, and the N sectors and C countries in the rows represent the sectors and countries of origin of value added. In the coefficient VXE_j^{sr}, we exclude intra-regional trade which is caused by aggregation of countries in the GTAP Data Base, that is, we set to zero the diagonal entries of $VXMD_j^{sr}$:

$$VXE_j^{sr} = \begin{Bmatrix} VXMD_j^{sr} & if\ r \neq s \\ 0 & if\ r = s \end{Bmatrix}.$$

generated in other countries producing the imported inputs used in exports. To facilitate GVC analysis in the GTAP Model, we define several indicators with a straightforward economic interpretation. The new sets and coefficients introduced for trade in VA analysis within GTAP are reported in Table 1 and Table 2, respectively. A detailed explanation of each indicator is provided in the rest of this section.

Table 1. New sets introduced in GTAP-VA module for trade in VA analysis.

Specific sets	Elements	Description
ORIGVALUE	(DVA, DDC, FVA)	Domestic, double-counting and foreign components of gross exports
ORIGSECT	(DVA_dir, DVA_indir)	Direct and indirect exports of the domestic sector
DVAT	(DVA_blt, DVA_mlt)	Bilateral and multilateral exports of domestic value added
ORIGFVA	(FVA_rfl, FVA_other)	Reflected and other countries foreign content of exports

Source: Authors' elaborations.

Table 2. New coefficients used in the VALUEADDED.har file.

Coefficients	Header	Description
TVA (i,j,t,s,r)	VA	VA originated in t (sector i) and embedded in s's exports (sector j) to r
DVA (i,j,t,s,r)		Domestic VA (sector i) embedded in s's exports (sector j) to r
DDC (i,j,s,r)		Double counting in DVA, s's exports to r
FVA (i,j,t,s,r)		Foreign VA (country t, sector i) embedded in s's exports (sector j) to r
VADECOMP (j,s,r,o)	VADE	Domestic and foreign (o) VA embedded in s's exports (sector j) to r
DVA_d (i,j,t,s,r)		Domestic VA in s's exports to r originated in the domestic exporting sector j
DVA_i (i,j,t,s,r)		Domestic VA in s's exports to r originated in the domestic sector i providing intermediate inputs for domestic sector j's exports
DVADECOMP (i,s,r,o)	DVAD	Domestic VA by sector of origin/export and importer r
DVAM (j,i,s,t,r)		Multilateral DVA in country s's exports to r originated in the domestic sector j and exported by t (sector i) to r
DVAEXP (j,s,r,o)	DVAT	Bilateral and multilateral (o) exports of domestic VA, by sector
FVA_r (i,j,r,s,r)		Foreign VA originated in r and reflected by s's exports
FVA_t (i,j,t,s,r)		Foreign VA originated in other countries (t) and exported by s to r
FVADECOMP (j,s,r,o)	FVAD	Reflected and other countries foreign VA (o) in exports from s (sector j) to r

Source: Authors' elaborations.

2.2.1 Domestic and foreign content of bilateral exports by sector

The original GTAP value for bilateral trade can be split into two main components: a) the domestic value added, giving the value added originating in all sectors of the exporting country s which is embedded in sector j's exports, and b) the foreign value added, which gives the value of imported intermediate inputs embodied in country s's exports in sectorj. The domestic content of gross trade flow refers to the origin country of the first export flow (see Section 2.1). Accordingly, we compute a double counted component which accounts for the portion of domestic value that has previously crossed international borders, and hence is already counted as domestic value added in other bilateral links.[12] Mathematically, this is implemented by introducing the local (or domestic) Leontief inverse, $\mathrm{LOC}_{ij}^{ss} = (I - A_{ij}^{ss})^{-1}$, which is computed on the domestic block of the technical coefficients matrix, thus representing intra-country processing only.

The difference between the global and the local Leontief inverse ($\mathrm{L}_{ij}^{ss} - \mathrm{LOC}_{ij}^{ss}$) gives the portion of the domestic value added that has crossed international borders at least twice.[13] Looking back to the example in the previous section: country A performs the first stage of a production process, ships the intermediate product abroad for a second processing stage in country B, re-imports it for further processing, and then exports it to country C. While the global multipliers compute the output produced in country A, generated both in the first and in the last stage, the local Leontief only takes into account the domestic output generated in the last stage of production performed in A. Thus, by subtracting the local from the global inverse, we get the value of output which is double counted in A's exports to C.

Thus, we can express bilateral exports in terms of three components: the domestic value added (DVA), the double counted term related to the domestic content (DDC), and the foreign content (FVA):

$$\begin{aligned} VXE_j^{sr} &= \sum_i \sum_t TVA_{ij}^{tsr} \\ &= \underbrace{\sum_i \widehat{VSH}_i^s LOC_{ij}^{ss} * VXE_j^{sr}}_{DVA_j^{sr}} + \underbrace{\sum_i \widehat{VSH}_i^s (L_{ij}^{ss} - LOC_{ij}^{ss}) * VXE_j^{sr}}_{DDC_j^{sr}} \\ &\quad + \underbrace{\sum_i \sum_{t \neq s} \widehat{VSH}_i^t L_{ij}^{ts} * VXE_j^{sr}}_{FVA_j^{sr}} \end{aligned} \tag{19}$$

The domestic value-added content of exports gives a measure of the actual contribution a given export makes to an economy's income, the remainder being the value of imported inputs representing the import content of exports (i.e., the vertical specialization component).

[12] It is worth recalling that there may also be double-counting related to the foreign component. For instance, in Figure 1, there could have been double-counting also in the foreign value-added component if B intermediate goods had been processed abroad. We do not single it out in our decomposition. However, in the 3x3 aggregation used in the illustrative application, the relevance is rather limited. Using Borin and Mancini (2015)'s method, we find that double counted intermediate exports originally produced abroad account for only 0.8% of total exports

[13] Formally, $L^{ss} - LOC^{ss} = \sum_t LOC^{ss} A^{st} L^{ts}$, where A^{st} is the share of intermediates from country s used in the production of the receiving country t (see Equation (6)). Thus, the difference ($L^{ss} - LOC^{ss}$) gives the output in s (LOC^{ss}) required to produce intermediate goods exported in t (A^{st}) and used in the production of t's exports back to s' production (L^{ts}). For a formal proof in a two-country case, refer to Wang et al. (2013).

In GTAP notation, the three components are:
Domestic (DVA):

```
Formula (all,i,TRAD_COMM)(all,j,TRAD_COMM)(all,t,REG)(all,s,REG)(all,r,REG)
DVA (i,j,t,s,r) = IF[t EQs,TVA(i,j,t,s,r)-DC_DVA(i,j,s,r)];
```

Double-counting (DDC):

```
Formula (all,k,TRAD_COMM)(all,j,TRAD_COMM)(all,s,REG)
DC (k,j,s) = sum[r,REG,L̂(k,j,s,r)]-LOC(k,j,s);
Formula (all,i,TRAD_COMM)(all,j,TRAD_COMM)(all,s,REG)(all,r,REG)
DDC(i,j,s,r) =
sum{k,TRAD_COMM,sum[t,REG,VSHDNL(i,k,s,t)*DC(k,j,s)]}*VXE(j,s,r);
```

where $\hat{\text{L}}$ is the diagonal block of the global Leontief L, and DC is the double-counting obtained by subtracting the local from the global Leontief inverse.

Foreign (FVA):

```
Formula (all,i,TRAD_COMM)(all,j,TRAD_COMM)(all,t,REG)(all,s,REG)(all,r,REG)
FVA (i,j,t,s,r) = IF[t NEs,TVA(i,j,t,s,r)];
```

A table summarizing these components is created in the code by introducing a new set "ORIGVALUE" containing the domestic (DVA), the double-counting (DDC), and the foreign (FVA) components of gross exports, and summing over all countries and sectors of origin of value:

```
Set ORIGVALUE (DVA,DDC,FVA);
Formula (all,j,TRAD_COMM)(all,s,REG)(all,r,REG)
VADECOMP(j,s,r,"DVA") = sum{i,TRAD_COMM,sum[t,REG,DVA(i,j,t,s,r)]};
Formula (all,j,TRAD_COMM)(all,s,REG)(all,r,REG)
VADECOMP(j,s,r,"DDC") = sum[i,TRAD_COMM,DC_DVA(i,j,s,r)];
Formula (all,j,TRAD_COMM)(all,s,REG)(all,r,REG)
VADECOMP(j,s,r,"FVA") =sum{i,TRAD_COMM,sum[t,REG,FVA(i,j,t,s,r)]};
```

2.2.2 Bilateral direct/indirect domestic value added by originating sector

Within the domestic value-added component, we compute the sector of origin of value added, assuming that the country of origin coincides with the exporting country. Accordingly, the aggregate domestic value-added component can be split by distinguishing between: a) the value originating in the domestic exporting sector (DVA_dir), and b) the value that originated in other domestic sectors providing intermediate inputs to the domestic exporting sector (DVA_indir):

$$\sum_j DVA_j^{sr} = \underbrace{\sum_i \widehat{VSH}_i^s LOC_{ii}^{ss} * VXE_i^{sr}}_{DVA\_dir_i^{sr}} + \underbrace{\sum_i \sum_{j \neq i} \widehat{VSH}_i^s LOC_{ij}^{ss} * VXE_j^{sr}}_{DVA\_indir_i^{sr}} \quad (20)$$ [14]

[14] In Equation (20) we consider the sector of origin of value added which allows to compute the contribution to value added exports in each domestic sector even when it does not export directly. Alternatively, we can assess the upstream linkages and find out the indirect requirement of domestic intermediates for the exporting sector, i.e.: $\sum_{i \neq j} \widehat{VSH}_i^s LOC_{ij}^{ss} * VXE_j^{sr}$.

In the code, we introduce a new set "ORIGSECT" which splits the value originating in the domestic sector into a direct component and an indirect one:

```
Formula (all,i,TRAD_COMM)(all,j,TRAD_COMM)(all,t,REG)(all,s,REG)(all,r,REG)
DVA_d (i,j,t,s,r) = IF[iEQj,DVA(i,j,t,s,r)];
Formula (all,i,TRAD_COMM)(all,j,TRAD_COMM) (all,r,REG)(all,s,REG)(all,t,REG)
DVA_i (i,j,t,s,r) = IF[iNEj,DVA(i,j,t,s,r)];
Set ORIGSECT (DVA_dir,DVA_indir);
Formula (all,i,TRAD_COMM)(all,s,REG)(all,r,REG)
DVADECOMP(i,s,r,"DVA_dir") = sum(j,TRAD_COMM,sum(t,REG,DVA_d(i,j,t,s,r)));
Formula (all,i,TRAD_COMM)(all,s,REG)(all,r,REG)
DVADECOMP(i,s,r,"DVA_indir") = sum{j,TRAD_COMM,sum[t,REG,DVA_i(i,j,t,s,r)]};
```

It should be noted that the total value added exported by each sector does not coincide with gross trade by commodity: it may be larger or smaller according to input demand to and from the other sectors of the economy. In practice, if the sector's value added embedded in other commodities exports is larger (smaller) than the other sectors' value added embedded in the sector own exports, gross flows by commodity underestimate (overestimate) the importance of the international markets.

It is also worth emphasizing that the DVA_indir refers to the inputs from a particular sector travelling through the local production chain, i.e. not crossing any border before reaching the exporting sector. Global value chains, that is, bilateral and multilateral production sharing relationships, are considered in the following section.

2.2.3 Bilateral and multilateral value added by sector, exporter, and importer

In order to assess the trade relevance of partner countries, gross bilateral exports are both too much and too little: "too much" because they include foreign value added and double-counting (see 2.2.1) and "too little" because they do not take into account the whole international trade network. As a matter of fact, a country's domestic value added reaches every importer through bilateral exports as well as through the value embedded in the exports of third countries to that market.

Recalling the numerical example in the previous section, the total value added of country A which is absorbed by country B is \$5: country A exports domestic value added to country B bilaterally (\$1 of bilateral exports) and multilaterally through country C's exports to B (\$4 of A's domestic value added exported to C to be processed and finally delivered to B).

We define the total exports of value added from country s to country r as the sum of the bilateral ($DVA\_blt_j^{sr}$) and multilateral ($DVA\_mlt_j^{sr}$) components:

$$DVAEXP_j^{sr} = \underbrace{\sum_i \widehat{VSH}_i^s LOC_{ij}^{ss} * VXE_j^{sr}}_{DVA\_blt_j^{sr}} + \underbrace{\left[\sum_i \sum_{t \neq s,r} \widehat{VSH}_j^s L_{ji}^{st} * VXE_i^{tr} - \sum_k \sum_l \sum_m \sum_i \sum_{t \neq s,r} \widehat{VSH}_j^s LOC_{jk}^{ss} A_{kl}^{sr} L_{lm}^{rs} L_{mi}^{st} * VXE_i^{tr}\right]^{15}}_{DVA\_mlt_j^{sr}} \quad (21)$$

The first term ($DVA\_blt_j^{sr}$) in the RHS corresponds to the domestic value in bilateral exports defined in the first term of Equation (19). The second term ($DVA\_mlt_j^{sr}$) represents the multilateral exports of country s′ value added to country r and includes two components.

The first component is the value added of intermediate good j exported by country s and embedded in all the third countries t's exports to country r. However, if in country s' exports to t there is some double-counting due to previous exports to country r, this would be included in the coefficient of the global inverse for country t using inputs from s (L_{ji}^{st}). In the numerical example, the $1 exported bilaterally by A to B would be counted again in A's multilateral exports of value added to B (through country C), which would then account for $5. In order to clean out the double-counting in the multilateral component, we need to distinguish within the domestic double-counting in a country's export the portion due to bilateral exports to the country that also receives multilateral exports.

The second component represents the double-counting. That is, it accounts for s' value added previously exported to country r as embedded in intermediates which are used by country r to re-exports to s; once again in country s, it is exported to country t which processes it again before exporting to country r. As in section 2.2.1, we implement this by exploiting the difference between the global and the local Leontief inverse of the country of origin of VA. However, the double-counting referred to multilateral exports of VA is distinct from the double-counting referred to bilateral exports of VA (see the second term in Equation (19)). Indeed, the first is generated by previous exchanges with the country representing both the bilateral and multilateral

---

[15] In the DVA_mlt component in Equation (21), the order of indices is reversed in order to express the bilateral and multilateral domestic value-added indicators for the same reference country and sector. Specifically, in DVA_mlt, the source country of value is indexed by s (instead of t as in all other equations) and j is the sector of origin of value (instead of i). This allows us to compute the value added originated in the reference country for a given sector that reaches the importer both bilaterally and multilaterally.

destination, while the second is generated by previous exchanges with all the countries other than the bilateral importer.[16]

The total exported value added to a given destination may be bigger or smaller than gross trade values, depending on the magnitude of backward and forward linkages. Specifically, gross exports exceed (are inferior to) total domestic value-added exported ($DVAEXP$) when the foreign content of bilateral exports (FVA) is larger (smaller) than the multilateral value-added component (DVA_mlt).

The decomposition of the total exports of value-added is implemented in the code as:

```
Formula (all,j,TRAD_COMM)(all,i,TRAD_COMM)(all,s,REG)(all,t,REG)(all,r,REG)
DVAM (j,i,s,t,r) = IF(s NE t and s NE r,TVA(j,i,s,t,r));
Set DVAT (DVA_blt,DVA_mlt);
Formula (all,j,TRAD_COMM)(all,s,REG)(all,r,REG)
DVAEXP(j,s,r,"DVA_blt") = sum{i,TRAD_COMM,sum[t,REG,DVA(i,j,t,s,r)]};
Formula (all,j,TRAD_COMM)(all,s,REG)(all,r,REG)
DVAEXP(j,s,r,"DVA_mlt") = sum{i,TRAD_COMM,sum[t,REG,DVAM(j,i,s,t,r)]}
                         -sum{f,REG,sum[t,REG,DC_DVAM(j,f,s,t,r)]};
```

where DVAM(j,i,s,t,r) is the multilateral domestic value added in country s' exports to r including the double-counting (second term of Equation 21)) and DC_DVAM(j,f,s,t,r) is the double-counting related to the multilateral value added exports as defined in the third term of Equation (21).

2.2.4 Reflected and other countries foreign value added by sector

Within the foreign VA component in country s' gross exports to country r, we define the reflected component as the value added embedded as intermediates in goods that are reflected back to the source/importing country r (FVA_rfl), and the other countries foreign value added as the value added originating in all countries (excluding r) providing inputs used by country s to export to r (FVA_other):

$$FVA\_ex_j^{sr} = \underbrace{\sum_i \widehat{VSH}_i^r L_{ij}^{rs} * VXE_j^{sr}}_{FVA\_rfl_j^{sr}} + \underbrace{\sum_i \sum_{t\neq s,r} \widehat{VSH}_i^t L_{ij}^{ts} * VXE_j^{sr}}_{FVA\_other_j^{sr}} \qquad (22)$$

Looking back to Figure 1, country A's exports to country C include $3 reflected value added (previously imported as intermediate inputs from C and subsequently exported back to C) and $2 foreign value added provided by

[16] The double-counting related to the multilateral component is obtained by distinguishing within the domestic double-counting the portion due to bilateral exports to the same country that receives the multilateral exports. Formally, we decompose the difference between the global and the local Leontief inverse in two terms:
$L^{ss} - LOC^{ss} = \sum_{t\neq s} LOC^{ss}A^{st}L^{ts} = LOC^{ss}A^{sr}L^{rs} + \sum_{t\neq s,r} LOC^{ss}A^{st}L^{ts}$,
and we exclude the first from the output from s required to produce in t (L^{st}) since it has already been counted in the bilateral exports from s to r, and include the second portion which is effectively output of s needed by t to export in r not accounted for in s' bilateral exports to r.

country B. In the code, the set "ORIGFVA" gathers over these two components of the foreign value added according to the country of origin of value:

```
Formula (all,i,TRAD_COMM)(all,j,TRAD_COMM) (all,t,REG)(all,s,REG)(all,r,REG)
FVA_r (i,j,t,s,r) = IF[r EQt,FVA(i,j,t,s,r)];
Formula (all,i,TRAD_COMM)(all,j,TRAD_COMM) (all,t,REG)(all,s,REG)(all,r,REG)
FVA_t (i,j,t,s,r) = IF[r NEt,FVA(i,j,t,s,r)];
Set ORIGFVA (FVA_rfl,FVA_other);
Formula (all,j,TRAD_COMM)(all,r,REG)(all,s,REG)
FVADECOMP(j,s,r,"FVA_rfl") = sum{i,TRAD_COMM,sum[t,REG,FVA_r(i,j,t,s,r)]};
Formula (all,j,TRAD_COMM)(all,r,REG)(all,s,REG)
FVADECOMP(j,s,r,"FVA_other") = sum{i,TRAD_COMM,sum[t,REG,FVA_t(i,j,t,s,r)]};
```

The decomposition we have proposed in this paper allows the main components proposed by the literature on trade in VA to be retrieved and we are able to replicate the main indicators provided by the main databases, such as TiVA or WIOD. However, unlike all the existing trade in value-added decompositions, our indicators are embedded in a simulation model that allows policy analysis to be performed. As a matter of fact, we can assess the effect of a policy change on the global structure of GVCs by comparing the baseline values and the updated values deriving from the shock that has been simulated.

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

3. Illustrative application

In this section, we show the information produced by the GTAP-VA module and present its possible use in the context of a bilateral tariff cut scenario. The numerical implementation of this theoretical model is carried out by a stylized scenario in order to keep the analysis tractable and provide a transparent interpretation of results. (This example can be replicated by the reader simply by downloading the supplementary files accompanying this paper.)

We use the GTAP 10 Data Base (prerelease). We aggregate the database to 3 regions: USA, EU and ROW and 3 sectors: Agrifood, Manufactures, and Services. To illustrate how the trade in VA decomposition can be used in a CGE model, we simulate an FTA agreement between the EU and the USA. The trade in VA decomposition results are presented below with the EU as exporter and the USA as importer. We first describe the trade in VA structure in the baseline. We then discuss the changes in terms of value added taking place as a consequence of the FTA.

3.1 Baseline

The value-added decomposition is obtained with an experiment computing the local and global inverse Leontief matrices.[17] The results of the decomposition are stored in a new HAR file named "VALUEADDED" which

[17] This is the "invert matrix" experiment in the sample version.

can be found in the version folder. In the following, we highlight each of the indicators presented in the previous section.

3.1.1 Domestic and foreign content of bilateral exports by sector

The "VADECOMP" coefficient is defined over 4 dimensions:

1. trading sector,
2. exporter,
3. importer,
4. origin of the value added: the domestic component (DVA), the foreign one (FVA), and the double-counting (DDC).

Table 3 shows the EU's gross exports to the USA and value-added decomposition.[18]

Table 3. EU exports to the USA: gross trade and value-added decomposition (VADECOMP coefficient, $ million).

VADECOMP	DVA	DDC	FVA	GROSS TRADE (VXE)
Agrifood	19,753	103	3,360	23,216
Manufactures	271,490	2,933	72,206	346,629
Services	129,874	346	9,705	139,925
Total	421,117	3,382	85,271	509,770

Source: GTAP-VA model.

Looking at the value-added components, we can see how much of the value added embodied in EU gross export is originated in the EU itself: $421,117 million out of $509,770 million of the gross exports. It follows that $85,271 million is the foreign value added provided by non-EU countries (including the USA itself). The double-counting component – i.e., the value of EU's exports that had already been exported, imported again, processed, and finally embedded in its exports to the USA - amounts to $3,382 million (0.7% of gross exports), and it is mostly in Manufactures.

Table 3 also shows the sectoral decomposition of both domestic and foreign value-added components. More than half of the EU value added bilaterally exported to the USA is embedded in Manufactures exports ($271,490 million). It is worth noticing that the share of Manufactures in gross exports (67.9%) is higher than its share in terms of value added (64.4%) while the opposite is true for Services (27.4% vs 30.8%). This implies that Manufactures includes a larger share of foreign value added through the use of foreign intermediate goods.

3.1.2 Bilateral direct/indirect domestic value added by originating sector

The EU bilateral domestic value-added component (corresponding to $421,117 million) can be disaggregated by distinguishing direct and indirect

[18] In this case, the selection of sets for VADECOMP is [AllTrad_comm, EU, USA, AllOrigvalue].

linkages across sectors. The "DVADECOMP" coefficient is defined over 4 dimensions:

1. sector of origin of the value added
2. exporter
3. importer
4. types of export: direct, when the origin and the trading sectors coincide (DVA_dir); indirect, when the trading sector differs from the origin one (DVA_indir).

Table 4 shows the direct and indirect component of the EU value added bilaterally exported to the USA for each sector.[19] In the case of the Agrifood and Services sectors, a large share of the value added generated in these sectors is actually exported embedded in the Manufactures goods. The high level of aggregation of this example does not allow us to comment on the value chain position of each sector. However, a more detailed analysis could highlight the upstreamness/downstreamness of different products.

Table 4. Direct and indirect decomposition of the domestic value-added component in the EU exports to the USA (DVADECOMP coefficient, $ million).

DVADECOMP	DVA_dir	DVA_indir	Total
Agrifood	11,482	12,638	24,120
Manufactures	162,979	8,991	171,970
Services	120,666	104,361	225,027
Total	295,126	125,990	421,117

Source: GTAP-VA model.

In Table 4, the totals by commodity do not coincide with the DVA values presented in Table 3 although the total over all commodities does. The reason is that Table 3 shows the value added by trading sector, whereas Table 4 shows the value added by originating sector. For instance, if some of the $24,120 million value added originating in the Agrifood sector is processed and exported as part of other sectors (Manufactures and Services), then in Table 3 this value added would be allocated to Manufactures and Services, while in Table 4 it is included in the DVA_indir component ($ 12,638 million) of the Agrifood sector.

If the total value added originating in the sector (e.g., Agrifood in Table 4) is greater than the total value added exported by the sector (e.g., Agrifood in Table 3), the indirect VA component is larger than the value added of other sectors (e.g., Manufactures and Services) embedded in its own exports.

3.1.3 Bilateral and multilateral value added by sector, exporter, and importer

The "DVAEXP" coefficient is defined over 4 dimensions:

1. trading sector

[19] In this case, the selection of sets for DVADECOMP is [AllTrad_comm, EU, USA, AllOrigvalue].

2. exporter
3. importer
4. types of export: bilateral, when the calculations refer to bilateral exports (DVA_blt); and multilateral, when we consider all possible trade flows conveying the value added of the exporter into the final market (DVA_mlt).

Table 5 presents the decomposition of the total value added exported by the EU to the USA market into bilateral and multilateral components.[20]

Table 5. EU exports to the USA: bilateral and multilateral decomposition of the value-added (DVAEXP coefficient, $ million).

DVAEXP	DVA_blt	DVA_mlt	Total
Agrifood	19,753	8,278	28,043
Manufactures	271,490	38,282	309,826
Services	129,874	45,949	175,893
Total	421,117	92,509	513,761

Source: GTAP-VA model.

The bilateral component refers to the domestic value added embodied in the bilateral export from EU to USA, i.e. DVA (Table 3). The multilateral component represents the value added of the EU embodied in the exports from third countries (ROW in our aggregation) to the USA. That is, EU exports of value added to third countries, which are then processed and exported to the USA. One fourth of total EU value added exported to the USA transits through other countries. The relevance of third countries as a platform to reach the US market is quite uneven across: a more detailed disaggregation would highlight which sectors would suffer more in the event of trade wars between the USA and non-EU countries.

3.1.4 Reflected and other countries foreign value added by sector

Moving on to the foreign component of value added, in order to decompose the "FVADECOMP" coefficient, we consider 4 dimensions:

1. trading sector
2. exporter
3. importer
4. type of foreign value added: ‘reflected’, when the foreign country providing intermediate inputs to the exporter coincides with the importing country; and ‘other countries’, when foreign inputs are provided by countries other than the importer.

Table 6 shows the origin of the foreign value added used by the EU in its exports to the USA.

[20] In this case, the selection of sets for DVAEXP is [AllTrad_comm, EU, USA, AllOrigvalue].

Table 6. EU exports to the USA: decomposition of the foreign value-added component (FVADECOMP coefficient, $ million).

	FVADECOMP
Reflected	12,399
Pure foreign	72,873
Total	85,271

Source: GTAP-VA model.

Out of a total FVA equal to $85,271 million (total in Table 3), $12,399 million are "reflected" since they originated in the USA. The other component, corresponding to $72,873 million, originates from the residual region (i.e., ROW) of our 3x3 aggregation. However, with aggregation including more than 3 countries, we can compute the share of each supplier.[21]

3.2 Simulation

In our simulation, we fully remove tariffs between the EU and the USA. It is worth recalling that this simulation is not meant to be realistic, it is merely used to provide an example of the results that can be obtained using the decomposition.

Table 7 shows the new value of gross trade and its decomposition by domestic and foreign value added for the FTA scenario.

Table 7. FTA scenario: EU exports to the USA, gross trade and value-added decomposition (VADECOMP coefficient, $ million and % change).

VADECOMP	DVA	DDC	FVA	GROSS TRADE (VXE)
Agrifood	23,503 (19.0%)	123 (19.4%)	4,033 (20.0%)	27,660 (19.1%)
Manufactures	291,930 (7.5%)	3,199 (9.1%)	78,607 (8.9%)	373,736 (7.8%)
Services	130,310 (0.3%)	351 (1.4%)	9,808 (1.1%)	140,468 (0.4%)
Total	445,743 (5.8%)	3,673 (8.6%)	92,448 (8.4%)	541,864 (6.3%)

Source: GTAP-VA model.

The changes in gross trade are weighted averages of the changes registered by each component, and this explains why they closely mimic the domestic value added. A more detailed sectoral disaggregation could highlight larger heterogeneity. Overall, EU exports to the USA increase from $509,770 million

[21] The sector of origin of the reflected foreign value added can be disaggregated, and this provides some policy indications regarding tariffs that could harm the competitiveness of exports. For example, with the following settings in the TVA coefficient, we can verify which are the most important inputs from the USA for EU exports to the USA itself: [AllTrad_comm, SumTrad_comm, USA, EU, USA].

to 541,864 (+6.3%). However, while the domestic, i.e. EU, value added grows by 5.8% due to the FTA with the USA, the foreign component increases by 8.4%, faster than the domestic one. In a traditional analysis of trade flows, the increased foreign component of EU exports to the USA is not usually examined, although since this foreign component includes value added from the ROW, it reduces the trade diversion effects of the FTA measured in terms of gross trade flows. This suggests that an FTA between the USA and the EU could provide a boost for other countries not involved in the agreement by increasing demand for imported intermediates from these countries to be used in the production of increased EU exports to the USA.

If we look at Table 8, we can examine the direct and indirect contribution of each sector to EU exports to the USA.

Table 8. FTA scenario: direct and indirect decomposition of the domestic value-added component in the EU exports to the USA (DVADECOMP coefficient, $ million and % change).

DVADECOMP	DVA_dir	DVA_indir	Total
Agrifood	13,669	13,385	27,054
	(19.0%)	(5.9%)	(12.2%)
Manufactures	175,240	9,270	184,510
	(7.5%)	(3.1%)	(7.3%)
Services	121,120	113,059	234,179
	(0.4%)	(8.3%)	(4.1%)
Total	310,029	135,714	445,743
	(5.0%)	(7.7%)	(5.8%)

Source: GTAP-VA model.

By comparing the simulation results with the baseline (Table 4), we observe the largest increase for the domestic value added directly exported by Agrifood (+19%), the sector with the largest declines in tariffs. Overall, the FTA between the EU and the USA will promote trade more in the indirect component (7.7% vs 5%), and this is a sign of the deepening of the value chain integration within the EU. This is mostly explained by Services: they represent a large part of the economy and they are required to allow for the increased exports by Agrifood and Manufactures (+8.3%). However, given the lack of tariffs on Services in the baseline, the increase of direct value-added exports in the Services sector is negligible (0.4%).[22]

Using bilateral and multilateral decomposition, we can observe the impact of the FTA on the total value added exported by the EU to the USA (Table 9).

[22] The latter point was (rightly) raised by an anonymous referee. However, it has to be acknowledged that the GTAP Data Base does not really allow an accurate analysis since the global transport sector collects services inputs from all countries.

Table 9. FTA scenario: EU exports to the USA, bilateral and multilateral decomposition of the value added (DVAEXP coefficient, $ million and % change).

DVAEXP	DVA_blt	DVA_mlt	Total
Agrifood	23,503	8,239	31,742
	(19.0%)	(-0.5%)	(13.2%)
Manufactures	291,930	38,123	330,053
	(7.5%)	(-0.4%)	(6.5%)
Services	130,310	45,818	176,128
	(0.3%)	(-0.3%)	(0.2%)
Total	445,743	92,180	537,923
	(5.8%)	(-0.4%)	(4.7%)

Source: GTAP-VA model.

The expected increase is concentrated in the goods sectors and the overall change is the net outcome of a large increase in the bilateral component and a reduction in the multilateral one. This is a consequence of the trade diversion taking place in terms of gross trade flows since after the bilateral agreement between EU and USA, EU and USA trade with the ROW decreases, thereby reducing the amount of EU value added that enters the USA indirectly through other countries.

Finally, Table 10 presents the results for the foreign value added component.

Table 10. FTA scenario: EU exports to the USA, decomposition of the foreign value-added component (FVADECOMP coefficient, $ million and % change).

	FVADECOMP	
	$ million	(% change)
FVA_rfl	14,336	(15.6%)
FVA_other	78,112	(7.2%)
Total	92,448	(8.4%)

Source: GTAP-VA model.

The comparison between the figures in Tables 6 and 10 shows an increase that is consistent with the overall change in bilateral exports from the EU to the USA, and the largest increase in the foreign value-added component as already mentioned. However, the rate of change of the two components is quite different and the larger increase of the USA value added included in EU exports (15.6%) suggests that the FTA leads to a deeper integration between the two countries' value chains.

Table 11 summarizes the trade in VA impact due to the removal of tariffs on EU exports to the USA, and presents the results for the other bilateral trade flows. The rows represent the exporting country so that the row sum gives the impact on gross bilateral exports to the USA (11 a), the EU (11 b), and the ROW (11 c). The first three columns distinguish the country of origin of the value added; the column sum gives the total impact on each country's exports in value added. The fourth column records the double-counting.[23] Note that these are the changes in trade and value-added due to the FTA.

Table 11. FTA scenario: changes in the value-added composition of exports ($ million).

a) Importer: USA

		Country of origin of VA				Gross exports
		USA	EU	ROW	DC	
Exporter	EU	1,937	24,626	5,200	331	32,094
	ROW	-728	-329	-3,011	-236	-4,304
Total		1,209	24,297	2,189	95	27,790

b) Importer: EU

		Country of origin of VA				Gross exports
		USA	EU	ROW	DC	
Exporter	USA	29,929	1,818	5,666	298	37,711
	ROW	-819	-444	-6,172	-280	-7,715
Total		29,110	1,374	-506	18	29,996

c) Importer: ROW

		Country of origin of VA				Gross exports
		USA	EU	ROW	DC	
Exporter	USA	-18,161	1,416	-3,512	5	-20,252
	EU	4,313	-6,453	-1,265	182	-3,223
Total		-13,848	-5,037	-4,777	187	-23,475

Source: GTAP-VA model.

First, we consider the impact on the EU. In gross terms, the EU exports more to the USA (+$32,094 million section a). However, a portion of that change in exports is foreign value added ($7,137 million, adding up the USA and ROW values in section a). This implies that the FTA increased the EU's value added exported bilaterally to the USA by only $24,626 million (section a). Some of the EU value added exported to the USA is used in USA exports to the ROW (+$1,416 million section c). Global value chains between EU and USA get thicker since both the USA and EU increase the value added reflected back (by $1,937 million section a), and $1,818 million section b), respectively).

[23] The double-counting reported in the fourth column (DC) includes the double-counting related to both the bilateral and multilateral exports of value added to the importer. For example, $331 million in the first row in section a) represents the sum of: i) the double-counting in EU exports to the USA (see the second term in Equation (19)), plus ii) the double-counting in ROW multilateral exports of value added to the USA through the EU platform (see the last term in Equation (21)).

As expected, the EU would decrease its exports to the ROW (-$3,223 million section c). The reduction is even larger in value added terms (-$6,453 million section c) since EU exports to the ROW would contain more USA value added (+$4,313 million section c), while the ROW value added reflected back by the EU to the ROW is going to decrease (-$1,265 million section c). On the other hand, the already mentioned increase in EU value added reaching ROW through USA's exports reduces the overall diversion of EU value-added exports to the ROW though the contraction (-$5,037 million section c) remains much larger than the gross EU export reduction.

Overall, the change in total EU value added exported is much smaller than in gross trade: the latter is equal to +$28,871 million (+$32,094 million section a) exported to the USA plus -$3,223 million section c) exported to ROW); the former is equal to +$20,634 million considering the increase in USA imports (+$24,297 million section a) and the reduction in ROW imports (-$5,037 million section c) as well as the increase in EU reflected imports (+$1,374 million section c).

In the case of the USA, results are broadly similar. However, the increase in trade in VA is slightly smaller ($16,471 million) than the increase in gross exports ($17,459 million).

Finally, the ROW would decrease its total exports by $12,019 million (-$7,715 million plus -$4,304 million). However, the decrease in terms of value added exported would be much smaller (-$3,094 million) since although bilateral exports fall, multilateral exports rise. As a matter of fact, there is an increase in the VA exported to the USA market (+$2,189 million section a) and only a small decrease in VA exported to the EU market (-$506 million section b).

4. **Conclusions**

Global value chain analysis requires global input-output tables in which national tables are combined and linked via international trade matrices. The release of global input-output datasets has fueled research into the implications of global value chains on trade, the economy, and the environment. In particular, a growing literature has devised new empirical methods to disentangle the value-added and intermediate input contents of gross bilateral international trade flows.

However, the complex matrix transformations at the basis of most value chain indicators still constitute a significant entry barrier to the field. The GTAP-VA Model solves this problem by implementing the algorithms for the analysis of trade in value added as GEMPACK procedures, thereby simplifying the decomposition process.

In this paper, we implement a decomposition of bilateral gross trade flows in different value-added components regarding exporter, importer and third countries. This provides a comprehensive picture of each country/sector level of integration in GVC activities from multiple dimensions. Indeed, each value-added component can be computed for each country and industry sourcing the value added, and each country exporting sector.

By computing these values using the standard GTAP Data Base, we produce a large set of results offering important economic insights. Although trade in value added decompositions are not new in the literature, this is the first attempt to integrate them in the GTAP model. Consequently, after each simulation, the impact can be assessed not only in terms of gross trade, but also in terms of value-added flows. However, even if gross trade decomposition provides a deeper understanding of the results produced by the existing models, it is worth emphasizing that proper modeling of global supply chains requires a new generation of CGE models that is able to incorporate the fragmentation of production processes, scale economies and global decision-making (Athukorala et al., 2017).

To illustrate how the VA decomposition module can offer a valuable addition to the CGE modeling community, we undertake a counterfactual analysis in which bilateral tariffs between the USA and the EU are removed. The value-added decomposition highlights that the overall impact on each sector value added depends on total exports since it may be embedded in other sector export flows. Further, we take into account multilateral production relationships, by assessing the total value-added exports in both bilateral and multilateral links. Moreover, tracing the value added makes it apparent that part of the indirect impact is due to re-exports whenever EU exports are embedded in USA exports to the EU, or vice versa. Finally, the traditional set of results would overlook the different types of indirect effects on each sector whereas the valued-added decomposition makes it clear that each country's production is not only affected by the tariff on its own exports but also by tariff changes on other countries' exports, whenever there are global production linkages.

Global value chains are now a major part of world trade. The absence of CGE models providing trade in value-added results leaves a vacuum in the policy-advising space. The GTAP-VA model makes it possible to show the changes in value-added flows resulting from trade policy simulations undertaken within the widely used GTAP family of CGE models.

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