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by Alessandro Borin and Michele Mancini

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FOLLOW THE VALUE ADDED: BILATERAL GROSS EXPORT ACCOUNTING

by Alessandro Borin* and Michele Mancini*

Abstract

The diffusion of international production networks has challenged the capability of traditional trade statistics to provide an adequate representation of supply and demand linkages among the economies. To address this issue, new statistical tools (the Inter-Country Input-Output tables) and new analytical frameworks have been developed. Koopman, Wang and Wei propose an accounting methodology to decompose a country's total gross exports by source and final destination of their embedded value added. We develop this approach further by deriving a fully consistent counterpart for bilateral trade flows, refining the original framework. Along with other contributions, our methodology completes the bridge between traditional trade statistics and the systems of national accounts and provides new tools for investigating global value chains. Here we present two empirical applications of two different versions of our decomposition of bilateral trade flows: one explores the forward linkages of Italian exports; the second derives a measure of the share of value-chain-related trade and assesses how its evolution since the mid-1990s has affected the relationship between world trade and income.

JEL Classification: E16, F1, F14, F15.

Keywords: global value chains, input-output tables, trade in value added, trade elasticity.

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“This is your last chance. After this, there is no turning back. You take the blue pill - the story ends, you wake up in your bed and believe whatever you want to believe. You take the red pill - you stay in Wonderland and I show you how deep the rabbit-hole goes. [...] sooner or later you’re going to realize just as I did that there’s a difference between knowing the path and walking the path.”

— Morpheus, *Matrix*

1 Introduction¹

The international fragmentation of production processes has challenged the capability of the standard trade statistics to truly represent supply and demand linkages among economies. In general bilateral exports differ from the portion of a country’s GDP related with the production of goods and services shipped to a certain outlet market. Indeed, on one hand exports also embed imported intermediate inputs, on the other hand the directly importing country often differs from the ultimate destination where the good is absorbed by final demand. Whenever production is organized in sequential processing stages in different countries, trade statistics repeatedly double-count the same value added. The diffusion of global value chains (GVC) has therefore deepened the divergence between gross flows, as recorded by traditional trade statistics, and the data on production and final demand as accounted for in statistics based on value added (above all GDP).

Koopman, Wang and Wei (2014) (hereafter KWW) propose a comprehensive decomposition of total gross exports that bridges the gap between the official gross trade statistics and the System of National Accounts. This is not the first scheme to classify trade flows by the source and destination of their embedded value added, but their framework does encompass most of the methodologies proposed in the literature (e.g. Hummels, Ishii and Yi, 2001; Daudin et al., 2009; and Johnson and Noguera, 2012). KWW point out that different schemes of international fragmentation of production yield different proportions of value added content in gross

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exports. In particular, they show that not all the double-counted flows in gross trade statistics are alike. Moreover, in the spirit of Johnson and Noguera (2012), they classify value added in exports in such a way as to take account also of the destination of final absorption.

Exports of a given country are often thought as a proxy for foreign demand, but gross trade flows give only a rough picture. Indeed some products are exported only for processing abroad, and then re-imported to supply domestic demand. Such exports, clearly, are not generated by foreign demand. In other cases, even when the final good is consumed abroad, the country of final absorption may be different from the original importer. Using inter-country input-output tables like the WIOD (Timmer et al. 2015) or the OECD-WTO TiVA, one can track value added along the supply chain from the origin to the country of final use and so better evaluate the role of foreign demand more precisely, distinguishing the intermediate exports for final use at home from those absorbed abroad, and pinpointing the final markets for exported inputs. Through the KWW taxonomy of total gross exports it is possible to exploit the data in these international input-output tables to link the country of origin of with the one where the value added is finally absorbed.

Following this reasoning, KWW break gross exports down into different components of domestic and foreign value added plus two items of 'pure' double counting. As to the latter, they show that gross exports do not in general consist only of value added that can be traced back to GDP generated either at home or abroad. Instead, some trade flows are purely double-counted, as when intermediate inputs cross a country's borders several times according to the different stages of production. A more detailed account of this mechanism is given below. In any event it is worth noting that double-counted items are increasingly important in international trade flows (see Wang et al., 2013 and Cappariello and Felettigh, 2015). This is one reason why it could be useful to adopt the KWW approach in the analysis of bilateral trade flows.

Our aim, in fact, is to extend KWW's methodology in order to obtain a consistent decomposition of bilateral exports. Measuring the value added composition of trade at bilateral level offers additional information on a good many matters that cannot be investigated using simple gross trade data or aggregate trade in value added, as in KWW. By focusing on bilateral trade flows, the methodology we propose can further contribute to form a bridge between traditional trade statistics and systems of national accounts.

In studying global value chains, it is useful to analyze the overall structure

of production networks and to identify all the international and intersectoral links. Methodologies like KWW's can track the value added linkages between the country of origin and that of final destination. But we may also be interested in the position of a country (or a sector) within the production process and in identifying its direct upstream and downstream trade partners. Furthermore deepening the knowledge of these linkages provides insight into the role and the level of participation of individual countries in the global value chains and the way in which this affects bilateral trade balances. The potential policy implications are clearly significant. Although the inter-country I-O tables are only available with a lag, we can still use our procedures as tools to interpret recent trends in gross trade or to project future dynamics, insofar as the value added structure of bilateral exports can be presumed to be quite persistent. For example, if we know that in motor vehicles manufacturing a considerable share of the intermediate components exported from Italy to Germany are used to produce cars for the American market, we presume that a slackening of US demand is likely to result in a reduction in shipments of parts from Italy to Germany.

Lastly, while the different components in the KWW taxonomy discriminate accurately between the value added in exports consumed abroad and that re-imported and finally used at home, their methodology cannot properly distinguish between the value added absorbed by direct importers and that going to final uses in a third country. Conversely, going through bilateral trade flows we can better pinpoint these two components, while also refining the classification of aggregate gross exports.

Our work is closely related to that of Nagengast and Stehrer (2014) and Wang et al. (2013). Nagengast and Stehrer (2014) point out that there are different ways to account value added in bilateral trade. Indeed they propose two alternative methodologies: a first one takes the perspective of the country where the value added originates (the source-based approach), a second one takes the perspective of the country that ultimately absorbs it in final demand (the sink-based approach). However, neither methodology can properly account for all the domestic value added exported in the bilateral flow. Wang et al. (2013) follow KWW closely and propose a single breakdown of bilateral exports that can be exactly mapped into the original KWW decomposition summing all the export flows across the destinations. Nevertheless they use different approaches to single out domestic value added of the different components, so that their methodology suffers from internal inconsistency. In this work we breakdown bilateral gross exports both using a fully consistent sink-based approach and adopting a source-based perspective. Both

our decompositions correctly take into account the domestic value added and the double-counted components as defined in the original KWW framework.

The paper is organized as follows. The second section recalls KWW’s accounting, derives a decomposition of bilateral exports consistent with their framework, and illustrates how this new tool can help to assess international production networks. The third section presents two empirical applications exploiting the decomposition of bilateral trade flows. Section four concludes.

2 The decomposition of bilateral gross exports

2.1 KWW’s breakdown of total exports

The methodology proposed by KWW constitutes a rigorous and comprehensive accounting framework for gross foreign trade. The way in which this tool can improve our evaluation of countries’ trade relationships is offered by the two stylized production-consumption-trade schemes shown in Figure 1. In panel 1.a) production is organized in stages, each in a different country. First country A produces 1 USD worth of intermediate components using only its own resources and ships them to B, which adds 1 USD of value to produce more refined intermediate products, which are sent to C. Here they undergo a final processing stage, worth another 1 USD, before being sold as final goods back to A for 3 USD. In panel 1.b, instead of having sequential stages of production in A and B, initially each country produces intermediate components worth 1 USD using only its own productive factors and ships them to C; here the different inputs are assembled, adding another 1 USD of value to produce final goods that are absorbed by final demand in A, as before.

Gross trade statistics indicate that in case 1.a country A’s exports are generated by demand from country B, and in case 1.b. by demand from C. Since KWW trace both the origin and the final destination of value added, however, their decomposition shows that in both cases the exports are actually activated by country A’s own domestic demand.

Before analyzing bilateral trade flows, let us start from the accounting framework for total exports introduced by Koopman, Wang and Wei (2014). Their methodology is based on a global input-output model with G countries and N sectors (for details see Appendix A which also gives an exhaustive definition of our notation, which is essentially identical to KWW). Here let us only recall that \mathbf{Y}_{sr}

indicates the demand vector of final goods produced in s and consumed in r , \mathbf{B} is the global Leontief inverse matrix for the entire inter-country model, \mathbf{A} is the matrix of input coefficients, \mathbf{V}_s incorporates the value added shares embedded in each unit of gross output produced by country s , \mathbf{E}_{s*} is the vector of total exports of country s for the N sectors, and \mathbf{u}_N is the $1 \times N$ unit row vector.

The essential decomposition of total exports of country s ($\mathbf{u}_N \mathbf{E}_{s*}$) in KWW is summarized by the following accounting relationship:

$$\begin{aligned}
\mathbf{u}_N \mathbf{E}_{s*} = & \left\{ \mathbf{V}_s \sum_{r \neq s}^G \mathbf{B}_{ss} \mathbf{Y}_{sr} + \mathbf{V}_s \sum_{r \neq s}^G \mathbf{B}_{sr} \mathbf{Y}_{rr} + \mathbf{V}_s \sum_{r \neq s}^G \sum_{t \neq s, r}^G \mathbf{B}_{sr} \mathbf{Y}_{rt} \right\} \\
& + \left\{ \mathbf{V}_s \sum_{r \neq s}^G \mathbf{B}_{sr} \mathbf{Y}_{rs} + \mathbf{V}_s \sum_{r \neq s}^G \mathbf{B}_{sr} \mathbf{A}_{rs} (\mathbf{I} - \mathbf{A}_{ss})^{-1} \mathbf{Y}_{ss} \right\} \\
& + \mathbf{V}_s \sum_{r \neq s}^G \mathbf{B}_{sr} \mathbf{A}_{rs} (\mathbf{I} - \mathbf{A}_{ss})^{-1} \mathbf{E}_{s*} \\
& + \left\{ \sum_{t \neq s}^G \sum_{r \neq s}^G \mathbf{V}_t \mathbf{B}_{ts} \mathbf{Y}_{sr} + \sum_{t \neq s}^G \sum_{r \neq s}^G \mathbf{V}_t \mathbf{B}_{ts} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \mathbf{Y}_{rr} \right\} \\
& + \sum_{t \neq s}^G \sum_{r \neq s}^G \mathbf{V}_t \mathbf{B}_{ts} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \mathbf{E}_{r*} \tag{1}
\end{aligned}$$

KWW defines the nine items in equation (1) as follows:

1. $\mathbf{V}_s \sum_{r \neq s}^G \mathbf{B}_{ss} \mathbf{Y}_{sr}$: domestic value added in direct final goods exports;
2. $\mathbf{V}_s \sum_{r \neq s}^G \mathbf{B}_{sr} \mathbf{Y}_{rr}$: domestic value added in intermediate exports absorbed by direct importers;
3. $\mathbf{V}_s \sum_{r \neq s}^G \sum_{t \neq s, r}^G \mathbf{B}_{sr} \mathbf{Y}_{rt}$: domestic value added in intermediate goods re-exported to third countries;
4. $\mathbf{V}_s \sum_{r \neq s}^G \mathbf{B}_{sr} \mathbf{Y}_{rs}$: domestic value added in intermediate exports reimported as final goods;
5. $\mathbf{V}_s \sum_{r \neq s}^G \mathbf{B}_{sr} \mathbf{A}_{rs} (\mathbf{I} - \mathbf{A}_{ss})^{-1} \mathbf{Y}_{ss}$: domestic value added in intermediate inputs reimported as intermediate goods and finally absorbed at home;
6. $\mathbf{V}_s \sum_{r \neq s}^G \mathbf{B}_{sr} \mathbf{A}_{rs} (\mathbf{I} - \mathbf{A}_{ss})^{-1} \mathbf{E}_{s*}$: double-counted intermediate exports originally produced at home;

7. $\sum_{t \neq s}^G \sum_{r \neq s}^G \mathbf{V}_t \mathbf{B}_{ts} \mathbf{Y}_{sr}$: foreign value added in exports of final goods;
8. $\sum_{t \neq s}^G \sum_{r \neq s}^G \mathbf{V}_t \mathbf{B}_{ts} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \mathbf{Y}_{rr}$: foreign value added in exports of intermediate goods;
9. $\sum_{t \neq s}^G \sum_{r \neq s}^G \mathbf{V}_t \mathbf{B}_{ts} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \mathbf{E}_{r*}$: double-counted intermediate exports originally produced abroad.

Although KWW's methodology allows to improve the knowledge of value added content of total exports, it provides no insight into the structure of single bilateral flows. This could be relevant, especially from a policy perspective, in assessing bilateral trade balances. For example, evaluated in terms of gross trade flows, in Figure 1.a A runs a 1 USD surplus with B and a 3 USD deficit with C; in case 1.b, A shows a net bilateral balance of -2 USD towards C and zero with respect to B. In value added terms, A has a net trade deficit position of 1 USD with B and C in both cases. Thus while A's overall deficit is exactly the same in value added as in gross terms (2 USD), its bilateral positions differ considerably between the two accounting methods. Using basic accounting relationships and inter-country I-O tables, we can compute the bilateral positions in value added terms (see equation (A.7) in Appendix A). Yet this is not enough to disentangle the international production linkages and the ultimate demand forces that generate a particular surplus/deficit between two countries in gross terms; nor does the original KWW breakdown shed light on these matters when multiple trade partners and sources of final demand are involved.

Moreover some of KWW's definitions are questionable, but this will become clear only in the analysis of bilateral trade flows, so we prefer to return to this issue at the end of the following section.

2.2 The decomposition of bilateral trade

Through the analysis of bilateral trade flows we can follow the pattern of value added in exports along the downstream phases of the value chain. However the input-output framework potentially allows for infinite rounds of production. Hence we face a trade-off between adding details about the international production linkages and providing an analytically tractable and conceptually intelligible framework. Our compromise is to track first where the value added is directly exported, then - if it is not absorbed there - we consider the additional destinations of re-export from the direct importers; at this stage, we take into account all the possible linkages to

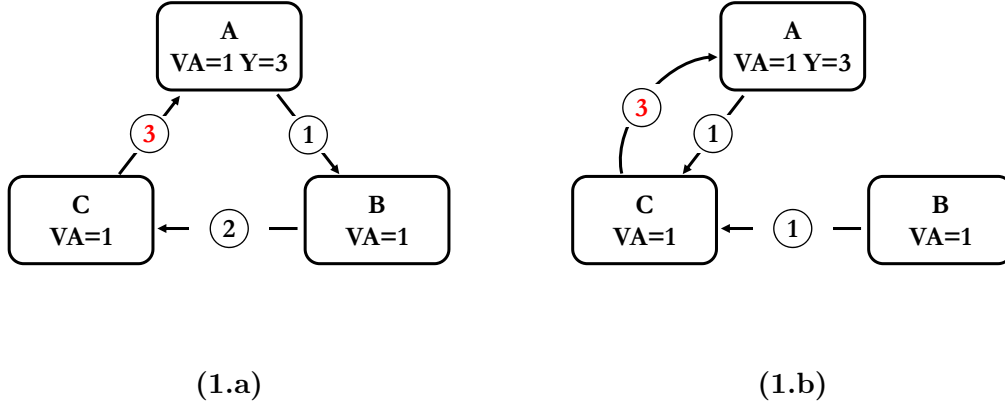


Figure 1: Value added versus gross export accounting of bilateral trade balances

the final producer and absorber in final demand through the Leontief inverse matrix **B**. In summary, our strategy is to decompose gross bilateral trade flows identifying the following actors: *i*) the country of origin of value added; *ii*) the direct importers; *iii*) the (eventual) second destination of re-export; *iv*) the country of completion of final products; *v*) the ultimate destination market.

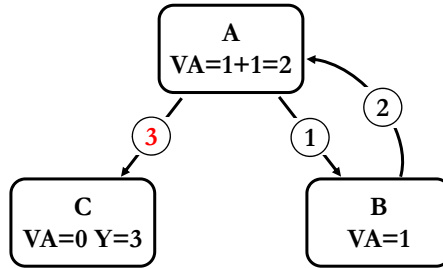


Figure 2: Value added and double counting in bilateral trade flows

Another conceptual issue that arises in considering the single bilateral flows regards the purely double counting items. As pointed out by Nagengast and Stehrer (2014), when a certain portion of value added crosses the same border more than once it has to be assigned to a particular gross bilateral trade flow, while it should be recorded as purely double counted in the other shipments. The issue is clearly pointed out by the scheme reported in Figure 2: here the 1 USD of value added originally produced in A is first exported to B as intermediate inputs, processed there, then shipped back to A and used to produce final goods for re-export to C. In this case, the value added generated in the very first stage of production in A is counted twice in its gross bilateral exports to B and C. The question is the following:

in which case should we consider it as ‘domestic value added’ and in which as ‘double counted’? Nagengast and Stehrer (2014) point out that it is an arbitrary choice and propose two alternative approaches: a first one takes the perspective of the country where the value added originates (the source-based approach), a second one that of the country that ultimately absorbs it in final demand (the sink-based approach). As regards the example in Figure 2, according to the source-based approach the original 1 USD of production of country A would be considered as ‘domestic value added’ in the gross exports to B (and ‘double counted’ in the shipments to C); vice-versa using the sink-based approach it would be considered as ‘domestic value added’ in the exports to C (and ‘double counted’ in the shipments to B).

In short we can say that the source-based method accounts the value added the first time it leaves the country of origin, while the sink-based approach considers it the last time it crosses the national borders. The choice between the two frameworks depends on the particular empirical issue we want to address. For instance if one is interested in inquiring the trade linkages through which the value added reaches a certain market of final destination, the sink-based approach is probably more appropriate. On the contrary the source-based method allows to trace the very first destination of value added from the country of origin. In section 3 we show two different empirical applications, each one adopting one of the two approaches described above. Hereafter we derive our decomposition of bilateral trade flows following a sink-based logic, since it represents the most significant contribution to the literature. In Appendix C we also provide a fully consistent counterpart for the source-based approach; while this decomposition of bilateral exports is more closely related to those proposed by Wang et al. (2013) and Nagengast and Stehrer (2014), we overcome some critical aspects of their methodologies.

The gross bilateral exports of country s to country r consist in final goods and intermediate inputs for the production of gross output in country r (\mathbf{X}_r):

$$\mathbf{E}_{sr} = \mathbf{Y}_{sr} + \mathbf{A}_{sr}\mathbf{X}_r. \quad (2)$$

In country r , in turn, the intermediate inputs imported from s undergo one or more processing phases to produce final products for domestic consumption or goods for re-export (both intermediate and final):

$$\mathbf{A}_{sr}\mathbf{X}_r = \mathbf{A}_{sr}(\mathbf{I} - \mathbf{A}_{rr})^{-1}\mathbf{Y}_{rr} + \mathbf{A}_{sr}(\mathbf{I} - \mathbf{A}_{rr})^{-1}\mathbf{E}_{r*}. \quad (2-bis)$$

Thus bilateral exports can be re-expressed as:

$$\mathbf{E}_{sr} = \mathbf{Y}_{sr} + \mathbf{A}_{sr}(\mathbf{I} - \mathbf{A}_{rr})^{-1}\mathbf{Y}_{rr} + \mathbf{A}_{sr}(\mathbf{I} - \mathbf{A}_{rr})^{-1}\mathbf{E}_{r*} \quad (3)$$

From equation (3) we can already identify some of the components of the KWW decomposition simply by applying the following property of the value added matrix \mathbf{VB} (see A.6):

$$\mathbf{u}_N = \mathbf{V}_s\mathbf{B}_{ss} + \sum_{t \neq s}^G \mathbf{V}_t\mathbf{B}_{ts}$$

Applying this equivalence to both sides of equation 3, we get an initial decomposition of bilateral gross exports in value added terms:

$$\begin{aligned} \mathbf{u}_N\mathbf{E}_{sr} &= \mathbf{V}_s\mathbf{B}_{ss}\mathbf{Y}_{sr} + \mathbf{V}_s\mathbf{B}_{ss}\mathbf{A}_{sr}(\mathbf{I} - \mathbf{A}_{rr})^{-1}\mathbf{Y}_{rr} \\ &+ \mathbf{V}_s\mathbf{B}_{ss}\mathbf{A}_{sr}(\mathbf{I} - \mathbf{A}_{rr})^{-1}\mathbf{E}_{r*} \\ &+ \sum_{t \neq s}^G \mathbf{V}_t\mathbf{B}_{ts}\mathbf{Y}_{sr} + \sum_{t \neq s}^G \mathbf{V}_t\mathbf{B}_{ts}\mathbf{A}_{sr}(\mathbf{I} - \mathbf{A}_{rr})^{-1}\mathbf{Y}_{rr} \\ &+ \sum_{t \neq s}^G \mathbf{V}_t\mathbf{B}_{ts}\mathbf{A}_{sr}(\mathbf{I} - \mathbf{A}_{rr})^{-1}\mathbf{E}_{r*} \end{aligned} \quad (4)$$

The first term in (4) is the counterpart of KWW's 'domestic value added in direct final goods exports'. Indeed, the sum of $\mathbf{V}_s\mathbf{B}_{ss}\mathbf{Y}_{sr}$ across all the r countries of destination gives exactly the first term in KWW's decomposition. Since it makes use of (a portion of) the global inverse Leontief matrix \mathbf{B} , this term fully account for the entire domestic value added embedded in exports of final goods. This means that if a certain product requires a first stage of processing at home, a second stage abroad and a final stage again at home, the domestic value added generated in both the first and the last stages is fully accounted for in this term. The peculiar feature of the sink-based approach is indeed to record the value added originated in all the upstream production stages the last time that a certain product leaves the country.

The last three terms in (4) correspond to the last three items of KWW accounting of total gross exports. $\sum_{t \neq s}^G \mathbf{V}_t\mathbf{B}_{ts}\mathbf{Y}_{sr}$ and $\sum_{t \neq s}^G \mathbf{V}_t\mathbf{B}_{ts}\mathbf{A}_{sr}(\mathbf{I} - \mathbf{A}_{rr})^{-1}\mathbf{Y}_{rr}$ measure respectively the foreign value added in final and intermediate goods exported to country r . As KWW point out, the last term represents pure double-counting of value added related to intermediate goods originally produced abroad.

We can define the second term in equation (4) ($\mathbf{V}_s \mathbf{B}_{ss} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \mathbf{Y}_{rr}$) as the actual ‘domestic value added in intermediate exports absorbed by direct importers’. However, this item differs from what KWW designate by this expression. Indeed, as Nagengast and Stehrer (2014) point out, the second term in KWW’s decomposition does not encompass only the domestic value added exports in the intermediate products directly exported to country r and then processed to satisfy r ’s final demand. Rather, it corresponds to the total value added generated in s and contained in the goods finally produced and consumed in r , including products undergoing other processing stages in third countries.

To reassemble all the components in KWW’s accounting method we still need to decompose the domestic content of intermediate goods processed in r and then re-exported to s or to third countries (i.e. the third term in 4). Recalling the accounting identity used in 2, we can split the (re)exports from country r into intermediate goods and final products, isolating among the latter the re-imports of the original exporter, country s .

$$\mathbf{E}_{r*} = \sum_{j \neq r, j \neq s}^G \mathbf{Y}_{rj} + \mathbf{Y}_{rs} + \sum_{j \neq r}^G \mathbf{A}_{rj} \mathbf{X}_j \quad (5)$$

Plugging the decomposition in (5) into the right-hand side of equation (4), we can identify portions of the third and fourth term in KWW’s decomposition. In particular $\mathbf{V}_s \mathbf{B}_{ss} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \sum_{j \neq r, s}^G \mathbf{Y}_{rj}$ correspond to the domestic value added embedded in the re-export of final goods by the direct bilateral importer r . Unlike the third term in KWW’s accounting, this term does not consider the goods that are further processed in other countries before reaching their final destination. Similarly, $\mathbf{V}_s \mathbf{B}_{ss} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \mathbf{Y}_{rs}$ represents only a portion of the domestic value added in re-imports of final goods, since it encompasses only the value added in intermediate inputs exported to r , processed and re-imported by s as final goods, without any further processing elsewhere.

In order to obtain a full decomposition of bilateral exports in the spirit of the KWW accounting, we still need to identify some components that are nested in the re-exports of intermediate goods from r to all the other j countries (i.e. $\sum_{j \neq r}^G \mathbf{A}_{rj} \mathbf{X}_j$). At this point, our aim is to find a way to link the gross output of country j with the demand in final destination countries, to retrieve the missing portions of domestic value added in exports included in terms 2, 3, 4 and 5 in the KWW decomposition. In principle this mapping is obtained readily through the Leontief inverse matrix \mathbf{B} (see equation A.2 in appendix); however, we must also

take into account the pure double-counting that stems from the trade flows that cross the borders of country s more than once. To isolate this double-counting component, let us look at the Leontief inverse as a sum of infinite series:

$$\mathbf{B} = \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \dots + \mathbf{A}^n \quad n \rightarrow \infty \quad (6)$$

This representation shows that the \mathbf{B} matrix identifies the gross output required to satisfy the final demand at the end of the process (\mathbf{I}) and in all the upstream production stages ($\mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \dots$). Since the pure double-counting issue stems from the re-export of intermediate inputs by s , we should exclude these particular flows at any stage of production and modify the series in 6 accordingly. Algebraically, this is done simply by setting the coefficients that identify the requirement of inputs imported from country s within the \mathbf{A} matrix equal to 0:

$$\mathbf{A}^{\not{s}} = \begin{bmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} & \cdots & \mathbf{A}_{1s} & \cdots & \mathbf{A}_{1G} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & \mathbf{A}_{ss} & \cdots & \mathbf{0} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ \mathbf{A}_{G1} & \mathbf{A}_{G2} & \cdots & \mathbf{A}_{Gs} & \cdots & \mathbf{A}_{GG} \end{bmatrix} \quad (7)$$

Then we can re-express the general relationship of production and trade in our global I-O setting (see A.1), disentangling the export flows from country s as follows:

$$\mathbf{X} = \mathbf{A}^{\not{s}}\mathbf{X} + \mathbf{A}^s\mathbf{X} + \mathbf{Y}^{\not{s}} + \mathbf{Y}^s \quad (8)$$

where $\mathbf{A}^s = (\mathbf{A} - \mathbf{A}^{\not{s}})$, $\mathbf{Y}^{\not{s}}$ is the final demand matrix \mathbf{Y} with the block matrix corresponding to exports of final goods from s equal to 0 (but including domestic final demand \mathbf{Y}_{ss}), and \mathbf{Y}^s is simply equal to $(\mathbf{Y} - \mathbf{Y}^{\not{s}})$. Given that the sum of $\mathbf{A}^s\mathbf{X}$ and \mathbf{Y}^s is a $GN \times N$ matrix with the total exports from country s in the corresponding block submatrix and zeros elsewhere (\mathbf{E}^s), we can re-arrange (8) as follows:

$$\mathbf{X} = \widehat{\mathbf{B}}^{\not{s}}\mathbf{Y}^{\not{s}} + \widehat{\mathbf{B}}^{\not{s}}\mathbf{E}^s \quad (9)$$

where $\widehat{\mathbf{B}}^{\not{s}} \equiv (\mathbf{I} - \mathbf{A}^{\not{s}})^{-1}$ is the Leontief inverse matrix derived from the new input coefficient matrix $\mathbf{A}^{\not{s}}$, which excludes the input requirement of other economies from country s .² Since $\mathbf{X}_j = \sum_l^G \mathbf{X}_{jl}$, we can apply the new accounting relationship in

²Notice that the domestic input coefficient matrix \mathbf{A}_{ss} is part of the $\mathbf{A}^{\not{s}}$ matrix, in which only

(9) to the decomposition of (re)exports from the original importer r (equation 5):

$$\begin{aligned}
\mathbf{E}_{r*} &= \sum_{j \neq r, j \neq s}^G \mathbf{Y}_{rj} + \mathbf{Y}_{rs} + \sum_{j \neq r}^G \mathbf{A}_{rj} \sum_{k \neq s}^G \sum_l^G \widehat{\mathbf{B}}_{jk}^\dagger \mathbf{Y}_{kl} \\
&+ \sum_{j \neq r}^G \mathbf{A}_{rj} \widehat{\mathbf{B}}_{js}^\dagger \mathbf{Y}_{ss} + \sum_{j \neq r}^G \mathbf{A}_{rj} \widehat{\mathbf{B}}_{js}^\dagger \mathbf{E}_{s*}
\end{aligned} \tag{10}$$

We can now fully decompose bilateral exports from s to r into the domestic and foreign value added embedded in final demand (\mathbf{Y}) and the pure double-counting components stemming from re-exports from the importing country (\mathbf{E}_{r*}) or from the country of origin (\mathbf{E}_{s*}). To come into line with the original decomposition by KWW, all we need to do now is further disentangle the third term in equation (10) to distinguish: *i*) the domestic value added finally absorbed in the country of origin through the imports of final goods ($\sum_{k \neq s}^G \mathbf{Y}_{ks}$); *ii*) the domestic value added finally absorbed in a foreign country as a local good ($\sum_{l \neq s}^G \mathbf{Y}_{ll}$); and *iii*) the domestic value added finally absorbed in a foreign country as a foreign good ($\sum_{k \neq s}^G \sum_{l \neq s, k}^G \mathbf{Y}_{kl}$).

A full sink-based decomposition of bilateral exports can be expressed by the following accounting relationship:

$$\begin{aligned}
&\mathbf{u}_N \mathbf{E}_{sr} = \mathbf{V}_s \mathbf{B}_{ss} \mathbf{Y}_{sr} \\
&+ \mathbf{V}_s \mathbf{B}_{ss} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \left[\mathbf{Y}_{rr} + \sum_{j \neq r}^G \mathbf{A}_{rj} \widehat{\mathbf{B}}_{jr}^\dagger \mathbf{Y}_{rr} + \sum_{j \neq r}^G \mathbf{A}_{rj} \sum_{k \neq s, r}^G \widehat{\mathbf{B}}_{jk}^\dagger \mathbf{Y}_{kk} \right] \\
&+ \mathbf{V}_s \mathbf{B}_{ss} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \left[\sum_{j \neq r, s}^G \mathbf{Y}_{rj} + \sum_{j \neq r}^G \mathbf{A}_{rj} \sum_{l \neq s, r}^G \widehat{\mathbf{B}}_{jr}^\dagger \mathbf{Y}_{rl} \right. \\
&\quad \left. + \sum_{j \neq r}^G \mathbf{A}_{rj} \sum_{k \neq s, r}^G \widehat{\mathbf{B}}_{jk}^\dagger \mathbf{Y}_{kr} + \sum_{j \neq r}^G \mathbf{A}_{rj} \sum_{k \neq s, r, l \neq s, r}^G \sum_{l \neq s, r}^G \widehat{\mathbf{B}}_{jk}^\dagger \mathbf{Y}_{kl} \right] \\
&+ \mathbf{V}_s \mathbf{B}_{ss} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \left[\mathbf{Y}_{rs} + \sum_{j \neq r}^G \mathbf{A}_{rj} \widehat{\mathbf{B}}_{jr}^\dagger \mathbf{Y}_{rs} + \sum_{j \neq r}^G \mathbf{A}_{rj} \sum_{k \neq s, r}^G \widehat{\mathbf{B}}_{jk}^\dagger \mathbf{Y}_{ks} \right]
\end{aligned}$$

the other \mathbf{A}_{st} submatrices, with $t \neq s$, have all the elements equal to zero. This allows to include in the domestic value added of exports of the goods that undergo a final processing stage in country s and are ultimately used there.

$$\begin{aligned}
& + \overset{\mathbf{5}}{\mathbf{V}_s \mathbf{B}_{ss} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \sum_{j \neq r}^G \mathbf{A}_{rj} \widehat{\mathbf{B}}_{js}^{\neq} \mathbf{Y}_{ss}} \\
& + \overset{\mathbf{6}}{\mathbf{V}_s \mathbf{B}_{ss} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \sum_{j \neq r}^G \mathbf{A}_{rj} \widehat{\mathbf{B}}_{js}^{\neq} \mathbf{E}_{s*}} \\
& + \overset{\mathbf{7}}{\sum_{t \neq s}^G \mathbf{V}_t \mathbf{B}_{ts} \mathbf{Y}_{sr}} + \overset{\mathbf{8}}{\sum_{t \neq s}^G \mathbf{V}_t \mathbf{B}_{ts} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \mathbf{Y}_{rr}} \\
& + \overset{\mathbf{9}}{\sum_{t \neq s}^G \mathbf{V}_t \mathbf{B}_{ts} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \mathbf{E}_{r*}} \tag{11}
\end{aligned}$$

We can define the items that form the bilateral decomposition of gross exports as follows:

- 1** domestic value added (VA) in direct final good exports;
- 2a** domestic VA in intermediate exports absorbed by direct importers as local final goods;
- 2b** domestic VA in intermediate exports absorbed by direct importers as local final goods only after additional processing stages abroad;
- 2c** domestic VA in intermediate exports absorbed by third countries as local final goods;
- 3a** domestic VA in intermediate exports absorbed by third countries as final goods from direct bilateral importers;
- 3b** domestic VA in intermediate exports absorbed by third countries as final goods from direct bilateral importers only after further processing stages abroad;
- 3c** domestic VA in intermediate exports absorbed by direct importers as final goods from third countries;
- 3d** domestic VA in intermediate exports absorbed by third countries as final goods from other third countries;
- 4a** domestic VA in intermediate exports absorbed at home as final goods of the bilateral importers;

- 4b** domestic VA in intermediate exports absorbed at home as final goods of the bilateral importers after additional processing stages abroad;
- 4c** domestic VA in intermediate exports absorbed at home as final goods of a third country;
- 5** domestic VA in intermediate exports absorbed at home as domestic final goods;
- 6** double-counted intermediate exports originally produced at home;
- 7** foreign VA in exports of final goods;
- 8** foreign VA in exports of intermediate goods;
- 9** double-counted intermediate exports originally produced abroad.

The enumeration of the items recalls the original KWW components, which can be obtained as a simple summation over the importing countries r of the corresponding items in our bilateral decomposition (e.g. the second term in KWW is equal to the sum across the r destinations of $\mathbf{2a}+\mathbf{2b}+\mathbf{2c}$).³

Comparing our definitions of the items here above with those originally assigned by KWW, which have been quoted below equation (1), despite the algebraical consistency between the two classifications, there are a few discrepancies. The reason is that KWW's classification does not properly allocate the domestic value added embedded in intermediate exports between the share going to direct importers and the share absorbed in third markets (see Nagengast and Sterher, 2014). Essentially, our breakdown of bilateral trade flows results in a refinement of the original KWW classification of aggregate exports.

According to KWW, the first and second components of domestic value added of exports go entirely to direct importers' final demand. Using the decomposition of bilateral exports in equation (11), we observe that only sub-items $\mathbf{2a}$ and $\mathbf{2b}$ are actually part of the direct importers' final demand. Conversely, part of the third item ($\mathbf{3c}$), which KWW classify as third countries' final demand, should be also considered as direct importers' absorption of domestic VA. This makes the total value added produced at home and finally absorbed by the bilateral trade partners equal to the sum across destinations of: $\mathbf{1}$, $\mathbf{2a}$, $\mathbf{2b}$ and $\mathbf{3c}$. This clearly differs from KWW's definition (i.e. $\mathbf{1}+\mathbf{2}$). The schemes reported in Figure 3 may clarify the differences between the two approaches.

³For a formal proof of this equivalence for each item in equation (11), see Appendix B.

Panel 3.a diagrams a simple trade relationship in which country A produces 1 USD of intermediate inputs, which are used by B to produce 4 USD of local final goods. In this case, both KWW and our own bilateral decomposition classify (in components **2** and **2a** respectively) the exports from A to B as ‘domestic VA in intermediate exports absorbed by direct importers’. In panel 3.b we now assume that B performs only a partial processing stage (worth 1 USD of VA) before sending the intermediate products to C, which assembles and consumes the final goods. The 1 USD of domestic VA exported by A is now absorbed in a third country (C), not the bilateral importer (B). This is correctly traced in our bilateral breakdown, as the A-B trade flow is allocated to component **2c** (i.e. ‘domestic VA in intermediate exports absorbed by third countries as local final goods’). In KWW’s breakdown, however, it would be recorded by the term $\mathbf{V}_A \mathbf{B}_{AC} \mathbf{Y}_{CC}$ and improperly classified as domestic VA of country A absorbed by the direct importer C, since in this case only B directly imports from A. Indeed the \mathbf{B}_{AC} , being part of the global inverse Leontief matrix, accounts for all the possible ways in which the intermediate inputs of country A contribute to final goods produced in C, not only those directly imported by C.

In the example diagrammed in Figure 3.c, the intermediate products are processed in two subsequent production stages in B and C, then returned to B for a final stage before serving final demand. The very first shipment from A to B is correctly classified as ‘domestic VA in intermediate exports absorbed by direct importers’ both in KWW and in our own decomposition. But only our decomposition correctly recognizes that the domestic VA is absorbed by direct importers as local final goods only after additional processing stages abroad (**2c**). This also indicates the differences between the two arrangements of international fragmentation of production in sub-schemes 3.a and 3.c.

Scheme 3.d differs from 3.c only in that the final assembly stage is performed in C rather than B, which is still the country of final destination. As regards country A, B is both the direct importer and the final demand absorber, so its exports to B should be considered as domestic VA absorbed by a direct importer, which is how they are mapped in our decomposition (in item **3c**), whereas in KWW’s method they are allocated to third countries’ absorption of domestic VA of exports.

The value added decomposition of bilateral trade flows offers useful information for valuing trade balances between countries, reconciling the gross export data with value added accounting. For instance, going back to the example in Figure 1, in case 1.a we see that the exports from A to B are generated by A’s demand for C’s final goods, since they are classified in item **4c** of equation (11) (i.e. ‘domestic VA

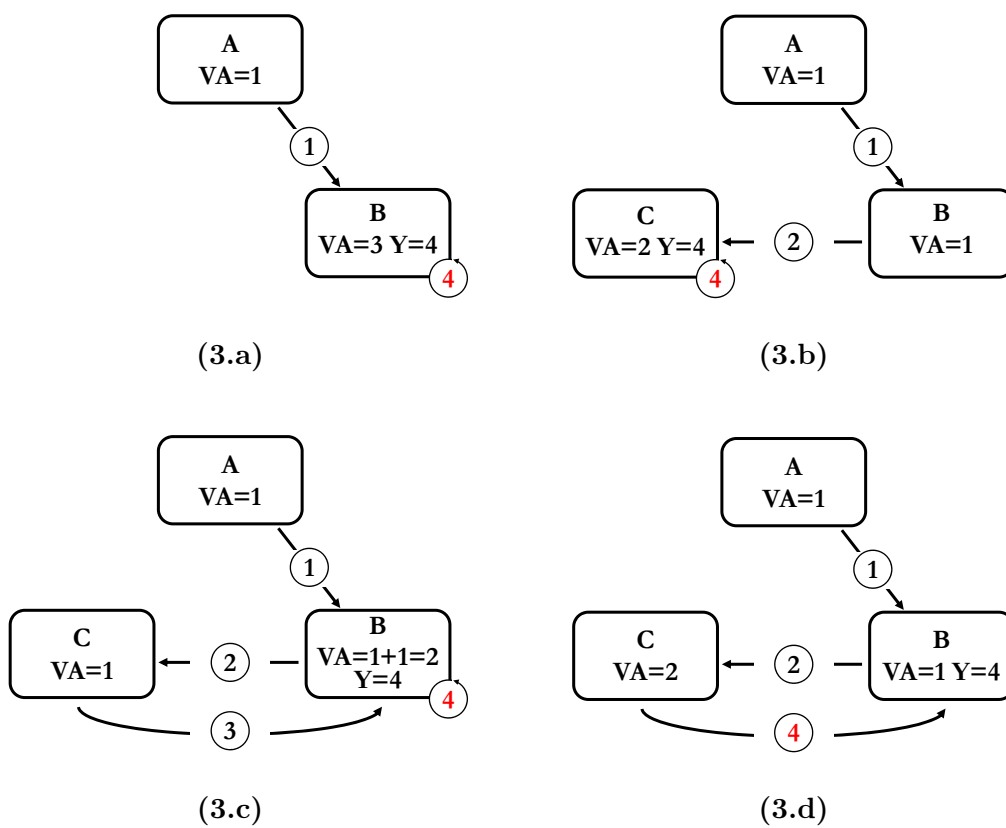


Figure 3: Accounting of the absorption of domestic value added of exports by direct importers

in intermediate exports absorbed at home as final goods of a third country’). In example 1.b, instead, exports from A to C are classed under **4a** (i.e. ‘domestic VA in intermediate exports absorbed at home as final goods of the bilateral importers’). This differentiation, which is not envisaged in KWW’s original framework, gives insights into the structure of international production and demand linkages, especially in dealing with the sort of complex production networks that prevail in the real world.

Our sink-based decomposition summarized by equation (11) differs also substantially from the one in Nagengast and Sterher (2014). In fact they classify as domestic value added absorbed by direct importers only that embedded in goods that do not leave this country again, assigning the remainder to the double counted component. In this way they do not take into account what we have classified in the **2b** and **3c** components, underestimating the domestic value added absorbed by direct importers. It means that, for instance, in the scheme 3.c and 3.d described above, the exports from country A to country B would be entirely classified as double counted in the decomposition of their bilateral flows. Also their definitions of the domestic value added finally absorbed at home and by third countries turn out to be imprecise, leading in this case to an overestimation of the domestic value added in exports. This drawback also applies to their source-based decomposition. The scheme diagrammed in Figure 4 highlights this particular issue. In this case, two stages of production, each worth 1 USD of value added, are performed both in country A and B, before the final good being shipped from B to the destination market C. The total bilateral gross exports from A to B are equal to 4 USD, which consist of 2 USD of VA generated in A, 1 USD of VA generated in B and 1 USD of double counted VA, originated in the first stage of production in A and embedded in the second shipment from A to B. Both in the source and in the sink-based approach of Nagengast and Sterher (2014) this 1 USD of double counted items would be assigned to the domestic value added of A absorbed by third country C, overestimating this component.⁴

⁴This overestimation stems from the double use of the global inverse Leontief matrix in some of the terms of the decomposition of Nagengast and Sterher (2014). In fact in the example of Figure 4, the domestic value added absorbed in third countries would be calculated as $\mathbf{V}_A \mathbf{B}_{AA} \mathbf{A}_{AB} \mathbf{B}_{BB} \mathbf{Y}_{BC}$ (both in sink and source-based methodology). Since \mathbf{B}_{AA} accounts for all the possible ways in which the intermediate inputs of country A contribute to the production in A, $\mathbf{V}_A \mathbf{B}_{AA}$ encompasses the entire value added of A generated both in the first and the second stage of production. Then the $\mathbf{V}_A \mathbf{B}_{AA}$ matrix should be applied only to the second export flow to B, in order to extract A’s value added following the sink-based logic. Instead, since they account the B’s gross output necessary for the production of the final good exported to C through the \mathbf{B}_{BB} matrix, they are recording both the first and the second stage of production in B and hence both the shipments of intermediate inputs from A. So they end up with an overestimation of the

This inaccuracy in defining some of the items entails that neither methodology proposed by Nagengast and Sterher (2014) can retrieve the entire domestic value added exported by a country summing the corresponding items across the bilateral flows. On the contrary both our sink and source-based methodologies, shown in Appendix C, provide this result. Also Wang et al. (2013) breakdown of bilateral exports shares this property. However, they use different approaches to single out the different components, so that their methodology suffers from internal inconsistency. In particular they follow a sink-based approach for the domestic value added embedded in direct exports of final goods, while the remainder of the bilateral gross flows is classified accordingly to a source-based approach. This makes the single items of the decomposition not comparable with each other. Moreover, since the trade in intermediaries and that in final goods are treated in different ways by Wang et al. (2013), it could be tricky also to use this methodology to compare the value added structure of two (or more) distinct trade flows, as in the analysis of bilateral trade balances. In general, having specific and internal consistent methodologies both for the sink-based and the source-based approach allows to choose the most appropriate to the purpose of the analysis.

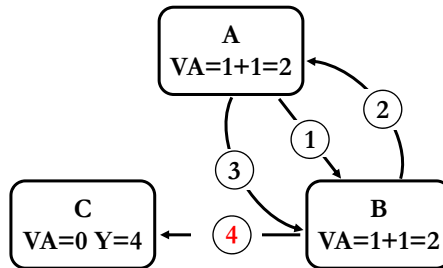


Figure 4: Domestic value added and double counting with final destination in third countries

3 Two empirical applications

We use the World Input-Output Database (see Dietzenbacher et al. 2013, Timmer et al. 2015) for the period 1995-2011 to show two different ways of exploiting our proposed value added decompositions of bilateral trade. The first application follows the sink-based approach developed in the previous section and focuses on Italian

VA produced in A.

exports of domestic VA, tracing flows from direct importers to final demand. The second follows the source-based approach and derives a new measure of the share of GVC-related trade in order to determine how its evolution since the mid-1990s has affected the long-run relationship between global demand and world trade.

3.1 Italian forward connections

Cappariello and Felettigh (2015) give a detailed assessment of the participation of Italy, France, Germany and Spain in global value chains. Applying the original KWW methodology to the WIOD data, they also analyze the way in which foreign demand has activated domestic value added in these four euro-area economies since the creation of the European monetary union. Among other results, they find that one common pattern is increasing dependence on final internal demand originated outside the EU. We use our decomposition of bilateral export flows to add information on the downstream structure of the production networks in which Italy is involved. In particular, we aim to investigate the channels through which Italian exports reach the markets of final destination. Then for this exercise the sink-based decomposition presented in equation (11) is better suited since it accounts the value the last time it crosses the national borders, which is the export flow more closely related with the market of ultimate absorption.⁵

We consider Italy’s exports to the top sixteen importing countries, which take two-thirds of total Italian exports of goods and services. First, we compute the shares of domestic VA, foreign VA and pure double-counting embedded in Italian exports in 2011 (the last year for which the WIOD tables are available). The first component is the sum of the following items of equation (11): **1**, **2** (i.e. $2\mathbf{a}+2\mathbf{b}+2\mathbf{c}$), **3**, **4** and **5** (divided by the total exports to each country). Similarly the foreign VA of exports is obtained by summing items **7** and **8**. Finally, pure double-counting comes from items **6** and **9**. Cappariello and Felettigh (2015) observe that in 2011 domestic value added accounted for 72.7% of Italy’s total gross exports, foreign VA for 20.5%, and pure double-counting for 6.8%. The bottom rows in Table 1 report the shares in Italy’s bilateral exports to each importer. The share of domestic VA turns out to be smaller than average in exports to the other EU economies except the UK, and particularly smaller in those to Spain and Austria. Conversely,

⁵To further clarify this point we refer to the example shown in Figure 2. With the sink-based approach all the value added generated in A and finally absorbed in C is entirely accounted within the bilateral exports of final goods from A to C, while with the source-based approach a part of this would be assigned to the bilateral flow from A to B.

the double-counting shares in those export flows are relatively large. Since this component is generated by trade flows that cross the same borders more than once, this finding should be taken as evidence of the deep interconnection of intra-EU production networks. At the same time, the export flows that embed the largest shares of domestic VA are those to the major emerging economies, such as China, Russia and Brazil.

The domestic VA embedded in exports can be further broken down according to country of final absorption. In particular, three sub-components can be defined on the basis of equation (11): the domestic VA that serves the final demand in the direct importing country (i.e. $\mathbf{1+2a+2b+3c}$, *direct absorption*); the domestic VA that ultimately comes back to the country of origin to be consumed there (i.e. $\mathbf{4a+4b+4c}$, *reflection*); and the domestic VA absorbed by final demand in third countries (i.e. $\mathbf{2c+3a+3b+3d}$, *redirection*). The first three rows in Table 1 show the weights of these three items in domestic VA exported by Italy. The non-European markets also have the largest proportion of direct absorption of value added generated and exported by Italy. Conversely, about a third of the domestic VA exported to Germany is embedded in intermediate goods that are processed there and re-exported to third markets. Similar shares for the redirection term are registered in exports to Austria and Poland.⁶ Thus Germany and, to a lesser extent, these other EU economies play an important role in the downstream stages of the international production chains in which Italy takes part. Indeed, between 40% and 60% of Italian domestic value added that passes through EU trade partners before being re-exported is ultimately absorbed in other European markets. But exports to Germany are different, in that substantial portions of Italian intermediate goods are used in the in production of goods that are finally consumed outside Europe, notably in the US and China. Briefly, the analysis of bilateral exports shows Italy's thorough integration into the 'factory of Europe' in which Germany plays the leading role (see also Amador et al., 2015)

⁶The *redirection* share is nearly 40% for Belgium and the Netherlands, whose import data are distorted by the substantial transshipment activity of the leading European ports (Rotterdam, Antwerp and Amsterdam).

Destination of bilateral gross exports from Italy

	DEU	FRA	USA	ESP	CHN	GBR	RUS	TUR
Absorption	64.9	76.0	91.7	76.6	81.7	80.6	85.7	93.4
Reflection	2.0	1.6	0.1	1.8	0.4	0.8	1.0	0.5
Redirection	33.1	22.3	8.2	21.6	17.9	18.6	13.4	6.1
EU27	39.8	42.6	20.2	51.2	19.4	37.7	47.5	31.8
USA	10.5	9.6	0.0	8.2	23.5	13.9	6.4	10.7
Japan	2.2	2.5	4.5	1.6	8.5	2.3	1.0	5.7
EME ASIA excl. China	3.8	3.2	6.6	2.1	9.4	3.8	2.4	5.4
China	9.9	6.7	10.7	3.5	0.0	7.0	3.1	11.3
Other EMEs countries	33.9	35.4	57.9	33.4	39.1	35.3	39.6	35.2
Italian VA	72.4	70.9	73.3	62.7	77.6	74.5	71.8	75.8
Foreign VA	16.2	21.0	24.0	27.0	18.2	19.7	23.4	22.1
Double counting	11.4	8.1	2.7	10.3	4.2	5.8	4.7	2.1
Bilateral gross exports	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
<i>Memorandum:</i> <i>share on total gross exports</i>	12.3	9.4	7.1	5.7	5.1	4.3	3.3	2.6

	AUT	POL	BEL	BRA	JPN	NLD	GRC	ROM
Absorption	65.1	65.4	57.9	91.1	92.8	61.6	79.1	88.6
Reflection	2.1	2.5	2.4	0.2	0.1	2.3	2.8	0.3
Redirection	32.9	32.1	39.6	8.7	7.1	36.0	18.1	11.1
EU27	49.8	56.2	58.1	21.4	13.5	58.6	47.1	16.9
USA	9.0	5.8	8.6	15.5	19.2	8.1	5.3	6.3
Japan	1.8	1.0	1.6	3.3	0.0	1.6	1.7	1.5
EME ASIA excl. China	2.9	1.6	3.9	3.8	10.2	3.5	2.6	2.7
China	6.6	3.7	5.4	12.1	19.6	5.9	3.2	3.2
Other EMEs countries	29.8	31.7	22.4	43.8	37.5	22.2	40.2	69.5
Italian VA	69.3	72.4	74.2	78.4	74.7	73.5	72.8	72.9
Foreign VA	19.2	16.9	13.5	19.6	23.1	14.6	21.1	24.5
Double counting	11.5	10.6	12.3	2.1	2.2	11.9	6.1	2.6
Bilateral gross exports	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
<i>Memorandum:</i> <i>share on total gross exports</i>	2.1	2.0	1.9	1.9	1.6	1.4	1.4	1.3

Table 1 : Value added decomposition of Italian bilateral gross exports

3.2 Measuring the weight of Global Value Chains in world trade

Following the seminal article of Hummels et al. (2001), a number of works have used input-output tables to gauge the relevance of GVCs in world trade (Johnson and Noguera, 2012; Rahman and Zhao, 2013; Los et al., 2014). Various measures of the integration of a country (or a region) in international production networks have been developed. One of the most common is the ‘vertical specialization’ indicator of Hummels et al. (2001), based on the content of foreign inputs in a country’s exports. As Cappariello and Felettigh (2014) observe, however, this is only a partial measure of participation in global value chains, as it considers only the backward linkages. To take forward linkages too into account, Rahman and Zhao (2013), based on Koopman et al. (2011), include in the share of trade generated by international fragmentation of production the domestic value added embedded in the intermediate exports absorbed by third countries and by the exporting country itself via re-imports. Cappariello and Felettigh (2014) take a similar approach, measuring the ‘international fragmentation of production’ of a country as the share of total exports consisting in components **3** to **9** in KWW’s breakdown. The idea is that all trade flows are related in some way to international production networks, except for the exports of domestic VA that is directly absorbed by the first importer (**1+2** in KWW’s classification).

As we have seen, however, KWW do not properly allocate the domestic VA embedded in intermediate exports between the share going to direct importers and that absorbed in third markets. Through the decomposition of bilateral exports we provide a more precise definition of ‘direct absorption’, which we also employed in the previous empirical application (section 3.1). Since in general our proposed classification aims to map value added accordingly to the ultimate destination market, we believe ‘direct absorption’ should also include the domestic VA absorbed by direct bilateral importers only after additional processing stages abroad, i.e. **2b** and **3c** in equation (11).

In order to measure the international fragmentation of production, a slightly different notion of ‘direct absorption’ is necessary. In this case the aim is to single out the trade flows involved in global value chains, conventionally defined as production processes that require at least two international shipments of goods (including both intermediate inputs and final products). It is therefore necessary to exclude from GVC-related trade flows only the fraction of domestic value added that never leaves the first importing country. Following this logic, a source-based methodology

is better suited than a sink-based one. In fact this breakdown of bilateral trade flows, shown in Appendix C, permits to single out the fraction of domestic value added that is exported just once by the domestic country and is directly absorbed by the importer (terms $\mathbf{1a}^*$ and $\mathbf{2a}^*$ in equation (C.1)). Summing across the bilateral flows, we obtain the entire domestic value added of country s absorbed by his direct importers without any further processing stages abroad or at home, a measure of traditional ‘Ricardian’ trade, as

$$DAVAX_s = \left[\overset{\sum_{r \neq s} \mathbf{1a}^*}{\mathbf{V}_s(\mathbf{I} - \mathbf{A}_{ss})^{-1} \sum_{r \neq s}^G \mathbf{Y}_{sr}} + \overset{\sum_{r \neq s} \mathbf{2a}^*}{\mathbf{V}_s(\mathbf{I} - \mathbf{A}_{ss})^{-1} \sum_{r \neq s}^G \mathbf{A}_{sr}(\mathbf{I} - \mathbf{A}_{rr})^{-1} \mathbf{Y}_{rr}} \right]. \quad (12)$$

Differently from the sink-based methodology (terms $\mathbf{1}$ and $\mathbf{2a}$ in equation (11)), here the domestic component of the global inverse Leontief matrix (i.e. \mathbf{B}_{ss}) is replaced with the local inverse Leontief matrix (i.e. $(\mathbf{I} - \mathbf{A}_{ss})^{-1}$). This allows to exclude all the backward linkages of the domestic country within the international production networks.⁷

Thus, it is possible to measure GVC-related trade flows simply by excluding the entire domestic value added of country s absorbed directly by his direct importers ($DAVAX_s$) from his total exports:

$$GVCX_s = \mathbf{u}_N \mathbf{E}_{s*} - DAVAX_s. \quad (13)$$

Therefore, GVC-related trade share in total exports is

$$GVC_s = \frac{GVCX_s}{E_{s*}}, \quad (14)$$

where $E_{s*} = \mathbf{u}_N \mathbf{E}_{s*}$.

Employing WIOD tables, we have computed the share of GVC-related trade

⁷To grasp the difference between these two measures, consider the following example. Suppose that country A performs the first stage of a production process, ships the intermediate products abroad for a second processing stage, and re-imports them for final completion. Finally, the goods are exported to serve final demand. Computing the domestic value added embedded in the exports of final goods using the local inverse Leontief matrix $(\mathbf{I} - \mathbf{A}_{AA})^{-1}$ we consider only the last stage of production performed in A, while with the sub-componet \mathbf{B}_{AA} of the global Leontief matrix we take account of the VA generated both in the first and in the last stage. Thus the \mathbf{B}_{ss} matrix differs from the local Leontief whenever two (or more) distinct stages of production are performed in the domestic country s . Since this entails some international fragmentation of production, it would appear better, in computing the portion of trade that is not involved in GVC, to use the local Leontief matrix.

in total world exports using three different methods (see Table 2): an index of vertical specialization very similar to Hummels et al., 2001; a GVC indicator based on components 3 to 9 of the original KWW decomposition (GVC-KWW), as calculated in Cappariello and Felettigh (2015); and our own GVC measure in equation (14). As expected, our indicator finds a considerably larger weight of GVCs in total trade than the KWW decomposition, which in turn gives a share about 10 percentage points greater than the fraction indicated by the vertical specialization indicator. The evolution of the three indicators over time is quite similar, however. Our indicator puts the share of GVC-related trade at between a third and nearly half the total during our sample period.⁸ Almost all of the difference between our indicator and the measure derived from the original KWW decomposition is due to the different classification of the value added absorbed by direct importers, whereas the impact of using the local as against the global-domestic Leontief is minor.⁹

As is shown by the black line in Figure 3, the GVC share of total trade, measured as in equation (14), has been growing since the mid-1990s, reaching 40% in 2000, then stagnating since until 2003 and rising to nearly 47% before the recession. In 2009 total trade contracted by about 10%. GVC trade fell even more sharply and has recovered only marginally since then.

These measures of international fragmentation can be employed to quantify the contribution of global value chains in explaining the decline of the income elasticity of trade, i.e. the ratio of trade to GDP growth. In fact, while cyclical factors - the investment slump, the weakness of economic activity in the euro area - have been key drivers of the trade slowdown, a major role has also been played by structural factors, including global value chains, as suggested by Constantinescu et al. (2015), Ferrantino and Taglioni (2014) and Escaith et al. (2010). Since world exports are equal to world imports (i.e. at any time t we have that $M_{(t)} = E_{(t)} = \sum_s^G E_{s*}$), we can express the latter as the sum of traditional ‘Ricardian’ trade ($DAVAX_{(t)}$) plus

⁸The weight of GVC-related trade might seem quite great, and to be sure there are some factors that could result in an overestimate of this and other measures of GVC-related trade. For example, in the WIOD tables a significant component of intermediate inputs is raw materials, whose inclusion in GVC trade is questionable (Cappariello and Felettigh 2015). In addition, the separate consideration of each country in the highly integrated euro area could engender an upward bias (Amador et al., 2015)

⁹Computing the GVC indicators for single countries, we find similar differences between countries with the sole exception of commodity exporters (such as Russia, Australia and Brazil), for which the difference between our indicator and the KWW-GVC index is much larger. For Italy, in 2011, GVC-related exports accounted for 43.7% of the total by our index and 36.3% by the KWW-GVC measure.

	<i>VS</i>		<i>GVC-KWW</i>		<i>GVC</i>	
	share	Δ	share	Δ	share	Δ
1995	19.5		28.5		35.2	
2000	22.7	3.2	33.1	4.6	40.4	5.2
2005	25.2	2.5	35.8	2.7	44.0	3.7
2011	25.5	0.3	35.8	0.0	44.5	0.5

Table 2: Indices of international fragmentation for world exports.

VS: vertical specialization, foreign value added and both domestic and foreign double counting on total exports; *GVC-KWW*: index of international fragmentation used in Cappariello and Felettigh (2015), summing terms 3 to 9 of KWW decomposition, on total exports; *GVC* refined index calculated as total exports excluding terms 1a* and 2a* of our source-based decomposition, on total exports.

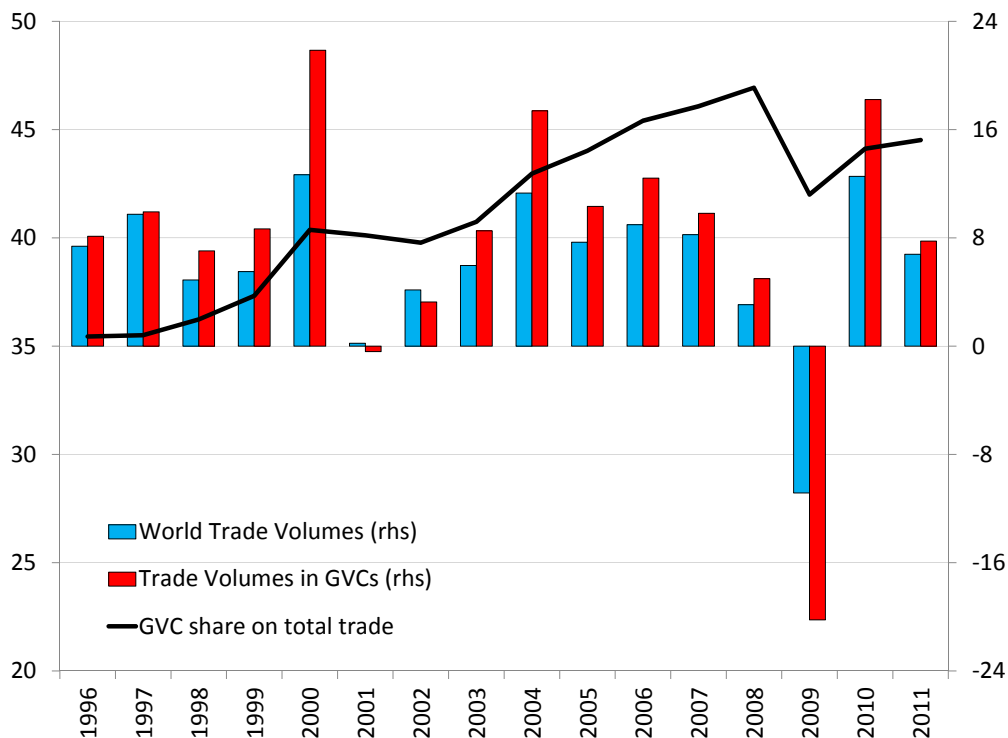


Figure 5: Growth rates of world trade volumes and GVC share

GVC-related trade ($GVCX_{(t)}$). We define world imports as

$$M_{(t)} \equiv \frac{M_{(t)}}{DAVAX_{(t)}} \frac{DAVAX_{(t)}}{Y_{(t)}} Y_{(t)}. \quad (15)$$

where the first ratio on the right hand side is a measure of international fragmentation strictly related to $GVC_{(t)}$: $GVC_{(t)}^* \equiv M_{(t)}/DAVAX_{(t)} = 1/(1 - GVC_{(t)})$; the second ratio $DMFD_{(t)} \equiv DAVAX_{(t)}/Y_{(t)}$ indicates the direct import content of final demand. Taking growth rates

$$\frac{\Delta M_{(t)}}{M_{(t)}} = \frac{\Delta GVC_{(t)}^*}{GVC_{(t)}^*} + \frac{\Delta DMFD_{(t)}}{DMFD_{(t)}} + \frac{\Delta Y_{(t)}}{Y_{(t)}}, \quad (16)$$

and dividing both sides by the GDP growth rate, we get an expression for the income elasticity of trade:

$$\frac{\Delta M_{(t)}}{M_{(t)}} \frac{Y_{(t)}}{\Delta Y_{(t)}} = \frac{\Delta GVC_{(t)}^*}{GVC_{(t)}^*} \frac{Y_{(t)}}{\Delta Y_{(t)}} + \frac{\Delta DMFD_{(t)}}{DMFD_{(t)}} \frac{Y_{(t)}}{\Delta Y_{(t)}} + 1. \quad (17)$$

The income elasticity of trade, then, has three components: the constant unitary value, the income elasticity of international fragmentation intensity, and the income elasticity of the (direct) import content of final demand:

$$\eta_{(t-s),(t)}^M = 1 + \eta_{(t-s),(t)}^{GVC} + \eta_{(t-s),(t)}^{DMFD}. \quad (18)$$

		η^{GVC}	η^{DMFD}	η^M
1996-2000	1.00	0.45	0.61	2.06
2001-2005	1.00	0.33	0.12	1.45
2006-2011	1.00	0.04	0.09	1.13

Table 3: Decomposition of income elasticity of trade.

The decomposition follows equation (18). η^M is the average income elasticity of trade.

As Table 3 shows, the contribution of global value chains to total trade elasticity was substantial until 2005 and has declined significantly since then. The considerable contribution of the (direct) import content of final demand to trade elasticity in the late 1990s is presumably linked to the trade liberalization that was carried out in that period, owing mainly to the Uruguay round of multilateral talks.

4 Concluding remarks

The diffusion of international production networks during the last two decades requires new tools for evaluating supply and demand relationships among countries, which can no longer be adequately gauged by gross trade flows. Global input-output tables have been instrumental in filling the gap in the statistical sources. New methodologies have been developed to utilize these data to measure trade in value added terms. This makes it possible to isolate the contribution of different countries' final demand and demand for intermediate inputs to production in any given economy. Koopman et al. (2014) have proposed a rigorous and comprehensive method for breaking aggregate export flows down according to the source and the destination of their value added content. Applying this framework to a global input-output database like WIOD, it is possible to explore many issues relating to the role of international fragmentation of production in trade (see Cappariello and Felettigh, 2015). However, this decomposition neglects the bilateral dimension of trade flows and may accordingly be inadequate for analysis of such other features as a country's backward and forward linkages within the global value chains.

We propose two decompositions of bilateral exports that are fully consistent with the KWW approach, in line with the spirit of Nagengast and Stehrer (2014). A first one takes the perspective of the country where the value added originates (the source-based approach), a second one that of the country that ultimately absorbs it in final demand (the sink-based approach). The original components in KWW can be exactly retrieved from our decompositions by summing the bilateral export flows across the destinations. At the same time, we also refine the classification of domestic value added embedded in exports, singling out additional sub-components. This disaggregation, finer than in KWW's original framework, proves to be quite helpful in analyzing trade flows and GVC structures. In particular, our approach can both account for the entire domestic value added embedded in bilateral shipments and discriminate precisely between the exports that are finally absorbed by the direct importers and those that are consumed in third countries. These issues have not been properly addressed by KWW or in the rest of the literature (see Wang et al., 2013; Nagengast and Stehrer, 2014).

Examining bilateral flows through the lens of their value added content, we can assess a country's position within the international production processes, identifying the direct upstream and downstream trade partners. In this way we can also gauge the effect on bilateral trade balances exerted by participation in GVCs and by final demand from third countries.

Applying our sink-based methodology to Italian exports, we find some heterogeneity in the roles of different trading partners. In particular, Germany, Austria and Poland contribute significantly to the downstream stages in Italy's international production chains. Conversely, direct exports to non-European markets, mainly serving local demand, have considerably greater content of Italian value added.

Thanks to our source-based bilateral decomposition, we develop a new measure of international fragmentation of production. GVC-related trade has been much more volatile than total trade; after reaching almost half of all world trade in 2008, it plunged by 20% in 2009, while trade unrelated to international fragmentation of production shrank only by 2.5%. In the aftermath of the recession the share of global value chains in total trade has recovered only marginally.

This measure of GVC-related trade has been used to inquire into the role played by international fragmentation of production in the changes of the long-term relation between trade and income. The contribution of GVCs on the income elasticity of trade was substantial until 2005, but since then it has declined significantly, suggesting that the slowdown in trade in 2012-14 may have been driven in part by structural factors.

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A Appendix

This appendix simply recalls our notation, which is broadly the same as KWW (2014), together with some basic accounting relationships.

We consider the general case of G countries producing N goods that are internationally traded both as intermediate inputs and as final good. Thus, $\mathbf{X}_s = (x_1^s \ x_2^s \ \cdots \ x_N^s)'$ is the $N \times 1$ vector of the gross output of country s and \mathbf{Y}_s is the $N \times 1$ vector of final goods, which is equal to the final demand for goods produced in s in each country of destination r : $\sum_r^G \mathbf{Y}_{sr}$. To produce one unit of gross output of good i a country uses a certain amount a of intermediate good j produced at home or imported from other countries. Thus each unit of gross output can be either consumed as a final good or used as an intermediate good at home or abroad:

$$\mathbf{X}_s = \sum_r^G (\mathbf{A}_{sr} \mathbf{X}_r + \mathbf{Y}_{sr})$$

where \mathbf{A}_{sr} is the $N \times N$ matrix of coefficients for intermediate inputs produced in s and processed further in r :

$$\mathbf{A}_{sr} = \begin{bmatrix} a_{1,1}^{sr} & a_{1,2}^{sr} & \cdots & a_{1,N}^{sr} \\ a_{2,1}^{sr} & a_{2,2}^{sr} & \cdots & a_{2,N}^{sr} \\ \vdots & \vdots & \ddots & \vdots \\ a_{N,1}^{sr} & a_{N,2}^{sr} & \cdots & a_{N,N}^{sr} \end{bmatrix}$$

Using the block matrix notation, the general setting of production and trade with G countries and N goods can be expressed as follows:

$$\begin{bmatrix} \mathbf{X}_1 \\ \mathbf{X}_2 \\ \vdots \\ \mathbf{X}_G \end{bmatrix}_{(NG \times 1)} = \begin{bmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} & \cdots & \mathbf{A}_{1G} \\ \mathbf{A}_{21} & \mathbf{A}_{22} & \cdots & \mathbf{A}_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{A}_{G1} & \mathbf{A}_{G2} & \cdots & \mathbf{A}_{GG} \end{bmatrix}_{(NG \times NG)} \begin{bmatrix} \mathbf{X}_1 \\ \mathbf{X}_2 \\ \vdots \\ \mathbf{X}_G \end{bmatrix}_{(NG \times 1)} + \begin{bmatrix} \mathbf{Y}_{11} & \mathbf{Y}_{12} & \cdots & \mathbf{Y}_{1G} \\ \mathbf{Y}_{21} & \mathbf{Y}_{22} & \cdots & \mathbf{Y}_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{Y}_{G1} & \mathbf{Y}_{G2} & \cdots & \mathbf{Y}_{GG} \end{bmatrix}_{(NG \times G)} \begin{bmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{bmatrix}_{(G \times 1)} \quad (\text{A.1})$$

from which it is straightforward to derive the following relationship between gross

output and final demand:

$$\begin{aligned}
\begin{bmatrix} \mathbf{X}_1 \\ \mathbf{X}_2 \\ \vdots \\ \mathbf{X}_G \end{bmatrix} &= \begin{bmatrix} \mathbf{I} - \mathbf{A}_{11} & -\mathbf{A}_{12} & \cdots & -\mathbf{A}_{1G} \\ -\mathbf{A}_{21} & \mathbf{I} - \mathbf{A}_{22} & \cdots & -\mathbf{A}_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ -\mathbf{A}_{G1} & -\mathbf{A}_{G2} & \cdots & \mathbf{I} - \mathbf{A}_{GG} \end{bmatrix}^{-1} \begin{bmatrix} \sum_r^G \mathbf{Y}_{1r} \\ \sum_r^G \mathbf{Y}_{2r} \\ \vdots \\ \sum_r^G \mathbf{Y}_{1G} \end{bmatrix} \\
&= \begin{bmatrix} \mathbf{B}_{11} & \mathbf{B}_{12} & \cdots & \mathbf{B}_{1N} \\ \mathbf{B}_{21} & \mathbf{B}_{22} & \cdots & \mathbf{B}_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{B}_{G1} & \mathbf{B}_{G2} & \cdots & \mathbf{B}_{GG} \end{bmatrix} \begin{bmatrix} \sum_r^G \mathbf{Y}_{1r} \\ \sum_r^G \mathbf{Y}_{2r} \\ \vdots \\ \sum_r^G \mathbf{Y}_{1G} \end{bmatrix} \tag{A.2}
\end{aligned}$$

where \mathbf{B}_{sr} denotes the $N \times N$ block of the Leontief inverse matrix in a global IO setting. It indicates how much of country's s gross output of a certain good is required to produce one unit of country r 's final production.

It is useful to recall two equivalences that are used extensively in KWW (2014) and that we use to derive the results presented in section 2. Considering the following property of inverse matrix B:

$$\mathbf{B}(\mathbf{I} - \mathbf{A}) = (\mathbf{I} - \mathbf{A})\mathbf{B} = \mathbf{I}$$

it is easily shown that the generic block diagonal element \mathbf{B}_{ss} may be expressed as follows:

$$\begin{aligned}
\mathbf{B}_{ss} &= \sum_{t \neq s}^G \mathbf{B}_{st} \mathbf{A}_{ts} (\mathbf{I} - \mathbf{A}_{ss})^{-1} + (\mathbf{I} - \mathbf{A}_{ss})^{-1} = \\
&= (\mathbf{I} - \mathbf{A}_{ss})^{-1} + (\mathbf{I} - \mathbf{A}_{ss})^{-1} \sum_{t \neq s}^G \mathbf{A}_{st} \mathbf{B}_{ts} \tag{A.3}
\end{aligned}$$

while the generic off-diagonal block element \mathbf{B}_{rs} corresponds to:

$$\begin{aligned}
\mathbf{B}_{rs} &= \sum_{t \neq s}^G \mathbf{B}_{rt} \mathbf{A}_{ts} (\mathbf{I} - \mathbf{A}_{ss})^{-1} = \\
&= (\mathbf{I} - \mathbf{A}_{rr})^{-1} \sum_{t \neq r}^G \mathbf{A}_{rt} \mathbf{B}_{ts} \tag{A.4}
\end{aligned}$$

The direct value added share in each unit of gross output produced by country s is equal to one minus the sum of the direct intermediate input share of all the

domestic and foreign suppliers:

$$\mathbf{V}_s = \mathbf{u}_N (\mathbf{I} - \sum_r^G \mathbf{A}_{rs}) \quad (\text{A.5})$$

where \mathbf{u}_N is the $1 \times N$ unit row vector. Thus the $G \times GN$ direct domestic value added matrix for all countries can be defined as:

$$\mathbf{V} = \begin{bmatrix} \mathbf{V}_1 & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \mathbf{V}_2 & \cdots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & \mathbf{V}_G \end{bmatrix}$$

while the overall $G \times GN$ value added share matrix is obtained by multiplying the \mathbf{V} matrix by the Leontief inverse \mathbf{B} :

$$\mathbf{VB} = \begin{bmatrix} \mathbf{V}_1 \mathbf{B}_{11} & \mathbf{V}_1 \mathbf{B}_{12} & \cdots & \mathbf{V}_1 \mathbf{B}_{1G} \\ \mathbf{V}_2 \mathbf{B}_{21} & \mathbf{V}_2 \mathbf{B}_{22} & \cdots & \mathbf{V}_2 \mathbf{B}_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{V}_G \mathbf{B}_{G1} & \mathbf{V}_G \mathbf{B}_{G2} & \cdots & \mathbf{V}_G \mathbf{B}_{GG} \end{bmatrix}$$

Since the domestic value shares of different countries in final demand have to sum to one the following property holds:

$$\sum_r^G \mathbf{V}_s \mathbf{B}_{sr} = \mathbf{u}_N \quad (\text{A.6})$$

Defining the $GN \times G$ final demand matrix as:

$$\mathbf{Y} = \begin{bmatrix} \mathbf{Y}_{11} & \mathbf{Y}_{12} & \cdots & \mathbf{Y}_{1G} \\ \mathbf{Y}_{21} & \mathbf{Y}_{22} & \cdots & \mathbf{Y}_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{Y}_{G1} & \mathbf{Y}_{G2} & \cdots & \mathbf{Y}_{GG} \end{bmatrix}$$

we can derive the $G \times G$ value added matrix by pairs of source-absorption countries:

$$\overline{\mathbf{VA}} \equiv \mathbf{VB}\mathbf{Y} =$$

$$= \begin{bmatrix} \mathbf{V}_1 \sum_r^G \mathbf{B}_{1r} \mathbf{Y}_{r1} & \mathbf{V}_1 \sum_r^G \mathbf{B}_{1r} \mathbf{Y}_{r2} & \cdots & \mathbf{V}_1 \sum_r^G \mathbf{B}_{1r} \mathbf{Y}_{rG} \\ \mathbf{V}_2 \sum_r^G \mathbf{B}_{2r} \mathbf{Y}_{r2} & \mathbf{V}_2 \sum_r^G \mathbf{B}_{2r} \mathbf{Y}_{r2} & \cdots & \mathbf{V}_2 \sum_r^G \mathbf{B}_{2r} \mathbf{Y}_{rG} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{V}_G \sum_r^G \mathbf{B}_{Gr} \mathbf{Y}_{rG} & \mathbf{V}_G \sum_r^G \mathbf{B}_{Gr} \mathbf{Y}_{rG} & \cdots & \mathbf{V}_G \sum_r^G \mathbf{B}_{Gr} \mathbf{Y}_{rG} \end{bmatrix} \quad (\text{A.7})$$

To get the domestic value added by sector, one must apply a different form of the direct value added matrix. Defining $\widehat{\mathbf{V}}_s$ as the $N \times N$ diagonal matrix with the direct value added coefficients along the principal diagonal, the $GN \times GN$ block diagonal matrix for all countries and sectors of origin becomes:

$$\widehat{\mathbf{V}} = \begin{bmatrix} \widehat{\mathbf{V}}_1 & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \widehat{\mathbf{V}}_2 & \cdots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & \widehat{\mathbf{V}}_G \end{bmatrix}$$

The $GN \times G$ matrix that reproduces the composition of value added by sector-county of origin and country of final destination is:

$$\mathbf{VA} \equiv \widehat{\mathbf{V}} \mathbf{BY} = \begin{bmatrix} \widehat{\mathbf{V}}_1 \sum_r^G \mathbf{B}_{1r} \mathbf{Y}_{r1} & \widehat{\mathbf{V}}_1 \sum_r^G \mathbf{B}_{1r} \mathbf{Y}_{r2} & \cdots & \widehat{\mathbf{V}}_1 \sum_r^G \mathbf{B}_{1r} \mathbf{Y}_{rG} \\ \widehat{\mathbf{V}}_2 \sum_r^G \mathbf{B}_{2r} \mathbf{Y}_{r2} & \widehat{\mathbf{V}}_2 \sum_r^G \mathbf{B}_{2r} \mathbf{Y}_{r2} & \cdots & \widehat{\mathbf{V}}_2 \sum_r^G \mathbf{B}_{2r} \mathbf{Y}_{rG} \\ \vdots & \vdots & \ddots & \vdots \\ \widehat{\mathbf{V}}_G \sum_r^G \mathbf{B}_{Gr} \mathbf{Y}_{rG} & \widehat{\mathbf{V}}_G \sum_r^G \mathbf{B}_{Gr} \mathbf{Y}_{rG} & \cdots & \widehat{\mathbf{V}}_G \sum_r^G \mathbf{B}_{Gr} \mathbf{Y}_{rG} \end{bmatrix} \quad (\text{A.8})$$

The off-diagonal elements of the \mathbf{VA} matrix correspond to the value added exports as defined in KWW(2014), i.e. the vector of domestic value added originated in country s and finally absorbed in country r :

$$\mathbf{VT}_{sr} \equiv \mathbf{VA}_{sr} = \widehat{\mathbf{V}}_s \sum_g^G \mathbf{B}_{sg} \mathbf{Y}_{gr} \quad (\text{A.9})$$

Finally we may be interested in relating the sector/country in which the value added is generated with the sector/country of final demand absorption. This result can be easily derived from equation A.8, simply by modifying the final demand matrix \mathbf{Y} . In particular we can define $\widehat{\mathbf{Y}}_{sr}$ as the $N \times N$ diagonal matrix with country r 's demand for final goods produced in country s along the principal

diagonal:

$$\widehat{\mathbf{Y}}_{sr} = \begin{bmatrix} y_1^{sr} & 0 & \cdots & 0 \\ 0 & y_2^{sr} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & y_N^{sr} \end{bmatrix}$$

Then the distribution of global value added by combinations of sector/county of origin and sector-country of final destination is represented by the following $GN \times GN$ matrix:

$$\begin{aligned} \widehat{\mathbf{V}}\mathbf{A} &\equiv \widehat{\mathbf{V}}\mathbf{B}\widehat{\mathbf{Y}} = \\ &= \begin{bmatrix} \widehat{\mathbf{V}}_1 \sum_r^G \mathbf{B}_{1r} \widehat{\mathbf{Y}}_{r1} & \widehat{\mathbf{V}}_1 \sum_r^G \mathbf{B}_{1r} \widehat{\mathbf{Y}}_{r2} & \cdots & \widehat{\mathbf{V}}_1 \sum_r^G \mathbf{B}_{1r} \widehat{\mathbf{Y}}_{rG} \\ \widehat{\mathbf{V}}_2 \sum_r^G \mathbf{B}_{2r} \widehat{\mathbf{Y}}_{r2} & \widehat{\mathbf{V}}_2 \sum_r^G \mathbf{B}_{2r} \widehat{\mathbf{Y}}_{r2} & \cdots & \widehat{\mathbf{V}}_2 \sum_r^G \mathbf{B}_{2r} \widehat{\mathbf{Y}}_{rG} \\ \vdots & \vdots & \ddots & \vdots \\ \widehat{\mathbf{V}}_G \sum_r^G \mathbf{B}_{Gr} \widehat{\mathbf{Y}}_{rG} & \widehat{\mathbf{V}}_G \sum_r^G \mathbf{B}_{Gr} \widehat{\mathbf{Y}}_{rG} & \cdots & \widehat{\mathbf{V}}_G \sum_r^G \mathbf{B}_{Gr} \widehat{\mathbf{Y}}_{rG} \end{bmatrix} \end{aligned} \quad (\text{A.10})$$

B Appendix

In this Appendix we show that each component of KWW's original decomposition (equation 36 in KWW, 2014) may be retrieved starting from our decomposition in equation (11), as total exports are simply the sum of all the bilateral export flows (i.e. $\mathbf{E}_{s*} = \sum_{r \neq s}^G \mathbf{E}_{sr}$). As observed, it is straightforward to recognize this correspondence for the first item (i.e. *the domestic value added in direct final good exports*) and for the last three items, which identify the foreign content of gross exports. In these cases, the original KWW components can be obtained as a simple sum over the importing countries r of the corresponding items in our bilateral decomposition. For the remaining components a few more steps are needed to prove the equivalence between the two expressions.

In deriving our bilateral decomposition we introduced a modified version of the Leontief inverse matrix, $\widehat{\mathbf{B}}^\dagger$. We start by showing how it relates to the original Leontief inverse \mathbf{B} that appears in the KWW equation. First, $\widehat{\mathbf{B}}^\dagger$ is obtained by setting equal to 0 the coefficients that identify the requirement of inputs from country s in the \mathbf{A} matrix (excepting only the domestic input requirement matrix \mathbf{A}_{ss}). Thus the modified matrix of input can be expressed as follows:

$$\mathbf{A}^\dagger = (\mathbf{A} - \mathbf{A}^s) \quad (\text{B.1})$$

where \mathbf{A}^s is the $GN \times GN$ matrix with the coefficients of intermediate inputs imported from s in the corresponding sub-matrices and zero elsewhere. Since $\widehat{\mathbf{B}}^\dagger$ is the inverse of $(\mathbf{I} - \mathbf{A}^\dagger)$, the following relationship holds:

$$(\mathbf{I} - \mathbf{A}^\dagger)\widehat{\mathbf{B}}^\dagger = \widehat{\mathbf{B}}^\dagger(\mathbf{I} - \mathbf{A}^\dagger) = \mathbf{I} \quad (\text{B.2})$$

Substituting (B.1) into (B.2) we get:

$$(\mathbf{I} - \mathbf{A})\widehat{\mathbf{B}}^\dagger + \mathbf{A}^s\widehat{\mathbf{B}}^\dagger = \mathbf{I} \quad (\text{B.3})$$

and multiplying both sides of (B.3) by $\mathbf{B} \equiv (\mathbf{I} - \mathbf{A})^{-1}$ we obtain the following equivalence:

$$\mathbf{B} = \widehat{\mathbf{B}}^\dagger + \mathbf{B}\mathbf{A}^s\widehat{\mathbf{B}}^\dagger \quad (\text{B.4})$$

Then we focus on the off-diagonal block element \mathbf{B}_{sr} that identifies the gross output generated in s necessary to produce one unit of r final good. According to

equation (B.4) this sub-matrix can be expressed as follows:

$$\mathbf{B}_{sr} = \widehat{\mathbf{B}}_{sr}^{\neq} + \mathbf{B}_{ss} \sum_{t \neq s} \mathbf{A}_{st} \widehat{\mathbf{B}}_{tr}^{\neq} \quad (\text{B.5})$$

where \mathbf{B}_{sr}^{\neq} is equal to $\mathbf{0}$ for each $r \neq s$, since it corresponds to a summation of infinite terms all equal to the null matrix. Therefore if we single out the $\widehat{\mathbf{B}}_{rr}^{\neq}$ element from the final summation of the right-hand side of equation (B.5) we get:

$$\mathbf{B}_{sr} = \mathbf{B}_{ss} \mathbf{A}_{sr} \widehat{\mathbf{B}}_{rr}^{\neq} + \mathbf{B}_{ss} \sum_{t \neq s, r} \mathbf{A}_{st} \widehat{\mathbf{B}}_{tr}^{\neq} \quad (\text{B.6})$$

Then applying to the elements of matrix $\widehat{\mathbf{B}}^{\neq}$ the properties of \mathbf{B} sub-matrices illustrated in (A.3) and (A.4):

$$\widehat{\mathbf{B}}_{rr}^{\neq} = (\mathbf{I} - \mathbf{A}_{rr})^{-1} + (\mathbf{I} - \mathbf{A}_{rr})^{-1} \sum_{j \neq r} \mathbf{A}_{rj} \widehat{\mathbf{B}}_{jr}^{\neq} \quad (\text{B.7})$$

$$\widehat{\mathbf{B}}_{tr}^{\neq} = (\mathbf{I} - \mathbf{A}_{tt})^{-1} \sum_{j \neq t}^G \mathbf{A}_{tj} \widehat{\mathbf{B}}_{jr}^{\neq} \quad (\text{B.8})$$

Plugging (B.7) and (B.8) into (B.6) we obtain the following expression for \mathbf{B}_{sr} :

$$\begin{aligned} \mathbf{B}_{sr} &= \mathbf{B}_{ss} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} + \mathbf{B}_{ss} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \sum_{j \neq r} \mathbf{A}_{rj} \widehat{\mathbf{B}}_{jr}^{\neq} \\ &+ \mathbf{B}_{ss} \sum_{t \neq s, r} \mathbf{A}_{st} (\mathbf{I} - \mathbf{A}_{tt})^{-1} \sum_{j \neq t}^G \mathbf{A}_{tj} \widehat{\mathbf{B}}_{jr}^{\neq} \end{aligned} \quad (\text{B.9})$$

Finally we can sum across the $G-1$ foreign countries (i.e. $\sum_{r \neq s}^G$) to show that the remaining items in the accounting of bilateral trade flows in equation (11) can be mapped into the corresponding components of the original KWW decomposition of aggregate exports. For instance, pre-multiplying by matrix \mathbf{V}_s , post-multiplying by \mathbf{Y}_{rr} and summing across r both sides of equation (B.9) we exactly retrieve the

second component of the KWW decomposition:

$$\begin{aligned}
\mathbf{V}_s \sum_{r \neq s} \mathbf{B}_{sr} \mathbf{Y}_{rr} &= \mathbf{V}_s \sum_{r \neq s} \mathbf{B}_{ss} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \mathbf{Y}_{rr} \\
&+ \mathbf{V}_s \sum_{r \neq s} \mathbf{B}_{ss} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \sum_{j \neq r} \mathbf{A}_{rj} \widehat{\mathbf{B}}_{jr}^\dagger \mathbf{Y}_{rr} \\
&+ \mathbf{V}_s \sum_{r \neq s} \mathbf{B}_{ss} \sum_{t \neq s, r} \mathbf{A}_{st} (\mathbf{I} - \mathbf{A}_{tt})^{-1} \sum_{j \neq t}^G \mathbf{A}_{tj} \widehat{\mathbf{B}}_{jr}^\dagger \mathbf{Y}_{rr}
\end{aligned} \tag{B.10}$$

where the left-hand side of equation (B.10) corresponds to the sum across all direct importers (r) of the components **2a**, **2b** and **2c** in equation (11):

$$\begin{aligned}
\sum_{r \neq s} (\mathbf{2a} + \mathbf{2b} + \mathbf{2c}) &= \mathbf{V}_s \sum_{r \neq s} \mathbf{B}_{ss} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \mathbf{Y}_{rr} \\
&+ \mathbf{V}_s \sum_{r \neq s} \mathbf{B}_{ss} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \sum_{j \neq r}^G \mathbf{A}_{rj} \widehat{\mathbf{B}}_{jr}^\dagger \mathbf{Y}_{rr} \\
&+ \mathbf{V}_s \sum_{r \neq s} \mathbf{B}_{ss} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \sum_{j \neq r}^G \mathbf{A}_{rj} \sum_{k \neq s, r}^G \widehat{\mathbf{B}}_{jk}^\dagger \mathbf{Y}_{kk}
\end{aligned} \tag{B.11}$$

The first two terms on the left-hand side are clearly identical, and the equivalence between the last items is readily verified by replacing the subscript k with r and the subscript r with t in the last term of equation (B.11). However, it should be noticed that for this last term the single addends in the summation across the r foreign countries differ between the two equations. This is because this portion of domestic value added produced in s for final use in r gets to the final destination markets by passing through one or more third countries; that is, it is not part of the bilateral exports from s to r .

Starting from the definition of the \mathbf{B}_{rs} matrix in equation (B.9) and following the same procedure employed for the second item of the KWW decomposition, it is easy to prove that the third and fourth components too can be obtained as the sum of the corresponding items in our bilateral decomposition across all the destinations.

Finally, we use a slightly different procedure to show that also the fifth and sixth terms in the KWW main accounting relationship are exactly mapped within the bilateral exports. We start by singling out the block matrix \mathbf{B}_{ss} from the principal diagonal of the \mathbf{B} matrix. According to equation (B.4) this matrix is

equal to:

$$\mathbf{B}_{ss} = \widehat{\mathbf{B}}_{ss}^{\dagger} + \mathbf{B}_{ss} \sum_{r \neq s} \mathbf{A}_{sr} \widehat{\mathbf{B}}_{rs}^{\dagger} \quad (\text{B.12})$$

We can then apply to the $\widehat{\mathbf{B}}^{\dagger}$ the property of the block diagonal elements of the \mathbf{B} matrix illustrated in (A.3):

$$\widehat{\mathbf{B}}_{ss}^{\dagger} = (\mathbf{I} - \mathbf{A}_{ss}^{\dagger})^{-1} + \sum_{t \neq s} \mathbf{B}_{st}^{\dagger} \mathbf{A}_{ts} (\mathbf{I} - \mathbf{A}_{ss}^{\dagger})^{-1} = (\mathbf{I} - \mathbf{A}_{ss})^{-1} \quad (\text{B.13})$$

where the last equality follows from the fact that, by construction, $\mathbf{B}_{st}^{\dagger}$ is equal to $\mathbf{0}$ for each $t \neq s$. Therefore (B.12) can be rewritten as follows:

$$\mathbf{B}_{ss} = (\mathbf{I} - \mathbf{A}_{ss})^{-1} + \mathbf{B}_{ss} \sum_{r \neq s} \mathbf{A}_{sr} \widehat{\mathbf{B}}_{rs}^{\dagger} \quad (\text{B.14})$$

Then, applying the same property of the block diagonal elements of the \mathbf{B} matrix to the left hand side of (B.14) and rearranging we obtain:

$$\sum_{r \neq s} \mathbf{B}_{sr} \mathbf{A}_{rs} (\mathbf{I} - \mathbf{A}_{ss})^{-1} = \sum_{r \neq s} \mathbf{B}_{ss} \mathbf{A}_{sr} \widehat{\mathbf{B}}_{rs}^{\dagger} \quad (\text{B.15})$$

Finally, using the property presented in (A.4) to the $\widehat{\mathbf{B}}_{rs}^{\dagger}$ matrix we get:

$$\sum_{r \neq s} \mathbf{B}_{sr} \mathbf{A}_{rs} (\mathbf{I} - \mathbf{A}_{ss})^{-1} = \sum_{r \neq s} \mathbf{B}_{ss} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \sum_{j \neq r} \mathbf{A}_{rj} \widehat{\mathbf{B}}_{js}^{\dagger} \quad (\text{B.16})$$

Now it is straightforward to see that the fifth and sixth terms in the KWW decomposition are simply the sum of the same terms in equation (11) across all the bilateral destinations.

C Appendix

The decomposition of bilateral exports in a source-based approach can be expressed as follows:

$$\begin{aligned}
\mathbf{u}_N \mathbf{E}_{sr} &= \mathbf{V}_s (\mathbf{I} - \mathbf{A}_{ss})^{-1} \mathbf{Y}_{sr} \tag{1a*} \\
&+ \mathbf{V}_s (\mathbf{I} - \mathbf{A}_{ss})^{-1} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \left[\sum_{j \neq r}^G \mathbf{A}_{rj} \mathbf{B}_{js} \mathbf{Y}_{sr} + \sum_{j \neq r}^G \mathbf{A}_{rj} \sum_{k \neq s,r}^G \mathbf{B}_{js} \mathbf{Y}_{sk} \right] \tag{1b*} \tag{1c*} \\
&+ \mathbf{V}_s (\mathbf{I} - \mathbf{A}_{ss})^{-1} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \left[\mathbf{Y}_{rr} + \sum_{j \neq r}^G \mathbf{A}_{rj} \mathbf{B}_{jr} \mathbf{Y}_{rr} + \sum_{j \neq r}^G \mathbf{A}_{rj} \sum_{k \neq s,r}^G \mathbf{B}_{jk} \mathbf{Y}_{kk} \right] \tag{2a*} \tag{2b*} \tag{2c*} \\
&+ \mathbf{V}_s (\mathbf{I} - \mathbf{A}_{ss})^{-1} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \left[\sum_{j \neq r,s}^G \mathbf{Y}_{rj} + \sum_{j \neq r}^G \mathbf{A}_{rj} \sum_{l \neq s,r}^G \mathbf{B}_{jr} \mathbf{Y}_{rl} \right. \\
&\quad \left. + \sum_{j \neq r}^G \mathbf{A}_{rj} \sum_{k \neq s,r}^G \mathbf{B}_{jk} \mathbf{Y}_{kr} + \sum_{j \neq r}^G \mathbf{A}_{rj} \sum_{k \neq s,r,l}^G \sum_{l \neq s,r}^G \mathbf{B}_{jk} \mathbf{Y}_{kl} \right] \tag{3a*} \tag{3b*} \tag{3c*} \tag{3d*} \\
&+ \mathbf{V}_s (\mathbf{I} - \mathbf{A}_{ss})^{-1} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \left[\mathbf{Y}_{rs} + \sum_{j \neq r}^G \mathbf{A}_{rj} \mathbf{B}_{jr} \mathbf{Y}_{rs} + \sum_{j \neq r}^G \mathbf{A}_{rj} \sum_{k \neq s,r}^G \mathbf{B}_{jk} \mathbf{Y}_{ks} \right] \tag{4a*} \tag{4b*} \tag{4c*} \\
&+ \mathbf{V}_s (\mathbf{I} - \mathbf{A}_{ss})^{-1} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \sum_{j \neq r}^G \mathbf{A}_{rj} \mathbf{B}_{js} \mathbf{Y}_{ss} \tag{5*} \\
&+ \mathbf{V}_s (\mathbf{I} - \mathbf{A}_{ss})^{-1} \sum_{t \neq s}^G \mathbf{A}_{rt} \mathbf{B}_{ts} \mathbf{E}_{sr} \tag{6*} \\
&+ \sum_{t \neq s}^G \mathbf{V}_t \mathbf{B}_{ts} \mathbf{Y}_{sr} + \sum_{t \neq s}^G \mathbf{V}_t \mathbf{B}_{ts} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \mathbf{Y}_{rr} \tag{7} \tag{8} \\
&+ \sum_{t \neq s}^G \mathbf{V}_t \mathbf{B}_{ts} \mathbf{A}_{sr} (\mathbf{I} - \mathbf{A}_{rr})^{-1} \mathbf{E}_{r*} \tag{9}
\end{aligned} \tag{C.1}$$

We can define the items above as:

1a* domestic value added (VA) in final good exports directly absorbed by bilateral

importers;

- 1b*** domestic VA in intermediate exports absorbed by bilateral importers as domestic final goods after additional processing stages;
- 1c*** domestic VA in intermediate exports absorbed by third countries as domestic final goods after additional processing stages;
- 2a*** domestic VA in intermediate exports absorbed by direct importers as local final goods;
- 2b*** domestic VA in intermediate exports absorbed by direct importers as local final goods only after further processing stages;
- 2c*** domestic VA in intermediate exports absorbed by third countries as local final goods;
- 3a*** domestic VA in intermediate exports absorbed by third countries as final goods from direct bilateral importers;
- 3b*** domestic VA in intermediate exports absorbed by third countries as final goods from direct bilateral importers only after further processing stages;
- 3c*** domestic VA in intermediate exports absorbed by direct importers as final goods from third countries;
- 3d*** domestic VA in intermediate exports absorbed by third countries as final goods from other third countries;
- 4a*** domestic VA in intermediate exports absorbed at home as final goods of the bilateral importers;
- 4b*** domestic VA in intermediate exports absorbed at home as final goods of the bilateral importers after further processing stages;
- 4c*** domestic VA in intermediate exports absorbed at home as final goods of a third country;
- 5*** domestic VA in intermediate exports absorbed at home as domestic final goods;
- 6*** double-counted intermediate exports originally produced at home;
- 7** foreign VA in exports of final goods;

8 foreign VA in exports of intermediate goods;

9 double-counted intermediate exports originally produced abroad.

As for the sink-based decomposition, the enumeration of the items here above recalls the original KWW components, which can be obtained as a simple summation over the importing countries r of the corresponding items in our bilateral decomposition (a formal proof is available upon request). Note that terms **7**, **8** and **9** are precisely equal to those of the sink-based methodology in equation (11).

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