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Economic Analysis with Inter-Country Input-Output Tables in Stata

Federico Belotti
Alessandro Borin
Michele Mancini

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Abstract

Several new statistical tools and analytical frameworks have been developed recently to measure countries' and sectors' involvement in global value chains. Such wealth of methodologies reflects that different empirical questions call for distinct accounting methods, along with different levels of aggregation of trade flows. This paper is a companion to the conceptual framework presented in Borin and Mancini (2019). The paper describes a new Stata module, icio, that allows the user to construct the most appropriate measure for given empirical questions on trade in value-added and participation in global value chains of countries and sectors. By exploiting inter-country input-output tables, icio provides decompositions of aggregate, bilateral, and sectoral exports and imports according to the source and destination of their value-added content. As different measures are suited to address distinct economic questions, icio is designed to be flexible also in this respect.

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`icio`: Economic Analysis with Inter-Country Input-Output Tables in Stata*

Federico Belotti[1], Alessandro Borin[2], and Michele Mancini[3]

[1]University of Rome Tor Vergata

[2,3]Bank of Italy

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1 Introduction

The diffusion of global production networks has called for new statistical tools providing a representation of complex production linkages between and within economies. New types of data sources, the Inter-Country Input-Output (ICIO) tables, and new analytical frameworks have been developed to measure supply and demand contributions of countries and sectors in global value chains (GVCs).[1]

In this paper we describe `icio`, a new Stata command that computes countries' and sectors' participation in GVCs as well as relevant measures of trade in value-added, following the conceptual framework proposed by Borin and Mancini (2019), which – in turn – extends, refines and reconciles the other main contributions in this strand of the literature.[2]

The command is flexible in many aspects. It allows to choose from different accounting methodologies, called perspectives. Each of these perspectives is best suited to address specific empirical questions, such as tracking production-demand linkages, assessing countries' participation to the global production sharing, quantifying value-added embedded in countries' and sectors' exports, evaluating the potential exposure to macroeconomic and trade policy shocks. It exploits the most famous ICIO tables - the World Input-Output Database (Timmer et al. 2015), the OECD TiVA database (OECD, 2018), and the Eora Global Supply Chain Database (Lenzen et al. 2013). Moreover, any user-provided ICIO table can be straightforwardly loaded and used to compute value-added trade and GVC participation measures.

More specifically, `icio` encompasses the most relevant measures of value-added in exports and imports at the aggregate, bilateral and sectoral levels. For a given trade flow, it disentangles the source country/sector and the destination country/sector of value-added content. Moreover, for export flows at any level of disaggregation, `icio` computes the component related to GVC trade, i.e., the one entailing more than a single border crossing. This measure - and its backward and forward GVC participation sub-components, is featured in the World Bank World Development Report 2020 (WDR, 2020).[3]

In addition, the `icio` command can be used to retrieve, from the ICIO tables,

[1]See, among others, Johnson and Noguera (2012), Wang et al. (2013), Koopman et al. (2014), Borin and Mancini (2015), Los et al. (2016), Nagengast and Stehrer (2016), Johnson (2018), Miroudot and Ye (2018), Los and Timmer (2018).

[2]The essential features and the algebraic derivation of the conceptual framework are reported in Appendices A to F.

[3]GVC measures are based on Borin and Mancini (2015, 2019), which consistently refine the vertical specialization index proposed by Hummels et al. (2001).

the GDP (i.e. value-added) produced by a given country or industry (origin), the final demand in different countries and sectors (destination), or a combination of the two (when both origin and destination are specified).

We are aware that many questions can be addressed only partially with the current version of `icio`. Thus, our plan is to release new modules in the near future. First, we will add a much broader set of measures to assess the participation of countries and sectors in GVCs (Borin and Mancini, 2017; Wang et al., 2017) and their position (Antràs and Chor, 2013; Fally 2012; Antràs and Chor, 2018). Second, we will build a set of indicators to better evaluate the direct and indirect effects of trade policies, taking into account the GVC structure.

The rest of the paper is organized as follows. In Section 2 we show how to load ICIO tables in `icio` using the command `icio_load`. In Section 3 we show how supply, demand and supply-demand linkages can be computed in `icio`. This is useful when the empirical questions are related by supply, demand or require linking the origin of the value added to its absorption in final demand, without considering explicitly international trade flows. In Section 4 we provide the tools for gathering a comprehensive overview of the production process and cross-country relationships, i.e., how to obtain value-added decompositions of trade flows by country of origin and destination. In Section 5 we focus on the measurement of GVC participation. In several instances, and for illustration purposes, we show how to replicate some of the measures of GVC participation and figures presented in the World Bank's Word Development Report 2020. Section 6 concludes.

Each section shares the same structure. At the beginning we provide a brief overview of the measures therein discussed. Then, we show how to compute those measures in `icio`, providing also some examples and a list of several relevant questions that could be addressed, with the related `icio`'s syntax. In addition, in the Appendices we present the related conceptual frameworks.

2 Inter-Country Input-Output tables

Input-Output (IO) models were developed by Leontief (1936) to represent and analyze production and consumption relationships within an economy. The related statistical tools, the IO tables, indicate the monetary amount of inputs of each sector necessary to produce the total output of a given industry and, in turn, how this output is used as final consumption (or investment) or as intermediate inputs for other productions. National IO tables distinguish only between domestic and foreign inputs; on the output side, exports represent one of the possible 'final' uses of output, as domestic consumption and investment. ICIO tables, which have been developed combining national IO statistics with trade data, describe sale-purchase relationships between industries within and between economies as well as the uses in different final demand components (e.g. consumption, investment and government spending). In particular, an ICIO table specifies the country-sector pairs that provide intermediate inputs to a given industry and the country-sector pairs to which that industry sells its output - in the case of intermediate products - or the ultimate destination markets for final goods. In Appendix A we present the basic conceptual framework of ICIO models while in Section 2.1 we show how to load ICIO tables with the command `icio_load`.

2.1 Implementation: Loading ICIO tables using the `icio_load` command

In order to use the `icio` command one needs to load a particular ICIO table by using the `icio_load` command. `icio_load` allows to work directly with the most popular ICIO tables - OECD TiVA database (OECD, 2018), World Input-Output Database (WIOD, Timmer et al. 2015), and Eora Global Supply Chain Database (Lenzen et al. 2013); in addition, any other user-provided ICIO table can be loaded.

2.1.1 Syntax

The basic syntax for `icio_load` is

`icio_load, [`*options*`]`

where the main *options* are:

`iciotable(`*table_name*`[, `*usertable_options*`])`, specifies the ICIO table to be used for the analysis; *default* is `wiodn`, the last WIOD release available (release 2016, see below for more details on the available tables' versions);

`year(`#`)`, sets the year to be used for the analysis; the *default* is the last available year: 2014 for the WIOD tables (`wiodn`), 2015 for TiVA tables (`tivan`), 2015 for the Eora Global Supply Chain Database tables (`eora`). Not needed for user-provided tables;

`info`, shows the data sources and the versions of the loadable ICIO tables.

2.1.2 Examples

`icio_load` can be used for the following purposes:

1. To display the list of the directly available ICIO tables and their releases:[4]

```
. icio_load, info
```

table	version	from	to
wiodn	2016	2000	2014
tivan	2018	2005	2015
eora	199.82	1990	2015
wiodo	2013	1995	2011
tivao	2016	1995	2011

   In this way the user can always recover which ICIO tables are directly available via the `icio` command. As can be seen from the previous output, at the time of writing, the following tables have been made available: the "2013" and the "2016" releases of the WIOD tables, the "2016" and "2018" of the TiVA tables, and the "199.82" version of the Eora Global Supply Chain Database tables.

2. To load a specific year of the ICIO table of interest; for example the following syntax allows to load the year 2014 of the WIOD tables released in 2016 (i.e. `wiodn`):[5]

```
. icio_load, iciot(wiodn) year(2014)
```

3. To load a user-provided ICIO table, by specifying `user`, instead of a specific ICIO table's code, in the `iciotable(`*table_name*`)` option. The user-provided ICIO table and the related country list must be provided using two different comma separated files (i.e. files with extension `.csv`). For example:

```
. icio_load, iciot(user, userp("path_to_the_table_folder") tablen(ADB_2011.csv) //
countrylist(adb_countrylist.csv)
```

   The syntax above shows that additional information has to be provided in order to instruct `icio` to load the user-provided table: *i*) the path to the folder where the `.csv` file containing the user-provided table is located, via the

[4]The ICIO tables directly available in `icio` are automatically downloaded the first time the user requests them through the `icio_load` command. These files are saved within the Stata system folder `"../ado/plus/i"` using a `.mmat` format (notice that the *filename* begins with the prefix `icio_`). For further details on the last release directly available through `icio`, run `icio_load, info` or visit the official websites `oe.cd/tiva` for the OECD TiVA database, `wiod.org` for the World Input-Output Database and `worldmrio.com` for the Eora Global Supply Chain Database. Please, also remember to cite the reference to the ICIO database you are analyzing through `icio`.

[5]Multiple years have to be loaded sequentially and then the results should be appended.

sub-option userpath("*string*"); *ii*) the name of the .csv file containing the table, via the sub-option tablename(*string*); the name of the file containing the country list, via the sub-option countrylistname(*string*).

Notice that the table's csv file must contain only one matrix of dimension $(G \times N) \times (G \times N + G \times U)$, where G is the number of countries, N the number of sectors and U the number of uses (i.e. consumption, investment, etc.). See the icio help file for more details.

3 Supply, demand and supply-demand linkages

ICIO tables can be used in combination with long-established accounting relationships (Leontief, 1936) to measure the net value of production (GDP) of a country/sector, the value of final demand in a given country/sector and to pin down the links between the country-sector where the value-added originates and the market where it is absorbed in final demand.

In Appendix B we show how to retrieve supply, demand and supply-demand linkages, i.e. GDP by country/sector of origin and/or destination, from ICIO tables while in Section 3.1 we describe how to compute these measures in icio, providing also some examples.

3.1 Implementation: Supply and demand with icio

The icio command can be used to retrieve the GDP (i.e. value-added) produced by a given country or industry (origin of value-added) by specifying the option origin(), to measure the final demand in different countries and sectors (destination of the value-added) by specifying the option destination(), or a combination of the two (both origin() and destination()).

3.1.1 Syntax

1. Gross Domestic Product:

icio, origin(*country_code*[,*sector_code*]) [*standard_options*]

2. Final demand:

icio, destination(*country_code*[,*sector_code*]) [*standard_options*]

3. Value-added by origin and final destination:

icio, origin(*country_code*[,*sector_code*])
destination(*country_code* [,*sector_code*]) [*standard_options*]

The list of available country/sector codes for the loaded ICIO table can be displayed by running icio, info. As for the [*standard_options*], they are:

save(*filename* [, replace]), which saves the command output (scalar, vector or matrix) in memory to an excel file (.xls);

groups(*grouping_rule* *"group_name"*[...]), which specifies a user-defined grouping of countries. In this way, output measures can be computed for a country group (e.g., the "Euro area", "MERCOSUR" or "ASEAN") as a whole while taking into account the specific supply/demand/trade structure of each member of the group. To define one or more country groups, the user has to provide a list of comma-separated country codes, which is the "*grouping_rule*", followed by a user defined "*group_name*".

3.1.2 Examples

icio is useful to address empirical questions related to supply, demand and supply-demand relationships, without considering explicitly international trade flows. For instance, it is possible to retrieve the GDP of Germany that is finally absorbed in China (i.e., Johnson and Noguera (2012) "value-added exports"), that according to the WIOD database in 2014 is:

```
. icio_load
Loading table wiod 2014...  loaded

. *What is the value-added originated in Germany and absorbed in China?
.   icio, origin(deu) destination(chn)

Value-Added by origin/destination:
Origin: DEU
Destination: CHN
Output: Value-Added
```

	Millions of $	% of total
Value-Added	101042.25	*100.00*

The Stata output displays the value, in millions of US dollars, and the share of total value-added produced in a specific country, when the complete list of countries or sectors of destination is selected by specifying the code all[6](or absorbed by

[6]This is the case if a certain country/sector of origin is specified, origin(*country_code*[,*sector_code*]), as well as the complete list of countries/sectors of destination, i.e.

a specific country/sector, if the complete list of countries or sectors of origin is specified with the same code).[7] If the option `all` is not specified the share will be clearly equal to 100%. For example

```
. *What is the value-added originated in Germany and absorbed in each country?
. icio, origin(deu) destination(all)

Value-Added by origin/destination:
Origin: DEU
Destination: ALL
Output: Value-Added
```

	Millions of $	% of total
AUS	12048.65	0.33
AUT	36839.13	1.02
BEL	20719.98	0.57
BGR	3004.85	0.08
BRA	15943.49	0.44
CAN	15305.40	0.42
CHE	37205.73	1.03
CHN	101042.25	2.79
CYP	768.14	0.02
CZE	16171.75	0.45
DEU	2446528.60	67.58
DNK	12205.44	0.34
ESP	33469.66	0.92
EST	1219.86	0.03
FIN	9049.83	0.25
FRA	85684.36	2.37
GBR	77158.04	2.13
GRC	6543.15	0.18
HRV	2473.71	0.07
HUN	8782.43	0.24
IDN	4689.61	0.13
IND	12267.21	0.34
IRL	5407.92	0.15
ITA	52128.41	1.44
JPN	23269.19	0.64
KOR	17377.73	0.48
LTU	1978.03	0.05
LUX	3989.54	0.11
LVA	1134.20	0.03
MEX	10619.36	0.29
MLT	321.40	0.01
NLD	34154.59	0.94
NOR	10257.55	0.28
POL	33030.97	0.91
PRT	6773.81	0.19
ROU	9065.05	0.25
ROW	235768.63	6.51
RUS	38509.83	1.06
SVK	6112.61	0.17

`destination(all[,`*sector_code*`])` or `destination(`*country_code*`,all)`.

[7] This is the case if the complete list of countries or sectors of origin is specified, i.e. `origin(all[,`*sector_code*`])` or `origin(`*country_code*`,all)`, as well as a specific country/sector of destination, `destination(`*country_code*`[,`*sector_code*`])`.

SVN	2618.50	*0.07*
SWE	20894.17	*0.58*
TUR	19070.35	*0.53*
TWN	6318.91	*0.17*
USA	122388.23	*3.38*

As can be noted, the share of the German GDP absorbed in China (on the total GDP produced by Germany), around 2.8%, is obtained either by looking for the `CHN` row in the previous output, or by taking the ratio of the dollar values obtained throughout the options `origin(deu) destination(chn)` and the value of the total German GDP, that can be obtained using:

```
. *What is the Germany´s GDP?
.   icio, origin(deu)

Value-Added by origin/destination:
Origin: DEU
Output: Value-Added
```

	Millions of $	% of total
Value-Added	3620310.26	*100.00*

Other examples of questions that could be answered (see the reported syntax) with the analysis of supply-demand linkages through `icio` are:

- *What is the GDP (value-added) produced by each country?*
  `icio, origin(all)`
- *How much value-added does each country produce in a given sector (e.g., sector code 19)?*
  `icio, origin(all,19)`
- *What is the aggregate final demand of each country?*
  `icio, destination(all)`
- *Where the value-added produced in the Italian sector 19 is absorbed?*
  `icio, origin(ita,19) destination(all)`
- *Which final demand sectors in China are the most important for the absorption of US-made value-added?*
  `icio, origin(usa) destination(chn,all)`
- *Where the GDP produced in each country is absorbed (and save the output as "supply_demand.xls" in the current working directory)?*
  `icio, origin(all) destination(all) save("supply_demand.xls")`

- *How much USMCA (former NAFTA) countries' final demand in sector 20 is satisfied by Chinese productions?*
  `icio, origin(chn) destination(usmca,20) groups(usa, mex, can, "usmca")`

4 Value-added in trade flows

The accounting relationships presented in the previous section provide a useful tool to link the origin of value-added (GDP) to its absorption in final demand. However, they provide only partial information on overall production processes and cross-country relationships. For instance, no information is provided on the production stages that take place as well as on the national borders that are crossed between the stage in which the value-added is generated and the one of its final absorption. Both the above represent critical information to understand countries interdependence in GVCs.

In many empirical applications it is important to trace value-added in gross trade flows, for instance, when we want to measure the value-added produced by a country that is involved in a certain trade relationship. Depending on the empirical issue under investigation, it is also necessary to consider trade flows at different levels of disaggregation and analyze their value-added content. In fact, in some cases we may be interested just to single-out the value-added embedded in global trade flows or in the total exports or imports of a country. In other cases, also the bilateral and sectoral dimensions of trade flows may matter. For instance, when studying the implications of GVCs, it is relevant to consider the position of a country (or sector) within the production chain and identify its direct upstream and downstream trade partners. This may be relevant in order to geographically map the production networks and analyze the international propagation of macroeconomic shocks.

A key issue in the value-added accounting of trade regards the definition of "double counted" components, i.e. items that are recorded several times in a given gross trade flow due to the back-and-forth shipments that occur in a cross-national production process (Koopman et al. 2014). For instance, imagine that a country is exporting cotton. After some processing stage abroad, the cotton is imported back, embedded in some fabric, to be further re-exported as apparel. The value of cotton will be counted twice in the aggregate exports of the country, i.e. "double counted" - in the first export flow and in the second one, embedded in the apparel - but once in the GDP (i.e. value-added).

Now imagine that the goal is to allocate the value-added across the two export flows. A reasonable way is to consider the cotton production as value-added in the first shipment, i.e. the one of cotton, and as double-counting in the second one, when cotton is embedded in the shipment of apparel. Summing the value-added terms in the two export flows, we end up with consistent aggregate figures at the country level, i.e. cotton classified once as value-added and once as double counting.

Consider now a different goal, i.e. assessing the value-added exposed to a specific trade barrier imposed by a partner. To this end, suppose that a tariff impairs the exports of apparel. Now, when considering the value-added embedded in the second flow, the one exposed to the tariff, also that one of cotton needs to be taken into account. In this way, we are able to correctly assess the value-added that could be impaired by the tariff.

More in general, depending on the type of trade flow and the objective of the analysis, it is necessary to define the "perimeter" according to which something is classified as "value-added" or "double counted", i.e. a specific accounting "perspective" has to be chosen.

Each perspective is better suited to address specific empirical issues. Whenever the empirical application requires to retrieve the entire value-added of a country/sector of origin that is embedded in a given trade flow, as in the second example above, the accounting perspective to be chosen should match the level of disaggregation of the trade flow considered, as reported in the first column of Table 1 (e.g., "exporting country" perspective for aggregate exports, "bilateral" perspective for an aggregate bilateral trade flow, "sectoral-bilateral" perspective for a trade flow between two countries in a given sector, etc.).[8] For instance, suppose a tariff is imposed on the imports of a given sector from a certain partner, and we are interested in evaluating what part of the exporting country GDP is exposed to the tariff. In this case we want to consider as "value-added" the entire GDP that is involved in this sectoral-bilateral relationship, even if part of that was previously exported to other countries/sectors (i.e. double counted in an "exporting country" perspective). The specific sectoral-bilateral relationship becomes the new relevant perimeter, and only the items that enter multiple times in this trade flow are considered as "double counted". Indeed, this is what is called a "sectoral-bilateral perspective", the one used in the second example on cotton.

However, these measures cannot be summed up to get a precise assessment of value-added contents in more aggregate trade flows, e.g. value added in the total exports of a country. In other words, they are non-additive.[9] Thus, if we

[8]See Section E for a complete overview of the perspectives available in `icio`).

[9]See also Johnson (2018) and Los and Timmer (2018) on this point. More specifically, when we use an accounting perspective based on a narrower perimeter to define the double counted items (e.g. the sectoral-bilateral one), by summing these indicators we obtain value-added content

are seeking a breakdown of the value-added measures by sectors of exports, by importing partners or by sector-partner combinations, consistent with exporters' aggregate figures, as in the first example on cotton, we need to apply the exporting-country perspective also to the decomposition of more disaggregated trade flows (see column two of Table 1). In this way, the resulting measures are additive, i.e. measures at a more aggregate level can be obtained summing disaggregate results. This accounting perspective can be used also for other purposes such as, for instance, to single out the portion of trade in any type of exports that crosses just one international border. Indeed, Section 5 shows that this is instrumental for measuring GVC-related trade.

Whenever the perspective is set at a more aggregate level as compared to the considered trade flow, it is also needed to select an approach to allocate double counting. `icio` implements two alternative approaches:[10] the first method, so called "*source*-based" approach, accounts for the value-added the first time it leaves the country of origin; the second, "*sink*-based" approach, considers it the last time it crosses the national borders. The choice between these two approaches depends on the particular issue we want to address. The "*source*" approach is designed to examine the production linkages and the country/sector participation to different types of production processes. This makes it more suited to assess, for instance, the share of an export flow that crosses just one border, i.e. traditional exports, as opposed to the share that is further re-exported, i.e. GVC-exports. Conversely, the value-added in the "*sink*" approach is recorded as closely as possible to the moment when it is ultimately absorbed. This makes it more suited to studying the relationship between value-added in exports and final demand, as in the analysis of bilateral trade balances.

As already mentioned, each perspective is more suited to address specific empirical questions. In Table 2 we provide a non-exhaustive overview of the most common ones, with the best suited accounting method to provide an answer. See Section 4.1 for additional examples, with the related `icio` syntax.

In the Appendix we show the conceptual framework of the value-added accounting in total exports, following an exporting-country perspective (Appendix C), in bilateral exports, both with a bilateral and an exporting-country perspective (Appendix D), and in all the possible trade flows (Appendix E). Instead, in Section 4.1, we show the implementation in `icio` and provide some empirical examples with the

measures which exceed the correct ones for the aggregate trade flow (i.e. those based on a broader perimeter for defining double counted items).

[10]These approaches were proposed by Nagengast and Stehrer (2016) and fully derived by Borin and Mancini (2015, 2017).

related syntax.

Table 1: A summary of the available perspectives and approaches for each trade flow

	Perspective in line with the trade flow	**Perspective consistent with more aggregate flows (i.e. additive)**
	(1)	**(2)**
1. Total exports		
1a. Aggregate	Exporting-country	World (source/sink)
1b. Sectoral	Sectoral-exporter	Exporting-country (source/sink)
2. Bilateral exports		
2a. Aggregate	Bilateral	Exporting-country (source/sink)
2b. Sectoral	Sectoral-bilateral	Exporting-country (source/sink)
3. Total imports		
3a. Aggregate	Importing-country	n.a.
3b. Sectoral	Sectoral-importer	n.a.

Table 2: Overview of the most common empirical questions

Empirical question	**Trade flow to select**	**Accounting method**
GDP embedded in the total exports of a country	total aggregate exports	exporting-country perspective
GDP potentially exposed to:		
— a shock on a bilateral trade relation (e.g. generic trade frictions between two countries)	bilateral aggregate exports	bilateral perspective
— a shock on a specific sectoral-bilateral trade relation (e.g. a specific tariff imposed by a trade partner in a given sector)	bilateral sectoral exports	sectoral-bilateral perspective
— a shock on the imports of a country (e.g. trade restrictions vis-à-vis all partners)	total aggregate imports	importing-country perspective
— a shock on the imports of a country in a given sector (e.g. a specific sectoral tariff vis-à-vis all partners)	total sectoral imports	sectoral-importer perspective
— a shock on the sectoral exports of a country (e.g. negative demand shock on the exports of a given country and sector)	total sectoral exports	sectoral-exporter perspective
Value-added breakdown in disaggregated export flows, consistent with total aggregate measures	sectoral/bilateral/sectoral-bilateral exports	exporting-country perspective, source or sink approach
Value-added breakdown of bilateral trade balances	bilateral exports	exporting-country perspective, sink approach
Traditional exports vs GVC-exports	any export flow	exporting-country perspective, source approach

4.1 Implementation: Accounting for value-added in gross trade

Depending on the specific empirical question, the user needs to choose the appropriate `icio`'s options in order to select: *i*) the desired trade flow; *ii*) the best suited accounting methodology to single out "double counted" components (see above for a definition of "double counting"); *iii*) the appropriate output measure(s).

As to the first point, the following types of trade flows are considered: *i*) aggregate exports; *ii*) sectoral exports; *iii*) bilateral exports, *iv*) sectoral-bilateral exports, *v*) aggregate imports, *vi*) sectoral imports. It is also worth recalling that the option `group()` allows to consider value-added decompositions for country aggregates, so that the set of trade flows' combinations is actually broader (see Section 3.1.2 for examples). For each trade flow, we consider the accounting perspectives and approaches that appear to be more economically important (see Appendix E for an overview).

We structured the `icio`'s syntax according to the different trade flows as follows

1. **Value-added and GVC participation in total exports of a country:**

    a) Value-added and GVC participation in **total aggregate exports**:
    `icio, exporter(`*country_code*`)` [*methods_1a*] [*output_exports*] [*origin_destination*] [*standard_options*]

    b) Value-added and GVC participation in **total sectoral exports**:
    `icio, exporter(`*country_code*`[, `*sector_code*`])` [*methods_1b*] [*output_exports*] [*origin_destination*] [*standard_options*]

2. **Value-added and GVC participation in bilateral exports:**

    a) Value-added and GVC participation in **bilateral aggregate exports**:
    `icio, exporter(`*country_code*`) importer(`*country_code*`)` [*methods_2a*] [*output_exports*] [*origin_destination*] [*standard_options*]

    b) Value-added and GVC participation in **bilateral sectoral exports**:
    `icio, exporter(`*country_code*`[, `*sector_code*`]) importer(`*country_code*`)` [*methods_2b*] [*output_exports*] [*origin_destination*] [*standard_options*]

3. **Value-added in total imports of a country:**

    a) Value-added in **total aggregate imports**:
    `icio, importer(`*country_code*`)` [*methods_3a*] [*output_imports*] [*origin_destination*] [*standard_options*]

b) Value-added in **total sectoral imports**:

`icio, importer(`*country_code*`[, `*sector_code*`]) [`*methods_3b*`]`
`[`*output_imports*`] [`*origin_destination*`] [`*standard_options*`]`

4.1.1 Accounting methods' options

The options `perspective()` and `approach()` can be used to select the appropriate accounting methodology (i.e. [*methods_**] in the syntax reported in Section 4.1) for answering the empirical question of interest. For the different trade flows, Table 3 reports a summary of the available perspectives.

As already mentioned at the beginning of Section 4, whenever the perspective is set at a more aggregate level as compared to the considered trade flow, two alternative approaches are available. By using the `icio` option `approach(source)` the item is classified as "value-added" the first time it crosses the national border, whereas the option `approach(sink)` allows to consider it as "value-added" the last time it crosses the border.

Table 3: A summary of the available perspectives and approaches for each trade flow: syntax

	Perspective in line with the trade flow	**Perspective consistent with more aggregate flows (i.e. additive)**
1. Total exports		
1a. Aggregate	`persp(exporter)`	`persp(world) approach(source)` `persp(world) approach(sink)`
1b. Sectoral	`persp(sectexp)`	`persp(exporter) approach(source)` `persp(exporter) approach(sink)`
2. Bilateral exports		
2a. Aggregate	`persp(bilateral)`	`persp(exporter) approach(source)` `persp(exporter) approach(sink)`
2b. Sectoral	`persp(sectbil)`	`persp(exporter) approach(source)` `persp(exporter) approach(sink)`
3. Total imports		
3a. Aggregate	`persp(importer)`	n.a.
3b. Sectoral	`persp(sectimp)`	n.a.

4.1.2 Output options

For the selected trade flow, `icio` allows to compute the main indicators of gross trade and value-added through the `output()` option.

For export flows (i.e. [*output_exports*] in Section 4.1) the *default* output option is `output(detailed)`. It allows to get a complete value-added decomposition of the trade flows according to the conceptual scheme of Figure C.2 in Appendix C. Gross trade - `gtrade` - is split in the part that is originally produced by the exporting country (domestic content - `dc`) and the part that is produced abroad (foreign content - `fc`); in turn, each of these components is broken up in a part of value-added item (domestic value-added - `dva` - and foreign value-added - `fva`) and in a part of double counting.[11] The methodology used to single out the value-added and double-counted components changes according to the selected perspective/approach options, while the `gtrade`, `dc` and `fc` measures are, by construction, the same regardless of the accounting methodology.

The detailed output also includes additional indicators of trade in value-added that have been singled out in the literature (e.g. **VAX** by Johnson and Noguera, 2012; Reflection by Koopman et al. 2014; **DAVAX** and **VAXIM** by Borin and Mancini, 2019, see Appendix C for an overview) and also measures of GVC participation[12] as developed in Borin and Mancini (2015, 2019). The additional indicators that are included in the detailed output vary consistently with the selected perspective/approach. The user can also ask for a specific trade indicator by specifying one of the following arguments of the `output()` option: `gtrade`, `dc`, `dva`, `fc` and `fva`.[13]

As an additional feature, it is also possible to single out the country/sector where the goods/services were originally produced by specifying the `origin(`*country_code*`[,` *sector_code*`])` option, as well as the market/sector where they are absorbed in the final demand, by specifying the `destination(`*country_code*`[,` *sector_code*`])` option (i.e. [*origin_destination*] in Section 4.1). Results for all countries or all sectors can be computed and displayed simultaneously, using `all` as argument for *country_code* or *sector_code*. Notice that *country_code* and *sector_code* cannot be both `all`. If the aim is to compute the value-added produced by a specific country/sector of origin, the option `output(va)` has to be specified.[14] The gross content term (i.e. value-added + double counted items) for a specific country (and sector)

[11] Double-counted terms are not singled out as output options in `icio`, but can be easily computed by subtracting the value-added component, either domestic or foreign, from the correspondent domestic or foreign content.

[12] See Section 5 for more details on these indicators and how to compute them.

[13] In addition to value-added and gross trade measures, for any export flow when `perspective(exporter)` and `approach(source)` are specified - these options are actually the *default* - it is also possible to compute the value of trade that is related to GVCs and its backward and forward sub-components, specifying `gvc`, `gvcb` or `gvcf` in `output()`, respectively. These measures are discussed in detail in Section 5.

[14] Note that, when the country in `origin()` corresponds to that specified in `exporter()`, icio provides the same results when selecting `output(dva)` or `output(va)`.

of origin can be computed by specifying `output(gtrade)`.

As far as import flows are concerned (i.e. [*output_imports*] in Section 4.1), the distinction between domestic and foreign items is less relevant, as the former would refer only to the items produced, exported and then re-imported by the importing country itself. For this reason, the *default* in this case is to compute the gross trade value (i.e. `gtrade`). The imported value-added (gross-content) can be traced back to the country of origin specifying the option `origin(`*country_code*`[, `*sector_code*`])` together with `output(va)` (`output(gtrade)`). Of special note is that it is possible to pin down also a specific market/sector of final demand by specifying the `destination(`*country_code*`[, `*sector_code*`])` option.

As for the standard options, (i.e. [*standard_options*] in Section 4.1), the `save()` and `group()` options are available for both export and import flows (see Section 3.1 for a description of these options).

4.1.3 Examples: Value-added in trade flows

In this section we provide some examples of the insights that `icio`, dealing with the break down of value-added in trade flows, can bring for the economic analysis of ICIO tables.

As running example, we select a specific trade flow, the Chinese total aggregate exports. After having loaded the year 2014 of the last release of the WIOD tables using

```
icio_load, iciot(wiodn) year(2014)
```

the user can easily obtain a detailed breakdown of the selected trade flow, both in millions of US dollars and as a share, using

```
. icio, exporter(chn)

Decomposition of gross exports:
Perspective: exporter
Exporter: CHN
Importer: total CHN exports
```

	Millions of $	% of export
Gross exports (GEXP)	2425406.15	*100.00*
Domestic content (DC)	2039474.07	*84.09*
Domestic Value-Added (DVA)	2016712.86	*83.15*
VAX -> DVA absorbed abroad	1957739.47	*80.72*
Reflection	58973.39	*2.43*
Domestic double counting	22761.21	*0.94*
Foreign content (FC)	385932.09	*15.91*
Foreign Value-Added (FVA)	380473.47	*15.69*

Foreign double counting	5458.62	*0.23*
GVC-related trade (GVC)	781287.59	*32.21*
GVC-backward (GVCB)	408693.30	*16.85*
GVC-forward (GVCF)	372594.29	*15.36*

The detailed decomposition can be also computed for a particular sector of export, e.g., "Manufacture of computer, electronic and optical products" (sector code 17 for the loaded ICIO table) by using[15]

```
. icio, exporter(chn,17)

Decomposition of gross exports:
Perspective: exporter
Exporter: CHN
Importer: total CHN exports
Sector of export: 17
```

	Millions of $	% of export
Gross exports (GEXP)	560552.89	*100.00*
Domestic content (DC)	417041.87	*74.40*
Domestic Value-Added (DVA)	404306.15	*72.13*
VAX -> DVA absorbed abroad	386215.71	*68.90*
DAVAX	315342.79	*56.26*
Reflection	18090.44	*3.23*
Domestic double counting	12735.72	*2.27*
Foreign content (FC)	143511.01	*25.60*
Foreign Value-Added (FVA)	140161.87	*25.00*
Foreign double counting	3349.14	*0.60*
GVC-related trade (GVC)	245210.09	*43.74*
GVC-backward (GVCB)	156246.74	*27.87*
GVC-forward (GVCF)	88963.36	*15.87*

```
DAVAX: Value-Added directly absorbed by the importer
```

We now show how the results can change by using a different perspective on the same trade flow. We move from the *default* - exporting country perspective - to a sectoral-exporter perspective by adding the option `perspective(sectexp)`

```
. icio, exporter(chn,17) perspective(sectexp)

Decomposition of gross exports:
Perspective: sectexp
Exporter: CHN
Importer: total CHN exports
Sector of export: 17
```

	Millions of $	% of export
Gross exports (GEXP)	560552.89	*100.00*

[15] Run `icio, info` after `icio_load` to get the complete country and sector lists.

Domestic content (DC)	417041.87	*74.40*
Domestic Value-Added (DVA)	409968.49	*73.14*
VAX -> DVA absorbed abroad	391624.68	*69.86*
Reflection	18343.80	*3.27*
Domestic double counting	7073.39	*1.26*
Foreign content (FC)	143511.01	*25.60*
Foreign Value-Added (FVA)	141076.94	*25.17*
Foreign double counting	2434.07	*0.43*

While the output confirms that domestic and foreign contents are not affected by changing perspective, the value-added terms are higher and, as a consequence, double counting items are smaller. This is not surprising since the sectoral-exporter perspective features a more restrictive definition of double counting (see Appendix E). Which perspective should be used? It depends on the specific empirical question. If the goal is to measure to what extent the GDP of a country could be exposed to a certain shock on the exports of a sector, a sectoral-exporter perspective might be appropriate. Indeed, in this case, the relevant border to trace value-added is the exporting country/sector's one. Instead, the *default* perspective (the "exporting country" one) is the most appropriate if the goal is to compute GVC-related trade indices - since to this end the relevant border is always the exporting country's one - and is suited to obtain measures of value-added trade traced in disaggregated trade flows that are consistent with the aggregate figures. Notice that this additivity property is a feature of the "exporting country" perspective only.[16] It can be easily verified by showing that value-added components and GVC-related trade in the aggregate Chinese exports - as computed before using the synatx `icio, exporter(chn)` - equal the sum of the very same measures obtained for each sector. A possible implementation of this check is the following

```
. qui icio, exporter(chn,all) output(gtrade)

. mata : st_matrix("sum_gtrade", colsum(st_matrix("r(gtrade)")))

. di  "aggregate Gross exports " %14.2f sum_gtrade[1,1]
aggregate Gross exports     2425406.15

.
. qui icio, exporter(chn,all) output(dva)

. mata : st_matrix("sum_dva", colsum(st_matrix("r(dva)")))

. di "aggregate Domestic Value-Added" %14.2f sum_dva[1,1]
aggregate Domestic Value-Added    2016712.86

.
. qui icio, exporter(chn,all) output(fva)

. mata : st_matrix("sum_fva", colsum(st_matrix("r(fva)")))
```

[16]Instead, all the other perspectives are non-additive, i.e. measures at a more aggregate level cannot be obtained summing disaggregate results.

```
. di "aggregate Foreign Value-Added" %14.2f sum_fva[1,1]
aggregate Foreign Value-Added     380473.47

.
. qui icio, exporter(chn,all) output(gvc)

. mata : st_matrix("sum_gvc", colsum(st_matrix("r(gvc)")))

. di %11.0g "aggregate GVC-related trade " %14.2f sum_gvc[1,1]
aggregate GVC-related trade      781287.59
```

We now select a different trade flow, moving to bilateral sectoral exports. In particular, we consider the Chinese exports of computer, electronic and optical products to the United States. The default assessment of the extent of GVC participation, as well as a breakdown of the flow in terms of value-added components consistent both with the aggregate Chinese exports and with total Chinese exports to the United States, is obtained using the *default* "exporting country" perspective as:

```
. icio, exporter(chn,17) importer(usa)

Decomposition of gross exports:
Perspective: exporter
Exporter: CHN
Importer: USA
Sector of export: 17
```

	Millions of $	% of export
Gross exports (GEXP)	107292.76	*100.00*
Domestic content (DC)	79824.00	*74.40*
Domestic Value-Added (DVA)	77386.31	*72.13*
VAX -> DVA absorbed abroad	76957.76	*71.73*
DAVAX	72570.84	*67.64*
Reflection	428.55	*0.40*
Domestic double counting	2437.68	*2.27*
Foreign content (FC)	27468.76	*25.60*
Foreign Value-Added (FVA)	26827.72	*25.00*
Foreign double counting	641.04	*0.60*
GVC-related trade (GVC)	34721.92	*32.36*
GVC-backward (GVCB)	29906.44	*27.87*
GVC-forward (GVCF)	4815.48	*4.49*

```
DAVAX: Value-Added directly absorbed by the importer
```

Again, we can select a perspective in line with the level of aggregation of the chosen trade flow, i.e. a sectoral-bilateral perspective - `perspective(sectbil)`, for instance to measure to what extent the Chinese GDP could be exposed to a tariff imposed by the United States on the imports of computer, electronic and optical products:

```
. icio, exporter(chn,17) importer(usa) perspective(sectbil)
```

```
Decomposition of gross exports:
Perspective: sectbil
Exporter: CHN
Importer: USA
Sector of export: 17
```

	Millions of $	% of export
Gross exports (GEXP)	107292.76	*100.00*
Domestic content (DC)	79824.00	*74.40*
Domestic Value-Added (DVA)	79815.64	*74.39*
VAX -> DVA absorbed abroad	79373.64	*73.98*
Reflection	442.00	*0.41*
Domestic double counting	8.36	*0.01*
Foreign content (FC)	27468.76	*25.60*
Foreign Value-Added (FVA)	27465.88	*25.60*
Foreign double counting	2.88	*0.00*

According to WIOD 2014 data, Chinese value-added potentially exposed to this tariff turns out to be around $79.8 billion, as shown by the value reported for the `Domestic Value-Added (DVA)`. This is higher than the $77.4 billion of Chinese value-added traced in the same export flow using an "exporting country" perspective (see the previous `icio` output above). Thus, if we had used the latter perspective, we would have understated the Chinese exposure. Again, each empirical question calls for the best suited perspective: the *default* "exporting country" is more useful if the aim is to assess GVC participation or to retrieve measures of value-added trade consistent with the figures at a more aggregate level; the perspective in line with the selected trade flow is more suited to encompass the entire value-added that might be affected by a shock hitting that particular flow.

The same reasoning applies when the objective is to choose the best suited perspective for bilateral aggregate exports. Here the choice will be, again, between the *default* "exporting country" perspective and the bilateral one. For example, Figure 4.9 of the World Bank World Development Report (WDR) 2020, reported here as Figure 1, aims at quantifying the potential exposure of other countries to a US-China trade war. In fact, US and Chinese exports embed a non-negligible amount of other countries foreign value-added that would be indirectly exposed to new tariffs. For instance, around 2% of the value-added in the Chinese exports to the United States consists of Japan's GDP and almost 1.8% of the Republic of Korea's GDP. In turn, around 2.5% of the value-added in the US exports to China is Canadian GDP. These numbers can be easily obtained using `icio` by selecting a bilateral perspective and retrieving the value-added by country of origin in a particular bilateral flow. The entire value-added, domestic and foreign, that crosses the specific bilateral border where the new tariffs could be in place, i.e. the GDP potentially affected by trade barriers, can be computed using the following syntax

```
. *Replicate data of WDR2020 Figure 4.9
.  icio_load, iciot(eora) year(2015)
Loading table eora 2015...  loaded

.  icio, exp(chn) imp(usa) persp(bilat) output(va) origin(all) save(wdr_4_9a.xls)

Decomposition of gross exports:
Perspective: bilateral
Origin: ALL
Exporter: CHN
Importer: USA
Output: Value-Added
```

	Millions of $	% of export
AUS	2115.55	*0.57*
BEL	610.65	*0.17*
BRA	1046.77	*0.28*
CAN	955.66	*0.26*
CHE	977.48	*0.27*
DEU	4058.78	*1.10*
FRA	1919.28	*0.52*
GBR	1604.30	*0.44*
HKG	1489.18	*0.40*
IDN	1692.15	*0.46*
IND	1123.87	*0.31*
ITA	1564.26	*0.42*
JPN	7535.08	*2.05*
KOR	6554.82	*1.78*
MYS	1604.49	*0.44*
NLD	748.18	*0.20*
RUS	2208.83	*0.60*
SGP	1005.21	*0.27*
THA	964.69	*0.26*
USA	5126.99	*1.39*

```
Output saved as: wdr_4_9a.xls into the current working directory

.  icio, exp(usa) imp(chn) persp(bilat) output(va) origin(all) save(wdr_4_9b.xls)

Decomposition of gross exports:
Perspective: bilateral
Origin: ALL
Exporter: USA
Importer: CHN
Output: Value-Added
```

	Millions of $	% of export
AUS	235.58	*0.18*
BRA	361.65	*0.28*
CAN	3326.80	*2.56*
CHE	295.33	*0.23*
CHN	2322.90	*1.79*
DEU	1255.74	*0.97*
FRA	559.10	*0.43*
GBR	649.05	*0.50*

IND	294.56	*0.23*
ITA	438.06	*0.34*
JPN	1293.39	*1.00*
KOR	541.96	*0.42*
MEX	1288.42	*0.99*
MYS	274.08	*0.21*
NGA	230.40	*0.18*
NLD	249.97	*0.19*
RUS	501.60	*0.39*
SAU	232.88	*0.18*
TTO	271.61	*0.21*
VEN	1547.39	*1.19*

```
Output saved as: wdr_4_9b.xls into the current working directory
```

As in Figure 1, we deliberately reported in the above Stata output only the 20 countries with the highest foreign value-added in the bilateral exports between the United States and China. Actually, by running the previous syntax, `icio` would report also the value-added of the other countries in the EORA MRIO database. Since the complete list is very long, the user may find it useful to exploit the `save()` option. As can be seen, by adding this option, the complete `icio` output has been saved into a file called `wdr_4_9b.xls` within the current working directory.

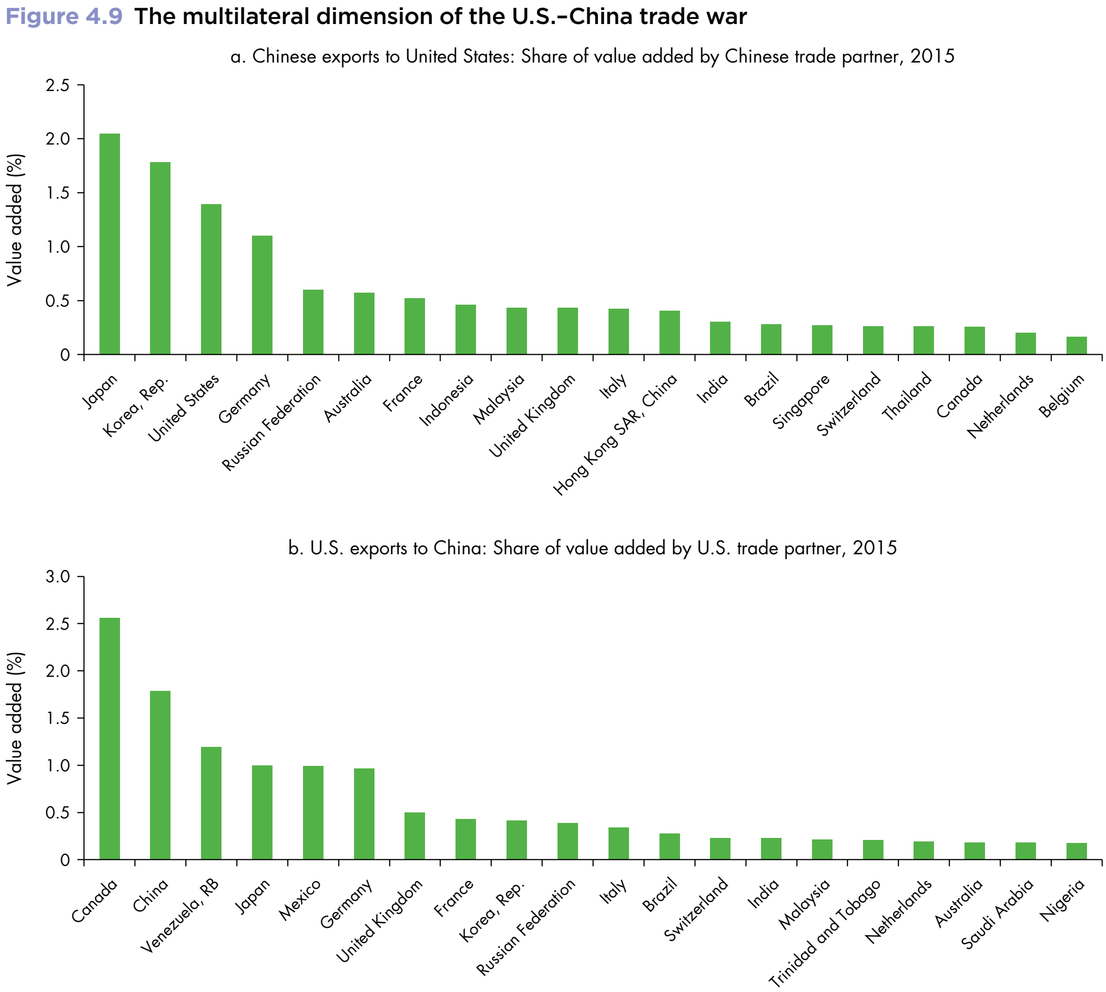
Lastly, we consider the analysis of value-added in the total imports of a country. To quantify the German GDP potentially exposed to US tariffs vis-à-vis all partners, according to WIOD 2014 data, we can use the following syntax

```
. icio_load
Loading table wiod 2014...  loaded

. icio, origin(deu) imp(usa) output(va)

Decomposition of gross imports:
Perspective: importer
Importer: USA
Origin: DEU
Exporter: total USA imports
Output: Value-Added
```

	Millions of $	% of import
Value-Added	133064.91	*5.53*

The Stata output indicates that around $133 billion of Germany's value-added are imported, directly and indirectly, by the United States (around 5.5% of the total US imports), and thus could be exposed to US trade barriers, according to WIOD 2014 data. German GDP exposure to these trade barriers can be computed taking the ratio with respect to the total German GDP - obtained with `icio, origin(deu)`. Thus, around 3.7% of German GDP could be affected by these

Figure 1: Replication of World Bank WDR 2020 Figure 4.9.



US trade barriers. In a GVC world, the GDP exposure to a trade barrier could be direct - through the country's exports to the economy that has imposed the trade restrictive measure - or indirect - through the exports of other countries. The former can be computed looking at the German GDP directly exported to the United States, running: `icio, origin(deu) exporter(deu) importer(usa) perspective(bilateral) output(va)`. Thus, 2.8% of German GDP could be directly affected by US tariffs, while 0.9% could be affected through other countries exports to the US of German products.

If the goal is to quantify the potential exposure of German value-added to a US tariff on a specific sector, e.g. motor vehicles from Germany, a sectoral-importer perspective is the right choice:

```
. icio, origin(deu,20) imp(usa,20) output(va)

Decomposition of gross imports:
Perspective: sectimp
Importer: USA
Origin: DEU
Exporter: total USA imports
Output: Value-Added
Sector of import: 20
Sector of origin: 20
```

	Millions of $	% of import
Value-Added	17216.14	6.59

```
. mat GDPsect=r(va)

. icio, origin(deu,20)

Value-Added by origin/destination:
Origin: DEU
Output: Value-Added
Sector of origin: 20
```

	Millions of $	% of total
Value-Added	147493.71	100.00

```
. mat GDPtot=r(vby)

. di "Germany exposure in sector 20: " GDPsect[1,1]/GDPtot[1,1]*100 "%"
Germany exposure in sector 20: 11.672456%
```

Again, the relative exposure can be easily obtained taking the ratio of the absolute exposure ($17.2 billion) with respect to the total German value-added in the motor vehicles industry ($147.5 billion). Thus, a US tariff hitting motor vehicles imports from Germany might affect around 11.7% of the value-added produced in the same sector in Germany.

Other examples of questions that could be answered using `icio` for the analysis of value-added trade are:

- *Which part of a country's total exports is home produced, i.e. is domestic GDP?*
  `icio, exporter(deu) output(dva)`

- *Which part of a country's total exports can be traced back to other countries GDP?*
  `icio, exporter(deu) output(fva)`

- *Where the foreign value-added in German exports is produced?*
  `icio, origin(all) exporter(deu) output(fva)`

- *Considering the bilateral exports from Italy to Germany, where the Italian GDP (domestic VA) re-exported by Germany is absorbed?*
  `icio, exporter(ita) importer(deu) destination(all) output(dva)`

- *How can be obtained the complete breakdown by origin and destination of the value-added (both domestic and foreign) for Chinese exports to the US?*
  `icio, origin(all) exporter(chn) importer(usa)`
  `destination(all) output(va) save(CHN_to_USA.xls)`

- *How can the (corrected) Koopman et al. (2014) decomposition be retrieved using icio?*
  `icio, exporter(deu) perspective(world) approach(sink)`

- *Which is the Chinese GDP that at any point in time, passes through a certain bilateral trade flow, say Chinese exports to the United States? In other terms, what is the Chinese GDP potentially exposed to US tariffs on imports from China?*
  `icio, exp(chn) imp(usa) persp(bilat) output(dva)`

- *Which is the German GDP potentially exposed to US trade barriers on all imports?*
  `icio, origin(deu) imp(usa) persp(importer) output(va)`

- *Which is the German GDP that could be affected by US tariffs on imports in sector 20?*
  `icio, origin(deu) imp(usa,20) persp(sectimp) output(va)`

- *Which is the exposure of US GDP to a Chinese tariff on US imports in sector 17?*
  `icio, exp(usa,17) imp(chn) persp(sectbil) output(dva)`

- *To what extent are Italian sectors exposed to a shock on German's exports in sector 20?*
  `icio, origin(ita,all) exp(deu,20) persp(sectexp) output(va)`

5 Measuring GVC-related exports

Following the original idea by Hummels et al. (2001), many contributions in the literature have shared the view that the trade flow related to GVC activity should consist in goods and services crossing more than one border along the production process. Borin and Mancini (2015) made this definition operational by proposing a way to isolate traditional trade from gross flows (i.e. the portion of trade crossing just one border) and considering the remaining part as a proxy of the GVC related trade. This GVC indicator presents three desirable features : *i*) it is bounded between 0 and 1, since it traces within a particular trade flow the share of it related to GVC activity, i.e., the numerator is a sub-component of the denominator; *ii*) it is additive at any level of aggregation/disaggregation of trade flows; thus, data can be summed at any level (total country exports/world exports/world sector exports/country groups) in order to obtain the proper GVC participation measures at the desired level of aggregation; *iii*) it can be broken down into two additive terms, i.e. a 'backward' component corresponding to import content of exports and a "forward" component, which measures the part of domestic production that is supplied to the importing country to be processed and re-exported.

In Appendix F we provide its conceptual framework while in Section 5.1 we show how to compute GVC measures in `icio` and present some examples.

5.1 Implementation: GVC in exports

To compute GVC measures with `icio`, the user needs to select: *i*) the desired trade flow and *ii*) the appropriate GVC measure to be computed (overall, backward or forward participation). The option `perspective(exporter)` is in this case imposed, since only this perspective allows to distinguish between the value of trade crossing just one border and the value of trade further re-exported, i.e. GVC trade.

5.1.1 Syntax

The `icio` syntax for the different export flows is the following:

1. **GVC participation in total exports of a country:**

   a) GVC participation in **total aggregate exports**:
   `icio, exporter(`*country_code*`)` [*output_gvc*] [*origin_destination*] [*standard_options*]

   b) GVC participation in **total sectoral exports**:
   `icio, exporter(`*country_code*`[,` *sector_code*`])` [*output_gvc*] [*origin_destination*] [*standard_options*]

2. **GVC participation in bilateral exports:**

   a) GVC participation in **bilateral aggregate exports**:
   `icio, exporter(`*country_code*`) importer(`*country_code*`)` [*output_gvc*] [*origin_destination*] [*standard_options*]

   b) GVC participation in **bilateral sectoral exports**:
   `icio, exporter(`*country_code*`[,` *sector_code*`]) importer(`*country_code*`)` [*output_gvc*] [*origin_destination*] [*standard_options*]

The `output()` option, i.e. [*output_gvc*] in the reported syntax, allows to get different measures of GVC-related trade by specifying `gvc`, `gvcb` and `gvcf` as arguments for total, backward and forward GVC indicators, respectively. As can be noted from the `icio` results reported in Section 4.1.3, GVC-related indicators are routinely reported as part of the detailed output, when an export flow-at any level of aggregation-is specified.

Also for GVC indicators it is possible to single out the country/sector where the goods/services were originally produced by specifying the `origin(`*country_code*`[,`*sector_code*`])` option, as well as the market/sector where the goods/services are absorbed in final demand by specifying the `destination(`*country_code*`[,`*sector_code*`])` option.

5.1.2 Examples: GVC-related exports

Figure 1.13 of the World Bank WDR 2020, here reported as Figure 2, is based on EORA MRIO 1990 and 2015 data and shows the GVC-related trade in agriculture (sectors 1 and 2 in EORA) and agri-food sectors (sector 4 in EORA). For instance, in the case of Tanzania, one of the Sub-Saharan African countries that experienced a significant increase in GVC participation in the agri-food sector, the data used for plotting panel b. of Figure 2 can be obtained by using the following syntax

```
. *Replicate data of WDR2020 Figure 1.13 panel b
.  icio_load, iciot(eora) year(2015)
Loading table eora 2015...  loaded

.  icio, exp(tza,4) output(gvc)

Decomposition of gross exports:
Perspective: exporter
Exporter: TZA
Importer: total TZA exports
Output: GVC-related trade
Sector of export: 4
```

	Millions of $	% of export
GVC	93.22	*52.74*

```
.  icio_load, iciot(eora) year(1990)
Loading table eora 1990...  loaded

.  icio, exp(tza,4) output(gvc)

Decomposition of gross exports:
Perspective: exporter
Exporter: TZA
Importer: total TZA exports
Output: GVC-related trade
Sector of export: 4
```

	Millions of $	% of export
GVC	38.80	*33.53*

In Figure B.2.1.1 of the WDR 2020, Vietnam's integration in the electronics global value chain is discussed. Panel a, here reported as Figure 3, is based on the EORA MRIO database and shows the GVC-backward related trade, i.e. backward integration, in the electrical and machinery sector. Data for 2015 can be obtained running:

```
. *Replicate data of WDR2020 Figure B.2.1.1 panel a
.  icio_load, iciot(eora) year(2015)
Loading table eora 2015...  loaded

.  icio, exp(vnm,9) output(gvcb)

Decomposition of gross exports:
Perspective: exporter
Exporter: VNM
Importer: total VNM exports
Output: GVC-backward related trade
Sector of export: 9
```

	Millions of $	% of export

GVC backward	859.70	*64.32*

Figure 2: Replication of World Bank WDR 2020 Figure 1.13.

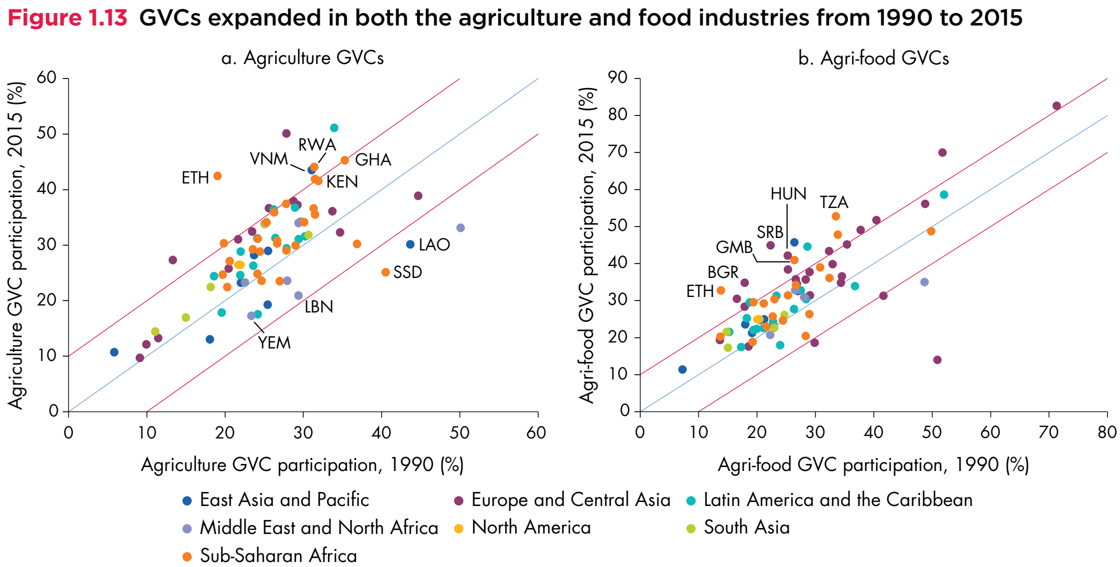
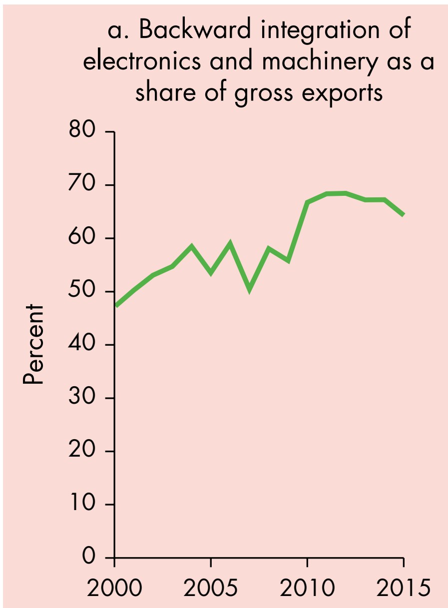


Figure 3: Replication of World Bank WDR 2020 Figure B2.1.1.



Throughout the WDR 2020, several figures on GVC-related trade at the world level are reported. These measures can be obtained with `icio` retrieving and then summing the GVC-related trade of each country in the loaded input-output table. Since this could be computationally intensive, we have also released a data set with GVC indicators and the most relevant measures of value-added in trade flows computed for any country/sector for each database available in `icio`. This database is available on the official WDR 2020 website in the data section.[17]

Other basic examples of questions on GVC participation and the related syntax are:

- *Which share of the German exports related to GVC is produced in Italy?*
  `icio, origin(ita) exporter(deu) output(gvc)`

- *Which share of the German exports is related to backward and forward GVC?*
  `icio, exporter(deu) output(gvcb)`
  `icio, exporter(deu) output(gvcf)`

6 Conclusions

In this paper we described the new Stata command `icio` for value-added trade and GVC analysis. It's most important features are the following:

- It exploits the most famous Inter-Country Input-Output (ICIO) tables - the World Input-Output Database (Timmer et al. 2015), the OECD TiVA database (OECD), and the Eora Global Supply Chain Database (Lenzen et al. 2013) - but also allows to load any user-provided ICIO table.

- It provides breakdowns of aggregate, bilateral and sectoral exports and imports according to the source and the destination of their value-added content, with a careful treatment of double counted items. These decompositions can be used to:

  - assess the exposure of countries/sectors to different kind of trade shocks, including tariffs.
  - get indicators for any level of disaggregation of trade flows that are consistent with more aggregate measures, i.e. disaggregated indicators can be summed up to get correct measures in more aggregate trade flows.

- It can break down export flows in terms of "traditional" vs GVC-trade, at any level of aggregation, also distinguishing between backward and forward participation in GVC.

[17]Go to https://www.worldbank.org/en/publication/wdr2020/brief/world-development-report-2020-data.

- It is flexible and open, as we plan to release updates to include new ICIO database, as soon as the data become available, as well as other measures to assess the participation and position of countries and sectors in GVCs and trade policy analysis.

It is worth noting that the measures computed with `icio`, as any other measure obtained from ICIO tables, suffer from some limitations (Antràs, 2019). In fact, ICIO tables are built under the strong proportionality assumptions, i.e. all output within each country-industry is built with the same input mix (de Gortari, 2019). However, input-output datasets will soon start exploiting customs data to allow for more heterogeneity in production and trade (United Nations, 2018). Once ICIO tables become more detailed, value-added trade measures obtained with the different perspectives featured in `icio` will diverge more and more, making it even more important to have available the best suited accounting framework to answer each specific empirical question.

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A Conceptual framework: ICIO models

A generic ICIO model with G countries and N sectors can be represented by the scheme in Figure 1, where $\mathbf{Z}_{ij}$ is the $N \times N$ matrix of intermediate inputs produced in country i (rows) and used in country j (columns); $\mathbf{Y}_{ij}$ is the $N \times 1$ vector of final goods and services completed in country i and absorbed in country j; $\mathbf{X}_i$ is the $N \times 1$ vector of gross output produced in country i; and $\mathbf{VA}_i$ is the $1 \times N$ vector of value-added generated in country i.

Figure A.1: Inter-Country Input-Output scheme

		Outputs				Final Demand				Total
		1	2	$\cdots$	G	1	2	$\cdots$	G	Output
Inputs	1	$\mathbf{Z}_{11}$	$\mathbf{Z}_{12}$	$\cdots$	$\mathbf{Z}_{1G}$	$\mathbf{Y}_{11}$	$\mathbf{Y}_{12}$	$\cdots$	$\mathbf{Y}_{1G}$	$\mathbf{X}_1$
	2	$\mathbf{Z}_{21}$		$\cdots$	$\mathbf{Z}_{2G}$	$\mathbf{Y}_{21}$		$\cdots$	$\mathbf{Y}_{2G}$	$\mathbf{X}_2$
	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
	G	$\mathbf{Z}_{G1}$	$\mathbf{Z}_{G2}$	$\cdots$	$\mathbf{Z}_{GG}$	$\mathbf{Y}_{G1}$	$\mathbf{Y}_{G2}$	$\cdots$	$\mathbf{Y}_{GG}$	$\mathbf{X}_G$
Value Added		$\mathbf{VA}_1$	$\mathbf{VA}_2$	$\cdots$	$\mathbf{VA}_G$					
Total Output		$(\mathbf{X}_1)'$	$(\mathbf{X}_2)'$	$\cdots$	$(\mathbf{X}_G)'$					

The specific column j, n of the ICIO table in Figure A.1 shows how the output of country j and sector n ($x_{j,n}$) is produced: i.e. sourcing intermediate inputs from the same and other country/sector pairs and adding its own value-added ($x_{j,n} = \sum_i^G \sum_m^N z_{ij,mn} + va_{j,n}$). In turn, the row j, n shows how output of country j and sector n is used: i.e. as intermediate inputs for different industries and countries and as final products to serve domestic and foreign demand ($x_{j,n} = \sum_i^G \sum_m^N z_{ji,nm} + \sum_i^G y_{ji,n}$). It is worth noting that IO models hinge upon key proportionality assumptions: the input composition in sectoral productions does not change by geographical destination of output and it is identical between intermediate and final goods.

B Conceptual framework: Supply and demand in ICIO models

Given a country s, each unit of its gross output can be either consumed as a final good or used as an intermediate good at home or abroad:

$$\mathbf{X}_s = \sum_r^G (\mathbf{A}_{sr}\mathbf{X}_r + \mathbf{Y}_{sr}), \tag{B.1}$$

where country r can either be s itself or any given importing country, $\mathbf{A}$ is the $GN \times GN$ matrix of intermediate inputs coefficients, obtained dividing $\mathbf{Z}$ by $\mathbf{X}$ (i.e. $\mathbf{A} = \mathbf{Z} \oslash (\mathbf{u} \otimes \mathbf{X}'))$.

Then the basic relationship between gross output and final demand is given by:

$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{Y} = \mathbf{B}\mathbf{Y}, \tag{B.2}$$

where $\mathbf{B}$ is the $GN \times GN$ "global" Leontief inverse that measures the total units of gross output in countries-sectors of origin necessary to produce a certain unit of final goods/services. Indeed, $\mathbf{B}$ accounts for all the gross output produced in all the rounds of production, as $\mathbf{B} = \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \ldots + \mathbf{A}^n = (\mathbf{I} - \mathbf{A})^{-1}$.

In each production stage some value-added is generated. The value-added share in each unit of gross output produced by country s ($\mathbf{V}_s$) is equal to one minus the sum of the direct intermediate input shares of all the domestic and foreign suppliers (i.e. $\mathbf{V}_s = \mathbf{u}_N(\mathbf{I} - \sum_r^G \mathbf{A}_{rs})$. Then the direct domestic value-added matrix for all countries can be defined as follows:

$$\mathbf{V} = \begin{bmatrix} \mathbf{V}_1 & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \mathbf{V}_2 & \cdots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & \mathbf{V}_G \end{bmatrix}. \tag{B.3}$$

Pre-multiplying the right-hand side of equation (B.2) by $\mathbf{V}$, it is possible to obtain a $G \times G$ GDP matrix reporting the GDP by country pairs of source (rows) and absorption (columns).

$$\mathbf{GDP} = \begin{bmatrix} \mathbf{V}_1 \sum_r^G \mathbf{B}_{1r}\mathbf{Y}_{r1} & \mathbf{V}_1 \sum_r^G \mathbf{B}_{1r}\mathbf{Y}_{r2} & \cdots & \mathbf{V}_1 \sum_r^G \mathbf{B}_{1r}\mathbf{Y}_{rG} \\ \mathbf{V}_2 \sum_r^G \mathbf{B}_{2r}\mathbf{Y}_{r2} & \mathbf{V}_2 \sum_r^G \mathbf{B}_{2r}\mathbf{Y}_{r2} & \cdots & \mathbf{V}_2 \sum_r^G \mathbf{B}_{2r}\mathbf{Y}_{rG} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{V}_G \sum_r^G \mathbf{B}_{Gr}\mathbf{Y}_{rG} & \mathbf{V}_G \sum_r^G \mathbf{B}_{Gr}\mathbf{Y}_{rG} & \cdots & \mathbf{V}_G \sum_r^G \mathbf{B}_{Gr}\mathbf{Y}_{rG} \end{bmatrix}. \tag{B.4}$$

More specifically, the GDP produced in country s can be computed as:

$$\mathbf{GDP}_s = \mathbf{V}_s \sum_k^G \sum_l^G \mathbf{B}_{sk} \mathbf{Y}_{kl} = \underbrace{\mathbf{V}_s \sum_k^G \mathbf{B}_{sk} \mathbf{Y}_{ks}}_{\substack{\text{domestically} \\ \text{absorbed GDP}}} + \underbrace{\mathbf{V}_s \sum_k^G \sum_{l \neq s}^G \mathbf{B}_{sk} \mathbf{Y}_{kl}}_{\substack{\text{GDP absorbed} \\ \text{abroad } (\mathbf{VAX}_s)}} . \tag{B.5}$$

where we have singled out the part that is absorbed at home and the part that is finally consumed abroad in country l, as a final good assembled in country k, which correspond to the "value-added exports" as defined by Johnson and Noguera (2012).

It is also possible to decompose the final demand of country s by distinguishing between the part of value-added domestically produced and the one that originates abroad:

$$\mathbf{FD}_s = \sum_j^G \sum_k^G \mathbf{V}_j \mathbf{B}_{jk} \mathbf{Y}_{ks} = \underbrace{\mathbf{V}_s \sum_k^G \mathbf{B}_{sk} \mathbf{Y}_{ks}}_{\substack{\text{domestically} \\ \text{produced FD}}} + \underbrace{\sum_{t \neq s}^G \mathbf{V}_t \sum_k^G \mathbf{B}_{tk} \mathbf{Y}_{ks}}_{\substack{\text{FD produced} \\ \text{abroad}}} . \tag{B.6}$$

To get a decomposition of GDP by sectors of origin, it is sufficient to substitute the direct value-added $\mathbf{V}_s$ in equation (B.5) and (B.6) with its diagonalized form $\widehat{\mathbf{V}}_j$ (i.e. the $N \times N$ diagonal matrix with the direct value-added coefficients along the principal diagonal and zeros elsewhere). Similarly, the decomposition by sectors of final absorption is obtained by replacing the vector of final demand with its diagonalized form. For instance, for goods completed in country k and absorbed in country l, the $N \times N$ diagonal matrix of final demand is as follows:

$$\widehat{\mathbf{Y}}_{kl} \equiv \begin{bmatrix} y_{kl,1} & 0 & \cdots & 0 \\ 0 & y_{kl,2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & y_{kl,N} \cdot \end{bmatrix} .$$

Then the decomposition of value-added by combinations of county-sector of origin and country-sector of final destination can be obtained from the $GN \times GN$ matrix:

$$\mathbf{VA}(\mathbf{origin/destination}) = \widehat{\mathbf{V}}\mathbf{B}\widehat{\mathbf{Y}}. \tag{B.7}$$

C Conceptual framework: Value-added in total exports

The problem of isolating value-added in trade flows has been addressed at length in the literature.[18] To provide a useful starting point, we begin from the analysis of the aggregate exports of a country. Gross exports of country s can be broken down according to the country that initially produced each component. The part that originated in country s itself is referred to as the 'domestic content of exports' ($\mathbf{DC}_s$), whereas the remaining part is called the 'foreign content of exports' ($\mathbf{FC}_s$, Koopman et al. 2010):

$$\mathbf{u}_N \mathbf{E}_{s*} = \underbrace{\mathbf{V}_s \mathbf{B}_{ss} \mathbf{E}_{s*}}_{\substack{\text{domestic} \\ \text{content } (\mathbf{DC}_s)}} + \underbrace{\sum_{t \neq s}^{G} \mathbf{V}_t \mathbf{B}_{ts} \mathbf{E}_{s*}}_{\substack{\text{foreign} \\ \text{content } (\mathbf{FC}_s)}} . \tag{C.1}$$

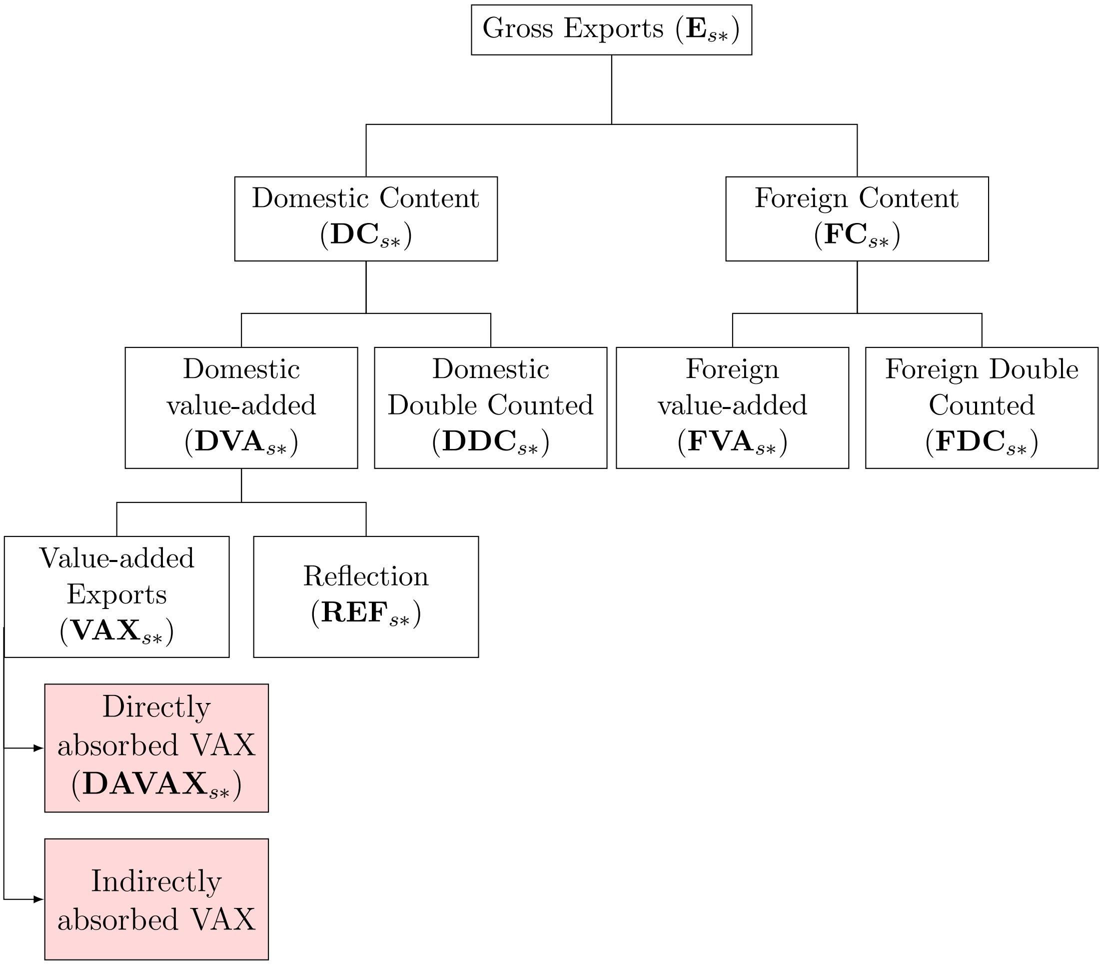
Although the above formula resembles closely those used to decompose the GDP of a country in equation (B.5) or the final demand in equation (B.6), the two components in (C.1) cannot be considered as "net" measures of production, i.e. value-added. In other terms, while they were indeed generated at home and abroad, respectively, they are not a measure of the GDP produced by the different countries. The reason is that $\mathbf{VB}$ pre-multiplies the vector of gross exports $\mathbf{E}_{s*}$ which does not include only final products (i.e. $\mathbf{Y}_{s*}$), as in equations (B.5) and (B.6), but also intermediate goods that later can be can re-imported and re-exported by the same country many times. Indeed, Koopman et al. (2014) point out that the same value-added may cross country s's borders several times along the production process so that it would be counted many times in its gross exports ($\mathbf{E}_{s*}$). This phenomenon, called "double counting", can be easily figured out by considering the following example of a simple sequential production chain. Suppose that 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. The value-added generated in the very first stage of production in A is counted twice: one in its gross bilateral exports with B and one in its exports to C.

Koopman et al. (2014) isolate these double counted items in aggregate trade flows, by proposing an accounting framework which allows to single out the entire

[18]See for example Wang et al. (2013), Koopman et al. (2014), Borin and Mancini (2015), Los et al. (2016); Nagengast and Stehrer (2016).

domestic and foreign value-added embedded in the aggregate exports of country s, as well as the double counted items originally produced at home and abroad. Figure C.2 shows a scheme of the basic breakdown of aggregate exports decomposition of total exports.

Figure C.2: A scheme of value-added decomposition of total exports based on Koopman et al. (2014), extended by Borin and Mancini (2019)



Notice that $\mathbf{VAX}_s$ is a subcomponent of the domestic value-added embedded in gross exports, the remaining part being the value-added that is finally absorbed by the exporting country itself (labeled "reflection" by Koopman et al., 2014). Borin and Mancini (2015) show how the $\mathbf{VAX}_s$ can be further split in the part that is directly absorbed by the countries which are importing from s, called **DAVAX** (i.e. Directly Absorbed Value-Added in exports), and a part that is re-exported to third countries. This distinction is particularly useful for identifying the portion of exports that is involved in GVCs (see Section 5).

Albeit the original Koopman et al. (2014) decomposition presents some drawbacks and limitations,[19] the general scheme they proposed remain a useful conceptual framework for the value-added decomposition of trade flows at any level of disaggregation. Indeed, in most of the cases, the *default* output of `icio` replicates the basic part of the scheme depicted in Figure C.2.

Different methodologies have been developed in the literature aiming to pin down the value-added embedded in gross export flows (see, among others, Wang et al., 2013; Koopman et al. 2014; Borin and Mancini, 2015, 2019; Los et al., 2016; Johnson, 2018; Miroudot and Ye, 2018).[20] Here we present one of the possible methodologies for measuring value-added in aggregate exports - i.e. the one proposed by Borin and Mancini (2019) that, in the accounting of domestic value-added, is algebraically equivalent to Los and Timmer (2016).

Double counting in the total gross exports of a given country s occurs whenever items that are first exported by s are then re-imported and used to produce goods and services to be exported again. Conceptually, one way to distinguish between "value-added" and "double counting" is to split the production chain in phases, each one delimited by an export flow of country s: what is generated within that particular production phase is accounted for as "value-added" in exports, what comes from further upstream production stages is "double counted". This can be implemented in a general ICIO framework by modifying the matrix $\mathbf{B}$ in such a way that we can slice down the production process along the outward boundaries of the exporting country s. To this end, consider the representation of the global Leontief inverse as a sum of infinite series of the gross output generated in all upstream stages of the production process:

$$\mathbf{B} = \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \ldots + \mathbf{A}^n \quad n \to \infty. \tag{C.2}$$

We can split the production process along country s's borders by carving out its intermediate export linkages at any stage of the above series. Algebraically, it can be implemented by setting to zero the coefficients of matrix $\mathbf{A}$ which identify the

[19]See Nagengast and Stehrer (2016), Miroudot and Ye (2017) and Borin and Mancini (2019) for a detailed discussion on this point.

[20]These contributions differ in the types of trade flows they consider, in the targeted measures, in the solutions they propose for the value-added decomposition of disaggregated trade flows (i.e. at bilateral and/or sectoral level) and in their approaches to the foreign value-added accounting. Nevertheless, they reach the same results when considering the domestic value-added embedded in the total exports of a country, while exploiting different computation techniques.

direct requirement of intermediate inputs from country s (i.e. $\mathbf{A}_{sj} = 0 \ \forall \ j \neq s$):

$$\mathbf{A}^{\not{s}} = \begin{bmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} & \cdots & \mathbf{A}_{1s} & \cdots & \mathbf{A}_{1G} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & \mathbf{A}_{ss} & \cdots & \mathbf{0} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ \mathbf{A}_{G1} & \mathbf{A}_{G2} & \cdots & \mathbf{A}_{Gs} & \cdots & \mathbf{A}_{GG} \end{bmatrix}. \tag{C.3}$$

Then, the corresponding inverse Leontief matrix is:

$$\mathbf{B}^{\not{s}} = (\mathbf{I} - \mathbf{A}^{\not{s}})^{-1}. \tag{C.4}$$

Given that $\mathbf{B}_{is} = \mathbf{B}^{\not{s}}_{is} + \mathbf{B}^{\not{s}}_{is} \sum_{j \neq s} \mathbf{A}_{sj}\mathbf{B}_{js}$, equation (C.1) can be re-written so that we can single out the "value-added" and "double counted" terms within each component:

$$\mathbf{u}_N\mathbf{E}_{s*} = \overbrace{\underbrace{\mathbf{V}_s\mathbf{B}^{\not{s}}_{ss}\mathbf{E}_{s*}}_{\substack{\text{domestic value}\\ \text{added}\\ (\mathbf{DVA}_{s*})}} + \underbrace{\mathbf{V}_s\mathbf{B}^{\not{s}}_{ss}\sum_{j\neq s}\mathbf{A}_{sj}\mathbf{B}_{js}\mathbf{E}_{s*}}_{\substack{\text{domestic double}\\ \text{counted}\\ (\mathbf{DDC}_{s*})}}}^{\substack{\text{domestic}\\ \text{content } (\mathbf{DC}_{s*})}} + \overbrace{\underbrace{\sum_{t\neq s}^{G}\mathbf{V}_t\mathbf{B}^{\not{s}}_{ts}\mathbf{E}_{s*}}_{\substack{\text{foreign value}\\ \text{added}\\ (\mathbf{FVA}_{s*})}} + \underbrace{\sum_{t\neq s}^{G}\mathbf{V}_t\mathbf{B}^{\not{s}}_{ts}\sum_{j\neq s}\mathbf{A}_{sj}\mathbf{B}_{js}\mathbf{E}_{s*}}_{\substack{\text{foreign double}\\ \text{counted}\\ (\mathbf{FDC}_{s*})}}}^{\substack{\text{foreign}\\ \text{content } (\mathbf{FC}_{s*})}}. \tag{C.5}$$

Equation (C.5) reproduces the breakdown of bilateral exports into the main items identified in Koopman et al. (2014) (see Figure C.2). The double counted items are measured by isolating the portion of country s that have been already exported by s in a previous stage of the production process. As far as the domestic components are concerned, it is worth noting that $\mathbf{B}^{\not{s}}_{ss}$ corresponds to the so-called local Leontief matrix $(\mathbf{I} - \mathbf{A}_{ss})^{-1}$. This means that the domestic value-added in exports is obtained by isolating all the domestic stages of production needed to produce the exported goods, while ignoring the domestic content of imported inputs.[21] The foreign value-added in (C.5) follows the same rationale, i.e. considering as value-added only the items crossing country s border once.[22]

[21]Notably, this measure of domestic value-added in exports represents the complement to the "import content of exports" proposed by Hummels et al. (2001), but it is also numerically equivalent to the domestic value-added found in other contributions that have analyzed aggregate export flows (e.g., Koopman et al., 2014; Los et al., 2016; Johnson, 2018; Miroudot and Ye, 2018).

[22]Instead, other contributions (see Koopman et al., 2014; Wang et al., 2013; Nagengast and Stehrer, 2016; Miroudot and Ye, 2018) in the literature adopt a different rationale - world perspective - for foreign value-added accounting, making this measure not commensurate to the domestic

In addition to the breakdown of the value-added by country of origin, it is also possible to consider the linkages with the market of final absorption. To this aim, total exports $\mathbf{E}_{s*}$ can be split into final goods ($\sum_{r\neq s}^{G}\mathbf{Y}_{sr}$) and intermediate inputs required by the production of gross output of the importing countries ($\sum_{r\neq s}^{G}\mathbf{A}_{sr}\mathbf{X}_{r}$):

$$\mathbf{E}_{s*} = \sum_{r\neq s}^{G}\mathbf{Y}_{sr} + \sum_{r\neq s}^{G}\mathbf{A}_{sr}\mathbf{X}_{r}. \tag{C.6}$$

Then, intermediate inputs imported by the direct partner ($\mathbf{A}_{sr}\mathbf{X}_{r}$) can be followed through the country of final completion and the market of ultimate demand. According to one of the basic IO accounting relation (i.e. $\mathbf{X} = \mathbf{BY}$), all the remaining (and potentially infinite) stages of production are accounted for by the Leontief inverse matrix $\mathbf{B}$. Finally, the domestic value-added (**DVA**) and the foreign value-added (**FVA**) in the total exports of s can be re-expressed as:

$$\mathbf{DVA}_{s*} = \mathbf{V}_{s}(\mathbf{I} - \mathbf{A}_{ss})^{-1}\left[\sum_{r\neq s}^{G}\mathbf{Y}_{sr} + \sum_{r\neq s}^{G}\mathbf{A}_{sr}\sum_{k}^{G}\sum_{l}^{G}\mathbf{B}_{rk}\mathbf{Y}_{kl}\right], \tag{C.7}$$

and

$$\mathbf{FVA}_{s*} = \sum_{t\neq s}^{G}\mathbf{V}_{t}\mathbf{B}_{ts}^{\not s}\left[\sum_{r\neq s}^{G}\mathbf{Y}_{sr} + \sum_{r\neq s}^{G}\mathbf{A}_{sr}\sum_{k}^{G}\sum_{l}^{G}\mathbf{B}_{rk}\mathbf{Y}_{kl}\right]. \tag{C.8}$$

It is worth recalling that the two subscripts on final demand matrix $\mathbf{Y}$ refer to the country of final completion and the market of final absorption.[23] With the `icio` command it is possible to single out the markets (and sectors) of final absorption using the option `destination()` (see Section 4.1). One can also obtain information on specific countries/sectors of origin of the value-added with the option `origin()`. The details on the sectors of origin/destination are obtained with the same algebraic formulation of matrices $\mathbf{V}$ and $\mathbf{Y}$ shown in equation (B.7).

In addition to identifying specific countries-sectors of origin/destination from equations (C.7) and (C.8), the domestic value-added can be also broken down in two main aggregate indicators (see Figure C.2) to distinguish between the **DVA** ultimately absorbed in the country of origin s (i.e. the "reflection" terms in Koom-

value-added at the country level. See Section 5.1 in Borin and Mancini (2019) for further details on this point.

[23]For instance $\mathbf{Y}_{kl}$ identifies the vector of goods finalized in k and sold in l.

pan et al., 2014, terminology, $\mathbf{REF}_{s*}$) or in a foreign market (i.e. the "value-added exports", or $\mathbf{VAX}_{s*}$, in Johnson and Noguera, 2012 nomenclature):

$$\mathbf{REF}_{s*} = \mathbf{V}_s(\mathbf{I} - \mathbf{A}_{ss})^{-1} \left[\sum_{r\neq s}^{G} \mathbf{Y}_{sr} + \sum_{r\neq s}^{G} \mathbf{A}_{sr} \sum_{k}^{G} \mathbf{B}_{rk}\mathbf{Y}_{ks} \right], \tag{C.9}$$

$$\mathbf{VAX}_{s*} = \mathbf{V}_s(\mathbf{I} - \mathbf{A}_{ss})^{-1} \left[\sum_{r\neq s}^{G} \mathbf{Y}_{sr} + \sum_{r\neq s}^{G} \mathbf{A}_{sr} \sum_{k}^{G} \sum_{l\neq s}^{G} \mathbf{B}_{rk}\mathbf{Y}_{kl} \right]. \tag{C.10}$$

D Conceptual framework: Value-added accounting in bilateral exports

Bilateral perspective If we are interested in measuring the total value-added that crosses a specific bilateral border, for instance to assess the exposure to tariffs imposed by the bilateral partner, we need an accounting method for value-added in bilateral exports that excludes from gross trade figures only the items that are double counted in the very same bilateral flow. In other words, the specific bilateral relation represents the perimeter for defining double-counted flows in gross exports. This matters, for example, when we are interested in singling out the value-added crossing a specific border which could be exposed to trade tensions between two countries on each side of the relationship.

By proceeding as for the derivation of value-added decomposition for aggregate trade flows (see Appendix C), we can modify the input coefficient matrix $\mathbf{A}$ to split the production process along the new perimeter and single out the "value-added" and "double counted" items. While in the exporting-country perspective we set to zero the coefficients that identify the direct requirement of intermediate inputs from country s to all the other countries, here we only set to zero the bilateral coefficient matrix $\mathbf{A}_{sr}$:

$$\mathbf{A}^{\not{sr}} = \begin{bmatrix} \mathbf{A}_{11} & \cdots & \mathbf{A}_{1s} & \cdots & \mathbf{A}_{1r} & \cdots & \mathbf{A}_{1G} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \mathbf{A}_{s1} & \cdots & \mathbf{A}_{ss} & \cdots & \mathbf{0} & \cdots & \mathbf{A}_{sG} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \mathbf{A}_{G1} & \cdots & \mathbf{A}_{Gs} & \cdots & \mathbf{A}_{Gr} & \cdots & \mathbf{A}_{GG} \end{bmatrix}. \tag{D.1}$$

Then, the corresponding inverse Leontief matrix can be defined as:

$$\mathbf{B}^{\cancel{sr}} = (\mathbf{I} - \mathbf{A}^{\cancel{sr}})^{-1}. \tag{D.2}$$

By analogy with the derivation of the decomposition of aggregate exports in (C.5), we can express the complete decomposition of bilateral exports based on a bilateral perspective:

$$\mathbf{u}_N\mathbf{E}_{sr} = \overbrace{\underbrace{\mathbf{V}_s\mathbf{B}_{ss}^{\cancel{sr}}\mathbf{E}_{sr}}_{\substack{\text{bilateral}\\ \text{perspective}\\ \mathbf{DVA}^{*}_{sr}}} + \underbrace{\mathbf{V}_s\mathbf{B}_{ss}^{\cancel{sr}}\mathbf{A}_{sr}\mathbf{B}_{rs}\mathbf{E}_{sr}}_{\substack{\text{bilateral}\\ \text{perspective}\\ \mathbf{DDC}^{*}_{sr}}}}^{\substack{\text{domestic}\\ \text{content } (\mathbf{DC}_{sr})}} + \overbrace{\underbrace{\sum_{t\neq s}^{G}\mathbf{V}_t\mathbf{B}_{ts}^{\cancel{sr}}\mathbf{E}_{sr}}_{\substack{\text{bilateral}\\ \text{perspective}\\ \mathbf{FVA}^{*}_{sr}}} + \underbrace{\sum_{t\neq s}^{G}\mathbf{V}_t\mathbf{B}_{ts}^{\cancel{sr}}\mathbf{A}_{sr}\mathbf{B}_{rs}\mathbf{E}_{sr}}_{\substack{\text{bilateral}\\ \text{perspective}\\ \mathbf{FDC}^{*}_{sr}}}}^{\substack{\text{foreign}\\ \text{content } (\mathbf{FC}_{sr})}}. \tag{D.3}$$

The measures of "domestic value-added" and "foreign value-added" in (D.3) correspond to those proposed by Johnson (2018) in a two-country context; the same measure of "domestic value-added" in bilateral exports is also obtained by Los et al. (2016) by using hypothetical extraction.

Similarly to the derivation of equations (C.6) to (C.8), equation (D.3) can be further developed to consider all the forward production linkages, as well as the countries of completion and the markets of final absorption.

Exporting-country perspective for bilateral trade flows

The methodology presented above provides a correct measure of the whole value-added that crosses a specific bilateral border, but these indicators cannot be summed across bilateral destinations to get the correct aggregate measure, i.e. they are not additive. Conversely, to obtain a consistent breakdown across bilateral flows, the "exporting-country perspective" has to be applied also to the decomposition of disaggregated trade flows.

However, in this case an approach to allocate value-added and double counted items across the different disaggregated trade flows is needed. In order to address this issue, we exploit two alternative approaches proposed by Nagengast and Stehrer (2016) and fully derived by Borin and Mancini (2015, 2017).

The "*source*-based" approach, in which a given item is accounted for as "value-added" the first time it leaves the country of origin and, in the case of multiple crossing, it is considered "double counted" in subsequent shipments; this definition is in line with the logic behind the accounting procedure presented in equations

(C.2)-(C.5) (C.2)-(C.5).[24] The "*sink*-based" approach, in which a given item is accounted for as "value-added" the last time it leaves the country of origin and, in the case of multiple crossing, it is considered "double counted" in prior shipments. Suppose, for instance, that along the production process a certain item is exported by country A first to country B and then to country C. With the "*source*-based" approach, the item is classified as "value-added" the

first time it crosses the national border (i.e. in the exports toward B), whereas the "*sink*-based" one allows to consider it as "value-added" the last time it crosses the border (i.e. in the exports toward C).

As already mentioned, the "*source*" approach is useful to separate traditional exports - crossing one border - from GVC-exports - crossing more than one border. Instead, the "*sink*" approach is more suited for the analysis of bilateral trade balances in terms of value-added.

The value-added decomposition of the exports form country s to country r according to a exporting country perspective/*source*-based approach can be obtained simply substituting the total exports of s in equation (C.5) with the considered bilateral trade flow (i.e. $\mathbf{E}_{sr}$):

$$\mathbf{u}_N\mathbf{E}_{sr} = \overbrace{\underbrace{\mathbf{V}_s\mathbf{B}^{\not s}_{ss}\mathbf{E}_{sr}}_{\substack{\text{domestic value}\\ \text{added}\\ (\mathbf{DVA}source_{sr})}} + \underbrace{\mathbf{V}_s\mathbf{B}^{\not s}_{ss}\sum_{j\neq s}\mathbf{A}_{sj}\mathbf{B}_{js}\mathbf{E}_{sr}}_{\substack{\text{domestic double}\\ \text{counted}\\ (\mathbf{DDC}source_{sr})}}}^{\substack{\text{domestic}\\ \text{content }(\mathbf{DC}_{sr})}} + \overbrace{\underbrace{\sum_{t\neq s}^{G}\mathbf{V}_t\mathbf{B}^{\not s}_{ts}\mathbf{E}_{sr}}_{\substack{\text{foreign value}\\ \text{added}\\ (\mathbf{FVA}source_{sr})}} + \underbrace{\sum_{t\neq s}^{G}\mathbf{V}_t\mathbf{B}^{\not s}_{ts}\sum_{j\neq s}\mathbf{A}_{sj}\mathbf{B}_{js}\mathbf{E}_{sr}}_{\substack{\text{foreign double}\\ \text{counted}\\ (\mathbf{FDC}source_{sr})}}}^{\substack{\text{foreign}\\ \text{content }(\mathbf{FC}_{sr})}}. \tag{D.4}$$

As to the value-added decomposition of the exports form country s to country r according to a exporting country perspective/*sink*-based approach, it is first necessary to isolate the portion of ultimate shipments within a certain bilateral trade flow. These "ultimate exports" ($\mathbf{E}_{sr}^{(\xrightarrow{\not s}\mathbf{Y}_*)}$) are made up of final goods ($\mathbf{Y}_{sr}$) and of intermediate goods that do not re-enter country s's exports, before reaching the ultimate destination ($\mathbf{A}_{sr}\mathbf{X}_r^{(\xrightarrow{\not s}\mathbf{Y}_*)}$). Since the latter are commensurate with final goods as concerns the exporting country s, the overall value-added can be computed

[24] There are also other ways to single out value-added in aggregate exports. See Koopman et al. (2014), Borin and Mancini (2015), Los et al. (2016), Miroudot and Ye (2017), Arto et al. (2019) for other accounting procedures yielding the same results, at least for the domestic value-added in the total exports of a country. As regard the foreign value-added in total exports, the differences between the various contributions are mainly due to the specific accounting perspective used for this component (the point is discussed in detail by Borin and Mancini, 2019).

by pre-multiplying the vector of "ultimate exports" by the **VB** matrix (i.e. in the same way as how the **VBY** matrix is used to measure the total value-added in final demand in Appendix B). In order to single out the value-added and double-counted components in the exports of intermediates of country s according to a exporting country perspective/*sink*-based approach, we can use the same algebraic device presented in equation (C.4) that allows to distinguish between the items re-exported by s and those that are not:[25]

$$\mathbf{A}_{sr}\mathbf{X}_r = \underbrace{\mathbf{A}_{sr}\left(\sum_{k\neq s}^{G}\sum_{l}^{G}\mathbf{B}_{rk}^{\not s}\mathbf{Y}_{kl} + \mathbf{B}_{rs}^{\not s}\mathbf{Y}_{ss}\right)}_{\mathbf{X}_r^{(\xrightarrow{\not s}\mathbf{Y}_*)}} + \mathbf{A}_{sr}\mathbf{B}_{rs}^{\not s}\mathbf{E}_{s*}. \tag{D.5}$$

Then, the value-added breakdown of bilateral exports in a "exporting country perspective"/"*sink*-based" framework can be expressed as follows:

$$\begin{aligned}\mathbf{u}_N\mathbf{E}_{sr} = {} & \overbrace{\underbrace{\mathbf{V}_s\mathbf{B}_{ss}\left[\mathbf{Y}_{sr} + \mathbf{A}_{sr}\left(\sum_{k\neq s}^{G}\sum_{l}^{G}\mathbf{B}_{rk}^{\not s}\mathbf{Y}_{kl} + \mathbf{B}_{rs}^{\not s}\mathbf{Y}_{ss}\right)\right]}_{\substack{\text{domestic value}\\ \text{added } (\mathbf{DVA}sink_{sr})}} + \underbrace{\mathbf{V}_s\mathbf{B}_{ss}\mathbf{A}_{sr}\mathbf{B}_{rs}^{\not s}\mathbf{E}_{s*}}_{\substack{\text{domestic double}\\ \text{counted } (\mathbf{DDC}sink_{sr})}}}^{\substack{\text{domestic}\\ \text{content } (\mathbf{DC}_{sr})}} \\ & + \overbrace{\underbrace{\sum_{t\neq s}^{G}\mathbf{V}_t\mathbf{B}_{ts}\left[\mathbf{Y}_{sr} + \mathbf{A}_{sr}\left(\sum_{k\neq s}^{G}\sum_{l}^{G}\mathbf{B}_{rk}^{\not s}\mathbf{Y}_{kl} + \mathbf{B}_{rs}^{\not s}\mathbf{Y}_{ss}\right)\right]}_{\substack{\text{foreign value}\\ \text{added } (\mathbf{FVA}sink_{sr})}} + \underbrace{\sum_{t\neq s}^{G}\mathbf{V}_t\mathbf{B}_{ts}\mathbf{A}_{sr}\mathbf{B}_{rs}^{\not s}\mathbf{E}_{s*}}_{\substack{\text{foreign double}\\ \text{counted } (\mathbf{FDC}sink_{sr})}}}^{\substack{\text{foreign}\\ \text{content } (\mathbf{FC}_{sr})}}.\end{aligned} \tag{D.6}$$

As highlighted above, the three different value-added decompositions of bilateral trade flows in equations (D.3), (D.4) and (D.6) can be used to address different issues, for instance the analysis of the exposure to tariffs imposed by the bilateral partner, the analysis of GVC-exports and that of bilateral trade balances, respec-

[25] A simple way to figure out how to decompose the exports of intermediates to country r is to re-express the general relationship of production and trade in our global I-O setting (see equation B.1) by separating the export flows from country s as follows: $\mathbf{X} = \mathbf{A}^{\not s}\mathbf{X} + \mathbf{A}^{s}\mathbf{X} + \mathbf{Y}^{\not s} + \mathbf{Y}^{s}$, 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 $(\mathbf{Y} - \mathbf{Y}^{\not s})$. This expression can be simplified by taking into account 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 (i.e. $\mathbf{E}^{s*}$) in the corresponding block submatrix and zeros elsewhere.

tively. Nevertheless, it is important to highlight that: *i*) at the bilateral level, the domestic and foreign contents are the same in the three breakdowns, only the value-added and double-counted components differ; *ii*) the value-added and double-counted terms of the two decompositions based on the exporting-country perspective (i.e. the *source*-based in equation (D.4) and the *sink*-based in equation D.6) differ only at the bilateral level and when summing across the destinations of a given exporter we obtain exactly the same aggregate indicators as those in equation (C.5).[26]

E Conceptual framework: Value-added accounting in different types of trade flows and accounting perspectives

Here we provide an overview of all the trade flows that can be analyzed with `icio`, with the corresponding perspectives that are available.

1. **Total exports of a country**

   a) **Total aggregate exports**

      - *Exporting-country perspective*: both the logic and the algebraic formulation of this accounting perspective are presented in Appendix C.
      - *World perspective*: This perspective has been considered only for the decomposition of the foreign content of exports. According to this methodology a certain item is accounted for as foreign value-added only once in all (i.e. world) trade flows, whereas in the exporting country perspective it occurs only once in all the exports of a single country. More specifically, by using a *source*- (*sink*-) based approach, a certain item is considered as value-added only the first (the last) time it crosses a foreign border whereas, all the other times it does, it is classified as double counted. The decompositions based on a "world perspective" can be used to address interesting questions regarding the breakdown of total world trade (i.e. by aggregating across countries the total exports' decompositions obtained with `icio`). For instance, we can measure the share of world's GDP

[26] See Borin and Mancini (2019) for a formal proof.

entering the exports of some other country. However, these measures are usually unsuited to addressing relevant issues regarding a country's exports. [27]

b) **Total sectoral exports**

- *Sectoral-exporter perspective*: This method, formally derived in Borin and Mancini (2019), can be chosen when the aim of the analysis is to compute the entire value-added that is embedded in all the exports of a country in a given sector. This occurs, for instance, when an economic shock (or policy intervention) affects all the exports of a country in a given sector (across all the destinations), and the interest of the analyst is to measure the spillovers from this shock into different countries/sectors. The domestic and foreign value-added embedded in total exports of country s and sector n can be computed similarly as in the decomposition of bilateral flows according to the "bilateral perspective" (see equation D.3). The only difference is that the original matrix of technical coefficients $\mathbf{A}$ needs to be modified such that $a_{sj,n}$ is set to zero $\forall\ j \neq s$; thus the inverse Leontief matrix is computed accordingly.
- *Exporting country perspective*: This accounting method for the analysis of sectoral trade flows follows exactly the logic of the same perspective described above for the analysis of bilateral trade flows. It provides a breakdown of sectoral exports consistent with the value-added indicators computed for the total aggregate exports of a country. Depending on whether the focus of the analysis is on the origin of the production or on the final absorption, a *source*- or a *sink*-based approach needs to be considered, respectively. The algebraic expressions follow closely the formulas in equations (C.5) (or eq. D.4) and (D.6), where total sectoral export flows are singled out through proper diagonalizations of the $\mathbf{VB}$ and the $\mathbf{VB}^{\not{s}}$ matrices.[28]

2. **Bilateral exports of a country**

[27]Borin and Mancini (2019) provide a more detailed discussion on this point, as well as the algebraic expressions for *source*- and *sink*-based breakdowns of the foreign content of exports based on a world perspective. The *source*-based decomposition corresponds to the one proposed by Borin and Mancini (2017) and Miroudot and Ye (2017). The *sink*-based one is similar to that reported in Koopman et al. (2014), however this part of their decomposition is affected by some drawbacks (see Borin and Mancini, 2019 for details).

[28]See Borin and Mancini (2019) for more details.

a) **Bilateral aggregate exports**: both the logic and the algebraic formulation of these accounting perspectives are presented in Appendix D.

- *Bilateral perspective*
- *Exporting-country perspective*

b) **Bilateral sectoral exports**:

- *Sectoral-bilateral perspective*: This methodology, developed in Borin and Mancini (2019), is useful for empirical analysis aiming at measuring the whole value-added of a country entering in the exports of country s in a specific sector (say n)to an importing country r. It can be used, for instance, to evaluate the GDP exposure to a tariff imposed by a country vis-à-vis a certain partner in a specific sector. As for the previous decompositions, for which the perspective corresponds to the trade flow under investigation, the value-added indicators are derived by modifying the input requirement matrix $\mathbf{A}$, setting to zero all the coefficients corresponding to the intermediate exports from s to r in (exporting) sector n.
- *Exporting country perspective*: This can be used to obtain a breakdown of total exports' value-added indicators across sectoral-bilateral flows. The formulation is a direct extension of that used for total sectoral exports to bilateral trade flows.

3. **Total imports of a country**

a) **Total aggregate imports**:

- *Importing country perspective*: This methodology can be exploited to compute the GDP of a given country j that enters, directly or indirectly, in the total imports of a given country r. This measure can be interesting, for instance, when a certain country is going to adopt a general protectionist stance (i.e. vis-à-vis all the exporting partners) and we want to compute the portion of the other countries' GDP at stake. In this case we define the relevant perimeter at the level of the importing country's borders as a whole. This can be implemented by following a procedure similar to that used to derive the (exporting) "country perspective" of Appendix C and is formally derived in Borin and Mancini (2019).

b) **Total sectoral imports**:

- *Sectoral-importer perspective*: This perspective, derived in Borin and Mancini (2019), can be useful when the focus is on a particular sector of a given importing country, e.g. when a certain shock affects only the imports of a country in a specific sector. The derivation is similar to that of the importing country perspective, where the double-counting perimeter is defined at the level of sectoral imports of a country.

F Conceptual framework: GVC participation

The "traditional" exports of country s to country r can be defined as the production of s that is directly absorbed in r without any further re-export. This component, called **DAVAX** - i.e. Directly Absorbed Value-Added in exports - can be computed as:

$$\mathbf{DAVAX}_{sr} = \mathbf{V}_s(\mathbf{I} - \mathbf{A}_{ss})^{-1}\mathbf{Y}_{sr} + \mathbf{V}_s(\mathbf{I} - \mathbf{A}_{ss})^{-1}\mathbf{A}_{sr}(\mathbf{I} - \mathbf{A}_{rr})^{-1}\mathbf{Y}_{rr}.$$

Then GVC-related exports can be simply obtained by excluding the entire domestic value-added of country s absorbed directly by its direct importer ($\mathbf{DAVAX}_{sr}$) from its exports to r:

$$\mathbf{GVCX}_{sr} = \mathbf{u}_N\mathbf{E}_{sr} - \mathbf{DAVAX}_{sr}.$$

Therefore, GVC-related trade share in total exports is given by:

$$\mathbf{GVC}_{sr} = \frac{\mathbf{GVCX}_{sr}}{\mathbf{u}_N\mathbf{E}_{sr}},$$

where $\mathbf{u}_N\mathbf{E}_{sr}$ is the total exports of country s to country r.

For the total exports of country s the GVC share will be easily computed as

$$\mathbf{GVC}_s = \frac{\sum_{r\neq s}^{G}\mathbf{GVCX}_{sr}}{\mathbf{u}_N\mathbf{E}_{s*}}, \tag{F.1}$$

while at world level we have:

$$\mathbf{GVC}_{world} = \frac{\sum_s^G\sum_{r\neq s}^{G}\mathbf{GVCX}_{sr}}{\sum_s^G(\mathbf{u}_N\mathbf{E}_{s*})}. \tag{F.2}$$

As already mentioned, the overall GVC indicator of equation (F.1) can be decomposed into a 'backward' component, corresponding to the **VS** Index proposed by Hummels et al. (2001) (see Borin and Mancini, 2019 for a formal proof) and a "forward" component, i.e. the part of domestic production that is supplied to the importing country to be re-exported:

$$\mathbf{GVC}_{sr} = \mathbf{GVC}backward_{sr} + \mathbf{GVC}forward_{sr} \tag{F.3}$$

where

$$\mathbf{GVC}backward_{sr} = \frac{\mathbf{V}_s(\mathbf{I}-\mathbf{A}_{ss})^{-1}\sum_{j\neq s}^{G}\mathbf{A}_{sj}\mathbf{B}_{js}\mathbf{E}_{sr} + \sum_{t\neq s}^{G}\mathbf{V}_t\mathbf{B}_{ts}\mathbf{E}_{sr}}{\mathbf{u}_N\mathbf{E}_{sr}} \tag{F.4}$$

and

$$\mathbf{GVC}forward_{sr} = \frac{\mathbf{V}_s(\mathbf{I}-\mathbf{A}_{ss})^{-1}\mathbf{A}_{sr}(\mathbf{I}-\mathbf{A}_{rr})^{-1}(\sum_{j\neq r}^{G}\mathbf{Y}_{rj} + \sum_{j\neq r}^{G}\mathbf{A}_{rj}\sum_{k}^{G}\sum_{l}^{G}\mathbf{B}_{jk}\mathbf{Y}_{kl})}{\mathbf{u}_N\mathbf{E}_{sr}}. \tag{F.5}$$

The $\mathbf{GVC}forward_{sr}$ indicator differs from the $\mathbf{VS1}_s$ index proposed by Koopman et al. (2014). $\mathbf{VS1}_s$ is computed by aggregating the content of a country's production embedded in other countries' exports and thus it is not necessarily a portion of country s's exports (like **VS**). Suppose, for instance, that a certain intermediate component exported by country s later undergoes other processing phases in different countries; the original component will be double-counted several times in the summation of country s's content in other countries' exports. The discrepancy between the original value of goods exported by s and the related amount that enters in Koopman et al.'s (2014) indicator increases with the relative "upstreamness" of country s's production.