Measuring Bilateral Exports of Value Added: A Unified Framework

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Abstract

In this paper we provide a unified framework for measuring the domestic value added content of bilateral exports. We outline a general methodology that encompasses the well-known measures introduced by Koopman et al. (2012) (domestic value added in exports) and Johnson and Noguera (2012) (value added consumed abroad) which we refer to as VAX-D and VAX-C. In addition we suggest a novel third measure, VAX-P, that indicates the value added absorbed abroad in the final stage of production. We show how the measures are related and can all be derived with the method of hypothetical extraction in a general input-output model outlined in Los et al. (2016). In addition we show that for VAX-C and VAX-P the sum of bilateral measures is equal to the corresponding unilateral measure, but this is not necessarily true for VAX-D. We illustrate all measures with some numerical examples using the World Input-Output Database.

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1. Introduction

Which countries are the most important for your exports? This is a pressing question for policy-makers seeking to (re)negotiate bilateral and multilateral trade agreements. In a simple world without traded intermediates, the answer to this question is simple and can be derived from bilateral gross export statistics as recorded through customs. If the exporting country relies on imported intermediate inputs, the domestic value added share in exports becomes a relevant measure, as argued by Koopman et al. (2012). For reasons that will become clear later on, we will refer to this as VAX-D. If the country is not only exporting final goods, but also intermediates, more complex answers are possible. Johnson and Noguera (2012) introduced the measure of domestic value added consumed by another country. In this case, partner countries are not necessarily the countries to which exports are made: e.g. they might be sent through a third country doing the final assembly. We will refer to this as VAX-C. Johnson (2014) provides an overview of the many issues for which this measure of trade is relevant.[1]

We argue that there is a third useful measure, namely domestic value added in exports that is used abroad for final stage production. We refer to this as VAX-P. This is a relevant measure as it is at the final stage where shocks to final demand are transmitted to production and associated intermediates trade flows, as in Bems et al. (2011, 2013). There might also be idiosyncratic shocks to the final-stage country that will percolate to its trading partners further up the chain, for example when final goods tariffs change as in the model by Blanchard et al. (2017). The final-stage partner country can also be relevant when it hosts the lead firms that dominate the governance structures within the chains (Antràs and Staiger, 2012). As for VAX-C, there can be flows of VAX-P between a pair of countries without a flow of direct exports.

The main aim of this paper to offer an integrated discussion on measures of bilateral exports when production is internationally fragmented. This is through providing a unified framework based on an application of the hypothetical extraction method in global input-output tables

[1] Trade in value added measurement has quickly expanded and broadened into a wider set of so-called global value chain (GVC) measures. See Johnson (2017) for a general overview. By now, these statistics are part of the toolkit for trade policy analysis. For example, they are published on a regular basis by the OECD/WTO Trade in value added (TiVA) initiative and in the WITS (World Integrated Trade Solution) database. Ongoing efforts in the international statistical community aim to improve and harmonize the underlying data sources and institutionalize their production in regular statistical programs, see e.g. Landefeld (2015).

along the lines of Los et al. (2016). We believe that this is helpful in cleaning up terminology and in standardizing concepts. In particular, we show that VAX-D and VAX-C are special cases of a general class of VAX measures which also encompasses VAX-P. The framework will also help to elucidate the relationship between unilateral and bilateral measures.[2] This is important as currently there are two definitions of bilateral VAX-D: one by Wang et al. (2018) and another by Los et al. (2016). We will argue that the latter is more meaningful for trade analysis. In particular, we will show that the sum of VAX-D to all destinations is not necessarily equal to VAX in unilateral exports and this is a desirable characteristic.[3]

The remainder of the paper is organized as follows. We will lay out concepts and terminology through some simple examples in section 2. This is to develop intuition. The actual computational formulas are given in section 3. Numerical examples based on data from the World Input-Output Database are shown in section 4. Section 5 concludes.

2. Concepts and terminology

In this section we will lay out our concepts and terminology, and illustrate these with an example of a simple sequential production chain (a "snake"). The general insights do not depend on the example however and as shown algebraically in section 3 they are generally applicable in any constellation of the production network.[4] Intuitions motivated by simple snake examples might actually fail in more complex situations. We will focus on one particular instance, namely when there are what we will call "loops" in the production chain. Put simply, in those cases a country is importing its own domestic value to produce exports. We will formalize this situation in section 2b and show that in such cases bilateral measures of value added exports do not always have to add up to the unilateral measure. We show that this result has a straightforward interpretation.

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[2] We use the term "unilateral exports" to refer to the total exports of a country, summed across all destinations. This is to be distinguished from "bilateral exports" that are for a specific destination.

[3] Wang et al. (2018) propose a decomposition framework of gross exports at the bilateral and sector level. They aim to allocate sectoral value added to trade flows using (combinations of) forward and backward linkage measures. One characteristic of their approach is that bilateral measures of VAX across partners always need to add up to the corresponding unilateral measure. In section 3 we will argue that this is actually *not* a desirable property of a VAX measure.

[4] It can consist of snakes, spiders or any combination of these (see Baldwin and Venables, 2013, for a discussion of the differences).

2a. A basic example

Figure 1 depicts a simple production process in which there are four stages of production, each taking place in a different country. We opt for the most simple constellation through which we can still illustrate our concepts. Country Z produces an intermediate input, used by country R to produce intermediates, which are subsequently used by country S to produce an intermediate for country T. Country T is what we call the country-of-completion. This is the country where the final stage of production takes place. Country U is importing the final good from Country T and consumes it.[5] In each stage of production 1 unit of value is added to the product, such that the price paid for the final product is 4.

In Table 1 we show the corresponding input-output table to this production chain. The intermediate use block has the very simple structure of a sequential production chain.[6] Note that gross output of each product (in the bottom row) is equal to its total use (indicated in the last column) as required to have a closed system such that use is equal to supply for all products.[7] We will use this IO-table in the next section to discuss the complications arising from "loops".

With this set-up we next introduce our family of bilateral export measures. These are shown in Table 2. We only report on those country pairs for which there is a non-zero export flow for at least one of the measures (so we do not report e.g. on bilateral exports from U to any other country). We also do not report on Z, as this is not needed for the making our main points. The numbers should be clear from the example, and can be checked using the information in Table 1 with the formulas to be presented in section 3. The first row indicates the traditional gross flows. The next rows show three different variants of value added exports (VAX): for direct use (VAX-D), for final stage production (VAX-P) and for consumption (VAX-C).

[5] Throughout the paper we will refer to consumption, but in the empirical exercise this is final use which includes household and government consumption, as well as private and public gross fixed capital formation.

[6] More formally, a snake is a production chain that can be represented (with suitable permutation) in the intermediate use matrix by a (non-main) diagonal of non-zeros, while having zeros elsewhere.

[7] The input-output table in this example and throughout the paper is in monetary units as we are interested in the value added content of production, not in technical requirements of production that are best stated in quantities (as in the original work by Leontief).

Figure 1 Example of sequential production chain

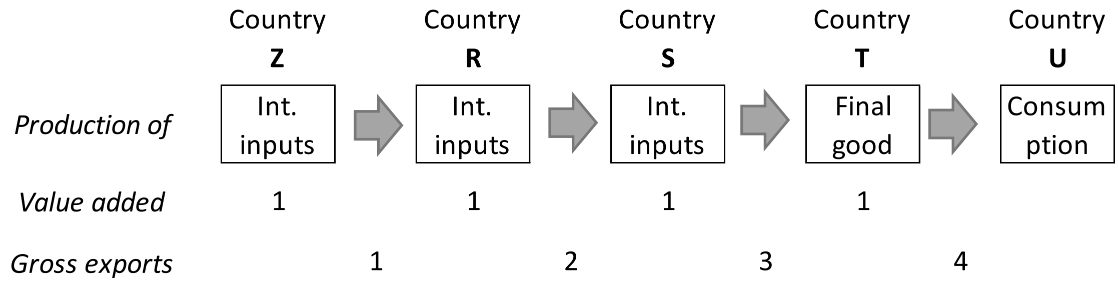

Figure 2 Input-output table corresponding to Figure 1

Produced by	*Intermediate use*					*Final use*					Total use
	Z	R	S	T	U	Z	R	S	T	U	
Z	0	**1**	0	0	0	0	0	0	0	0	1
R	0	0	**2**	0	0	0	0	0	0	0	2
S	0	0	0	**3**	0	0	0	0	0	0	3
T	0	0	0	0	0	0	0	0	0	**4**	4
U	0	0	0	0	0	0	0	0	0	0	0
value added	1	1	1	1	0						
gross output	1	2	3	4	0						

Table 1 Measures of bilateral exports

	From R to			From S to		From T to
	S	T	U	T	U	U
Gross exports	2	0	0	3	0	4
Domestic value added exports (VAX)						
for direct use (VAX-D)	1	0	0	1	0	1
for final stage production (VAX-P)	0	1	0	1	0	0
for consumption (VAX-C)	0	0	1	0	1	1

Note: based on Figure 1

The unilateral concept of value added exports for direct use (VAX-D) has been introduced by Koopman et al. (2012) (KWW henceforth).[8] This is equal to gross exports when all activities needed to produce the exported good are performed within the exporting country. Put otherwise, all stages of production take place domestically. The share is declining in the amount of intermediates imported by the country in any domestic stage of production. In this case, the share of VAX-D in gross exports is 0.5. Note that VAX-D includes value added in the export of intermediates (as in exports from S to T) as well as final goods (as in exports from T to U).

Johnson and Noguera (2012) introduced the concept of what they called “value added exports”. It is defined as the domestic value added that is generated in a country but consumed abroad.[9] We refer to it as VAX-C. VAX-D includes all value added that crosses the border, irrespective of where it is ultimately consumed. Considered unilaterally, it is therefore always at least as large as VAX-C, and strictly larger when some VAX-D is consumed domestically (Koopman et al., 2014). This is not true when considering bilateral flows however. It is here that the conceptual difference is most visible. There can be a bilateral flow of VAX-C between a pair of countries without a direct flow of exports, as in the case of R to U, or S to U, as indicated in Table 1.

We introduce a third measure of VAX, namely VAX for final stage production (VAX-P). It is the domestic value added in exports that is used abroad in the production of a final good. In principle, an unlimited number of related measures could be introduced, only bounded by the number of stages in the chain. We view this one as the most relevant however, as it clearly delineates between trade in intermediate and in final products. After this stage there is only trade in final goods in the chain, and before this stage there is only trade in intermediates in the chain. More generally, it is the stage at which shocks to final demand are transmitted to production and associated trade flows, as in Bems et al. (2011, 2013). As for VAX-C, there can be bilateral flows of VAX-P between a pair of countries without a flow of direct exports, as from R to T.

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[8] In fact, Hummels et al. (2001) suggested the complement to VAX-D: the import content of exports, and referred to these as VS. Koopman et al. (2012) showed that VAX-D is equal to gross exports minus VS (see also Los et al., 2016).

[9] Johnson and Noguera (2012, 2017) define it as “value added absorbed abroad”. In the context of VAX-P and VAX-C, “absorbed by” is ambiguous (as it could be absorbed by the final producer, or the consumer) and we therefore use the term “consumed abroad” instead.

It can be easily seen that the unilateral measures for each of the three VAX measures are equal to the sum of the bilateral measures across all destinations (not shown). This is because of the simple constellation of the chain and generally this is not the case as discussed next.

2b. The case of chains with feedback loops

In this section we expand the simple example in the previous section and show intuitively that it can lead to situations in which the sum of the bilateral measures across all destinations is not equal to the unilateral measure. This is so in the case of a "feedback loop" (Miller, 1966) which arises when a country is importing its own value added. Obviously this can only be indirectly through another country. An example is easily created by replacing country T in Figure 1 by country R, see Figure 3. In that case R is importing its own value added that was generated in an earlier stage when producing for exports to S. The corresponding input-output table is shown in Figure 4.

Mathematically, an input-output table has a loop when there is no permutation of the intermediate use matrix possible that results in a *triangular matrix*, that is the below diagonal block to have only zeroes. Note that such permutations of the matrix can only involve simultaneous permutations of the columns and corresponding rows, otherwise the equality of row (use) and column sum (supply) is violated.[10] In this example it is clear that there are loops as S delivers intermediates to R and vice versa, hence there is always a non-zero in the below diagonal block no matter how the countries are ordered in the table.

In Table 2 we report on the bilateral VAX measures, as well as the unilateral (in the columns headed by "All"). Again we only report on pairs of countries where there is a non-zero flow for one of the VAX measures. The measures for S are not surprising and basically repeating those for T in the previous snake example (see Table 1). R is the country of interest. It carries out two stages of production, and is now exporting directly to two countries: S and U. Its gross exports are 6, while it generated only 2 units of value added in the chain. This is clear from VAX-C: both units are ultimately absorbed in U and the sum of the bilateral measures is equal to the

[10] Chenery and Watanabe (1951) discuss triangularization of input-output matrices in order to make matrix manipulations computationally less cumbersome (which at that time was of course an important topic). Simpson and Tsukui (1956) discuss the economic meaning of (block)triangular input-output tables.

unilateral one. This is also true for VAX-P, which in this case is not so insightful as R is the country of completion so VAX-P is zero by definition for all bilateral pairs as well as unilateral.

Figure 3 Example of production chain (with loop)

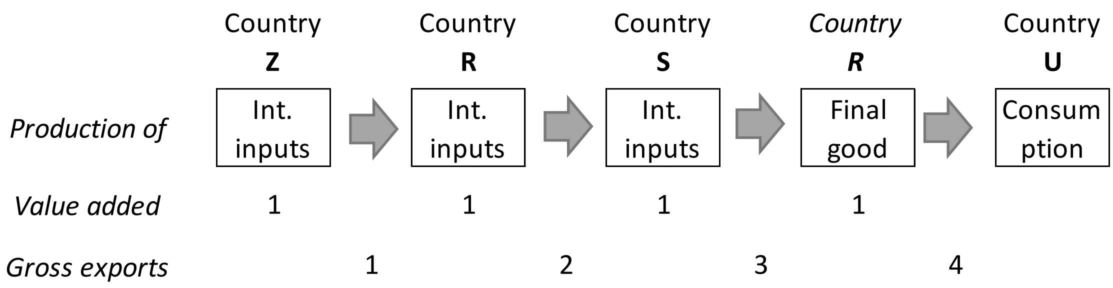

Figure 4 Input-output table corresponding to Figure 3

Produced by	*Intermediate use*				*Final use*				Total use
	Z	R	S	U	Z	R	S	U	
Z	0	**1**	0	0	0	0	0	0	1
R	0	0	**2**	0	0	0	0	**4**	6
S	0	**3**	0	0	0	0	0	0	3
U	0	0	0	0	0	0	0	0	0
value added	1	2	1	0					
gross output	1	6	3	0					

Table 2 Measures of bilateral exports

	From R to			From S to		
	S	U	*All*	R	U	*All*
Gross exports	2	4	*6*	3	0	*3*
Domestic value added exports (VAX)						
for direct use (VAX-D)	1	2	*2*	1	0	*1*
for final stage production (VAX-P)	0	0	*0*	1	0	*1*
for consumption (VAX-C)	0	2	*2*	0	1	*1*

Note: based on Figure 3

The interesting case arises for VAX-D. It is exporting 1 unit of value added to S. And it is exporting 2 units of its value added to U: the value added in the second stage of the chain and in the fourth stage. Yet, the unilateral VAX-D is also 2. This is obvious as R added only 2 units of value added to the chain. We now have a case where the sum of the bilaterals is higher (3) than the unilateral one (2). The reason is that R is exporting the value added it generated in the second stage of the chain twice: first directly to S, and again embodied in exports to U. We therefore refer to the difference between the sum of bilaterals and the unilateral VAX-D as the *double count of domestic value added when summing bilaterals*.

With this example we have shown that bilateral VAX does not always sum to unilateral VAX. This is only true for VAX-D however. It affects neither VAX-P nor VAX-C because it only arises in situation where there are loops: value added delivered to the final stage, or the final consumer, will obviously never return to the exporting country.

2c. On the meaning of double counts.

In a recently revised paper Wang et al. (2018, WWZ from hereon) provide an alternative measure of bilateral VAX-D, which rules out this type of double counts by definition. This is because the authors wish to develop an accounting system in which the overall value added (GDP) of a country is assigned to (bilateral) export flows in a mutually exclusive way. From that perspective it is only natural to impose an aggregation restriction up front. But there is a cost involved regarding understanding trade relationships. In the WWZ accounting framework, the value added in exports from R to U would be only 1 unit, not 2. In that way the bilateral measure sums to the unilateral. This might be justified when accounting for GDP, but it is counter-intuitive from a trade perspective. When R is no longer demanding the final good from U, value added in U will decline by 2 units of value added, as both stages of production are no longer needed. The hypothetical extraction method introduced in the next section provides a mathematical underpinning for this intuition.

One could argue (as in WWZ) that by tracing the exports and contributions *of different industries in a country* this double counting would be eliminated. Assume that the first task carried out by R is done in industry R1 such that the exports to S are made by R1, and the second task in industry R2 such that the exports to U are made by R2. When considering the exports to U one could say that the exports *from R2* contain 1 unit of value added *by R2.* Yet, it remains true that the unilateral exports from R contain 2 units of value added from country R.

Having more detailed input-output tables will thus not resolve this as long as one wishes to study aggregate exports from a country, rather than from separate industries in a country.[11]

In empirical terms, the double counts have (so far) been minor. Table 3 provides information on the double count in VAX-D. It is defined as the sum of the bilateral VAX-D cross all partners minus the unilateral VAX-D, expressed as a percentage of the latter. It follows that this term is not large, and typically less than 1.0 per cent. The maximum (1.8 per cent) is found for the case of Germany, signifying that this country has sizeable back-and-forth trade that is bigger than for other countries. The lowest double counts are found for Australia and Brazil, countries that specialize in exporting natural resources. The value added generated in mining is not returning to these countries in the form of intermediate inputs.

Table 3 VAX-D double counts, selected countries, 2014

	VAX-D double count
China	0.8%
United States	0.7%
Germany	1.8%
Japan	0.3%
United Kingdom	0.3%
Australia	0.1%
Brazil	0.1%

Note: VAX-D double count is the sum of the bilateral VAX-D cross all partners minus the unilateral VAX-D. It is expressed as percentage of unilateral VAX-D. Authors' calculations based on WIOD 2016 release.

[11] We do not claim that the WWZ decomposition is mathematically "wrong". As long as the accounting restrictions are obeyed, an accounting framework is correct. But we do claim that the decomposition is essentially arbitrary as one can come up with many alternatives that are equally valid. Without an economic model, it is impossible to defend any choice among these. This point is also made by Nagengast and Stehrer (2016) and they propose to identify the trade flow in which value added is actually recorded for the first time in international trade statistics. Actually, there is a deep and fundamental problem in trying to allocate value added to gross flows. Note that the elements in an IO table are summations of transactions within a particular time frame, typically a year. It does not record the sequence of the transactions. This is important to stress, because it implies that it is generally impossible to retrieve the underlying production chain except in very simple cases such as a snake (as stressed by Nomaler and Verspagen, 2014). If loops are present, many networks can underlie the same IO-table. Hence, it is impossible to allocate value added to gross flows and any "solution" is essentially arbitrary.

3. The hypothetical extraction method for bilateral VAX (value added export) measures

3a. Prelims and notation

In this section, we show how the three indicators of bilateral exports of domestic value added can be computed if a global input-output table is available. The general structure of such a table is given by Figure 5.

Figure 5: The structure of a global input-output table

			Use by country-industries							Final use by countries			Total use
			Country 1			…	Country M			Country 1	…	Country M	
			Industry 1	…	Industry N	…	Industry 1	…	Industry N				
Supply from country-industries	Country 1	Industry 1											
		…											
		Industry N											
	…	…											
	Country M	Industry 1											
		…											
		Industry N											
Value added by labour and capital													
Gross output													

Notes: Global IO tables do not have country detail for all countries in the world. Hence, Country M often refers to a region labelled "Rest of the World".
Source: Timmer et al. (2015).

In what follows, we will assume that the countries in a global input-output table can be grouped into three groups: (i) the country (or group of countries) for which we want to compute VAX-indicators, indicated by *r*; (ii) the country (or group of countries) that acts as the destination of the VAX, indicated by *s*; and (iii) the other countries in the world, indicated by *t*. In matrix notation, the input-output structure of Figure 5 can in this context be represented by a limited number of matrices and vectors:[12]

$$\mathbf{Z} \equiv \begin{bmatrix} \mathbf{Z}_{rr} & \mathbf{Z}_{rs} & \mathbf{Z}_{rt} \\ \mathbf{Z}_{sr} & \mathbf{Z}_{ss} & \mathbf{Z}_{st} \\ \mathbf{Z}_{tr} & \mathbf{Z}_{ts} & \mathbf{Z}_{tt} \end{bmatrix};\ \mathbf{Y} \equiv \begin{bmatrix} \mathbf{y}_{rr} & \mathbf{y}_{rs} & \mathbf{y}_{rt} \\ \mathbf{y}_{sr} & \mathbf{y}_{ss} & \mathbf{y}_{st} \\ \mathbf{y}_{tr} & \mathbf{y}_{ts} & \mathbf{y}_{tt} \end{bmatrix};\ \mathbf{w} \equiv \begin{bmatrix} \mathbf{w}_{r} \\ \mathbf{w}_{s} \\ \mathbf{w}_{t} \end{bmatrix};\ \mathbf{x} \equiv \begin{bmatrix} \mathbf{x}_{r} \\ \mathbf{x}_{s} \\ \mathbf{x}_{t} \end{bmatrix}$$

There are *M* countries, each with *N* industries. **Z** is the *NM*x*NM* matrix of which the elements indicate the transaction values of sales among industries in the accounting period, usually a year. The rows refer to the supplying industries, the columns to using industries. Both transactions within a country (in the diagonal submatrices) and cross-border transactions (in the

[12] Matrices are indicated by bold capitals, column vectors by bold lowercases and scalars by italics. Primes denote transposition and hats diagonal matrices.

off-diagonal submatrices) are included in this matrix. It should be noted that the submatrices generally do not have the same dimensions. In order to avoid aggregation biases (Morimoto, 1970), all industry and country detail should be retained in the computations. If r is a single country, $\mathbf{Z}^{rr}$ has N rows and columns. If s is a group of M_s countries, $\mathbf{Z}^{ss}$ has NM_s rows and columns.

$\mathbf{Y}$ is the rectangular matrix of which the elements give the transaction values of sales by industries to final users. Like in $\mathbf{Z}$, both domestic and international transactions are contained in this matrix. Since we treat all final use categories (household consumption, gross fixed capital formation, etc.) in the same way, $\mathbf{Y}$ contains M columns (one column for each country). Since all industries in all countries can sell to final users, the number of rows is NM. The dimensions of the subvectors vary, depending on the numbers of countries included in r, s and t.

Value added in each of the industries in each country is contained in the NM-vector $\mathbf{w}$, and gross output levels in the NM-vector $\mathbf{x}$. The well-known input-output identities apply. The sum of intermediate sales and sales to final users (both summed over countries of destination) equals gross output, $\mathbf{x} = \mathbf{Zi} + \mathbf{Yi}$, in which $\mathbf{i}$ denotes a summation vector of appropriate length containing ones; the sum of purchases of intermediate inputs and payments for production factors (value added) also add up to these values, $\mathbf{x} = \mathbf{i}'\mathbf{Z} + \mathbf{w}$.

The production requirements *per unit of output* are given by the NMxNM matrix $\mathbf{A}$ (for intermediate inputs) and the NM-vector $\mathbf{v}$ (for factor payments):

$$\mathbf{A} = \mathbf{Z}\hat{\mathbf{x}}^{-1} = \begin{bmatrix} \mathbf{A}_{rr} & \mathbf{A}_{rs} & \mathbf{A}_{rt} \\ \mathbf{A}_{sr} & \mathbf{A}_{ss} & \mathbf{A}_{st} \\ \mathbf{A}_{tr} & \mathbf{A}_{ts} & \mathbf{A}_{tt} \end{bmatrix}; \quad \mathbf{v} = \hat{\mathbf{x}}^{-1}\mathbf{w} \equiv \begin{bmatrix} \mathbf{v}_r \\ \mathbf{v}_s \\ \mathbf{v}_t \end{bmatrix} \tag{1}$$

Country r's GDP can now be obtained by linking value added generation to the final demand levels in $\mathbf{Y}$ by means of Leontief's demand-driven input-output model:

$$GDP_r = \tilde{\mathbf{v}}_r(\mathbf{I} - \mathbf{A})^{-1}\mathbf{Yi} \tag{2}$$

in which $\tilde{\mathbf{v}}_r$ denotes the *NM*-vector that is identical to $\mathbf{v}$ as defined in (1) with respect to the part $\mathbf{v}_r$, but in which all other elements are set equal to zero.[13] The matrix $(\mathbf{I}-\mathbf{A})^{-1}$ is known as the "Leontief inverse". It explicitly takes into account that the industry that is producing the final product often does not only use its own production factors, but also intermediate inputs from first-tier suppliers. These can be located in the same country, but also elsewhere. First-tier suppliers generate value added themselves, but might also use intermediate inputs for their activities. The same goes for second-tier suppliers producing these, and so on.[14]

In their comment on Koopman et al. (2014), Los et al. (2016) showed that using a particular type of the "Hypothetical Extraction Method" (HEM) as pioneered by Paelinck et al. (1965) and Strassert (1968) can be used to derive VAX-D.[15] The main part of Los et al. (2016) dealt with the unilateral case, in which domestic value added in the exports of country *r* to all other countries is considered at once. They also proposed a bilateral extension, to which we will turn now.

3b. The hypothetical extraction method (HEM)

HEM-applications usually "extract" industries or countries from input-output structures by setting corresponding parts of matrices that are involved to zero. Equation (2) is then recomputed for the modified matrices: this is called the hypothetical GDP level. The difference between the actual and the hypothetical GDP levels is an indicator of the importance of the extracted industry. In computing VAX-D, we do not extract entire industries (or countries) from the system, but just some transactions. If we are interested in VAX-D between *r* and *s*, we set all elements of $\mathbf{A}_{rs}$ and $\mathbf{Y}_{rs}$ to zero, thereby assuming that *s* does not use any imports of intermediate and final products from *r*. One might think of this as a situation in which *s* sets import tariffs on goods from *r* that are prohibitively high. We indicate the modified matrices with a *:

$$\mathbf{A}_r^{*s} \equiv \begin{bmatrix} \mathbf{A}_{rr} & \mathbf{0} & \mathbf{A}_{rt} \\ \mathbf{A}_{sr} & \mathbf{A}_{ss} & \mathbf{A}_{st} \\ \mathbf{A}_{tr} & \mathbf{A}_{ts} & \mathbf{A}_{tt} \end{bmatrix}; \quad \mathbf{Y}_r^{*s} \equiv \begin{bmatrix} \mathbf{y}_{rr} & \mathbf{0} & \mathbf{y}_{rt} \\ \mathbf{y}_{sr} & \mathbf{y}_{ss} & \mathbf{y}_{st} \\ \mathbf{y}_{tr} & \mathbf{y}_{ts} & \mathbf{y}_{tt} \end{bmatrix} \tag{3}$$

[13] If the vector $\mathbf{v}$ would be used instead, we would obtain world GDP rather than GDP of *r*.
[14] See, e.g., the appendix of Los et al. (2015) for a more extensive exposition.
[15] See Miller and Lahr (2001) for a comprehensive overview of HEM-based input-output analyses, and Dietzenbacher et al. (1993) for an application involving multiple countries.

Next, we compute the GDP level in r for the situation in which these matrices would have represented the global production structure and final demand levels:

$$GDP_r^{*s} = \tilde{\mathbf{v}}_r'(\mathbf{I} - \mathbf{A}_r^{*s})^{-1}\mathbf{Y}_r^{*s}\mathbf{i} \tag{4}$$

The value added of r contained in direct exports to s is now given by the difference between r's actual GDP level and its hypothetical GDP level:

$$VAXD_{rs} = GDP_r - GDP_r^{*s} \tag{5}$$

We would like to emphasize that GDP_r^{*s} should not be seen as the GDP level that would result if exports to s would be prohibitive. In a general setting with more flexible demand functions, substitution effects will play a role. As a consequence, the global production structure and final demand levels will change and $\mathbf{A}_r^{*s}$ and $\mathbf{Y}_r^{*s}$ will not be realized. $VAX_D_{rs}$is therefore to be regarded as an upper limit to the loss in GDP_r and is most meaningful when compared to other scenarios of extracted transactions. Put otherwise, it is an indicator of the relative importance of country s for exports of value added by r.[16]

We now show for the first time how VAX-P can be computed in a similar framework by setting elements of one or more matrices in (2) to zero (see below for a simpler computational formula). VAX-P is the amount of value added absorbed abroad for final production. If we hypothetically extract all final demand for output produced by industries in country s, we have

$$\mathbf{Y}_r^{\#s} \equiv \begin{bmatrix} \mathbf{y}_{rr} & \mathbf{y}_{rs} & \mathbf{y}_{rt} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{y}_{tr} & \mathbf{y}_{ts} & \mathbf{y}_{tt} \end{bmatrix} \tag{6}$$

and hypothetical GDP in r is given by

$$GDP_r^{\#s} = \tilde{\mathbf{v}}_r'(\mathbf{I} - \mathbf{A})^{-1}\mathbf{Y}_r^{\#s}\mathbf{i} \tag{7}$$

For VAX-P, we now have the expression

[16] See, for example, Chen et al. (2018), who measure regional GDP-shares "at risk" to Brexit using this HEM-approach, but argue that substitution effects will most probably lead to smaller actual losses of GDP.

$$VAXP_{rs} = GDP_r - GDP_r^{\#s} \quad (8)$$

Johnson and Noguera's (2012) VAX-C indicator can also be easily be covered by the HEM-approach (see below for a simpler computational formula for VAX-C). If we hypothetically extract all demand by final users in country *s*, we have

$$\mathbf{Y}_r^{\&s} \equiv \begin{bmatrix} \mathbf{y}_{rr} & \mathbf{0} & \mathbf{y}_{rt} \\ \mathbf{y}_{sr} & \mathbf{0} & \mathbf{y}_{st} \\ \mathbf{y}_{tr} & \mathbf{0} & \mathbf{y}_{tt} \end{bmatrix} \quad (9)$$

The hypothetical GDP-level associated with this extraction reads

$$GDP_r^{\&s} = \tilde{\mathbf{v}}_r'(\mathbf{I} - \mathbf{A})^{-1}\mathbf{Y}_r^{\&s}\mathbf{i} \quad (10)$$

and we obtain the following expression for VAX-C:

$$VAXC_{rs} = GDP_r - GDP_r^{\&s} \quad (11)$$

This completes the discussion of the unified framework in which the three measures of bilateral exports of value added can be presented. The unilateral counterpart of VAX-D can be obtained by setting $\mathbf{A}_{rs}$, $\mathbf{A}_{rt}$, $\mathbf{y}_{rs}$ and $\mathbf{y}_{rt}$, equal to zero in (3) to obtain $\mathbf{A}_r^{*st}$ and $\mathbf{Y}_r^{*st}$. The unilateral counterpart of VAX-P is computed by not only setting the row associated with final demand for output from country *s* equal to zero in (6), but also the row for output from country *r*. Finally, if both columns for consumption in *s* and in *r* in (10) are set to zero, (12) yields the unilateral VAX-C.

3c. Simplified expressions for calculation of VAX

So far, we derived VAX measures using the HEM approach. We did this to stress the relationships between the three VAX indicators. Yet, VAX-P and VAX-C can also be computed in a simpler way given the fact that it only involves the tracing of parts of the final demand matrix. Following the exposition by Los et al. (2015), VAX-P from *r* to *s* can be expressed as a simple multiplication with demand for products finalized in *s* (by any country in the world, this including *r*):

$$VAXP_{rs} = \tilde{\mathbf{v}}_r'(\mathbf{I} - \mathbf{A})^{-1}[\mathbf{y}_{sr} \quad \mathbf{y}_{ss} \quad \mathbf{y}_{st}]\mathbf{i} \quad (12)$$

Likewise, Johnson and Noguera's (2012) bilateral VAX-C from r to s is usually written as:

$$VAXC_{rs} = \tilde{\mathbf{v}}_r'(\mathbf{I} - \mathbf{A})^{-1} \begin{bmatrix} \mathbf{y}_{rs} \\ \mathbf{y}_{ss} \\ \mathbf{y}_{ts} \end{bmatrix}, \tag{13}$$

involving only the demand of *s* for products finalized in any country, including country *r* itself.

4. Empirical Illustrations

In this section we provide some empirical illustrations of the measures we introduced using the 2016 release of the World Input-Output Database (Timmer et al., 2015). We study the VAX of some major countries in the world (China, Japan, Germany, United Kingdom and United States) as well as some global suppliers of raw materials (Australia and Brazil). We show that bilateral measures can vary widely across the various measures and provide some intuitive interpretation. All results are for the year 2014 and values are given in million US$. For background, we first provide a comparison of unilateral measures of GX, VAX-D, VAX-P and VAX-C in Table 4. Tables 5 to 11 provide for each country the bilateral GX and VAX flows to each of the 42 partner countries (and the rest-of-the-world region), the share of each partner in total flows as well as the ranking based on these shares. We highlight some interesting results.

Table 4 Various unilateral VAX measures, 2014

	VAX-D / GX	VAX-C / VAX-D	VAX-P / VAX-D
China	82.4%	96.3%	47.1%
United States	87.0%	92.1%	61.1%
Germany	70.2%	95.4%	53.8%
Japan	74.7%	98.4%	56.8%
United Kingdom	77.4%	97.9%	63.1%
Australia	83.9%	99.1%	83.7%
Brazil	77.1%	99.4%	74.6%

Note: Authors' calculations based on WIOD, 2016 release.

VAX-D compared to GX

Column 1 in Table 4 confirms the finding of Koopman et al. (2014) that unilateral VAX-D is smaller than gross exports (GX). Ratios vary from 70 per cent for Germany up to 87 per cent for the U.S. reflecting the difference in the import content of their exports as stressed by Hummels et al. (2001). As argued by Koopman et al. (2012), these ratios are likely to be an overestimation when there is firm heterogeneity such that more export-intensive firms have lower VAX-D ratios. They showed that this was the case for China, using data that distinguishes between processing and non-processing firms.

Tables 5 through 11 provide information on the bilateral VAX-D ratios. In general, the ranking of export destinations does not change much when moving from the gross export to the VAX-D measure of bilateral trade. This is not surprising given the nature of the data at hand. Input requirement information generally does not vary across export partners, that is, the production technology of the exporting industry is not destination specific, and the WIOD is no exception. Put otherwise, the VAX-D to GX ratio for a given product is the same across all partners. The variation in results across bilateral partners hence comes from variation in the export product mix towards the various destinations. For example, Canada and Mexico become less important as export partners for the US in terms of VAX-D compared to gross exports. This is because the US exports to these countries is skewed towards products with a low VAX-D ratio. On the other hand, China becomes more important for Brazil as an export destination in terms of VAX-D as Brazilian exports to China mainly consist of raw materials which have a very high VAX-D ratio.

VAX-C compared to VAX-D

VAX-D includes all value added that crosses the border, irrespective of where it is ultimately consumed. From a unilateral perspective, it is therefore always at least as large as VAX-C as VAX-C only considers value added that is also ultimately consumed abroad (Johnson and Noguera, 2012). Koopman et al. (2014) showed that the empirical differences are small, and we confirm this in the second column of Table 4. This is not true when considering bilateral flows, however, and it is here that the conceptual and empirical differences are clearly visible. First of all, bilateral VAX-C can be higher than GX, and we find many examples of this, in particular in exports towards major consumer markets such as China, Japan and United States. Countries export directly towards these destinations, but also indirectly through other countries (as also found by Johnson and Noguera, 2012).

Second, for individual countries, the importance of various destinations do change compared to VAX-D. For example, South Korea and Taiwan are less important for Japan as consumers of its value added than as direct export markets, while the US is more important as a consumer than as a direct export destination. Similarly, Canada and Mexico are less important for the US, and continental Europe is less important for Germany as consumers than as direct export destination. These findings confirm the well-documented existence of regional production network structures. Johnson and Noguera (2017) provide an insightful analysis of value added exports between pairs of countries and show that both distance and adoption of trade agreements successfully predicts changes in bilateral VAX-C to gross export ratios.

VAX-P compared to VAX-D

The last column of Table 4 provides a comparison of unilateral VAX-P with VAX-D. It reveals interesting variation across countries. VAX-P must be lower than VAX-D by definition as it only captures exports of value added that are used in final production abroad. Hence VAX-P will not include exports of final goods and the ratio of VAX-P to VAX-D will thus be mainly influenced by the share of intermediates in a country's exports. Not surprisingly, the ratio varies from 47 per cent in China, which exports relatively little intermediates, up to 84 per cent in Australia which mainly exports primary intermediates.

The bilateral measures shown in Tables 5 to 11 reveal additional patterns. The share of VAX-P going to China is typically (much) higher than the share of VAX-D or VAX-C going to this country, confirming its important role as a final assembler using intermediates produced elsewhere. For example 15.3 per cent of direct VAX from Japan goes to China, yet 19.6 per cent of VAX-P. Similarly, 5.7 percent of US VAX-D goes to China, while 8.1 per cent of VAX-P. Interestingly, Chinese VAX-P goes more to less advanced countries (such as India, Indonesia and Mexico) and South Korea (relative to VAX-D or VAX-C shares). Yet the US and Japan are still the largest receivers of Chinese VAX-P.

5. Concluding remarks

In this paper we provided an integrated discussion of three useful measures of value added exports at the bilateral level: VAX-D as introduced by Los et al. (2016), VAX-C as introduced by Johnson and Noguera (2012) and VAX-P, a novel measure that indicates the value added absorbed abroad in the final stage of production. We showed that the measures have different interpretations while belonging to the same class of indicators. All can be derived with the method of hypothetical extraction in a general input-output model. In addition we show that the sum of bilateral measures for VAX-D might differ from the corresponding unilateral measure (but not for VAX-P and VAX-C). This happens if production networks contain feedback loops, i.e. when the production of exports of a country requires imported intermediates to which the country contributed value added in upstream stages of production. This is typically the case in real world input-output tables and an inherent feature of intricate production networks. We illustrate all measures with some numerical examples using the World Input-Output Database and show that they do not only differ conceptually, but also in practice.

Many extensions are possible, in particular using economic indicators other than value added, such as labor income or hours worked (see e.g. Chen et al., 2018). Progress will depend on the further availability of new and improved data sources. The popularity of VAX measures in the policy arena is not (yet) properly matched by the quality of the available data, as many gaps and inconsistencies in primary data collection remain. Harmonizing national and international data collection efforts and institutionalizing their production in regular statistical programs is a major challenge, see e.g. Landefeld (2015). Ongoing efforts in the international statistical community towards this goal are therefore very welcome and deserve full support.

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Table 5 Bilateral exports by China, 2014.

	million US$				Shares in total			Ranking of countries			
	GX	VAX-D	VAX-P	VAX-C	VAX-D	VAX-P	VAX-C	GX	VAX-D	VAX-P	VAX-C
Rest of world	1,038,525	870,577	385,318	771,233	43.6%	40.9%	40.1%	1	1	1	1
United States	347,311	280,320	123,637	320,289	14.0%	13.1%	16.7%	2	2	2	2
Japan	172,861	140,285	55,341	137,386	7.0%	5.9%	7.1%	3	3	3	3
South Korea	101,924	81,605	46,955	56,392	4.1%	5.0%	2.9%	4	4	4	6
Germany	88,465	72,334	35,614	71,375	3.6%	3.8%	3.7%	5	5	5	4
Russian Federation	65,198	56,474	14,834	62,062	2.8%	1.6%	3.2%	6	6	14	5
United Kingdom	51,850	42,270	21,216	49,968	2.1%	2.3%	2.6%	7	7	9	7
Canada	49,636	40,763	21,667	43,000	2.0%	2.3%	2.2%	8	8	8	9
Australia	48,459	39,568	19,714	43,198	2.0%	2.1%	2.2%	9	9	11	8
India	44,869	36,269	24,407	39,846	1.8%	2.6%	2.1%	10	10	6	10
Taiwan	43,622	34,210	14,413	20,401	1.7%	1.5%	1.1%	11	12	15	17
Netherlands	42,640	34,215	13,863	26,891	1.7%	1.5%	1.4%	12	11	16	14
France	41,291	34,061	21,759	38,267	1.7%	2.3%	2.0%	13	13	7	11
Brazil	38,988	31,703	19,966	36,926	1.6%	2.1%	1.9%	14	14	10	12
Mexico	38,330	30,554	17,932	25,082	1.5%	1.9%	1.3%	15	15	13	16
Indonesia	34,969	28,644	19,225	29,300	1.4%	2.0%	1.5%	16	16	12	13
Italy	28,865	23,873	13,690	25,699	1.2%	1.5%	1.3%	17	17	17	15
Turkey	23,149	18,558	10,112	18,765	0.9%	1.1%	1.0%	18	18	18	19
Spain	21,496	17,849	9,595	19,998	0.9%	1.0%	1.0%	19	19	19	18
Poland	14,316	11,541	5,868	11,771	0.6%	0.6%	0.6%	20	20	21	20
Belgium	11,804	9,862	6,303	9,490	0.5%	0.7%	0.5%	21	21	20	21
Sweden	11,173	9,445	5,849	9,005	0.5%	0.6%	0.5%	22	22	22	22
Czech Republic	8,898	6,855	3,952	4,800	0.3%	0.4%	0.2%	23	23	23	28
Switzerland	7,293	5,911	3,944	7,879	0.3%	0.4%	0.4%	24	24	24	23
Finland	6,870	5,644	3,781	5,056	0.3%	0.4%	0.3%	25	25	25	26
Denmark	6,199	5,215	3,553	5,101	0.3%	0.4%	0.3%	26	26	26	25
Hungary	5,396	4,135	3,035	2,342	0.2%	0.3%	0.1%	27	27	27	33
Norway	4,563	3,786	2,270	5,183	0.2%	0.2%	0.3%	28	28	30	24
Austria	4,242	3,500	2,493	4,875	0.2%	0.3%	0.3%	29	29	28	27
Greece	4,190	3,436	1,246	4,399	0.2%	0.1%	0.2%	30	30	33	29
Ireland	3,471	2,816	2,342	3,204	0.1%	0.2%	0.2%	31	31	29	30
Romania	2,614	2,089	1,573	2,850	0.1%	0.2%	0.1%	32	32	32	31
Portugal	2,251	1,844	1,219	2,620	0.1%	0.1%	0.1%	33	33	34	32
Slovak Republic	2,002	1,596	1,711	1,700	0.1%	0.2%	0.1%	34	34	31	34
Slovenia	1,369	1,137	482	1,167	0.1%	0.1%	0.1%	35	35	36	35
Estonia	1,073	862	457	683	0.0%	0.0%	0.0%	36	36	38	40
Bulgaria	1,029	847	536	1,150	0.0%	0.1%	0.1%	37	37	35	36
Lithuania	947	780	381	948	0.0%	0.0%	0.0%	38	38	39	37
Luxembourg	911	711	458	920	0.0%	0.0%	0.0%	39	39	37	38
Croatia	714	586	344	832	0.0%	0.0%	0.0%	40	40	40	39
Latvia	654	544	269	646	0.0%	0.0%	0.0%	41	41	41	41
Cyprus	583	487	189	569	0.0%	0.0%	0.0%	42	42	43	42
Malta	455	376	211	350	0.0%	0.0%	0.0%	43	43	42	43
Sum of bilaterals	2,425,464	1,998,134	941,724	1,923,618	100%	100%	100%				
Unilateral	2,425,464	1,981,364	941,724	1,923,618							

Table 6 Bilateral exports by United States of America, 2014.

	million US$				Shares in total			Ranking of countries			
	GX	VAX-D	VAX-P	VAX-C	VAX-D	VAX-P	VAX-C	GX	VAX-D	VAX-P	VAX-C
Rest of world	642,853	577,983	312,213	559,590	34.5%	30.5%	36.2%	1	1	1	1
Canada	291,930	242,458	120,217	185,228	14.5%	11.7%	12.0%	2	2	2	2
Mexico	178,587	146,127	91,872	99,465	8.7%	9.0%	6.4%	3	3	3	4
China	112,051	95,421	83,364	120,552	5.7%	8.1%	7.8%	4	4	4	3
Germany	79,939	70,486	46,817	69,805	4.2%	4.6%	4.5%	5	5	5	6
United Kingdom	73,796	62,847	35,678	69,873	3.7%	3.5%	4.5%	6	6	8	5
Japan	63,598	54,682	40,820	61,562	3.3%	4.0%	4.0%	7	8	6	7
Ireland	61,756	58,371	29,031	16,962	3.5%	2.8%	1.1%	8	7	9	16
France	57,720	49,924	37,565	49,212	3.0%	3.7%	3.2%	9	9	7	8
Netherlands	47,920	42,699	20,478	26,914	2.5%	2.0%	1.7%	10	10	12	12
South Korea	43,887	38,138	24,817	32,619	2.3%	2.4%	2.1%	11	11	11	10
Brazil	40,464	33,572	25,773	36,374	2.0%	2.5%	2.4%	12	12	10	9
Belgium	29,823	26,553	15,603	19,119	1.6%	1.5%	1.2%	13	13	14	14
Australia	26,813	23,109	13,636	27,004	1.4%	1.3%	1.7%	14	14	16	11
Luxembourg	20,862	19,896	7,786	2,130	1.2%	0.8%	0.1%	15	15	19	33
Italy	19,655	17,071	16,581	22,286	1.0%	1.6%	1.4%	16	16	13	13
Taiwan	16,415	13,934	7,661	10,924	0.8%	0.7%	0.7%	17	18	21	21
India	16,233	13,937	14,511	18,889	0.8%	1.4%	1.2%	18	17	15	15
Sweden	13,598	12,437	7,675	12,559	0.7%	0.7%	0.8%	19	19	20	18
Switzerland	13,415	11,797	9,671	12,484	0.7%	0.9%	0.8%	20	20	17	20
Spain	10,955	9,312	9,049	13,821	0.6%	0.9%	0.9%	21	21	18	17
Turkey	8,302	6,855	6,944	9,032	0.4%	0.7%	0.6%	22	22	22	22
Russian Federation	7,081	5,811	4,984	12,557	0.3%	0.5%	0.8%	23	24	25	19
Denmark	6,837	6,209	5,103	5,223	0.4%	0.5%	0.3%	24	23	24	28
Norway	6,564	5,726	4,271	6,797	0.3%	0.4%	0.4%	25	25	26	24
Finland	6,197	5,612	3,917	5,314	0.3%	0.4%	0.3%	26	26	28	27
Indonesia	5,864	5,069	6,458	8,331	0.3%	0.6%	0.5%	27	27	23	23
Poland	4,602	3,999	4,189	6,351	0.2%	0.4%	0.4%	28	29	27	25
Austria	4,581	4,031	3,834	5,504	0.2%	0.4%	0.4%	29	28	29	26
Hungary	3,402	3,093	2,582	2,523	0.2%	0.3%	0.2%	30	30	30	31
Czech Republic	2,746	2,439	2,570	2,985	0.1%	0.3%	0.2%	31	31	31	30
Greece	2,274	2,062	1,931	3,084	0.1%	0.2%	0.2%	32	32	32	29
Portugal	1,566	1,383	1,595	2,429	0.1%	0.2%	0.2%	33	33	33	32
Romania	1,223	1,042	1,376	2,000	0.1%	0.1%	0.1%	34	34	34	34
Slovak Republic	763	687	1,111	1,159	0.0%	0.1%	0.1%	35	35	35	35
Bulgaria	546	484	526	829	0.0%	0.1%	0.1%	36	36	36	36
Croatia	480	437	436	625	0.0%	0.0%	0.0%	37	37	38	38
Lithuania	435	368	269	659	0.0%	0.0%	0.0%	38	38	40	37
Slovenia	372	327	327	596	0.0%	0.0%	0.0%	39	39	39	39
Malta	356	313	491	285	0.0%	0.0%	0.0%	40	40	37	43
Estonia	252	221	227	360	0.0%	0.0%	0.0%	41	41	41	41
Latvia	233	207	213	394	0.0%	0.0%	0.0%	42	42	42	40
Cyprus	146	130	181	341	0.0%	0.0%	0.0%	43	43	43	42
Sum of bilaterals	1,927,091	1,677,256	1,024,353	1,544,752	100%	100%	100%				
Unilateral	1,927,091	1,666,117	1,024,353	1,544,752							

Table 7 Bilateral exports by Germany, 2014.

	million US$				Shares in total			Ranking of countries			
	GX	VAX-D	VAX-P	VAX-C	VAX-D	VAX-P	VAX-C	GX	VAX-D	VAX-P	VAX-C
Rest of world	275,991	204,172	111,575	226,516	17.3%	17.6%	20.1%	1	1	1	1
United States	135,642	95,970	58,466	117,597	8.1%	9.2%	10.4%	2	2	2	2
France	133,788	92,097	49,683	82,206	7.8%	7.8%	7.3%	3	3	4	4
China	122,900	87,554	50,447	97,226	7.4%	7.9%	8.6%	4	4	3	3
United Kingdom	103,347	73,161	39,573	74,075	6.2%	6.2%	6.6%	5	5	5	5
Italy	84,740	58,590	33,124	49,916	5.0%	5.2%	4.4%	6	6	6	6
Austria	77,551	52,540	21,284	35,208	4.4%	3.4%	3.1%	7	7	7	9
Netherlands	72,853	48,837	19,555	32,708	4.1%	3.1%	2.9%	8	8	10	10
Switzerland	63,955	45,823	20,935	35,731	3.9%	3.3%	3.2%	9	9	8	8
Poland	61,604	41,328	20,485	31,549	3.5%	3.2%	2.8%	10	10	9	12
Spain	50,542	35,337	19,104	32,109	3.0%	3.0%	2.9%	11	11	11	11
Russian Federation	49,265	33,299	17,645	36,857	2.8%	2.8%	3.3%	12	12	12	7
Czech Republic	42,855	29,056	14,061	15,467	2.5%	2.2%	1.4%	13	13	13	18
Belgium	41,918	28,491	14,032	19,838	2.4%	2.2%	1.8%	14	14	14	15
Sweden	32,584	22,950	10,117	20,040	1.9%	1.6%	1.8%	15	15	17	14
Turkey	28,860	19,362	10,744	18,239	1.6%	1.7%	1.6%	16	16	16	16
Hungary	27,183	19,047	10,099	8,425	1.6%	1.6%	0.7%	17	17	18	28
South Korea	25,415	17,721	9,823	16,690	1.5%	1.5%	1.5%	18	18	19	17
Japan	24,757	17,315	12,309	22,324	1.5%	1.9%	2.0%	19	19	15	13
Denmark	24,165	16,554	9,784	11,677	1.4%	1.5%	1.0%	20	20	20	22
Brazil	17,775	12,327	9,248	15,288	1.0%	1.5%	1.4%	21	21	21	19
Canada	17,148	12,039	7,501	14,709	1.0%	1.2%	1.3%	22	22	23	20
Finland	15,078	10,670	5,867	8,688	0.9%	0.9%	0.8%	23	23	26	26
Mexico	14,849	10,388	7,519	10,197	0.9%	1.2%	0.9%	24	24	22	24
Slovak Republic	14,645	10,062	5,918	5,840	0.9%	0.9%	0.5%	25	25	25	32
Romania	13,071	9,083	5,177	8,676	0.8%	0.8%	0.8%	26	26	27	27
India	13,025	8,964	7,302	11,778	0.8%	1.1%	1.0%	27	27	24	21
Norway	12,835	8,880	4,694	9,832	0.8%	0.7%	0.9%	28	28	29	25
Australia	12,143	8,540	4,795	11,568	0.7%	0.8%	1.0%	29	29	28	23
Taiwan	10,385	7,129	3,086	6,073	0.6%	0.5%	0.5%	30	31	32	31
Luxembourg	10,284	7,548	2,671	3,816	0.6%	0.4%	0.3%	31	30	34	35
Portugal	9,998	6,895	3,358	6,489	0.6%	0.5%	0.6%	32	33	31	29
Ireland	9,475	7,077	4,238	5,174	0.6%	0.7%	0.5%	33	32	30	33
Greece	7,710	5,514	1,975	6,266	0.5%	0.3%	0.6%	34	34	35	30
Slovenia	4,664	3,232	1,416	2,506	0.3%	0.2%	0.2%	35	35	36	37
Indonesia	4,215	2,916	2,820	4,492	0.2%	0.4%	0.4%	36	36	33	34
Bulgaria	4,150	2,852	1,303	2,877	0.2%	0.2%	0.3%	37	37	37	36
Croatia	3,231	2,268	1,138	2,369	0.2%	0.2%	0.2%	38	38	38	38
Lithuania	2,752	1,882	705	1,888	0.2%	0.1%	0.2%	39	39	39	39
Estonia	2,139	1,427	652	1,166	0.1%	0.1%	0.1%	40	40	40	40
Latvia	1,396	964	459	1,085	0.1%	0.1%	0.1%	41	41	41	41
Cyprus	924	668	231	735	0.1%	0.0%	0.1%	42	42	43	42
Malta	442	320	246	307	0.0%	0.0%	0.0%	43	43	42	43
Sum of bilaterals	1,682,253	1,180,849	635,165	1,126,218	100%	100%	100%				
Unilateral	1,682,253	1,159,581	635,165	1,126,218							

Table 8 Bilateral exports by Japan, 2014.

	million US$				Shares in total			Ranking of countries			
	GX	VAX-D	VAX-P	VAX-C	VAX-D	VAX-P	VAX-C	GX	VAX-D	VAX-P	VAX-C
Rest of world	305,935	241,127	107,149	224,819	39.5%	30.9%	37.4%	1	1	1	1
China	129,230	93,215	67,837	95,238	15.3%	19.6%	15.9%	2	2	2	3
United States	121,144	89,546	50,727	104,210	14.7%	14.6%	17.4%	3	3	3	2
South Korea	56,449	37,847	23,791	22,927	6.2%	6.9%	3.8%	4	4	4	4
Taiwan	44,809	31,139	12,680	16,457	5.1%	3.7%	2.7%	5	5	5	5
Germany	20,383	15,187	9,546	15,068	2.5%	2.8%	2.5%	6	6	6	6
Indonesia	16,155	11,296	9,496	11,389	1.9%	2.7%	1.9%	7	7	7	9
Mexico	14,993	11,081	8,487	9,028	1.8%	2.4%	1.5%	8	8	8	12
Australia	14,950	10,140	4,710	11,992	1.7%	1.4%	2.0%	9	10	13	8
Russian Federation	14,597	11,026	3,506	13,274	1.8%	1.0%	2.2%	10	9	15	7
Canada	11,500	8,678	6,272	10,190	1.4%	1.8%	1.7%	11	11	9	10
United Kingdom	9,647	7,403	5,970	10,143	1.2%	1.7%	1.7%	12	12	10	11
India	8,031	5,347	5,889	7,615	0.9%	1.7%	1.3%	13	14	11	13
Netherlands	7,893	5,888	3,107	5,041	1.0%	0.9%	0.8%	14	13	16	16
France	6,978	5,232	4,768	7,393	0.9%	1.4%	1.2%	15	15	12	14
Brazil	5,558	4,082	4,380	6,676	0.7%	1.3%	1.1%	16	16	14	15
Belgium	3,808	2,838	1,885	2,562	0.5%	0.5%	0.4%	17	17	18	20
Italy	3,135	2,369	2,709	3,981	0.4%	0.8%	0.7%	18	18	17	17
Spain	2,794	2,121	1,807	3,450	0.3%	0.5%	0.6%	19	19	20	18
Turkey	2,587	1,853	1,846	2,873	0.3%	0.5%	0.5%	20	22	19	19
Switzerland	2,495	1,958	1,290	2,335	0.3%	0.4%	0.4%	21	21	22	21
Ireland	2,485	2,040	1,302	1,374	0.3%	0.4%	0.2%	22	20	21	25
Poland	2,017	1,497	1,097	2,219	0.2%	0.3%	0.4%	23	23	23	22
Sweden	1,524	1,152	738	1,695	0.2%	0.2%	0.3%	24	24	26	23
Norway	1,476	1,071	598	1,412	0.2%	0.2%	0.2%	25	25	28	24
Czech Republic	1,396	1,041	873	911	0.2%	0.3%	0.2%	26	26	24	27
Austria	1,245	904	646	1,260	0.1%	0.2%	0.2%	27	27	27	26
Hungary	1,146	873	773	532	0.1%	0.2%	0.1%	28	28	25	31
Finland	546	409	432	647	0.1%	0.1%	0.1%	29	29	31	29
Denmark	512	403	552	694	0.1%	0.2%	0.1%	30	30	29	28
Slovak Republic	367	277	495	367	0.0%	0.1%	0.1%	31	31	30	34
Portugal	342	256	310	482	0.0%	0.1%	0.1%	32	33	33	32
Luxembourg	325	274	192	267	0.0%	0.1%	0.0%	33	32	35	35
Greece	241	183	200	585	0.0%	0.1%	0.1%	34	34	34	30
Romania	233	168	320	465	0.0%	0.1%	0.1%	35	35	32	33
Cyprus	150	115	21	158	0.0%	0.0%	0.0%	36	36	43	38
Estonia	128	95	58	134	0.0%	0.0%	0.0%	37	37	38	39
Slovenia	101	74	84	162	0.0%	0.0%	0.0%	38	38	37	37
Bulgaria	84	62	103	180	0.0%	0.0%	0.0%	39	39	36	36
Malta	41	29	36	48	0.0%	0.0%	0.0%	40	40	42	43
Lithuania	33	25	57	116	0.0%	0.0%	0.0%	41	41	40	40
Croatia	27	21	57	114	0.0%	0.0%	0.0%	42	42	39	41
Latvia	25	18	36	68	0.0%	0.0%	0.0%	43	43	41	42
Sum of bilaterals	817,514	610,362	346,832	600,551	100%	100%	100%				
Unilateral	817,514	608,320	346,832	600,551							

Table 9 Bilateral exports by United Kingdom, 2014.

	million US$				Shares in total			Ranking of countries			
	GX	VAX-D	VAX-P	VAX-C	VAX-D	VAX-P	VAX-C	GX	VAX-D	VAX-P	VAX-C
Rest of world	230,852	183,150	107,091	184,102	31.5%	29.2%	32.3%	1	1	1	1
United States	85,559	64,519	47,428	77,249	11.1%	12.9%	13.6%	2	2	2	2
Germany	54,147	40,702	25,403	36,615	7.0%	6.9%	6.4%	3	3	4	3
France	46,573	36,845	25,954	34,209	6.3%	7.1%	6.0%	4	4	3	4
Ireland	34,477	27,275	13,478	14,828	4.7%	3.7%	2.6%	5	5	6	7
China	27,405	19,194	18,140	29,480	3.3%	4.9%	5.2%	6	7	5	5
Luxembourg	23,757	20,654	8,153	2,404	3.6%	2.2%	0.4%	7	6	9	30
Netherlands	23,602	17,874	8,065	12,956	3.1%	2.2%	2.3%	8	8	11	9
Italy	21,798	17,132	11,863	17,953	2.9%	3.2%	3.2%	9	9	7	6
Belgium	21,045	16,017	8,138	11,526	2.8%	2.2%	2.0%	10	10	10	12
Switzerland	19,449	15,218	7,844	13,332	2.6%	2.1%	2.3%	11	11	13	8
Canada	17,523	13,282	9,360	12,365	2.3%	2.5%	2.2%	12	12	8	11
Russian Federation	14,236	10,309	3,625	12,742	1.8%	1.0%	2.2%	13	13	21	10
Spain	12,959	9,666	5,975	10,234	1.7%	1.6%	1.8%	14	14	14	14
Sweden	11,769	9,048	4,627	7,796	1.6%	1.3%	1.4%	15	15	18	16
Norway	11,426	8,671	5,017	7,679	1.5%	1.4%	1.3%	16	16	17	17
Japan	9,919	7,414	8,036	11,280	1.3%	2.2%	2.0%	17	17	12	13
South Korea	9,694	7,405	5,808	7,148	1.3%	1.6%	1.3%	18	18	15	18
Australia	8,990	6,920	3,998	8,393	1.2%	1.1%	1.5%	19	19	20	15
Denmark	8,101	6,271	4,354	4,900	1.1%	1.2%	0.9%	20	20	19	22
India	7,260	4,781	5,528	6,261	0.8%	1.5%	1.1%	21	22	16	19
Poland	7,153	5,509	3,281	5,880	0.9%	0.9%	1.0%	22	21	23	21
Turkey	6,082	4,262	3,042	4,662	0.7%	0.8%	0.8%	23	23	24	23
Brazil	5,091	3,838	3,439	5,885	0.7%	0.9%	1.0%	24	24	22	20
Finland	3,784	2,940	1,957	2,810	0.5%	0.5%	0.5%	25	25	27	26
Austria	3,486	2,658	2,061	3,342	0.5%	0.6%	0.6%	26	26	26	25
Czech Republic	3,060	2,313	1,654	2,051	0.4%	0.5%	0.4%	27	28	28	31
Portugal	3,050	2,372	1,433	2,606	0.4%	0.4%	0.5%	28	27	29	27
Mexico	2,784	2,134	2,616	3,705	0.4%	0.7%	0.7%	29	29	25	24
Greece	2,627	2,097	1,131	2,588	0.4%	0.3%	0.5%	30	30	34	28
Taiwan	2,228	1,705	1,403	2,453	0.3%	0.4%	0.4%	31	32	31	29
Hungary	2,122	1,657	1,249	1,339	0.3%	0.3%	0.2%	32	33	32	34
Malta	1,983	1,717	1,175	653	0.3%	0.3%	0.1%	33	31	33	38
Romania	1,567	1,204	988	1,547	0.2%	0.3%	0.3%	34	34	35	33
Cyprus	1,080	853	303	836	0.1%	0.1%	0.1%	35	35	38	35
Indonesia	972	722	1,415	1,993	0.1%	0.4%	0.4%	36	36	30	32
Slovak Republic	810	605	608	730	0.1%	0.2%	0.1%	37	37	36	36
Bulgaria	754	577	349	676	0.1%	0.1%	0.1%	38	38	37	37
Lithuania	544	409	191	499	0.1%	0.1%	0.1%	39	40	42	40
Croatia	521	420	294	519	0.1%	0.1%	0.1%	40	39	39	39
Estonia	476	364	177	393	0.1%	0.0%	0.1%	41	41	43	42
Latvia	465	359	194	416	0.1%	0.1%	0.1%	42	42	41	41
Slovenia	421	315	225	376	0.1%	0.1%	0.1%	43	43	40	43
Sum of bilaterals	751,599	581,373	367,067	569,411	100%	100%	100%				
Unilateral	751,599	579,453	367,067	569,411							

Table 10 Bilateral exports by Australia, 2014.

	million US$				Shares in total			Ranking of countries			
	GX	VAX-D	VAX-P	VAX-C	VAX-D	VAX-P	VAX-C	GX	VAX-D	VAX-P	VAX-C
Rest of world	93,652	78,402	55,886	75,384	32.6%	27.7%	31.6%	1	1	2	1
China	76,645	64,395	59,484	59,182	26.7%	29.5%	24.8%	2	2	1	2
Japan	46,272	39,248	30,752	32,570	16.3%	15.3%	13.6%	3	3	3	3
South Korea	16,058	13,436	9,498	8,734	5.6%	4.7%	3.7%	4	4	5	5
Taiwan	11,409	9,636	5,196	4,717	4.0%	2.6%	2.0%	5	5	7	8
United States	10,161	8,294	9,546	17,430	3.4%	4.7%	7.3%	6	6	4	4
India	7,844	6,305	6,625	6,661	2.6%	3.3%	2.8%	7	7	6	6
Indonesia	6,361	5,294	5,010	5,962	2.2%	2.5%	2.5%	8	8	8	7
United Kingdom	3,736	3,134	2,517	4,267	1.3%	1.2%	1.8%	9	9	9	9
Brazil	1,952	1,683	2,149	2,873	0.7%	1.1%	1.2%	10	10	10	11
Canada	1,807	1,506	1,275	2,482	0.6%	0.6%	1.0%	11	11	13	12
Germany	1,602	1,346	2,056	3,046	0.6%	1.0%	1.3%	12	12	11	10
France	1,271	1,084	1,670	2,232	0.4%	0.8%	0.9%	13	13	12	13
Switzerland	1,086	954	741	1,032	0.4%	0.4%	0.4%	14	14	19	19
Netherlands	941	785	771	1,147	0.3%	0.4%	0.5%	15	15	18	16
Italy	887	745	1,220	1,519	0.3%	0.6%	0.6%	16	16	14	15
Turkey	677	482	952	973	0.2%	0.5%	0.4%	17	19	16	20
Spain	674	566	851	1,131	0.2%	0.4%	0.5%	18	18	17	17
Belgium	672	569	640	638	0.2%	0.3%	0.3%	19	17	20	21
Poland	475	408	472	626	0.2%	0.2%	0.3%	20	20	22	22
Mexico	475	387	990	1,110	0.2%	0.5%	0.5%	21	21	15	18
Sweden	389	331	306	451	0.1%	0.2%	0.2%	22	22	23	23
Russian Federation	360	292	623	1,631	0.1%	0.3%	0.7%	23	23	21	14
Denmark	329	287	285	312	0.1%	0.1%	0.1%	24	24	24	25
Ireland	230	202	254	259	0.1%	0.1%	0.1%	25	25	25	27
Norway	205	170	188	328	0.1%	0.1%	0.1%	26	26	28	24
Austria	197	166	228	310	0.1%	0.1%	0.1%	27	28	26	26
Bulgaria	192	167	128	127	0.1%	0.1%	0.1%	28	27	30	33
Czech Republic	143	123	225	214	0.1%	0.1%	0.1%	29	29	27	29
Finland	108	88	147	198	0.0%	0.1%	0.1%	30	30	29	31
Romania	73	62	120	203	0.0%	0.1%	0.1%	31	31	34	30
Luxembourg	66	61	60	59	0.0%	0.0%	0.0%	32	32	36	37
Slovak Republic	47	40	122	116	0.0%	0.1%	0.0%	33	33	32	34
Greece	41	36	121	222	0.0%	0.1%	0.1%	34	34	33	28
Slovenia	34	28	41	60	0.0%	0.0%	0.0%	35	35	37	36
Hungary	25	21	126	110	0.0%	0.1%	0.0%	36	36	31	35
Portugal	22	18	117	157	0.0%	0.1%	0.1%	37	37	35	32
Estonia	9	8	20	29	0.0%	0.0%	0.0%	38	38	40	42
Lithuania	8	6	32	51	0.0%	0.0%	0.0%	39	39	38	38
Croatia	7	6	31	48	0.0%	0.0%	0.0%	40	40	39	39
Latvia	7	6	17	29	0.0%	0.0%	0.0%	41	42	41	41
Cyprus	7	6	13	31	0.0%	0.0%	0.0%	42	41	42	40
Malta	5	4	12	15	0.0%	0.0%	0.0%	43	43	43	43
Sum of bilaterals	287,162	240,786	201,516	238,674	100%	100%	100%				
Unilateral	287,162	240,468	201,516	238,674							

Table 11 Bilateral exports by Brazil, 2014.

	million US$				Shares in total			Ranking of countries			
	GX	VAX-D	VAX-P	VAX-C	VAX-D	VAX-P	VAX-C	GX	VAX-D	VAX-P	VAX-C
Rest of world	113,484	87,038	49,074	76,775	41.8%	31.5%	37.1%	1	1	1	1
China	41,012	33,493	32,027	32,570	16.1%	20.6%	15.7%	2	2	2	2
United States	29,552	20,999	18,184	25,488	10.1%	11.7%	12.3%	3	3	3	3
Japan	9,054	7,084	6,202	8,508	3.4%	4.0%	4.1%	4	4	4	4
Netherlands	8,682	6,497	3,385	3,828	3.1%	2.2%	1.8%	5	5	9	10
Germany	7,025	5,359	4,938	6,015	2.6%	3.2%	2.9%	6	7	6	5
India	6,891	5,654	5,695	5,804	2.7%	3.7%	2.8%	7	6	5	6
France	4,871	3,879	3,771	4,737	1.9%	2.4%	2.3%	8	8	7	8
Mexico	4,856	3,388	2,419	3,193	1.6%	1.6%	1.5%	9	11	13	14
United Kingdom	4,779	3,840	3,047	5,107	1.8%	2.0%	2.5%	10	9	10	7
South Korea	4,341	3,416	3,407	3,471	1.6%	2.2%	1.7%	11	10	8	11
Italy	4,090	3,169	2,908	3,290	1.5%	1.9%	1.6%	12	12	11	12
Russian Federation	3,656	2,833	1,125	4,055	1.4%	0.7%	2.0%	13	13	19	9
Canada	3,495	2,600	2,300	2,949	1.2%	1.5%	1.4%	14	16	15	15
Indonesia	3,476	2,736	2,851	3,209	1.3%	1.8%	1.5%	15	14	12	13
Spain	3,302	2,601	2,418	2,632	1.2%	1.6%	1.3%	16	15	14	16
Belgium	3,121	2,408	1,296	2,013	1.2%	0.8%	1.0%	17	17	18	17
Taiwan	2,572	2,058	1,637	1,723	1.0%	1.1%	0.8%	18	18	16	19
Norway	1,708	1,362	855	1,095	0.7%	0.5%	0.5%	19	19	21	21
Turkey	1,677	1,280	1,509	1,504	0.6%	1.0%	0.7%	20	20	17	20
Portugal	1,185	940	720	849	0.5%	0.5%	0.4%	21	22	22	22
Australia	1,164	942	1,086	1,943	0.5%	0.7%	0.9%	22	21	20	18
Denmark	908	744	556	531	0.4%	0.4%	0.3%	23	23	24	27
Ireland	832	606	293	654	0.3%	0.2%	0.3%	24	24	30	26
Sweden	697	546	498	712	0.3%	0.3%	0.3%	25	25	25	25
Poland	646	510	589	760	0.2%	0.4%	0.4%	26	26	23	23
Switzerland	561	424	413	740	0.2%	0.3%	0.4%	27	28	26	24
Finland	560	435	362	397	0.2%	0.2%	0.2%	28	27	27	29
Romania	347	273	328	383	0.1%	0.2%	0.2%	29	29	28	30
Austria	341	265	319	491	0.1%	0.2%	0.2%	30	30	29	28
Slovenia	323	254	243	251	0.1%	0.2%	0.1%	31	31	31	33
Bulgaria	195	163	137	147	0.1%	0.1%	0.1%	32	32	35	35
Hungary	187	142	189	169	0.1%	0.1%	0.1%	33	34	33	34
Greece	183	148	202	330	0.1%	0.1%	0.2%	34	33	32	31
Czech Republic	143	110	182	271	0.1%	0.1%	0.1%	35	35	34	32
Slovak Republic	65	48	121	128	0.0%	0.1%	0.1%	36	37	36	36
Croatia	61	49	65	91	0.0%	0.0%	0.0%	37	36	37	37
Estonia	50	34	30	50	0.0%	0.0%	0.0%	38	39	40	41
Lithuania	46	36	50	88	0.0%	0.0%	0.0%	39	38	39	38
Cyprus	42	31	20	56	0.0%	0.0%	0.0%	40	40	42	40
Latvia	30	23	28	46	0.0%	0.0%	0.0%	41	42	41	42
Luxembourg	29	24	54	77	0.0%	0.0%	0.0%	42	41	38	39
Malta	22	15	13	26	0.0%	0.0%	0.0%	43	43	43	43
Sum of bilaterals	270,263	208,455	155,545	207,157	100%	100%	100%				
Unilateral	270,263	208,346	155,545	207,157							