

The Value-added Structure of Gross Exports and Global Production Network

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(Preliminary draft, comments are welcome)

Abstract

This paper first refines a methodology in KPWW (2011) that completely decomposes a country's gross exports into its value-added components. By identifying which parts of such value-added are "double counted," it bridges official trade statistics and national accounts, making the standard measure of trade consistent with SNA standards.

We implement the decomposition on a database of global production and trade covering 62 countries/regions and 41 industries from version 8 of the Global Trade Analysis Project (GTAP) database for 2007 with additional processing trade information from China and Mexico. We recompute the RCA index at the country-sector level for all the countries and sectors in our database using domestic content in exports and compare them with RCA index based on traditional trade statistics.

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1. Introduction

It is a well-known fact that national income accounts record domestic output (transactions) in value added terms while standard trade statistics record trade in gross terms. This shortcoming in official trade statistics and their inconsistency with the system of national account standards has long been recognized by both economists and economic policymakers.¹ Efforts are underway at both the national and international levels to address the problem, although a global consensus has yet to emerge.

An accurate assessment of value added in trade has to go beyond a single country's effort, as it requires information on cross-border input-output relationships. A team of experts organized by the U.S. National Research Council² to study U.S. content of imports and foreign content of exports pointed out (Leamer et al, 2006): at country and industry aggregate levels, it is impractical to directly measure the foreign content of exports and the domestic content of imports for a country such as the United States. However, they acknowledged that the imported content of a country's exports can be estimated by proxy and with some accuracy given available input-output (IO) statistics. However they raised serious concerns about data quality and the assumptions required to obtain such estimates. The team's most serious reservation was the lack of consistent supply and use tables that could be linked across countries.

Significant progress has been made since the NRC report due to the efforts of the statistics and academic communities. Most developed countries, such as the 27 European Union member states and the United States, now compile and publish annual supply and use tables. Major initiatives are under way to help developing countries to comply with the 1993 System of National Accounts (SNA), including publishing supply and use tables.³ The European Commission, has funded a consortium of eleven European research institutions to develop a worldwide time series of national input-output tables, called the World Input Output Database (or WIOD), that are fully linked through bilateral trade data (27 EU member and 13 other major economies), generating a time series, multi-country IO table (for 1995-2009). WIOD contains tables in both current and constant international prices. The OECD is also constructing an inter-country IO table for three benchmark years (1995, 2000 and 2005) by combining their individual

¹ See, for example, Leamer et al. (2006), Grossman and Rossi-Hasberg(2008), and Lamy (October 2010).

² The committee was chaired by Professor Edward Leamer and consisted of members drawn from the council of National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

³ ADB organized a project with participation of 17 developing countries (RETA 6483) in Asia Pacific to construct supply and use tables for each participating country.

country IO databases and STAN bilateral industry trade statistics, covering about 50 countries. Since early 2009, the OECD and the WTO have been collaborating to advance the issue of measuring trade in value added. Four international organizations (UNSD, Eurostat, WTO and UNCTAD) proposed in a background document to have "a closer integration between trade statistics and the productive and financial sides of national accounts and balance of payments" by setting up an ambitious set of goals for the year 2020, including to establish a specialized satellite account of trade in value-added.⁴

It is a consensus among international statistical agencies that the direct measurement of value-added trade is extremely difficult, primarily because the information is not available in business record-keeping systems. Without such data it appears that the most feasible and most promising approaches to developing comprehensive and consistent value-added trade measures that go beyond case studies of individual high-profile products (such as the iPod) have to involve the use of International Input-Output (IIO) tables. IIO tables integrate official national accounts and bilateral trade statistics on goods and services into a consistent accounting framework. Conceptually, it is a natural extension and integration of the SNA. In statistical practice, it requires reconciling individual country's IO statistics (supply and use tables) with official bilateral trade statistics in an accounting framework that goes beyond the current SNA⁵. Because supply and use tables and input-output accounts are already a central part of the 1993 SNA, which by international consensus is the best framework for data gap assessment and GDP estimation⁶, accounting frameworks built on IIO tables could be a basis for a possible future extension of the SNA to traditional trade data, which enables integration through value-added trade derived from IIO tables into future versions of the SNA. This approach could be a workable and cost-effective way for national and international statistical agencies to remedy the missing information in current official trade statistics without dramatically changing the existing data collection practices of national customs authorities.

To achieve these goals, it is important to discover, or "estimate", the value-added structure of gross exports and establish a formal relationship between value-added measures and

⁴ "International Trade Information Systems in 2020" Global Forum on Trade Statistics, Geneva, 2-4 February 2011, *Background note by UNSD, Eurostat and WTO*.

⁵ See Isard (1960) Leontief and Strout (1963), and Leontief (1975).

⁶ 1993 SNA recommended using supply and use table as a coordinating framework for economic statistics, both conceptually and numerically to assure consistency for data draw from different sources, especially in reconciling GDP estimates from production, expenditure and income sides. See SNA 1993 pp343-371.

officially reported trade statistics, identifying those parts of value-added in gross trade statistics that is double counted, thus creating a measure of trade that is consistent with the SNA standard. This calls for a methodology to completely decompose gross exports into its various value-added components. In addition, since value-added trade measures based on IIO table are estimates and indirect measures, which are not observable and so it is difficult to assess their accuracy, a full decomposition of gross exports into its various value-added components would benchmark value-added trade estimates from IIO tables with observed trade statistics.

Hummels et al. (2001) (HIY in subsequent discussion) proposed to decompose a country's exports into domestic and foreign content shares based on a country's IO table. For a sample of 11 OECD and 3 non-OECD countries, they calculated that the average share of foreign content in exports was about 21% in 1990. There are two key assumptions in HIY's foreign content (VS) share estimation: the intensity in the use of imported inputs is the same between production for exports and production for domestic sales; and imports are 100% foreign sourced. The first assumption is violated in the presence of processing exports, which is significant portion of exports for a large number of developing countries (Koopman, Wang and Wei, 2008 and 2012). The second assumption will not hold when there is more than one country exporting intermediate goods. Therefore, HIY's measures do not hold generally in the multi-country, back-and-forth nature of current global production chains and they tend to underestimate domestic content share in exports. This is particularly important for developed countries since their imports often embody a large share of their own value-added.

Research efforts to overcome the limitations of HIY have proceeded along two lines. There is a growing literature to estimate value-added trade with the advent of global Inter-Country Input-Output (ICIO) tables based on the GTAP database⁷ in recent years. Such tables provide globally consistent bilateral trade flows, and allow comparison of production networks in different regions. This line of work is an extension of the factor content in trade literature. Daudin, Riffart, and Schweisguth (2011) compute "value-added trade" for 66 countries and analyze how vertical specialization of trade (vertical trade, in short) generates regionalization in trade patterns, intending to answer the question "who produces for whom?" in the world. They follow HIY's definition of vertical specialization and sum HIY's VS and VS1 measures as

⁷ Though usefully global in scope, the GTAP database does not separate imported intermediate and final goods in bilateral trade flows, so improvements have to be made.

vertical trade. They define value-added trade as standard trade minus vertical trade, which measures only the trade flow between producers and final users. They further distinguish the part of VS1 that returns to the country of origin as VS1*, the domestic value-added in intermediate goods exports that is ultimately consumed back at home via final goods imports. They found that the industrial and geographic patterns of value-added trade are very different from those of standard trade. We will show that their definition of VS1* should be broadened to include domestic value-added returned home via intermediate goods imports in order to be consistent with the core idea of vertical specialization and to give a full (100%) accounting of the various value-added components of a country's gross exports.

Johnson and Noguera (2012) estimate value-added trade flows among 87 countries based on the GTAP database and addresses the inaccuracies of the HIY measures. They provide a formal definition of value-added exports: which is value-added produced in a country but absorbed in another country. In contrast to HIY's measure of foreign content in exports, they propose a measure of the ratio of value-added exports to gross exports, or the VAX ratio, to measure the intensity of production sharing. As an example, they show that the U.S.-China trade imbalance in 2004 is 30-40% smaller when measured in value added terms. However, they did not realize there are conceptual differences between their VAX ratio and HIY's content share in exports, and thus interpret their VAX ratio as a metric of the domestic content of exports at the country aggregate level. We will highlight both the conceptual differences and the connections between the two concepts. In addition, we will also show how each of them can be further decomposed.

Trefler and Zhu (2010) develop a multi-country input-output framework to define a Vanek-consistent measure of the factor content of multilateral net exports, and find that once the correct factor content definition is used, the Vanek prediction performs well except for the presence of missing trade in a 41 country IO table data set. Foster, Stehrer and de Vries (2011) follow Trefler and Zhu's analytical framework, further decomposing value-added trade into factor payments in detailed categories based on the recently compiled World Input-Output Database (WIOD) sponsored by the European Commission. Specifically, they split value added into capital and labor income, and these two into ICT and Non-ICT capital and high, medium and low educated (by ISCED categories) labor income, respectively. They also mathematically

prove that value-added and gross trade balance equal each other at the country aggregate level and are able to show the net trade balance by each factor of production. For example, they found the United States still runs a surplus for highly educated labor despite its overall growing trade deficit in value-added terms. China's surplus seems evenly distributed between medium and low educated labor, but is running a deficit in highly educated labor, while Germany is increasingly running surplus in both medium and highly educated labor. However, their framework is not able to distinguish value-added components that are counted only once and those that are counted multiple times, and therefore mistakenly state that total gross exports (imports) equal total value-added trade. "The ratio of value-added exports (imports) to gross exports (imports) is equal to one" (page 8). As pointed out by Koopman et. al (2010, KPWW in subsequent discussion), although these value-added components are all created by production factors employed somewhere in the global economy, some portion of them are "double counted". Therefore, at the global and aggregate levels, value-added trade is always smaller than gross trade. The key to clarify this point is a conceptual difference between domestic content in exports and value-added trade that will be discussed in detail by this paper.

Despite the fact that most authors in the value-added trade literature discussed above link their work with HIY, their work are more closely related to the factor content discussions in the trade literature. KPWW is the only paper in this recent literature that try to consistently extend HIY's original concepts to a global setting and make HIY a special case of their more general framework. They point out value-added trade is the value generated by one country but absorbed by another country, while the domestic content of exports depends only on where value is produced, not where and how that value is used, thus showing, both conceptually and numerically, the similarities and differences between value-added trade measures and domestic content in exports measures for the first time in the literature. However, KPWW did not document their methodology clearly and especially did not explicitly discuss how those "double counted" value-added components are measured. This may have caused a serious misunderstanding, and the possibility of misuse of the gross exports decomposition method they proposed.⁸

⁸ We are grateful to Dr. Arjan Lejour and his colleagues at the Netherlands Bureau for Economic Policy Analysis, and two anonymous referees for helping us to fully realize the consequences that the description of the decomposition method in our NBER working paper may cause readers to misunderstand the method.

This paper refines the accounting framework in KPWW. After laying out the ICIO model and defining the basic measure of value-added shares by source of production, we first specify a gross output decomposition matrix based on all country's final demand which reflects the basic and uncontroversial Leontief insight, and define value-added trade. We then demonstrate mathematically how the “double counted” portion of value-added in intermediate goods trade could be measured so that gross exports can be fully decomposed into its various value-added components and how these value-added components (or combinations of them) can be connected to measures of value-added trade and vertical specialization in the previous literature and define the measure of domestic content in exports, thus clearly show its connection and differences with value-added trade. Finally, we show a potential application of our domestic value-added in exports measure by re-computing the RCA index at the country-sector level for all the countries and sectors in our database and compare them with RCA index based on traditional trade statistics and find some very interesting results. For example, if one uses the gross trade data to compute revealed comparative advantage, the machinery and equipment sector is a comparative advantage sector for China in 2007. In contrast, if one uses domestic value added in exports instead, the same sector becomes a revealed comparative disadvantage sector for China.

Rest of the paper is organized as follows. Section 2 presents the conceptual framework for decomposing gross exports into its various value added components. Section 3 discusses how the required inter-country IO model can be estimated from currently available data sources and report major empirical decomposition and RCA index computation results for the year 2007. Section 4 concludes.

2. Decomposing Gross Trade into Value Added Components: Concepts and Measurement

In this section, we first lay out the major measures of vertical specialization and value-added trade in the literature in their original forms. We pay special attention to a key conceptual difference that separates some measures from others, namely when it is appropriate to include double-counted items for some purposes but not for others.

We then propose a way to fully decompose a country's gross exports into the sum of components that include both the country's value added exports and various double-counted value-added components. In the process, we show how we can generalize the notion of vertical

specialization without the restrictive assumption on intermediate goods trade made in the original HIY framework. We also show how the existing measures of vertical specialization and value-added exports are linear combinations of the terms in our decomposition formula. The formula makes it possible to see the connections and differences among these measures precisely.

2.1 Concepts

With modern international production chains, value added originates in many locations. As noted, four measures have been proposed in the vertical specialization and value-added trade literature:

1. HIY (2001) proposed a measure of vertical specialization from the import side, which is the imported content in a country's exports. We follow HIY and label it as VS. It includes both the direct and indirect imported input content in exports. However, HIY has only considered the case in which the Home country does not export intermediary goods though it imports intermediary goods from the rest of the world. In mathematical terms, a country's VS in total exports at the sector level can be expressed as⁹ :

$$VS = A^M (I - A^D)^{-1} E$$

and, across all sectors, the average VS share in a country's total exports as

$$\frac{uA^M (I - A^D)^{-1} E}{uE}$$

2. HIY (2001) also proposed a second measure of vertical specialization from the export side (which they call VS1). It measures the value of exported goods that are used as imported inputs by other countries to produce their exports, however, HIY did not provide a mathematical definition as they did for VS;

3. Daudin et al (2011) proposed to measure a particular subset of VS1, the value of a country's exported goods that are used as imported inputs by the rest of the world to produce goods and shipped back to home. They call it VS1*;

⁹ D. Hummels et al. , *Journal of International Economics* 54 (2001) page 80.

4. Johnson and Noguera (2012) defined value-added exports as value-added produced in source country s and absorbed in destination country r and proposed the value-added to gross export ratio, "VAX ratio" as a measure of the value-added content of trade.

By definition, as value-added is a "net" concept, double counting is not allowed. As the first three measures of vertical specialization all involve values that show up in more than one country's gross exports, they, by necessity, have to include some double-counted portions of the official trade statistics. More border crossing by intermediate goods (more double counting) means a larger difference between value-added trade and these vertical specialization measures. This implies that these two type measures are not equal to each other in general because double counting is only allowed in one of them. They equal each other only in some special cases as we will show later. In addition, these existing measures are all proposed as stand-alone indicators. No common mathematical framework proposed in the literature provides a unified accounting for them and spells out their relationships explicitly. More importantly, as noted earlier, the most widely used HIY measure (VS) needs two strong assumptions and is only valid in special cases; there is no mathematically specified measure for indirect value-added exports through third countries, and all four measures proposed so far do not identify all value-added components in gross exports.

To better understand the difference between the measures of value-added trade and vertical specialization as well as their relation with gross exports, we need to define them precisely in mathematical terms and derive them from a common mathematical framework.

2.2 The G-country N-sector Inter-Country Input-Output (ICIO) Model

Assume a world with G -countries, in which each country produces goods in N differentiated tradable sectors. Goods in each sector can be consumed directly or used as intermediate inputs, and each country exports both intermediate and final goods to all other countries.

All gross output produced by country s must be used as an intermediate good or a final good at home or abroad, or

$$X_s = \sum_r^G (A_{sr} X_r + Y_{sr}), \quad r, s = 1, 2, \dots, G \quad (1)$$

Where X_s is the $N \times 1$ gross output vector of country s , Y_{sr} is the $N \times 1$ final demand vector that gives demand in country r for final goods produced in s , and A_{sr} is the $N \times N$ IO coefficient matrix, giving intermediate use in r of goods produced in s .

The G -country, N -sector production and trade system can be written as an ICIO model in block matrix notation

$$\begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_G \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1G} \\ A_{21} & A_{22} & \cdots & A_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ A_{G1} & A_{G2} & \cdots & A_{GG} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_G \end{bmatrix} + \begin{bmatrix} Y_{11} + Y_{12} + \cdots + Y_{1G} \\ Y_{21} + Y_{22} + \cdots + Y_{2G} \\ \cdots \\ Y_{G1} + Y_{G2} + \cdots + Y_{GG} \end{bmatrix}, \quad (2)$$

and rearranging,

$$\begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_G \end{bmatrix} = \begin{bmatrix} I - A_{11} & -A_{12} & \cdots & -A_{1G} \\ -A_{21} & I - A_{22} & \cdots & -A_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ -A_{G1} & -A_{G2} & \cdots & I - A_{GG} \end{bmatrix}^{-1} \begin{bmatrix} \sum_r^G Y_{1r} \\ \sum_r^G Y_{2r} \\ \vdots \\ \sum_r^G Y_{Gr} \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} & \cdots & B_{1G} \\ B_{21} & B_{22} & \cdots & B_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ B_{G1} & B_{G2} & \cdots & B_{GG} \end{bmatrix} \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_G \end{bmatrix} \quad (3)$$

where B_{sr} denotes the $N \times N$ block Leontief inverse matrix, which is the total requirement matrix that gives the amount of gross output in producing country s required for a one-unit increase in final demand in destination country r . Y_s is a $N \times 1$ vector that gives the global use of s 's final goods.

While variations of this framework have been used in a number of recent studies, none uses the block matrix inverse as their mathematical tool and works out a complete tracing of all sources of value added. We turn to this task next.

2.3 Value-added share by source matrix

Let V_s be the $1 \times N$ direct value-added coefficient vector. Each element of V_s gives the ratio of direct domestic value added in total output for country s . This is equal to one minus the intermediate input share from all countries (including domestically produced intermediates):

$$V_s = u(I - \sum_r^G A_{rs}), \quad (4)$$

Define V , the $G \times GN$ matrix of direct domestic value added for all countries,

$$V = \begin{bmatrix} V_1 & 0 & \cdots & 0 \\ 0 & V_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & V_G \end{bmatrix}. \quad (5)$$

Multiplying these direct value-added shares with the Leontief inverse matrices produces the $G \times GN$ value-added share (VB) matrix, our basic measure of value-added shares by source of production.

$$VB = \begin{bmatrix} V_1 B_{11} & V_1 B_{12} & \cdots & V_1 B_{1G} \\ V_2 B_{21} & V_2 B_{22} & \cdots & V_2 B_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ V_G B_{G1} & V_G B_{G2} & \cdots & V_G B_{GG} \end{bmatrix}. \quad (6)$$

Within VB, each element in the diagonal block $V_s B_{ss}$ (a 1 by N row vector) denotes domestic value-added share of domestically produced products in a particular sector at home. Similarly, each element in the off-diagonal block $V_s B_{sr}$ in the same column denotes the share of other countries' value-added in these same goods. Each of the first N columns in the VB matrix includes all value added, domestic and foreign, needed to produce one additional unit of domestic products in country 1. Each of the next N columns present value-added shares for production in country 2, 3,... G . Because all value added must be either domestic or foreign, the sum along each column is unity:

$$\sum_s^G V_s B_{sr} = u. \quad (7)$$

It is important to note that the VB matrix is not any arbitrary share matrix, but rather the one that reflects the underlying production structure embedded in the inter-country input-output (ICIO) model specified in equations (2) and (3). It contains all the needed information on value-added production by source, from which we can separate domestic and imported content shares in each country's production at the sector level.

There is an important conceptual difference between the measure of domestic content of exports and the measure of value-added trade. Although they both measure the value generated by factors employed in the producing country, domestic content of exports depends only on where the value is produced regardless where and how it is used. In contrast, value-added trade depends not only on where the value is produced, but also on how it is used by importers. It is the value-added produced by a country but absorbed by another country. By such definitions, a country's gross exports minus its domestic content in exports will be the foreign content in its exports (which we show below), and, when expressed as a share of the country's gross exports, is equivalent to the vertical specialization measure (VS share) proposed by HIY (2001). A country's "value-added exports", in the language of Johnson and Noguera (2012), on the other hand, does not have a natural link with the vertical specialization measure as we discussed earlier. It is a subset of the domestic content in a country's exports at the aggregate. In other words, value added in exports must be always smaller than or at most equal to domestic content in exports in the aggregate.

To better understand the relationship between these two important concepts as well as their relation to gross exports, let us define them precisely in mathematical terms.

2.4 Gross output decomposition matrix and value-added trade

To define value added trade and domestic content in a country's exports in mathematical terms so their relationship can be transparent, it is useful to first decompose each country's gross output in terms of final demand according to where it is absorbed by geographical location. We do this by rearranging the final demand into a matrix format by source and destination, and rewrite equation (3) as follows:

$$\begin{bmatrix} B_{11} & B_{12} & \cdots & B_{1G} \\ B_{21} & B_{22} & \cdots & B_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ B_{G1} & B_{G2} & \cdots & B_{GG} \end{bmatrix} \begin{bmatrix} Y_{11} & Y_{12} & \cdots & Y_{1G} \\ Y_{21} & Y_{22} & \cdots & Y_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ Y_{G1} & Y_{G2} & \cdots & Y_{GG} \end{bmatrix} = \begin{bmatrix} \sum_r^G B_{1r} Y_{r1} & \sum_r^G B_{1r} Y_{r2} & \cdots & \sum_r^G B_{1r} Y_{rG} \\ \sum_r^G B_{2r} Y_{r1} & \sum_r^G B_{2r} Y_{r2} & \cdots & \sum_r^G B_{2r} Y_{rG} \\ \vdots & \vdots & \ddots & \vdots \\ \sum_r^G B_{Gr} Y_{r1} & \sum_r^G B_{Gr} Y_{r2} & \cdots & \sum_r^G B_{Gr} Y_{rG} \end{bmatrix} \equiv \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1G} \\ X_{21} & X_{22} & \cdots & X_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ X_{G1} & X_{G2} & \cdots & X_{GG} \end{bmatrix} \quad (8)$$

Where Y_{sr} is a N by 1 vector defined in equation (1), giving the final goods produced in country s and consumed in country r. This final demand matrix on the left-hand-side of Equation (8) is a GN by G block matrix, summing along row s of the final demand matrix equals Y_s , which represents the global use of the final goods produced in country s as specified in equation (3). We label the GN by G matrix on the far right hand side of Equation (8) the “gross output decomposition matrix.” Each element X_{sr} (a N by 1 vector) in this matrix is the gross output in source country s necessary to sustain final demand in destination country r. Summing along its row equals gross output in country s as the N by 1 vector X_s specified in equation (1).

Equation (8) fully decomposes each country’s gross outputs according to where it is absorbed. A typical diagonal element is gross output absorbed in the producing (home) country, while a typical off diagonal element could be divided into different groups based on analytical need, such as gross output absorbed by the direct importing country and gross output re-exported by the direct importing country to all other third countries.¹⁰

Let $\hat{V}_s$ be a N by N diagonal matrix with direct value-added coefficients along the diagonal. (Note $\hat{V}_s$ is related to but different from V_s , which is a 1 by N row vector). We then define a GN by GN diagonal value-added coefficient matrix as

¹⁰ We name this matrix as “gross output decomposition matrix” and think it is better than the term of “output transfer” used in Johnson & Noguera (2010), since decomposing a country’s gross output by geographical location that sustains global final goods production is the major role of this matrix. Johnson & Noguera (2010) defined a G by 1 output vector, which they call “output transfer,” similar to our equation (3). Our “gross output decomposition matrix” is a decomposition of this vector.

$$\hat{V} = \begin{bmatrix} \hat{V}_1 & 0 & \cdots & 0 \\ 0 & \hat{V}_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \hat{V}_G \end{bmatrix} \quad (9)$$

Multiplying this value-added coefficient matrix with the right hand side of equation (8), we obtain a GN by G value-added production matrix $\hat{V}BY$

$$\hat{V}BY = \begin{bmatrix} \hat{V}_1 & 0 & \cdots & 0 \\ 0 & \hat{V}_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \hat{V}_G \end{bmatrix} \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1G} \\ X_{21} & X_{22} & \cdots & X_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ X_{G1} & X_{G2} & \cdots & X_{GG} \end{bmatrix} \quad (10)$$

Its diagonal elements give each country's production of value-added absorbed at home while its off diagonal elements constitute the GN by G bilateral value-added trade matrix. Because the value-added trade matrix is the off-diagonal elements of $\hat{V}BY$, it excludes value-added produced by the home country that returns home after being processed abroad. Each of its off-diagonal elements can be written as:

$$VT_{sr} \equiv V_s X_{sr} = V_s \sum_g^G B_{sg} Y_{gr} \quad (11)$$

This is the value-added produced in source country s and absorbed in destination country r, the definition of value-added exports, similar to Johnson and Noguera (2010), but in terms of all countries' final demand.

A country's total value-added exports to the world equal:

$$VT_{s*} = \sum_r^G VT_{sr} = V_s \sum_{r \neq s}^G \sum_{g=1}^G B_{sg} Y_{gr} \quad (12)$$

By rewriting equation (12) into three groups according to where the value-added exports are absorbed, we obtain a decomposition as follows:

$$VT_{s*} = V_s \sum_{r \neq s}^G B_{ss} Y_{sr} + V_s \sum_{r \neq s}^G B_{sr} Y_{rr} + V_s \sum_{r \neq s}^G \sum_{t \neq s, r}^G B_{sr} Y_{rt} \quad (13)$$

This is the value-added export decomposition in terms of all countries' final demands. The first term is value-added in the country's final goods exports; the second term is value-added in the country's intermediate exports used by the direct importer to produce final goods consumed by the direct importer, the third term is value-added in the country's intermediate exports used by the direct importing country to produce final goods for third countries. Please note equation (13) excludes the value-added in a country's exports that finally returned and consumed at home.

After defining value-added trade in term of final demand, let us show next how a country's gross exports can be decomposed into its various value-added components and how its double counted portion can be measured.

2.5 Decomposition of gross exports to its various value-added components

Let E_{sr} be the $N \times 1$ vector of gross bilateral exports from s to r .

$$E_{sr} \equiv A_{sr} X_r + Y_{sr} \quad \text{for } s \neq r \quad (14)$$

A country's gross exports to the world equal

$$E_{s*} = \sum_{r \neq s}^G E_{sr} = \sum_{r \neq s}^G (A_{sr} X_r + Y_{sr}) \quad (15)$$

From equation (8) we know that

$$\sum_{r=1}^G \sum_{g=1}^G B_{sg} Y_{gr} = \sum_{r=1}^G X_{sr} = X_s \quad (16)$$

Therefore, following identity hold

$$V_s X_s \equiv V_s \sum_{r=1}^G \sum_{g=1}^G B_{sg} Y_{gr} \quad (17)$$

Multiplying both sides of (15) by (7), we have

$$uE_{s*} = (B_{ss} + \sum_{t \neq s}^G B_{ts}) E_{s*} = V_s B_{ss} \sum_{r \neq s}^G (A_{sr} X_r + Y_{sr}) + \sum_{t \neq s}^G V_t B_{ts} \sum_{r \neq s}^G (A_{sr} X_r + Y_{sr}) \quad (18)$$

Now we add and subtract VT_{s*} , defined by equation (12), to the first term on RHS of (18). This gives

$$V_s B_{ss} E_{s*} = VT_{s*} + V_s B_{ss} \sum_{r \neq s}^G (A_{sr} X_r + Y_{sr}) - V_s \sum_{r \neq s}^G \sum_{g=1}^G B_{sg} Y_{gr} \quad (19)$$

Recall that $X_s = \sum_{r=1}^G (A_{sr} X_r + Y_{sr})$ as defined in (1), insert it together with equation (16) into (19)

gives

$$V_s B_{ss} E_{s*} = VT_{s*} + V_s B_{ss} (X_s - A_{ss} X_s - Y_{ss}) - V_s (X_s - \sum_{g=1}^G B_{sg} Y_{gs}) \quad (20)$$

Where $X_s - A_{ss} X_s - Y_{ss}$ equals the difference between country s' gross output and gross output

sold in domestic market, i.e. what country s' gross exports to the world market; $X_s - \sum_{g=1}^G B_{sg} Y_{gs}$

equals the difference between country s' gross output and the its gross output finally consumed at domestic market . By rearranging terms,

$$V_s B_{ss} E_{s*} = VT_{s*} + V_s [B_{ss} (I - A_{ss}) - I] X_s + V_s [\sum_{g=1}^G B_{sg} Y_{gs} - B_{ss} Y_{ss}] \quad (21)$$

Substitute $B_{ss} (I - A_{ss}) - I$ in equation (21) by $\sum_{r \neq s}^G B_{sr} A_{rs}$ (the property of inverse matrix , see

equation (28) bellow) we have

$$V_s B_{ss} E_{s*} = V_s \sum_{r \neq s}^G \sum_{g=1}^G B_{sg} Y_{gr} + V_s \sum_{r \neq s}^G B_{sr} Y_{rs} + V_s \sum_{r \neq s}^G B_{sr} A_{rs} X_s \quad (22)$$

Insert (22) into (18) and rearrange terms, we obtain our gross export decomposition equation as follows:

$$\begin{aligned} uE_{s*} &= V_s B_{ss} E_{s*} + \sum_{r \neq s}^G V_r B_{rs} E_{s*} \\ &= VT_{s*} + \{V_s \sum_{r \neq s}^G B_{sr} Y_{rs} + V_s \sum_{r \neq s}^G B_{sr} A_{rs} X_s\} + \{\sum_{t \neq s}^G \sum_{r \neq s}^G V_t B_{ts} Y_{sr} + \sum_{t \neq s}^G \sum_{r \neq s}^G V_t B_{ts} A_{sr} X_r\} \end{aligned} \quad (23)$$

where

$$V_s \sum_{r \neq s}^G B_{sr} A_{rs} X_s = V_s \sum_{r \neq s}^G B_{sr} A_{rs} (I - A_{ss})^{-1} Y_{ss} + V_s \sum_{r \neq s}^G B_{sr} A_{rs} [X_s - (I - A_{ss})^{-1} Y_{ss}] \quad (24)$$

$$\sum_{t \neq s}^G \sum_{r \neq s}^G V_t B_{ts} A_{sr} X_r = \sum_{r \neq s}^G V_r B_{rs} A_{sr} (I - A_{rr})^{-1} Y_{rr} + \sum_{t \neq s}^G V_t B_{ts} A_{sr} \sum_{r \neq s}^G [X_r - (I - A_{rr})^{-1} Y_{rr}] \quad (25)$$

The first term in equation (23) is value-added exports (which can be further decomposed into 3 parts according to equation (13)), the second term in the first bracketed expression, includes country s' value-added in both final goods and intermediate goods that is first exported but eventually returned home, both of which are parts of the double counting in gross export statistics. The third term in the second bracketed expression, is foreign value-added in country s' gross exports, include both final and intermediate goods. It is also a double counted portion in the official gross export statistics, because in value-added terms, they are already counted at least once as the producing foreign country's domestic value-added, if we consider the world as a whole. Equation (24) further partitions the double counted domestic value-added in intermediate goods returned to the source country into two parts: one is domestic value-added embodied in the source country's intermediate goods exports that is returned home in its intermediate goods imports used to produce final goods that are consumed at home; the other is a pure double counted portion of the source country's domestic value-added in its gross intermediate goods exports. Similarly, equation (25) further identifies the pure double counted portion of foreign value-added in the source country's intermediate goods exports. A detailed derivation of equations (24) and (25) is given in next sub-section. The gross export decomposition made by equations (13) and (23) to (25) is also diagrammed in Figure 1.

2.6. Further partition and interpretation of the double counted terms

Because the two terms that measure double counted of intermediate goods trade in (23) still expressed in gross intermediate exports, we need decompose them further to see precisely what is double counted. We can show that $V_s \sum_{r \neq s}^G B_{sr} A_{rs} X_s$ can be further split into two parts: one is part of the home country's domestic value-added that first exported but finally returns home in its intermediate imports to produce final goods and consumed at home, the other is a pure double counting portion due to two way intermediate trade.

Using the relation $X_s = Y_{ss} + A_{ss} X_s + E_{s*}$, it is easy to show that

$$X_s - (I - A_{ss})^{-1} Y_{ss} = (I - A_{ss})^{-1} E_{s*}. \quad (26)$$

$(I - A_{ss})^{-1} Y_{ss}$ is the gross output needed to sustain final goods that is both produced and consumed in country s, using domestically produced intermediate goods (gross output sold directly in the domestic market); deduct it from country s' total gross output, what left is the

gross output needed to sustain country s' production of its gross exports. Therefore, the left hand side of equation (26) has straightforward economic meanings. We can further show that

$$(I - A_{ss})^{-1}Y_{ss} = B_{ss}Y_{ss} - \sum_{r \neq s}^G B_{sr}A_{rs}(I - A_{ss})^{-1}Y_{ss} \quad (27)$$

the last term in RHS of (27) is the final gross output needed to sustain final goods that is both produced and consumed in country s, but using intermediate goods that was originated in country s but shipped to other countries for processing before being re-imported by the source country in its intermediate goods imports (gross output sold indirectly in domestic market).

Given (27), it easy to see why equation (24) holds.

Equation (27) can be proven by using the property of inverse matrix :

$$\begin{bmatrix} B_{11} & B_{12} & \dots & B_{1G} \\ B_{21} & B_{22} & \dots & B_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ B_{G1} & B_{G2} & \dots & B_{GG} \end{bmatrix} \begin{bmatrix} I - A_{11} & -A_{12} & \dots & -A_{1G} \\ -A_{21} & I - A_{22} & \dots & -A_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ -A_{G1} & -A_{G2} & \dots & I - A_{GG} \end{bmatrix} \begin{bmatrix} I & 0 & \dots & 0 \\ 0 & I & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & I \end{bmatrix}$$

we therefore have

$$B_{ss}(I - A_{ss}) - I = \sum_{r \neq s}^G B_{sr}A_{rs} \quad (28)$$

Using (28), we have

$$(I - A_{ss})^{-1}Y_{ss} + [B_{ss}(I - A_{ss}) - I](I - A_{ss})^{-1}Y_{ss} = B_{ss}Y_{ss} \quad (29)$$

Insert equation (16) into equations (24), we can express the pure double counting term (the last term) in equation (24) in terms of all countries final demand as follows:

$$\begin{aligned} V_s \sum_{r \neq s}^G B_{sr}A_{rs}[X_s - (I - A_{ss})^{-1}Y_{ss}] &= V_s \sum_{r \neq s}^G B_{sr}A_{rs}[\sum_{r=1}^G \sum_{g=1}^G B_{sg}Y_{gr} - (I - A_{ss})^{-1}Y_{ss}] \\ &= V_s \sum_{r \neq s}^G B_{sr}A_{rs}[\sum_{r \neq s}^G \sum_{g=1}^G B_{sg}Y_{gr} + B_{ss}Y_{ss} - (I - A_{ss})^{-1}Y_{ss}] \\ &= V_s \sum_{r \neq s}^G B_{sr}A_{rs}[\sum_{r \neq s}^G \sum_{g=1}^G B_{sg}Y_{gr} + \sum_{r \neq s}^G B_{sr}A_{rs}(I - A_{ss})^{-1}Y_{ss}] \end{aligned} \quad (30)$$

An inspection of the bracketed expression in the RHS of (30) and compare it with the first three value-added terms in equation (23) (the first two terms in equation (23) plus the first term in equation (24)) shows that they have a similar B_{sr} and Y_{sr} combinations. This indicates double counting occurs in two way intermediate goods trade, because a part of the final gross

output (in terms of $B_{sr}Y_{sr}$) to sustain country s' gross exports is double counted (they are already counted once in the three value-added terms), thus leading to double counting value-added embodied in it due to the two way cross border intermediate goods trade (expressed by

$$\sum_{t \neq s}^G B_{sr}A_{rs}).$$

However, these double counted terms are also part of the value of the source country's gross export, missing them the decomposition will be incomplete.

In addition, the pure double counting measure when expressed in all country's final demand in equation (30) further illustrate how it captures the multiple counting nature of the intermediate goods trade. For example, A_{rs} is country s' direct use of imported intermediate input from country r in its production, while B_{sr} is country r's total use of intermediate imported input from country s in its production, $B_{sr}A_{rs}$ gives the total request gross output in country s that makes for country r's production of each unit of intermediate goods export back to country s possible. This is exactly reflect the back and forth, double counting nature of intermediate goods trade between country s and country r, because such intermediate goods may travel between Country s and Country r many times (perhaps also via several third countries), before being used to produce final goods by Country s, which then may be consumed by Country s, or exported again to Country r and/or other third countries. The two foreign value-added terms in the last bracketed expression of equation (23) also counted as a double counting because it is already counted at least once as the producing foreign country's domestic value-added, if we consider the world as a whole.

Following the same logic and using the property of inverse matrix and equation (16) again, we can show that equation (25) also holds and can be expressed in terms of all countries' final demand.

Equation (23) provides a clear relationship between a country's value-added exports and its gross exports. Such a relationship cannot be easily discerned if we define value-added exports from the gross output decomposition matrix in equation (8) similar to Johnson and Noguera (2012) rather than as equations (11) in terms of final demand.

2.7. Gross exports decomposition and measures of vertical specialization

All measures of vertical specialization in the previous literature can be expressed and generalized as linear combination of the various value-added components identified by equation (23) as follows:

$$VS_s = \sum_{r \neq s}^G V_r B_{rs} E_{s^*} = \sum_{t \neq s}^G \sum_{r \neq s}^G V_t B_{ts} Y_{sr} + \sum_{t \neq s}^G \sum_{r \neq s}^G V_t B_{ts} A_{sr} X_r \quad (31)$$

Which is the fourth and last terms in Equation (23), and the aggregate VS share of country s

equals $\frac{\sum_{r \neq s}^G V_r B_{rs} E_{s^*}}{u E_{s^*}}.$

We can verify that Equation (31) is reduced to more familiar expressions in some special cases. As shown by Koopman, Wang and Wei (2008), in a single country IO model (i.e., one in which no two-way international trade in intermediate goods takes place)

$$VS \text{ share} = u - A_v (I - A^D)^{-1} = u A^M (I - A^D)^{-1} \quad (32)$$

In the G-country world, at the sector level

$$VS \text{ share} = u - V_s (I - A_{ss})^{-1} - \sum_{r \neq s}^G V_s B_{sr} A_{rs} (I - A_{ss})^{-1} = u - V_s B_{ss} = \sum_{r \neq s}^G V_r B_{rs} \quad (33)$$

The last term in the second step is the adjustment made for domestic value-added returned to the source country. Therefore, our foreign content measure of gross exports is a natural generalization of HIY's VS measure in a multi-country setting with unrestricted intermediate goods trade. Because $\sum_{r \neq s}^G V_r B_{rs} + \sum_{r \neq s}^G V_s B_{ss} = u$, it is natural to define a country's domestic content in its exports as:

$$DC_s = V_s B_{ss} E_{s^*} = VT_{s^*} + V_s \sum_{r \neq s}^G B_{sr} Y_{rs} + V_s \sum_{r \neq s}^G B_{sr} A_{rs} X_s \geq \sum_r^G VT_{sr} \quad (34)$$

It clearly shows that a country's domestic content in its exports is generally greater than its value-added exports in aggregate. The two measures equal each other only in the case where there is no returned domestic value-added in imports, i.e. when both $V_s \sum_{r \neq s}^G B_{sr} Y_{rs}$ and $V_s \sum_{r \neq s}^G B_{sr} A_{rs} X_s$ are zero.

The second HIY measure of vertical specialization (labeled as VS1 by HIY) details how much exported goods in the source country that are used as imported inputs to produce other countries' export goods. Although an expression for such indirectly exported products has not been previously defined mathematically in the literature, it can be specified precisely based on some of the terms in our export decomposition equation (13) and (23).

$$VS1_s = V_s \sum_{r \neq s}^G B_{sr} E_{r*} = V_s \sum_{r \neq s}^G \sum_{t \neq s, r}^G B_{sr} Y_{rt} + V_s \sum_{r \neq s}^G \sum_{t \neq s, r}^G B_{sr} A_{rt} X_t + V_s \sum_{r \neq s}^G B_{sr} Y_{rs} + V_s \sum_{r \neq s}^G B_{sr} A_{rs} X_s \quad (35)$$

This means HIY's VS1 could expressed as the last term in equation (13) (part of the first term in (23)) plus the second and third terms in equation (23) as well as an additional term that measures how much domestic value-added in exported goods from the source country that are used as imported inputs to produce other countries' intermediate goods exports. It also show clearly that HIY's VS1 measure is generally greater than indirect value-added exports (IV) because the latter only includes the first term of (35) but excludes domestic value-added that is returned home and value-added embodied in intermediate goods exports via third countries (they are already counted as other countries' foreign value-added in these third countries' exports, part of the last term in (23)), i.e.

$$IV_s = V_s \sum_{r \neq s}^G \sum_{t \neq s, r}^G B_{sr} Y_{rt} \leq VS1_s \quad (36)$$

$$VS1_s^* = \sum_{s \neq t} V_s B_{sr} E_{rs} = V_s \sum_{r \neq s}^G B_{sr} Y_{rs} + V_s \sum_{r \neq s}^G B_{sr} A_{rs} X_s \quad (37)$$

As Equation (37) shows, we define VS1* as part of VS1(last two terms of (35)). This definition differs from Daudin et al. (2011), as they include only domestic value-added returned home in final goods imports (the first term in equation (37)) but exclude domestic value-added returned home by being embodied in the imports of intermediate goods (the second term in equation (37)). [Note that the second term can be further decomposed into two terms in equation (24).] If omitting the second term, then VS1* would have been inconsistent with the core idea to measure vertical specialization from the exports side, as it fails to account for the source country's exports used by third countries to produce their exports of intermediate goods. It would have consistently under-estimated actual extent of vertical specialization. To put it differently, the same domestic value-added embodied in a country's intermediate goods exports manifests itself in international trade flows in two ways: (a) as foreign value-added in other countries

exports, and (b) as the source country's indirect exports of value added via a third country. In other words, the foreign value-added in one country's exports is the domestic value-added of another country embodied in its indirect exports. As an example, the Japanese value added in the form of Japan-made computer chips used in China's exports of electronic toys to the United States represents foreign value added in China's exports, and it is also simultaneously Japan's indirect exports of its domestic value added to the United States. While these two perspectives produce the identical numbers when aggregating across all countries at the global level, their values for a given country can be very different. Therefore, when measuring a country's participation in vertical specialization it is useful to be able to trace the two perspectives separately. This is also why HIY proposed two measures of vertical specialization, because a complete picture of vertical specialization and a country's position in a vertical integrated production network has to involve both measures. Indeed, for a given country, the ratio of the two measures provides insight for the country's position in global value chains. Downstream countries tend to have a higher share of vertical specialization from the import side, i.e higher foreign content (VS) in their exports, while upstream countries tend to have a higher share of vertical specialization from the export side (VS1), a higher share of exports via third countries. In addition, as we show in equation (23), ignoring domestic value-added returning home via intermediate goods imports, one of the value-added components in a country's gross exports, would leave the decomposition incomplete.

These generalized measures of vertical specialization specified in equations (31), (34) and (35) can be combined more succinctly by the VBE matrix as follows:

$$VBE = \begin{bmatrix} V_1 B_{11} E_{1*} & V_1 B_{12} E_{2*} & \cdots & V_1 B_{1G} E_{G*} \\ V_2 B_{21} E_{1*} & V_2 B_{22} E_{2*} & \cdots & V_2 B_{2G} E_{G*} \\ \vdots & \vdots & \ddots & \vdots \\ V_G B_{G1} E_{1*} & V_G B_{G2} E_{2*} & \cdots & V_G B_{GG} E_{G*} \end{bmatrix} \quad (38)$$

Its diagonal terms measure domestic content in a country's gross exports; the sum of its off-diagonal elements *along a column* is the generalized measure of foreign content embodied in a country's gross exports; the sum of its off-diagonal elements *along a row* provides information on a country's exports used as intermediate inputs in producing third countries' gross exports, the generalized VS1. These generalized measures of vertical specialization are only equal to value-added trade measures defined in equation (12) in some special cases when there is no two

way intermediate goods trade and generally greater than value-added trade measures in the aggregate.

Finally, the VAX ratio can be defined as the first term in equation (23) divided by the country's gross exports at the bilateral and aggregate levels, respectively:

$$VAX_{sr} = \frac{V_s \sum_{g=1}^G B_{sg} Y_{gr}}{uE_{sr}} \quad VAX_s = \frac{V_s \sum_{r \neq s} \sum_{g=1}^G B_{sg} Y_{gr}}{uE_{s*}} \quad (39)$$

To summarize, equations (23) to (25) provide a new way of thinking about the gross exports statistics. The various double counted items identified in the decomposition formula can be used to gauge the depth of a country's participation in global production chains and provide useful quantitative information to construct various measures of vertical specialization. In other words, the relative importance of the various double-counted terms in addition to the value-added trade estimates contain useful and important information on how a country participates in the global production chains and vertical specialization. Simply stripping away double counted items and focusing just on value added trade would miss such useful information. (We provide some numerical examples in next section.)

It is important to bear in mind that avoiding double counting is critical in value-added trade estimation, but the gross export decomposition and measuring vertical specialization have to include both the double counted items and the value added exports. Otherwise, the decomposition would be incomplete and the measures will be consistently underestimate the actual degree of vertical specialization that reflected by official trade statistics. Because our decomposition approach can simultaneously produce estimates of the domestic/foreign content in exports, which is a natural extension of HIY's measure in global setting, estimates of value added exports, and estimates of various double counted measures in gross exports, which reflect the depth of a country's participation in vertical specialization, our approach can have many useful applications.

Equations (13) and (23) (or Figure 1) also integrates the older literature on vertical specialization with the newer literature on value added trade, while ensuring that measured value-added components from all sources, including what is double counted, accounts for total gross exports. The vertical specialization literature only decomposes gross exports into two

components: domestic and foreign content. Equation (23) shows that a country's domestic content can be further broken down into additional components that reveal the destination of a country's exported value added, including its own value-added that returns home in its imports and what is double counted due to cross border intermediate goods trade. Similarly, Equation (23) also traced the foreign content in a country's exports to its sources.

On the other hand, the value-added trade literature's emphasis on estimating of value-added exports by eliminating double counting, ignoring the structure of the double counted components in current trade statistics. One unfortunate consequence is that it is not able to fully address what the vertical specialization literature intends to do, and to infer a country's position in the global production chains. Our decomposition method integrates the major concepts in the literature on the one hand, and clearly distinguishes them on the other hand.

Finally, please note that a single subscript is used for the domestic content measure and two subscripts are used for the value-added trade measure. This is to suggest that the value-added trade measure holds for both aggregate and bilateral trade, while the gross export decomposition method we propose only holds for a country's total exports to the world. Additional research is needed to investigate if and how one may decompose bilateral gross trade flows. We leave this to our future research.

III. Data and Application

3.1 Construction of an Inter-Country Input-output (ICIO) table and its data sources

To provide a workable dataset and empirically conduct our gross export decomposition and estimate domestic value-added in exports, we construct a global ICIO table for 2007 based on version 8 of the GTAP database as well as detailed trade data from UN COMTRADE, and two additional IO tables for major emerging economies where processing exports are a large portion of their external trade. We integrate the GTAP database and the additional information with a quadratic mathematical programming model that (a) minimizes the deviation of the resulting new data set from the original GTAP data, (b) ensures that supply and use balance for each sector and every country, and (c) keeps all sectoral bilateral trade flows in the GTAP database constant. The new database covers 62 countries/regions and 41 sectors and is used as the major data source of

this paper¹¹. ICIO tables specify destination country r 's use in sector i of imports from sector j from source country s . To estimate these detailed inter-industry and inter-country intermediate flows, we need to (i) distinguish intermediate and final use of imports from different sources in each sector, and (ii) allocate intermediate goods from a particular country source to each sector it is used within all destination countries. We address the first task by concordancing detailed bilateral trade statistics to end-use categories (final and intermediate) using UN Broad Economic Categories (BEC). No additional information is available to properly allocate intermediates of a particular sector from a specific source country to its use industries at the destination economy, however. Thus, sector j 's imported intermediate inputs of a particular product are initially allocated to each source country by assuming they are consistent with the aggregate source structure of that particular product.¹²

Although the GTAP database provides bilateral trade flows, it does not distinguish whether goods are used for intermediate or final demands. Our initial allocation of bilateral trade flows into intermediate and final uses is based on the UN BEC applied to detailed trade statistics at the 6-digit HS level from COMTRADE¹³. This differs from the approaches in Johnson and Noguera (2012) and Daudin, Riffart, and Schweisguth (2011), which also transform the MCIO table in the GTAP database into an ICIO table. However, they do not use detailed trade data to identify intermediate goods in each bilateral trade flow. Instead, they apply a proportionality method directly to the GTAP trade data; i.e., they assume that the proportion of intermediate to final goods is the same for domestic supply and imported products.

The use of end-use categories to distinguish imports by use is becoming more widespread in the literature and avoids some noted deficiencies of the proportionality method.¹⁴ Feenstra and Jensen (2009) use a similar approach to separate final goods from intermediates in U.S. imports

¹¹ Please refer to Tsigas, Wang and Ghelhar (2012) for details on how such database can be constructed from the GTAP database.

¹² For example, if 20% of U.S. imported intermediate steel comes from China, then we assume that each U.S. industry obtains 20% of its imported steel from China. Such an assumption ignores the heterogeneity of imported steel in different sectors. It is possible that 50% of the imported steel used by the U.S. construction industry may come from China, while only 5% of the imported steel used by auto makers may be Chinese.

¹³ Both the zero/one and a weighting scheme can be used with BEC. We used a zero/one classification. Shares based on additional information could be applied to dual use products to further improve the allocation. These are areas for future research.

¹⁴ The literature notes that the UN BEC classification has shortcomings of its own however, particularly its inability to properly identify dual-use products such as fuels, automobiles, and some food and agricultural products.

in their recent re-estimation of the Feenstra-Hanson measure of material offshoring. Dean, Fung, and Wang (2009) show that the proportionality assumption underestimates the share of imported goods used as intermediate inputs in China's processing trade. The intermediate share estimates based on detailed trade statistics and UN BEC provides a better row total control for each block matrix of A_{sr} in the ICIO coefficient matrix A , thus improving the accuracy of the most important parameters (the IO coefficients) in an ICIO model. However, it still does not properly allocate particular intermediate goods imported from a specific source country to each using industry (the coefficients in each cell of a particular row in each block matrix A_{sr} still have to be estimated by proportionality assumption). This allocation is especially important to precisely estimate value-added by sources for a particular industry, although it is less critical for the country aggregates because total imports of intermediates from a particular source country are fixed by observed data, so misallocations across sectors will likely cancel out.

3.2 Complete decomposition of gross exports

Table 1 presents a complete decomposition of each country's gross exports to the world in 2004 using the five basic value-added components specified in equation (13) and (23). The column number in the first five columns corresponds to the box number in Figure 1. The first three columns also correspond to the three terms in the RHS of equation (13) and columns (4) and (5) also correspond to the two bracketed terms in equation (23).

We compute the terms in equations (13) and (23) independently and verify that they sum to exactly 100 percent of gross exports. The resulting estimates constitute the first such decomposition in a global setting and clearly highlight what is double counted in the official trade statistics. Column (10) reports the percentage of double counting by adding columns (4) and (5). At the global level, only domestic value added in exports absorbed abroad are value-added exports. In addition to foreign content in exports, domestic content that returns home from abroad is also a part of double counting in official trade statistics, since it crosses borders at least twice. Such returned value added has to be separated from domestic value-added absorbed abroad in order to fully capture multiple counting in official trade statistics. Therefore, for any country's gross exports, the double counting portion equals the share of gross exports in excess

of the value-added exports. This share is about 25.1% for total world exports in 2007 based on our ICIO database.

The decomposition results reported in table 1 also provide a more detailed breakdown of domestic content in exports than has been previously available in the literature. The variations in the relative size of different components across countries provide a way to gauge the differences in the role that countries play in global production networks. For example, for the United States, the share of foreign value added in its exports is 15.4%, indicating that most of its exports reflect its own domestic value added. In comparison, for China's processing exports, the share of foreign value added is 53.2%, indicating China's domestic value added accounts for less than half the value of its processing exports. More importantly, about 40% of the double counting in U.S. exports – reflected as 1-VAX ratio in column 10 - comes primarily from its own value-added returns home via imports (9.5% over 24.9%). In contrast, almost all of the double counting in China's processing exports comes from imported foreign contents (53.2% over 53.5%). These calculations highlight U.S. exports producers and Chinese processing exporters' respective positions at the head and tail of the global production chain.

To reiterate the connection of the five basic value-added components reported in the left-hand panel of table 1 to measures in the existing literature by numerical estimates, column (7) reports the ratio of value-added exports to gross exports (VAX ratio) as proposed by Johnson and Noguera (2012) by adding up columns (1), (2), and (3); column (9) lists the share of domestic content extensively discussed in the vertical specialization literature by summing columns (1), (2), (3) and (4); Finally, column (11) gives the share of vertical trade by adding columns (5)¹⁵ and (8), which is an indicator of how intensively a country is participating in the global production chain.

Comparing domestic content share estimates (Column 9) and Johnson & Noguera's VAX ratio (Column 7) reported in table 1, we see interesting differences between high-income countries and emerging market economies. For most emerging market economies, the numerical difference of these two measures is quite small. This means that only a tiny part of domestic value-add returns home for most countries. In comparison, for the United States, Western Europe

¹⁵Column (5) corresponds to the VS share in HIY(2001).

and Japan, the difference between domestic content share and the value added export share is more significant. This reflects the fact that advanced economies export relatively more components and machinery, and some of the value added embedded in these intermediate goods returns home as part of other countries' exports to the advanced countries. Such differences between high-income countries and emerging market economies would not be apparent if one does not compute the domestic content share and value added export share separately.

For columns (4), (5), and (8) in Table 1, our formula provides additional layers of decomposition. These results are reported in Table 2. The left-hand panel splits domestic content returns home (Column 1) into domestic value-added embodied in the country's final goods and intermediate goods imports, and a pure double counted portion of domestic value-added due to round-trip intermediate goods trade. The middle panel provides similarly detailed information on the three-way split of foreign content in exports (in column (5)). The right-hand panel report the three channels that a country can participate in global vertical specialization by providing intermediate goods for other countries – those intermediate goods may be used by the importing countries to produce final goods or intermediate goods that are exported to third countries or to produce goods that are exported back to the home country.

The structure of double counted terms in each country's gross exports offers additional information on how each country participate in vertical specialization and its relative position in the global production chain. For example, for the United States, the double counted terms are almost equally split between domestic content returned home and foreign content (9.5/15.4). In comparison, for most developing countries, the foreign content tends to dominate, with only a very tiny portion of their domestic content returning home. Within foreign content, Maquiladora economies in Mexico, export processing zones in China and Viet Nam, tend to have a large portion embodied in their final goods exports (34.0%, 32.6% and 27.2%, respectively), reflecting their position as the assemblers of final goods in global production chains. For developed and newly industrialized economies, the shares in intermediate goods exports and the pure double counted portion due to multiple border crossing intermediate goods trade are much higher. Similarly, upstream natural resource producers such as Australia & New Zealand, Russia, and Indonesia, have a significant portion of their intermediate exports used by other countries to

produce their intermediate goods exports. This is also true for upstream producers of manufacturing intermediates such as Japan.

3.3 Revealed Comparative Advantage index based on gross and domestic contents in exports

The concept of revealed comparative advantage (RCA for short), proposed by Balassa (1965), has proven to be useful in many research and policy applications. In standard applications, it is defined as the share of a sector in a country's total gross exports relative to the world average of the same sector in world exports. When the RCA exceeds one, the country is said to have a revealed comparative advantage in that sector; when the RCA is below one, the country is said to have a revealed comparative disadvantage in that sector. The problem of multiple counting of certain value added components in the official trade statistics suggests that the traditional computation of RCA could be noisy and misleading. Our value added decomposition of exports provides a way to remove the distortion of multiple counting by focusing on domestic value added in exports.

We re-compute the RCA index at the country-sector level for all the countries and sectors in our database. Due to space constraints, we report only the results for manufacturing sectors and compare the country rankings of RCAs using both gross exports and domestic value-added in exports. There are 16 figures. In each figure, we report two sets of RCA indices for each manufacturing industry according to each country's RCA ranking in that sector, and comparing the changes by using gross or value-added data. There are dramatic differences in the RCA index rank for many countries in almost all the sectors we reported. For example, using gross exports data, China show a strong revealed comparative advantage (ranked the first if not considering processing trade, and sixth if taking processing trade into account, among the set of countries in our database, and with the absolute values of RCA at 2.59 and 1.80, respectively) in finished metal products (figure 1). However, when looking at domestic value added in that sector's exports, China's ranking in RCA drop precipitously to 19th and 17th place, respectively.¹⁶ Unsurprisingly, the ranking for some other countries moves up. For example, for the United States, not only its RCA ranking moves up from 26th place under the conventional calculation to

¹⁶ Sectoral value added here includes value produced by the factors of production employed in the finished metal products sector and then embodied in gross exports of all downstream sectors, rather than the value added employed in upstream sectors that are used to produce finished metal products in the exporting country. This distinction is particularly important in the business services sector, discussed next.

the 16th place under the new calculation, finished metal products industry also switches from being labeled as a comparative disadvantage sector to a comparative advantage sector. France, UK, Korea and Hungary show a similar pattern as the US, many other developed countries, such as Italy, Germany and Spain are also moving up their ranking significantly.

Another example is the “Machinery and Equipment” sector. Using data on gross exports, China exhibits a strong revealed comparative advantage in that sector on the strength of its high share of machinery and equipment exports in its overall exports, especially when processing exports is considered (Figure 2). However, once we compute RCA using domestic value added in exports, the same sector becomes a comparative disadvantage sector for China! One key reason for the change is that there are high imported content in China’s gross machinery and equipment exports, majority of those parts and components come from developed countries or Asian newly industrialized countries. Indeed, the RCA rankings for this sector in the United States, some EU member countries and Korea all move up using data on the domestic value added in exports. Therefore, compared to the share of this sector in other countries’ exports (after taking into account indirect value added exports), the China’s share of the sector in its exports becomes much less impressive.

These examples illustrate the possibility that our understanding of trade patterns and revealed comparative advantage could be modified substantially once we have the right data on domestic value added in exports.

We want to end this section with a note of caution in using our sector-level estimates on domestic value-added in exports. As we discussed earlier, the lack of information in our current database on how imported inputs are distributed among sector users within each country may introduce unknown noise into those sector level estimates, therefore sector level results are only indicative and cannot be very accurate. This is why we focus on country rankings rather than the exact numerical numbers, and hope this will make the impact of the possible errors in imports allocation become smaller.

IV. Concluding Remark

In this paper, we refine the accounting framework and gross exports decomposition method proposed in KPWW (2010). We make Leontief original idea underlying our methodology clear and discuss how it could be applied to measure double counting in gross trade statistics and decompose gross exports into its various value-added components. We have shown how the decomposition results could be used to re-compute revealed comparative advantages index at country/sector level and believe there are many other applications that may affect our understanding of the pattern of global trade if we could improve the value-added trade and domestic content estimates at the sector levels. For instance, current end use classifications, such as the UN BEC, need to be extended to dual use products and services trade. In addition, methods also need to be developed to properly distribute imports to domestic users either based on cross country statistical surveys of the domestic distribution of imports or based on firm level and Customs transaction-level trade data. This will need joint efforts by statistical agencies and academic communities across the world.

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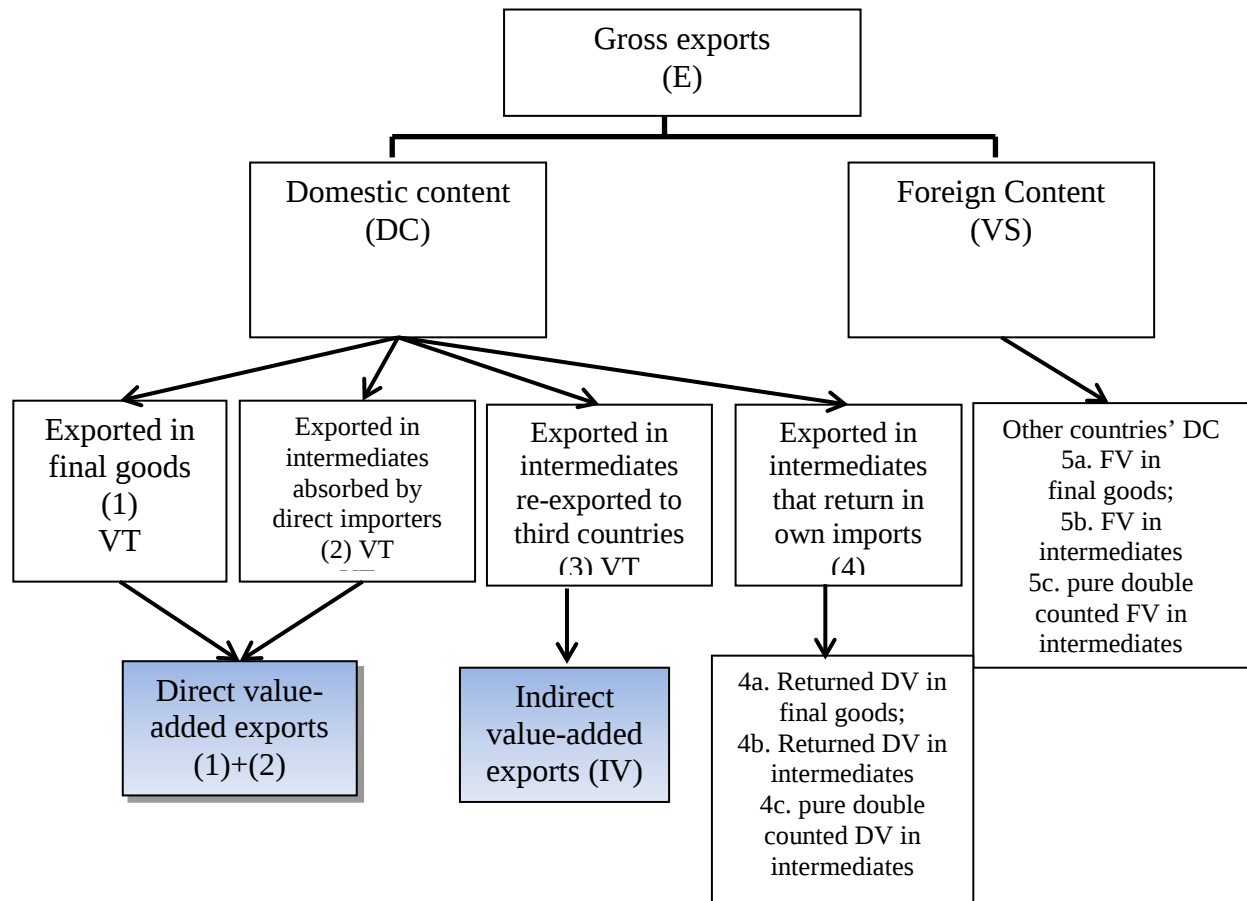
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Figure 1 Decomposition of gross export: concepts



Note:

- a. value-added exports by a country equals $(1) + (2) + (3)$.
- b. domestic content in a country's exports equals $(1) + (2) + (3) + (4)$.
- c. (5) is labeled as VS, and $(3) + (4)$ is part of VS1 labeled by HIY (2001).
- d. (4.a) are also labeled as VS1* by Daudin et al (2011).
- e. (4) and (5) involve value added that crosses national borders at least twice, and are the sources of multiple counting of value added in standard trade statistics¹⁷.

¹⁷ (3) should not be included in double counting, because when this value crosses a border for the second time, it becomes foreign value in the direct importer's exports. For this reason, it is not included as double counting to avoid an over-correction.

Table 1 Decomposition of gross exports, 2007

Country or region	Value-added exports				Double counting		Total	Connection with existing measures				
	Gross exports (Billions U.S. Dollars)	Direct exports of final goods	Intermediates absorbed by direct importer	Re-exports to third countries	Domestic content returns home	VS share (HIY)		VAX ratio (J&N)	VS1 share (HIY)	Domestic content share (KWW)	Share of Double counting	Share of Vertical trade (OECD)
	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Advanced economies												
Australia	189.1	22.9	53.9	10.9	0.7	11.6	100.0	87.7	31.4	88.4	12.3	43.0
Canada	415.5	21.4	47.6	4.6	1.5	25.0	100.0	73.5	15.1	75.0	26.5	40.1
EFTA	378.1	22.5	45.2	4.8	0.9	26.6	100.0	72.5	15.3	73.4	27.5	41.8
Western EU	2,276.8	35.4	39.8	4.4	7.2	13.2	100.0	79.7	19.9	86.8	20.3	33.1
Japan	742.1	34.3	33.9	11.6	2.2	18.0	100.0	79.8	28.6	82.0	20.2	46.6
United States	1,363.4	30.4	39.1	5.6	9.5	15.4	100.0	75.1	25.0	84.6	24.9	40.4
Asian NICs												
Hong Kong	143.3	26.2	37.8	7.9	0.5	27.5	100.0	72.0	18.2	72.5	28.1	45.8
Korea	405.5	25.3	28.2	10.6	1.0	35.0	100.0	64.1	23.5	65.0	35.9	58.4
Taiwan	278.4	15.2	27.4	14.7	0.8	41.9	100.0	57.3	29.2	58.1	42.7	71.1
Singapore	205.4	13.9	26.0	6.7	0.5	53.0	100.0	46.5	17.0	47.0	53.5	70.0
Emerging Asia												
China Normal	623.9	43.1	33.4	7.1	1.4	15.0	100.0	83.5	20.1	85.0	16.5	35.1
China Processing	543.3	32.6	12.4	1.4	0.3	53.2	100.0	46.5	3.9	46.8	53.5	57.1
China total	1,167.2	38.2	23.6	4.4	0.9	32.8	100.0	66.3	12.6	67.2	33.7	45.4
Indonesia	127.7	18.0	53.6	10.8	0.6	17.1	100.0	82.4	31.0	83.0	17.6	48.0
Malaysia	194.6	15.9	33.9	9.3	0.8	40.2	100.0	59.0	22.9	59.8	41.0	63.1
Philippines	72.3	16.0	29.2	15.2	0.3	39.3	100.0	60.4	31.3	60.7	39.6	70.6
Thailand	175.1	28.7	26.5	8.1	0.4	36.3	100.0	63.3	19.0	63.7	36.7	55.3
Vietnam	53.0	27.2	25.3	4.5	0.3	42.7	100.0	57.0	14.5	57.3	43.0	57.2
Rest of East Asia	39.9	29.2	42.8	6.0	0.3	21.8	100.0	77.9	18.8	78.2	22.1	40.6
India	210.8	24.6	45.6	6.7	0.5	22.6	100.0	76.9	18.0	77.4	23.1	40.6
Rest of South Asia	45.9	47.5	24.9	4.6	0.1	22.9	100.0	77.0	10.3	77.1	23.0	33.2
Other emerging												
Brazil	176.2	25.9	54.0	7.4	0.5	12.2	100.0	87.3	21.0	87.8	12.7	33.2
New EU countries	451.4	27.2	36.0	4.1	1.3	31.4	100.0	67.3	11.7	68.6	32.7	43.1
Mexico Normal	95.7	22.4	59.4	7.7	1.0	9.4	100.0	89.6	25.3	90.6	10.4	34.7
Mexico Processing	177.2	34.0	16.8	1.8	0.2	47.1	100.0	52.6	4.3	52.9	47.4	51.5
Mexico total	272.9	30.0	31.8	3.9	0.5	33.9	100.0	65.6	11.7	66.1	34.4	45.6
Rest of Americas	328.2	18.8	58.0	8.3	1.1	13.8	100.0	85.1	25.6	86.2	14.9	39.4
Russian	309.4	11.1	71.5	8.1	1.0	8.3	100.0	90.7	29.6	91.7	9.3	37.9
South Africa	84.9	20.9	49.5	7.9	0.2	21.4	100.0	78.3	24.6	78.6	21.7	46.0
Rest of the world	1,305.8	10.8	65.4	6.8	3.2	13.8	100.0	83.1	28.9	86.2	16.9	42.7
World average	11,412.5	26.9	41.4	6.6	3.5	21.6	100.0	74.9	21.6	78.4	25.1	43.2

Source: Authors' estimates

Notes: All columns are expressed as a share of total gross exports. Country groupings follow IMF regions (www.imf.org/external/pubs/ft/weo/2010/01/weodata/groups.htm#oem). First Columns corresponding the five box in Figure 1. (7) = (1)+(2)+(3);(9) =(1)+(2)+(3)+(4);(10)=(4)+(5);(11) = (5)+(8); further decomposition of (4), (5) and (8) is given in table 2

Table 2 Further decomposition of the double counted terms, 2007

Country or region	Domestic content returns home				Foreign content (VS share, HIY)				VS1 share (HIY)		
	Total	In final goods imports	In intermediates imports	Pure double counting	Total	In final goods exports	In intermediate exports	Pure double counting	Total	Via other country's final goods	Via other country's intermediates
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
<i>Advanced economies</i>											
Australia	0.7	0.3	0.3	0.1	11.6	3.4	5.3	2.9	31.4	10.9	19.8
Canada	1.5	0.5	0.5	0.5	25.0	9.9	11.4	3.7	15.1	4.6	9.1
EFTA	0.9	0.3	0.3	0.3	26.6	9.4	12.5	4.8	15.3	4.8	9.5
Western EU	7.2	2.7	3.4	1.0	13.2	5.1	5.3	2.7	19.9	4.4	8.4
Japan	2.2	0.9	0.8	0.5	18.0	6.3	6.1	5.6	28.6	11.6	14.8
United States	9.5	5.0	3.6	0.9	15.4	4.7	6.4	4.3	25.0	5.6	9.9
<i>Asian NICs</i>											
Hong Kong	0.5	0.3	0.1	0.1	27.5	9.7	11.0	6.9	18.2	7.9	9.8
Korea	1.0	0.3	0.3	0.4	35.0	11.2	12.0	11.8	23.5	10.6	11.9
Taiwan	0.8	0.2	0.1	0.5	41.9	9.2	14.3	18.4	29.2	14.7	13.7
Singapore	0.5	0.1	0.1	0.3	53.0	12.3	22.5	18.2	17.0	6.7	9.8
<i>Emerging Asia</i>											
China Normal	1.4	0.4	0.9	0.1	15.0	6.4	5.7	2.9	20.1	7.1	11.6
China Processing	0.3	0.0	0.0	0.3	53.2	32.9	10.7	9.6	3.9	1.4	2.2
China total	0.9	0.2	0.5	0.2	32.8	18.8	8.1	6.0	12.6	4.4	7.2
Indonesia	0.6	0.2	0.3	0.1	17.1	5.9	6.7	4.4	31.0	10.8	19.6
Malaysia	0.8	0.2	0.1	0.6	40.2	12.0	14.9	13.2	22.9	9.3	12.8
Philippines	0.3	0.0	0.0	0.2	39.3	8.0	12.7	18.6	31.3	15.2	15.8
Thailand	0.4	0.1	0.1	0.2	36.3	15.1	11.4	9.8	19.0	8.1	10.5
Vietnam	0.3	0.0	0.1	0.1	42.7	25.4	10.7	6.6	14.5	4.5	9.7
Rest of East Asia	0.3	0.0	0.1	0.1	21.8	11.6	7.2	3.0	18.8	6.0	12.5
India	0.5	0.1	0.3	0.1	22.6	5.5	12.2	5.0	18.0	6.7	10.8
Rest of South Asia	0.1	0.0	0.0	0.0	22.9	15.3	5.2	2.4	10.3	4.6	5.6
<i>Other emerging</i>											
Brazil	0.5	0.2	0.2	0.1	12.2	3.9	6.0	2.3	21.0	7.4	13.1
New EU countries	1.3	0.5	0.4	0.4	31.4	13.2	13.7	4.5	11.7	4.1	6.4
Mexico Normal	1.0	0.1	0.8	0.0	9.4	2.7	5.1	1.6	25.3	7.7	16.6
Mexico Processing	0.2	0.1	0.0	0.2	47.1	29.5	12.5	5.2	4.3	1.8	2.3
Mexico total	0.5	0.1	0.3	0.1	33.9	20.1	9.9	3.9	11.7	3.9	7.3
Rest of Americas	1.1	0.4	0.5	0.2	13.8	3.4	7.2	3.2	25.6	8.3	16.2
Russian	1.0	0.5	0.4	0.1	8.3	1.3	4.9	2.1	29.6	8.1	20.5
South Africa	0.2	0.1	0.1	0.1	21.4	5.5	11.0	5.0	24.6	7.9	16.5
Rest of the world	3.2	1.0	1.5	0.6	13.8	2.6	7.8	3.3	28.9	6.8	18.9
<i>World average</i>	3.5	1.4	1.4	0.6	21.6	8.0	8.4	5.2	21.6	6.6	11.5

Source: Authors' estimates.

Notes: All columns are expressed as a share of total gross exports. Country groupings follow IMF regions (www.imf.org/external/pubs/ft/weo/2010/01/weodata/groups.htm#oem). Column (1), (5) and (9) are from column (4), (5) and (8) in Table 1 respectively. Column (9) = (1)+(10)+(11), and column (10) is from column (3) in table 1. Columns (2) and (6) correspond to the first terms in the two bracketed expressions in equation (23) respectively; Columns (3) and (4) corresponds to the two terms in the RHS of equation (24); Columns (7) and (8) corresponds to the two terms in the RHS of equation (25); Columns (10) and (11) corresponds to the first two terms in the RHS of equation (34).

Gross and Domestic Value-added-adjusted Revealed Comparative Advantage Indicators – 2007
Figure 1

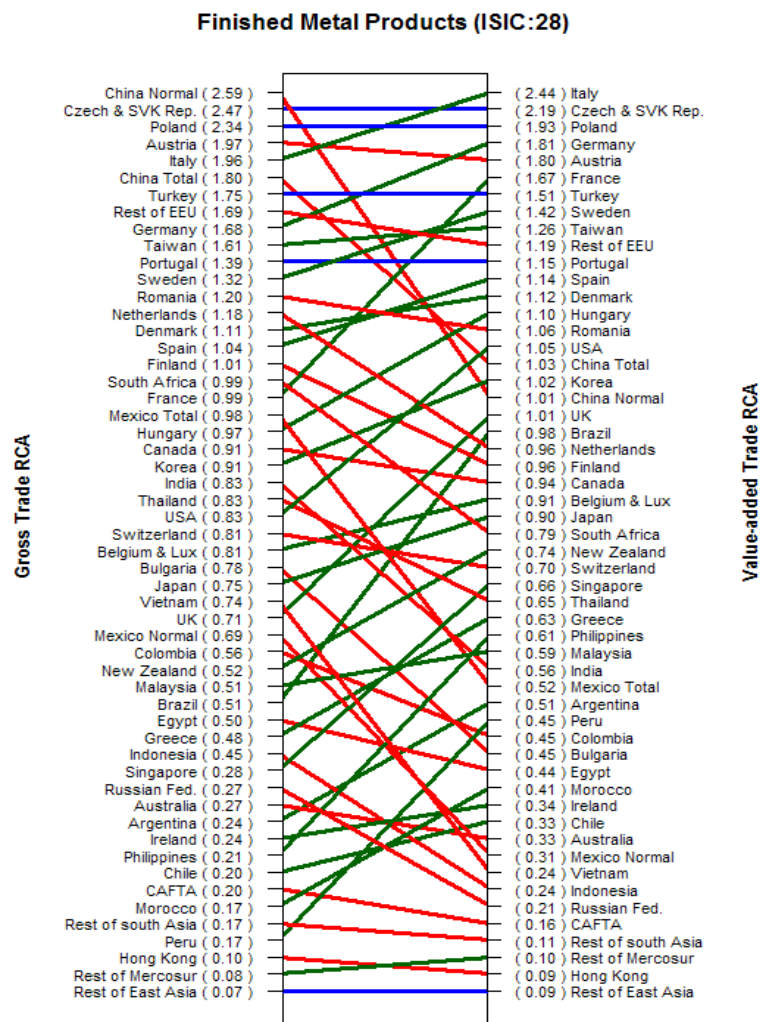
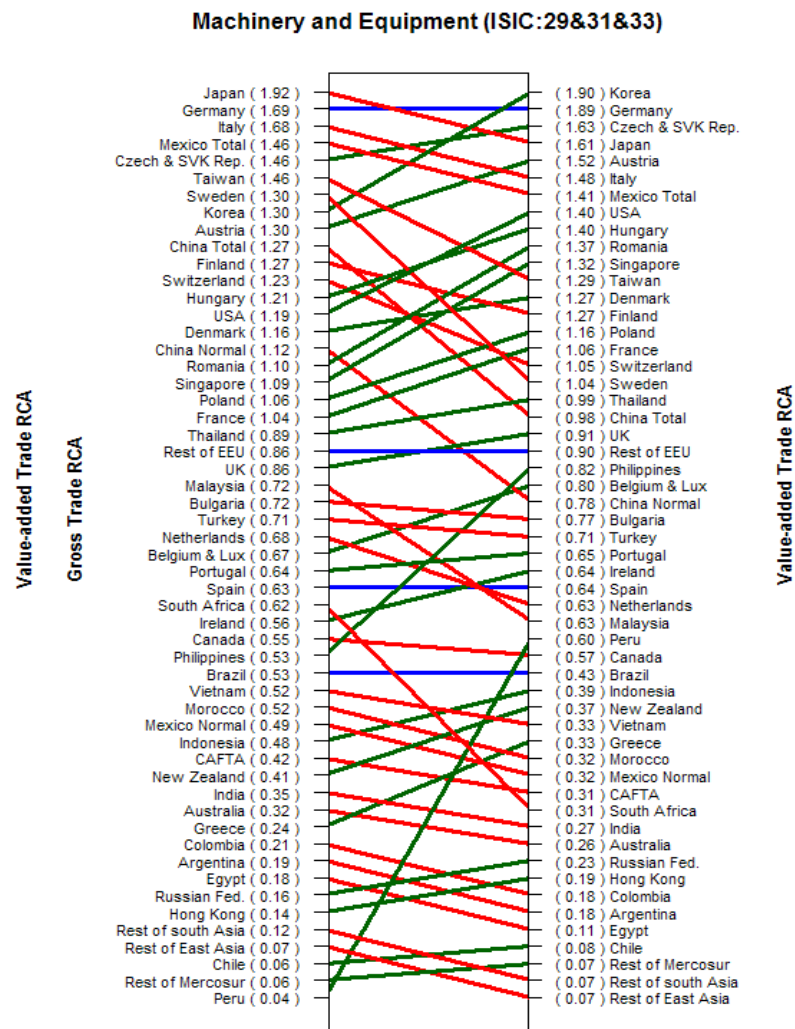


Figure 2



Gross and Domestic Value-added-adjusted Revealed Comparative Advantage Indicators – 2007
Figure 3

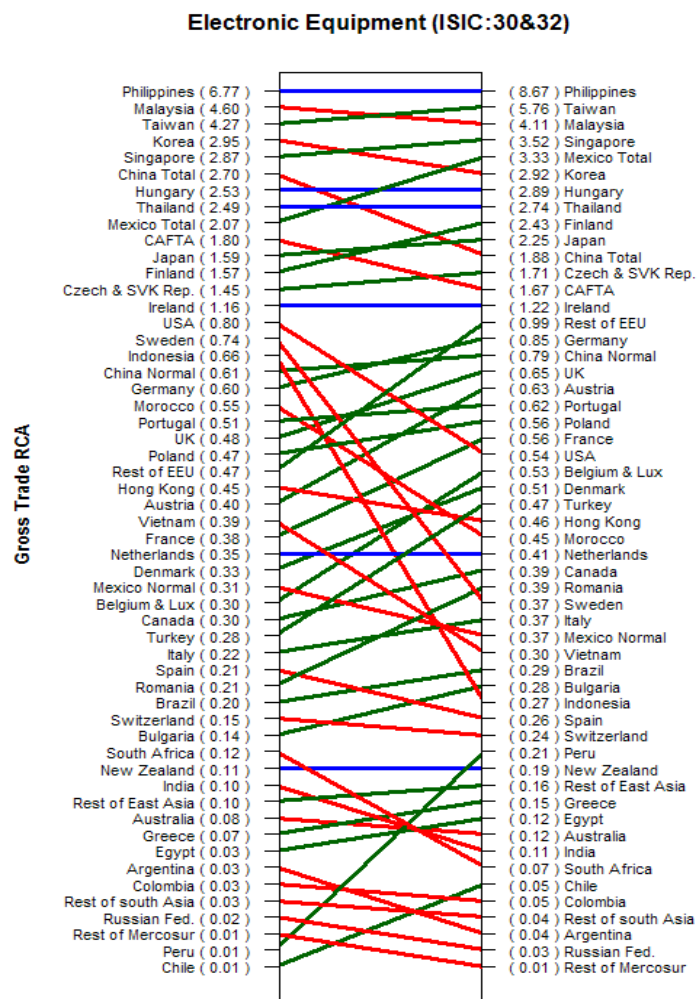
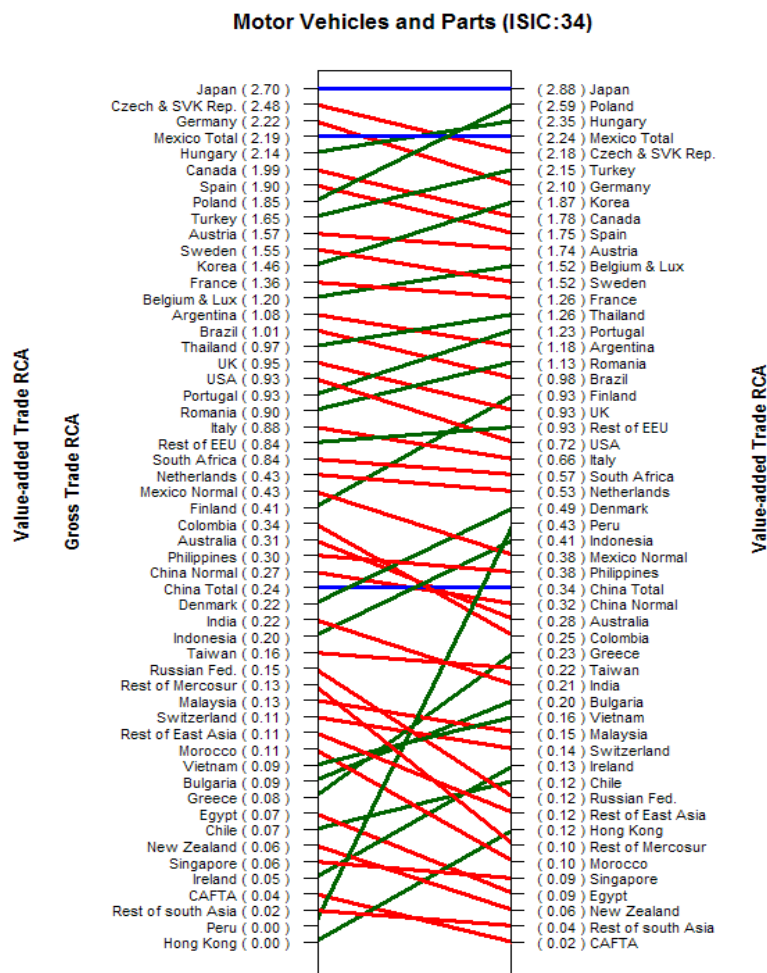


Figure 4



Gross and Domestic Value-added-adjusted Revealed Comparative Advantage Indicators – 2007
Figure 5

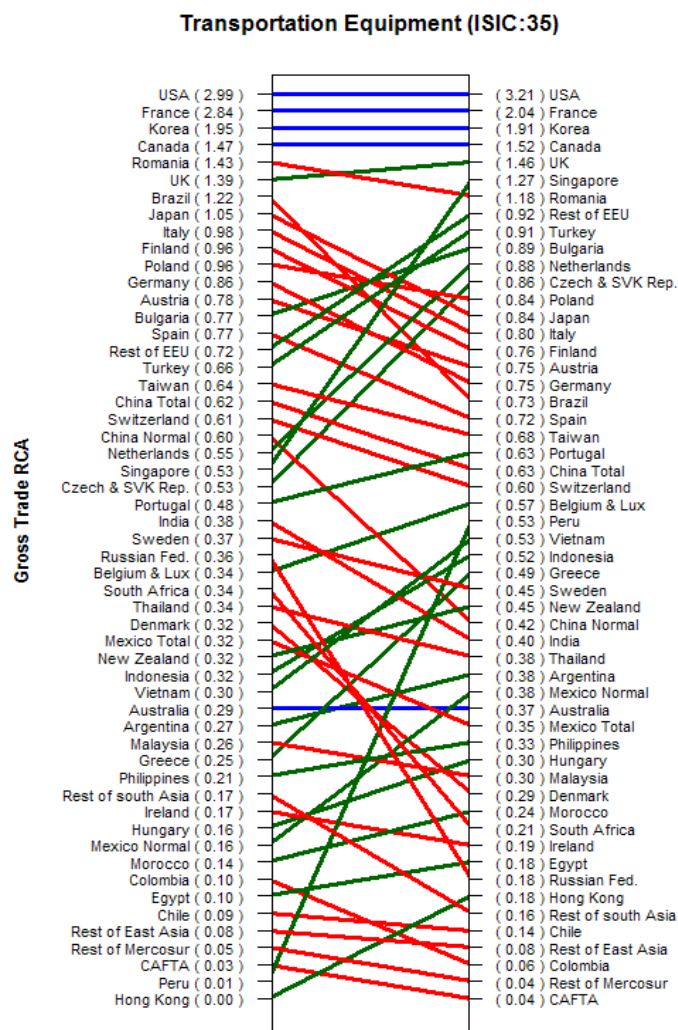
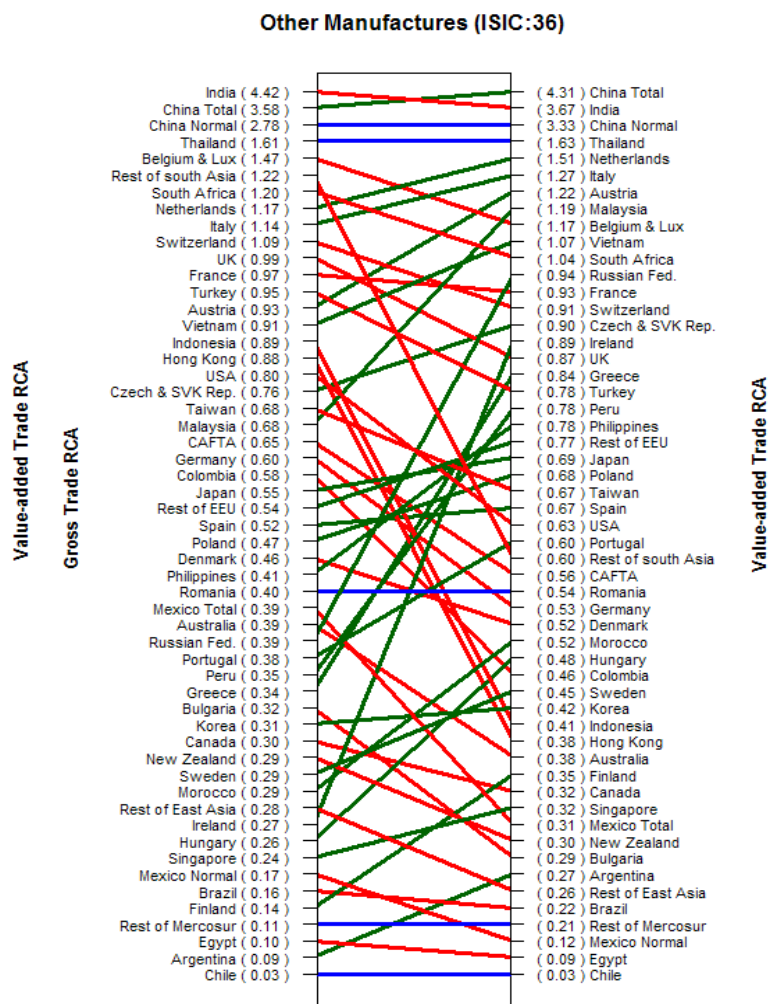


Figure 6



Gross and Domestic Value-added-adjusted Revealed Comparative Advantage Indicators – 2007
Figure 7

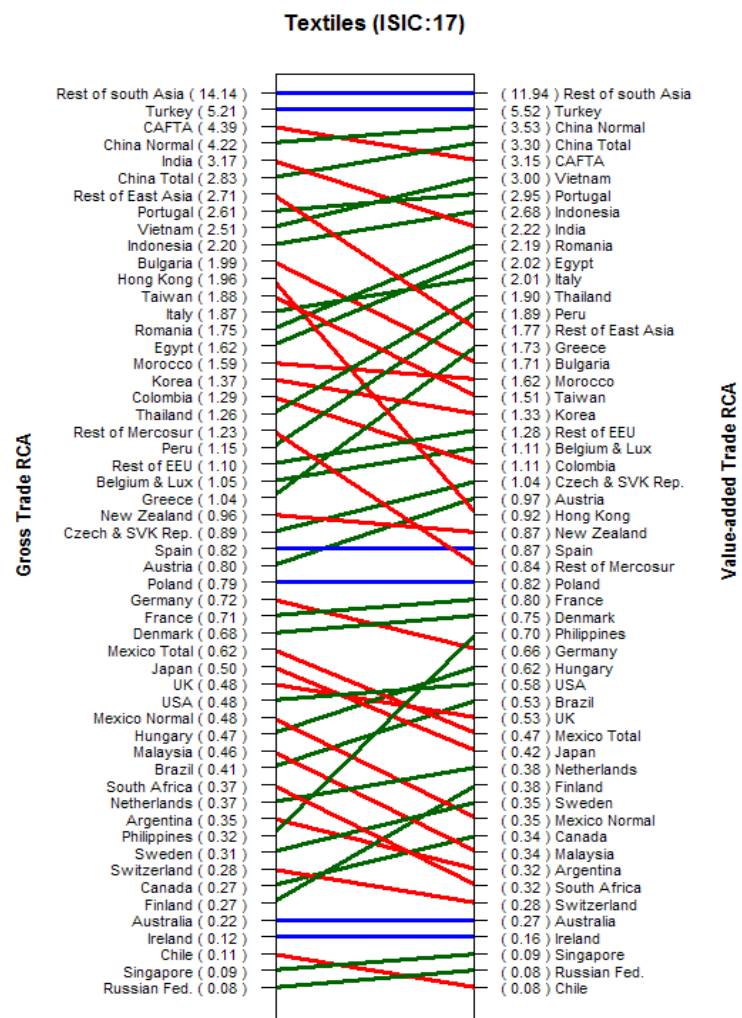
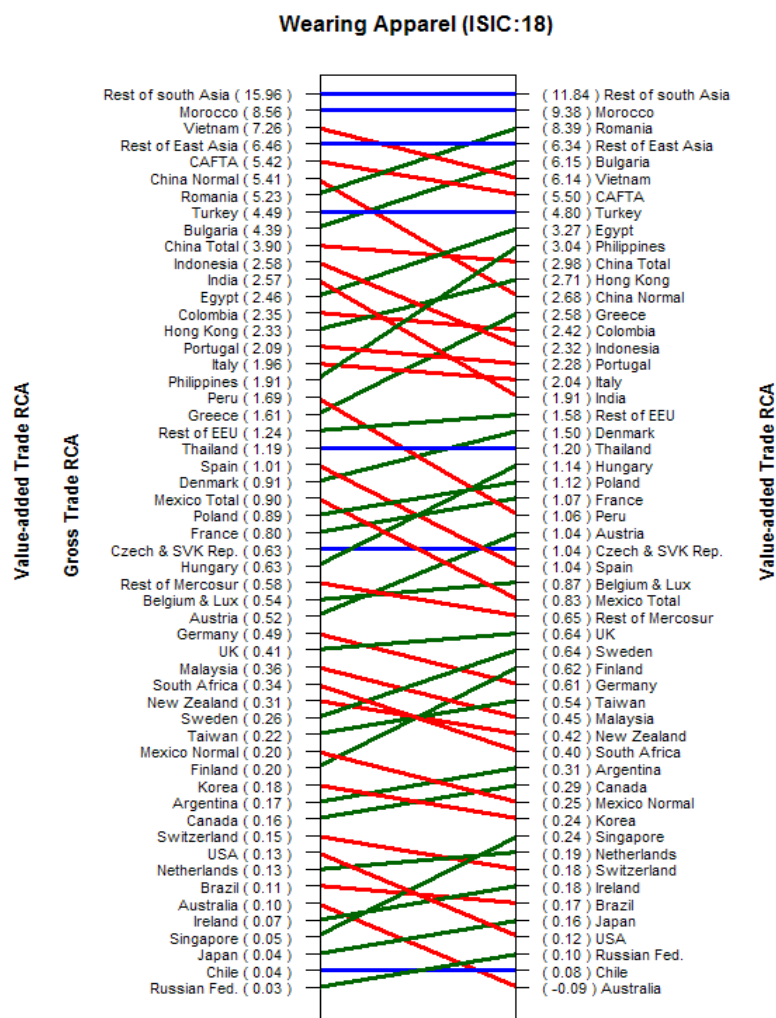


Figure 8



Gross and Domestic Value-added-adjusted Revealed Comparative Advantage Indicators – 2007
Figure 9

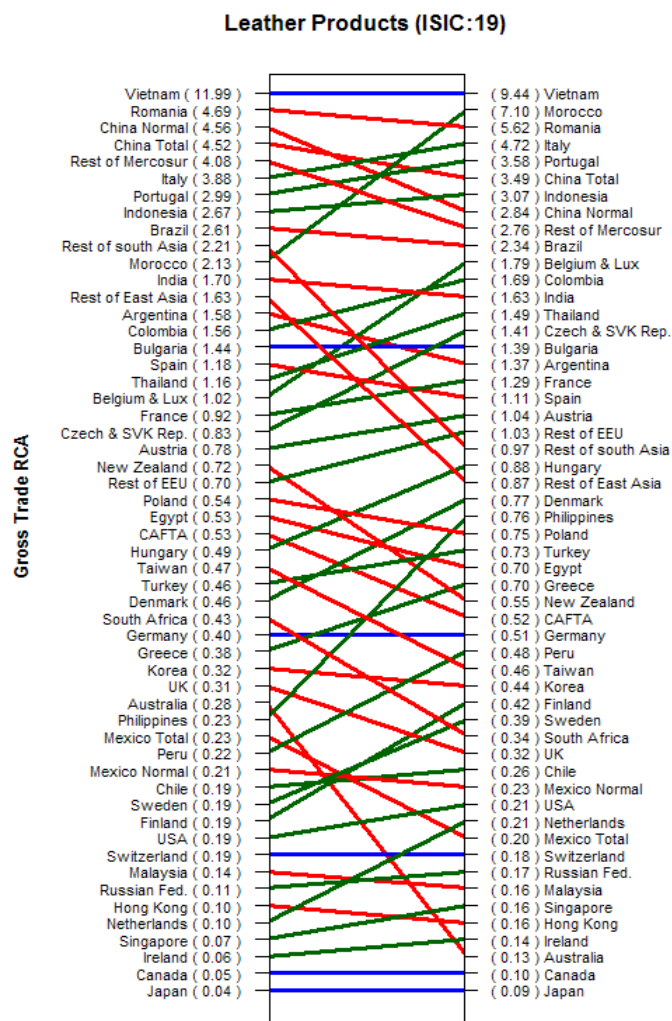
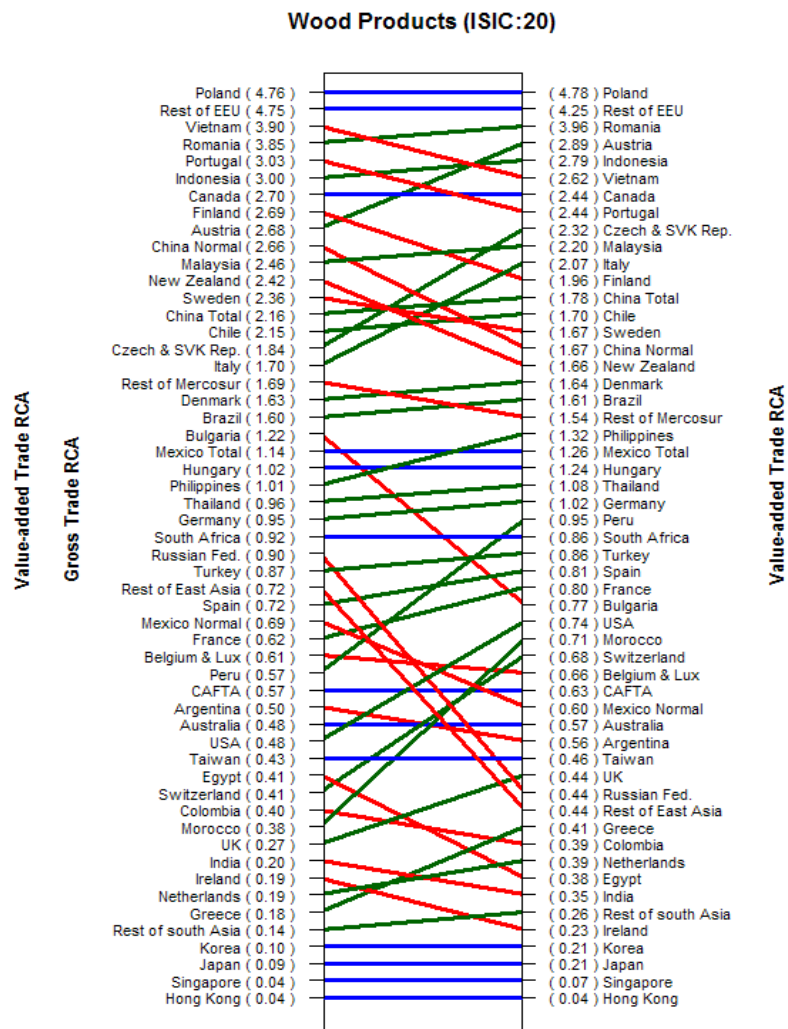


Figure 10



Gross and Domestic Value-added-adjusted Revealed Comparative Advantage Indicators – 2007
Figure 11

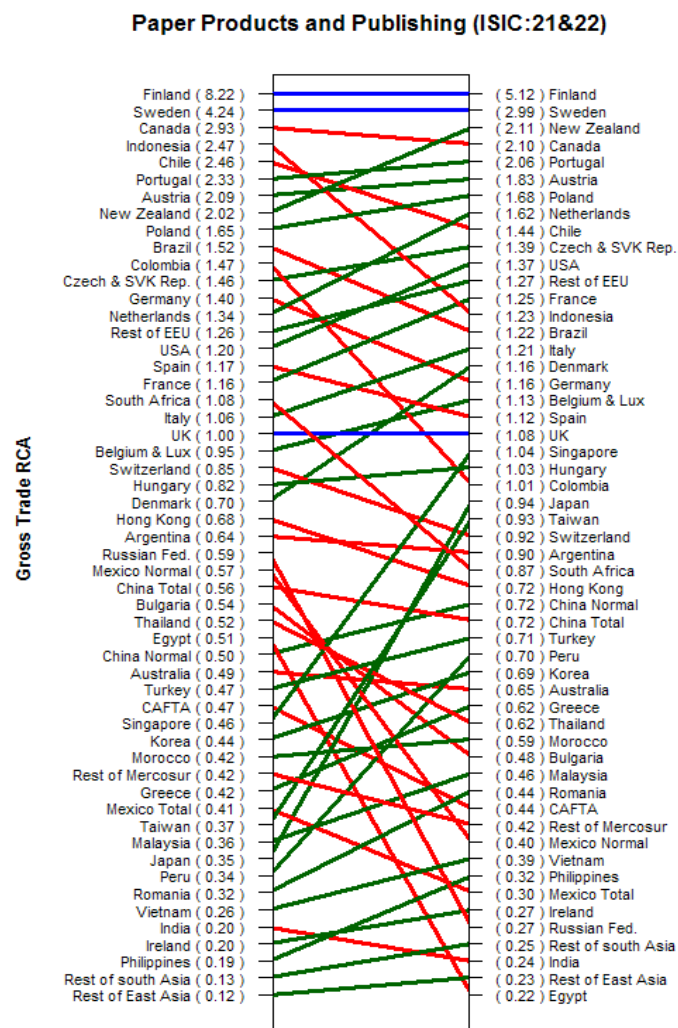
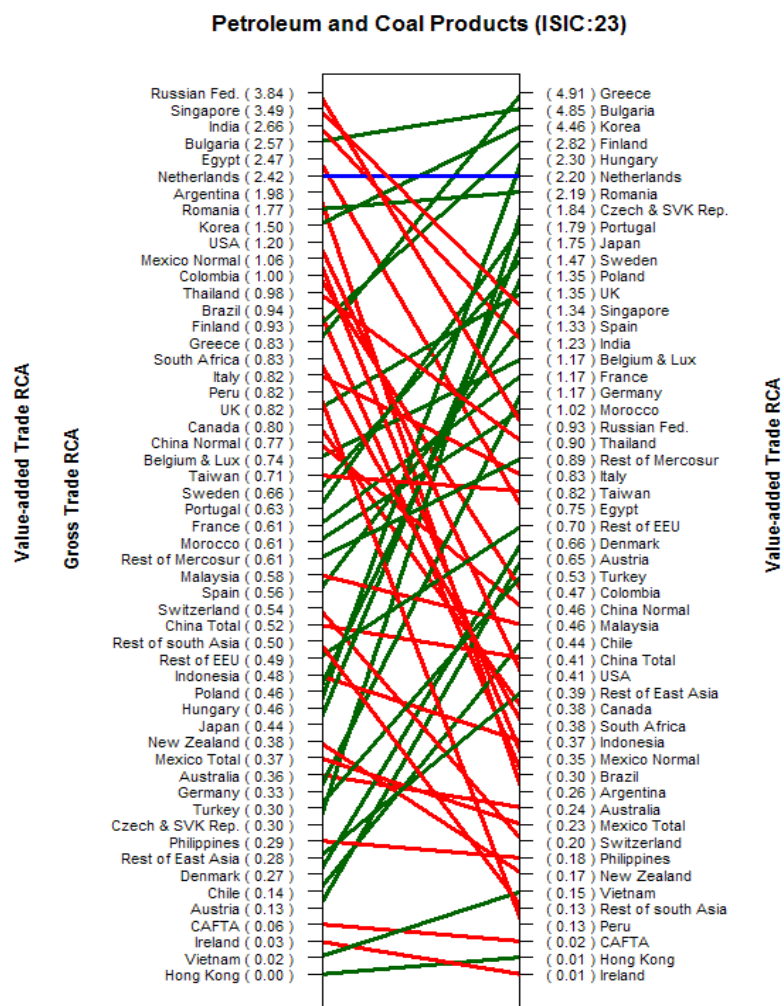
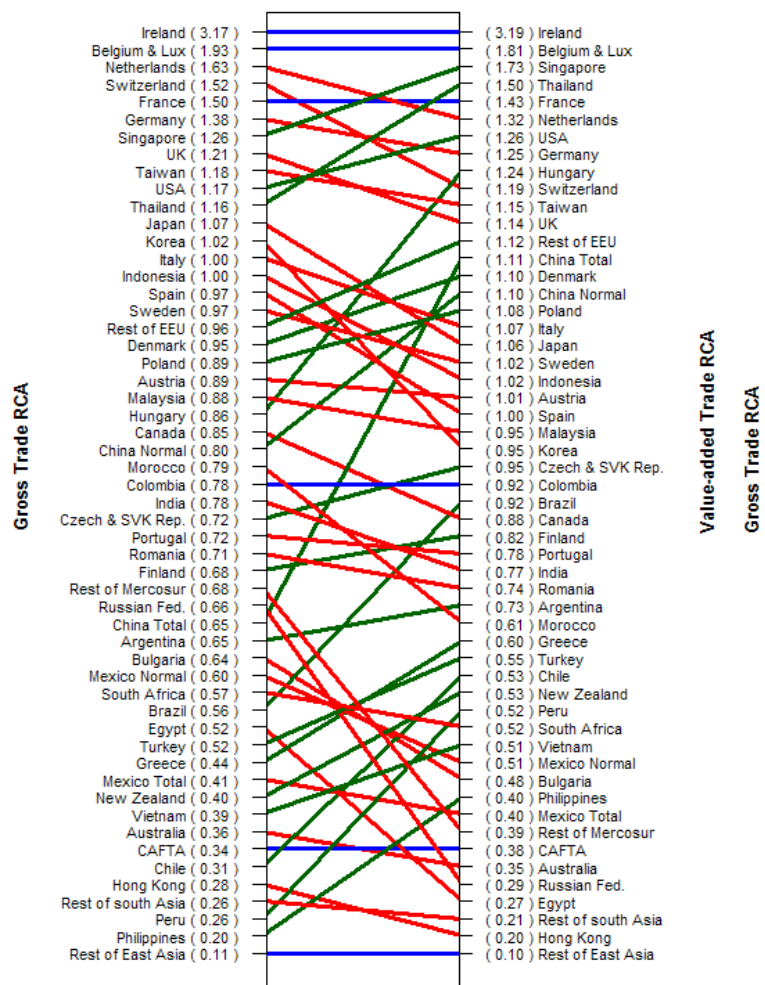


Figure 12

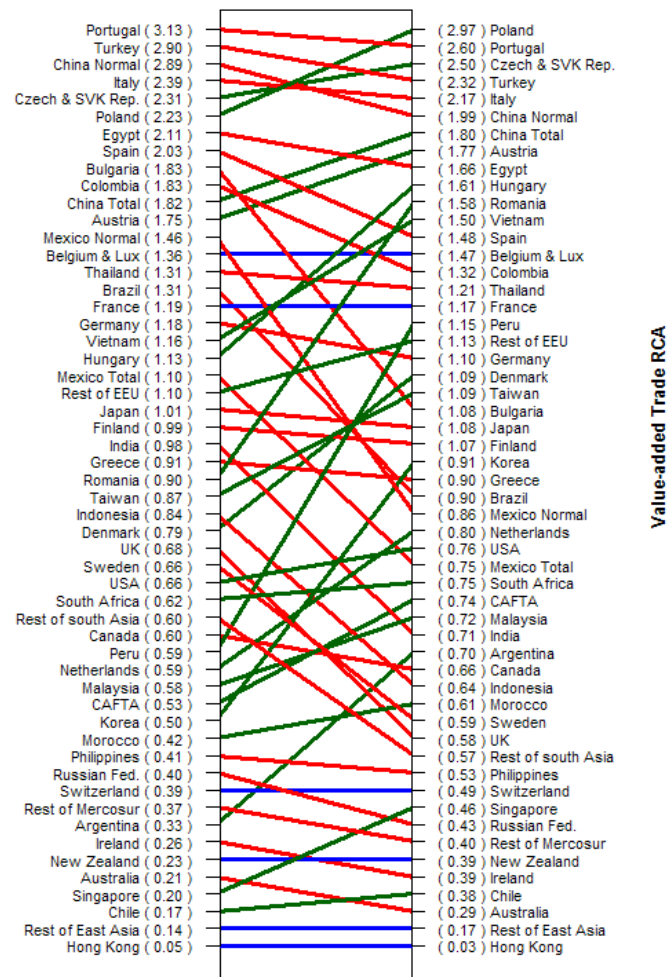


Gross and Domestic Value-added-adjusted Revealed Comparative Advantage Indicators – 2007
Figure 13

Chemical, Rubber and Plastic Products (ISIC:24&25)



Mineral Products (ISIC:26)



Gross and Domestic Value-added-adjusted Revealed Comparative Advantage Indicators – 2007
Figure 15

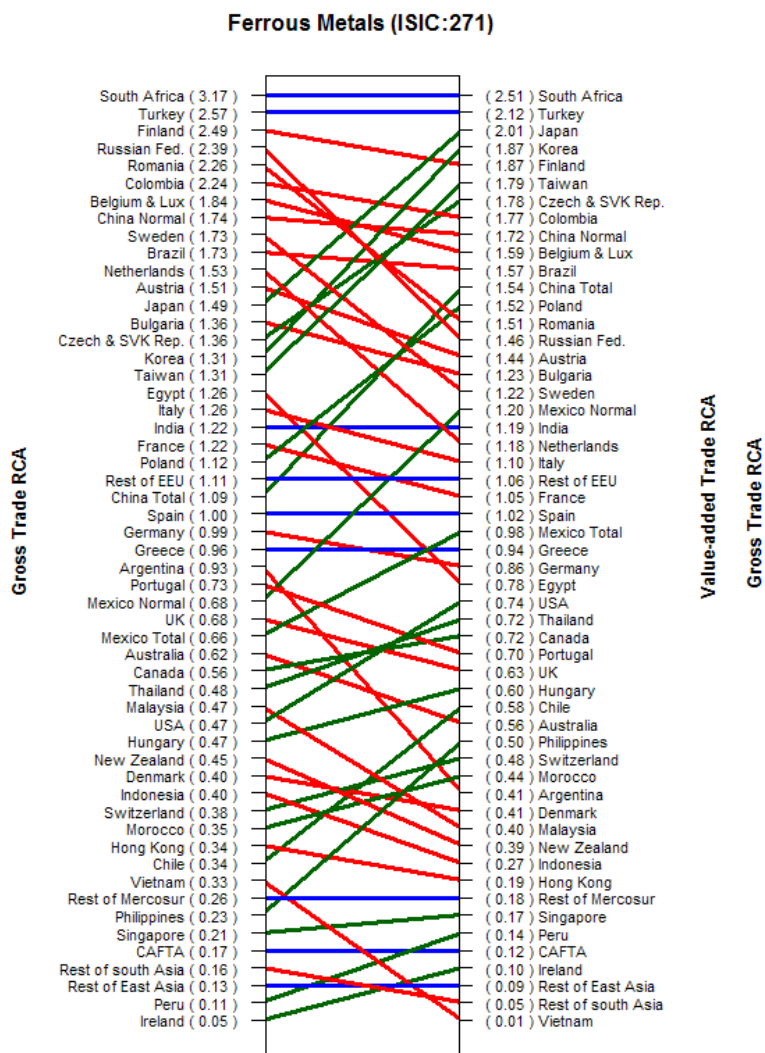


Figure 16

