The Value-added Structure of Gross Exports: Measuring Revealed Comparative Advantage by Domestic Content in Exports

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(Preliminary draft, not for quotation)

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 "multiple counted," it bridges official trade statistics and national accounts, making measure of trade consistent with SNA standard.

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 re-compute 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.

JEL No. F1

Paper for Present at 2012 AEA Annual Meeting
Chicago, January 7, 2012

* The views in the paper are solely those of the authors and may not reflect the views of the USITC, its Commissioners, or of any other organization that the authors are affiliated with. The authors thank Ravinder Ubee, for efficient research assistance, and We are deeply grateful to Professor Peter Dixon of Monash University for constructive, generous, and lengthy discussions in helping us to develop this accounting framework mathematically.

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 accounts 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 Council[2] 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 significant 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 SNA[5]. 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 estimation[6], 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 repeatly, or 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 value added 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 value added in exports is about 21% in 1990**.** HIY make two key assumptions in their foreign value-added 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. Processing exports are characterized by imports for exports with favorable tariff and other tax treatment: firms import parts and other intermediate materials from abroad, with tariff exemptions on the imported inputs and other tax preferences from local or central governments, and, after processing or assembling, export the finished products. Ignoring processing exports is likely to lead to estimation errors, especially for economies that engage in substantial amounts of tariff/tax-favored processing trade, such as the China, Mexico and Viet Nam. The second assumption will not hold when there is more than one country exporting intermediates. In the HIY model, a country cannot import intermediate inputs, add value, and then export semi-finished goods to another country to produce final goods. Nor can a country receive intermediate imports that embody its own value added, returned home after processing abroad. Therefore, HIY's measures do not hold generally with the multi-country, back-and-forth nature of current global production networks.

Recognizing the first limitation of the HIY method, Koopman, Wang and Wei (2008, and forthcoming, JDE) present a formula for computing shares of foreign and domestic value added in a country's exports when processing exports are pervasive and establish the HIY formula as a special case of their more general formula. They apply this new method to China using data for 1997, 2002 and 2007, and find the share of foreign value added in China's manufactured exports was about 50% before China's WTO membership (almost twice as high as that implied by the HIY method) and declining to about 40% since then. They also found interesting variations across sectors. Those sectors that are likely labeled as relatively sophisticated, such as computers, telecommunication equipment, and electronic devices have particularly high imported content (more than 70%).

Research efforts to overcome the second limitation of HIY have proceeded along two lines. There is a growing literature to estimate value-added trade based on IIO tables in recent years. This line of work is an extension of the factor content in trade literature. Daudin, Rifflart, and Schweisguth (2011, forthcoming, Canadian Journal of Economics) computes "value-added trade" for 66 countries based on the GTAP database 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 vertical trade. They define value-added trade as standard trade minus vertical trade, which measures only the trade flow between producer and final users. They further distinguish the part of VS1 that returns to the country of origin as VS1*, the domestic content of final goods imports or exports that ultimately consumed back at home. They found that 27% of world trade was vertical trade in 2004 and that the industrial and geographic patterns of value-added trade are very different from those of standard trade.

Johnson and Noguera (2010, JN in subsequent discussion) also 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 with HIY's measure of foreign content in exports, JN propose a measure of value-added exports to gross exports ratio or VAX ratio to measure the intensity of production sharing and found exporters of manufactures have lower VAX ratios and, at the bilateral level, imbalances measured in value added can differ substantially from gross trade imbalances. 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, JN did not realize there are differences between their VAX ratio and HIY's content share in exports, and thus misinterpret their VAX ratio as a metric of the domestic content of exports at the country aggregate level.

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 WIOD database. 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 counted only once and those that are counted multiple times, or "double counted", 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", or counted multiple times. The source of this misconception is that they ignore the difference between domestic content in exports and value-added trade as identified by KPWW. It is true as we view a trade deficit from each individual country that gross exports are a form of final demand, but in IIO framework, value-added in intermediate goods may be double counted. Therefore, at the global and aggregate levels, value-added trade is always smaller than gross trade. They are not and should not be equal.

Although there is nothing conceptually new beyond Leontief's original idea, in Erumban**,** Los,' Stehrer**,** Timmer and de Vries (2011), using the newly compiled WIOD database allow them to find an increasing part of the output value in Chinese manufacture is captured as income by production factors outside of China for instance, up to 32 per cent in electrical machinery in 2006. The value captured by China in foreign production appears to be smaller, but increasing over time. They also find that the growth of Chinese manufacturing has led to major changes in the income of production factors around the world. Overall labor income related to global manufacturing in the EU and NAFTA changed only marginally, even for low- and medium-skilled workers. In contrast, incomes in Japan declined for all production factors, in particular medium-skilled labor and capital.

Despite the fact that most authors in the value-added trade literature discussed above link their work with HIY, KPWW is the only paper in this recent literature 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 propose.[7]

This paper refines the accounting framework in KPWW. To keep Leontief's original insights clear and also make it applicable to new areas, such as the decomposition of gross exports, we first specify a gross output decomposition matrix based on all country's final demand and mathematically define domestic content in exports and value-added trade, thus clearly showing that the former equals value-added exports plus domestic value-added in gross exports that returns home country at least once. We then demonstrate mathematically how the "double counted" portion of value-added in intermediate goods trade could be measured and adjusted so that gross exports can be fully decomposed into its various value-added components. Finally, we

[7] 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.

show a potential application of our domestic content 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.

II. General Accounting Framework and Measures of Multiple Counting in Gross Trade

2.1. Setup

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

$$X_s = \sum_{r}^{G}(A_{sr}X_r + Y_{sr}), \quad r,s = 1,2\ldots \text{G} \tag{1}$$

Where X_s is the N×1 gross output vector of country *s*, Y_{sr} is the N×1 final demand vector that gives demand in country *r* for final goods produced in *s*, and A_{sr} is the N×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

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

and rearranging,

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

where B_{sr} denotes the N×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×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.

2.2. Value-added share by source matrix

Let V_s be the 1×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):

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

Define *V*, the G×GN matrix of direct domestic value added for all countries,

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

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.

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

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, including both intermediate and final goods. 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:

$$\sum_{s}^{G} V_s B_{sr} = u \, . \tag{7}$$

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 gross output at the sector level, for both intermediate and final goods. Note that this separation is independent of how these outputs are used domestically or exported.

It is also important to bear in mind that at the sector level, this measure of value-added by source captures all upstream sectors' contributions to value added in a specific sector's production and exports. For example, in the electronics sector, VB includes value added in the electronics sector itself as well as value added in inputs from all other sectors (such as glass, rubber, transportation, and design) used to produce electronics for domestic use or exports. Such a measure aligns well with case studies of supply chains of specific products, such as the iPhone or iPad. As an alternative, one could measure the value added produced by the factors of production employed in a specific sector and then embodied in production and exports of all downstream sectors by pre-multiplying the Leontief inverse matrix B with a GN by GN direct value-added coefficient matrix. This produces a value-added production and trade matrix. Such a measure at the sector level would include, for example, the value added by the electronics sector and then incorporated into gross exports of computers, consumer appliances, and automobiles (KPWW, 2010). This type of measure is closely related to the literature on factor content in trade. However, at the country aggregate level, the two measures produce exactly the same amounts of value-added production and trade estimates in levels.

Domestic content in exports and value-added trade, while related, are different concepts. Although both measure the value generated by factors employed in the producing country, domestic content of exports is independent of where that value is used. In contrast, value-added trade depends on how a country's exports are used by importers. It is the value-added generated by a country but absorbed by another country. At the level of a country's total exports, value added exports is a subset of domestic content in exports. In other words, value added in exports must be always smaller than or equal to domestic content in exports in the aggregate. However, at the sector level or at bilateral level, value added in exports could be either smaller than, equal to, or greater than domestic content in exports.

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.

2.3. Gross output decomposition matrix, value-added trade and domestic content in exports

To define value added exports and the domestic content in a country's exports, it is useful to first decompose each country's gross output in terms of the 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:

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

$$\begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1G} \\ X_{21} & X_{22} & \cdots & X_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ X_{G1} & X_{G2} & \cdots & X_{GG} \end{bmatrix} \qquad (8)$$

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.[8]

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

[8] 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.

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

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

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

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:

$$VT_{sr} \equiv V_s X_{sr} = V_s \sum_{g}^{G} B_{sg} Y_{gr} \tag{11}$$

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:

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

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

:

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

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 precisely defining value-added exports in term of final demand, let us define domestic content in exports.

Let E_{sr} be the N×1 vector of gross bilateral exports from *s* to *r*.

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

A country's gross exports to the world equal

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

Combining equations (7) and (15)

$$E_{s*} = \sum_{r \neq s}^{G} E_{sr} = V_s B_{ss} \sum_{r \neq s}^{G} (A_{sr} X_r + Y_{sr}) + \sum_{r \neq s}^{G} V_r B_{rs} (A_{sr} X_r + Y_{sr}) \qquad (16)$$

The first term on the right hand of equation (16) equals

$$V_s B_{ss} E_{s*} = V_s B_{ss} \sum_{r \neq s}^{G} Y_{sr} + V_s B_{ss} \sum_{r \neq s}^{G} A_{sr} X_r \qquad (17)$$

because $V_s B_{ss}$ is the share of domestic value-added in production and trade in the source country determined by the source country's production technology, equation (17) can be used as the definition of domestic content in exports. Note, however, since $V_s B_{ss}$ already includes country s' domestic value-added embodied in country s' intermediate exports to country r, but returned to country s as intermediates that are embedded in country r's intermediate goods exports to Country s, so some of Country s' value-added embodied in its intermediate exports to country r, $\sum_{r\neq s}^{G} V_s B_{ss} A_{sr} X_r$, is double counted. In other words, the measure of domestic content in a country's gross exports includes double-counted items in terms of value-added. This is the nature of gross exports, and does not present a problem for accounting as long as we recognize it and has a way to measure it. By subtracting Equation (12), value-added exports from Equation (17) we can identify and gauge these double counted value-added components by following equation:

$$V_s B_{ss} E_{s*} - VT_{s*} = V_s \sum_{r\neq s}^{G} B_{sr} Y_{rs} + V_s \sum_{r\neq s}^{G} B_{sr} A_{rs} X_s \tag{18}$$

A proof of Equation (18) is sketched in the appendix.

Therefore, domestic content in exports can also be defined as

$$DV_s = V_s B_{ss} E_{s*} = VT_{s*} + V_s (\sum_{r\neq s}^{G} B_{sr} Y_{rs} + \sum_{r\neq s}^{G} B_{sr} A_{rs} X_s) \tag{19}$$

The last term in the RHS of equation (19) is domestic value-added in country s' gross exports that returned home from abroad at least once.[9] It is important to note that the three terms in equation (19) are mutually exclusive. We can see that equation (19) provides a clear relationship between a country's value added exports and the domestic content in 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) rather than from equations (11) in terms of final demand.

3.4. Exports decomposition and value-added structure of gross exports

Now let us work out a complete decomposition of a country's gross exports.

[9] Define DV_s as equations (17) and (19) has the advantage of being consistent with HIY's original definition of domestic content and making domestic content share always equals one minus foreign content share (FV share). On the other hand, including value-added in intermediate exports that are returned home more than once may make the domestic content measure inconsistent with measures of GDP. This topic needs further investigation. Since the purpose of our study is to decompose gross exports, not to measure GDP, we adopt the definition as in equation (19).

Inserting equation (19) into equation (16), we obtain a gross export decomposition computation formula as follows:

$$E_{s*} = VT_{s*} + \{V_s \sum_{r \neq s}^{G} B_{sr} Y_{rs} + V_s \sum_{r \neq s}^{G} B_{sr} A_{rs} X_s\} + \{\sum_{r \neq s}^{G} V_r B_{rs} Y_{sr} + \sum_{r \neq s}^{G} V_r B_{rs} A_{sr} X_r\} \qquad (20)$$

The first term in the right hand of equation (20) is value-added exports (which can be further decomposed into 3 parts according equation (13)), the second term in the first bracketed expression on the right hand side, 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. Specifically, the term $V_s \sum_{r \neq s}^{G} B_{sr} A_{rs} X_s$ is the home country 's value-added in its gross intermediate exports to country r to produce intermediate goods that is shipped back to and used by country s to produce its own final goods. This term has already counted once by $V_s B_{ss}$. This is the key to understanding our gross export decomposition formula and why we believe the VS1* computed by Daudin et al. (forthcoming, Canadian Journal of Economics) is incomplete when decomposing gross exports, as it only includes value-added in final goods that is returned and consumed at home. If the purpose is to estimate value-added exports, this is correct, however, if one ignores this domestic value-added in intermediate goods that is returned home at least once (although it is double counted in value-added terms) you will not only underestimate HIY's VS1 but also make the decomposition of gross exports incomplete. This is because such intermediate goods may travel between country s and r several times (perhaps also via several third countries) before being used to produce final goods in country s, which may then be consumed by country s, or exported again to country r and/or other third countries.[10] The first term in the second set of brackets on the right hand side is other

[10] We define vertical trade differently with Daudin et al (2011) and think their definition is inconsistent with HIY's original idea. It will under estimate actual vertical specialization reflected in trade statistics. It appears that they confuse the concepts of value-added trade and domestic contents in exports, excluding value-added in intermediate goods that had returned home at least once or travel via third countries which may cross borders many times in the global production process before being embodied in final goods. The only vertical trade in intermediate goods included in their estimates is foreign value-added in a country's intermediate goods exports. Therefore their definition is also inconsistent in terms of coverage (some parts of these double counted value-added in intermediates are included in their definition, and others are not). Although the double counted value-added in intermediate goods may be equal at global level when they are counted as foreign value-added in exports or as indirect exports to the third countries, however their distribution across country and sectors are quite different for different countries. They are both important for assessing a country's position in global value chains.

country's value-added in the source country' s final goods exports to country r (net foreign value-added), and the other term in the second set of brackets is other countries' value-added in the source country's intermediate exports to country r. Both terms are also double counted portions 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.

To Summarize, the first two terms of this equation sum to domestic value-added (DV_s) and the last two terms sum to foreign value-added (FV_s). It is easy to see that DV_s and FV_s are mutually exclusive. None of the same double counted terms appear simultaneously in both DV_s and FV_s. Combining equation (20) with the value-added export decomposition equation (13) we then have a complete decomposition of gross exports.

A comment is in order on the two terms in Equation (20) that capture the double counting of value-added in intermediate goods are expressed as value-added shares from the off diagonal of VB matrix multiplied by gross intermediate exports. One may still argue that this may also cause double counting. However, we think this may just properly reflect the back and forth, double counting nature of intermediate goods trade and our objective is to fully decompose gross exports, not just estimating value-added trade. Even the exact partition of value added between these two double counted terms could be further refined, it will be less important because it does not affect the calculation of the value added exports or the domestic content in a country's exports. In addition, when all the decomposition results are reported as shares in a country's gross exports, the errors in the precise partition between different double-counted items will likely become negligible in a numerical sense.

It also important to bear in mind that avoiding double counting is critical in value-added trade estimation, but the gross export decomposition have to include both the double counted items and the value added exports. Otherwise, the decomposition would be incomplete. Because our decomposition approach can simultaneously produce estimates of the domestic content in exports, which can be linked to various vertical specialization measures in the literature through simple transformations, estimates of value added exports, and estimates of various double counted items in gross exports, which reflect the depth of a country's participation in global production chains, our approach can have many useful applications.

Finally, please note we are intentionally using a single subscript for the domestic content measure and two subscripts for the value-added measure. This is to suggest that the value-added 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 trade flows.

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 content 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 paper. 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 concording 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.[11]

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 COMTRADE[12]. This differs from the approaches in Johnson and Noguera (2010) and Daudin, Rifflart, and Schweisguth (2010), 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.[13] Feenstra and Jensen (2009) use a similar approach to separate final goods from intermediates in U.S. imports 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

[11] 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.

[12] 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.

[13] 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.

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 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 content 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.[14] 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

[14] 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 Hungry 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 content 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 multiple 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.

Appendix: Proof of equation (18)

To simplify the algebra, we provide a proof for equations (18) in a 3 country world. In such a case, the block matrix inverse is still analytically tractable but no generality is lost going from the 3-country case to the arbitrary G-country case.

Let us start from the 3 country gross output decomposition matrix:

$$\begin{bmatrix} X_{11} & X_{12} & X_{13} \\ X_{21} & X_{22} & X_{23} \\ X_{31} & X_{32} & X_{33} \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{bmatrix} \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix}$$

$$= \begin{bmatrix} B_{11}Y_{11} + B_{12}Y_{21} + B_{13}Y_{31} & B_{11}Y_{12} + B_{12}Y_{22} + B_{13}Y_{32} & B_{11}Y_{13} + B_{12}Y_{23} + B_{13}Y_{33} \\ B_{21}Y_{11} + B_{22}Y_{21} + B_{23}Y_{31} & B_{21}Y_{12} + B_{22}Y_{22} + B_{23}Y_{32} & B_{21}Y_{13} + B_{22}Y_{23} + B_{23}Y_{33} \\ B_{31}Y_{11} + B_{32}Y_{21} + B_{33}Y_{31} & B_{31}Y_{12} + B_{32}Y_{22} + B_{33}Y_{32} & B_{31}Y_{13} + B_{32}Y_{23} + B_{33}Y_{33} \end{bmatrix} \quad (21)$$

Based on the definition of the inverse matrix and a bit of algebra, we can verify the following identities[15]:

$$B_{11}A_{12} = B_{12}(I - A_{22}) - B_{13}A_{32}$$

$$B_{11}A_{13} = B_{13}(I - A_{33}) - B_{12}A_{23}$$

Applying these identities to Equation (17) for country 1, we obtain

$$\begin{aligned} &V_1B_{11}E_{1*} = V_1B_{11}(Y_{12} + Y_{13}) + V_1(B_{11}A_{12}X_2 + B_{11}A_{13}X_3) \\ &= V_1B_{11}(Y_{12} + Y_{13}) + V_1\{[B_{12}(I - A_{22}) - B_{13}A_{32}]X_2 + [B_{13}(I - A_{33}) - B_{12}A_{23}]X_3\} \end{aligned} \tag{22}$$

By definition (equations (12)) and using the relation between Y_r and X_r in equation (2), we obtain

$$\begin{aligned} &VT_{1*} + V_1(B_{12}Y_{21} + B_{13}Y_{31}) = V_1B_{12}(Y_2 + Y_3) + V_1B_{13}(Y_2 + Y_3) + V_1B_{11}(Y_{12} + Y_{13}) \\ &= V_1[B_{12}(I - A_{22})X_2 - A_{21}X_1 - A_{23}X_3] + V_1B_{13}[(I - A_{33})X_3 - A_{31}X_1 - A_{32}X_2] + V_1B_{11}(Y_{12} + Y_{13}) \\ &= V_1\{[B_{12}(I - A_{22}) - B_{13}A_{32}]X_2 + [B_{13}(I - A_{33}) - B_{12}A_{23}]X_3\} + V_1B_{11}(Y_{12} + Y_{13}) \\ &- V_1(B_{12}A_{21}X_1 + B_{13}A_{31}X_1) \end{aligned} \tag{23}$$

Subtracting equation (23) from (22), it is easy to obtain

$$\begin{aligned} &V_1B_{11}E_{1*} - VT_{1*} = V_1(B_{12}Y_{21} + B_{13}Y_{31}) + V_1(B_{12}A_{21}X_1 + B_{13}A_{31}X_1) \\ &= V_1\sum_{r \neq 1}^{3} B_{1r}Y_{r1} + V_1\sum_{r \neq 1}^{3} B_{1r}A_{r1}X_1 \end{aligned} \tag{24}$$

Because V_1B_{11} already includes country 1's value-added in its intermediate goods imports from country 2 and country 3, multiplying it by gross intermediate exports produces a double counting, so it must be adjusted in order to obtain value-added exports. The last term in the RHS of equation (24) represent such an adjustment. The first term in the RHS of equation (24) is double counted domestic value-added embodied in country 1's final goods imports. This is equation (18) in a 3 country world for country 1.

The second term of equation (16) for country 1 equals:

[15] Please see the detailed derivation of the block matrix inverse in Appendix (page 36-38) in Wang, Zhi, William Powers, and Shang-Jin Wei. 2009. "Value Chains in East Asian Production Networks." USITC Working Paper No. 2009-10-C, October.

$$\sum_{r\neq 1}^{3} V_r B_{r1}(A_{1r}X_r + Y_{1r}) = V_2 B_{21} Y_{12} + V_3 B_{31} Y_{13} + V_2 B_{21} A_{12} X_2 + V_3 B_{31} A_{13} X_3 \tag{25}$$

Combining equations (24) and (25), we obtain the full decomposition of gross exports for country 1 as:

$$\begin{aligned} E_{1*} &= VT_{1*} + V_1(B_{12}Y_{21} + B_{13}Y_{31}) + V_1(B_{12}A_{21}X_1 + B_{13}A_{31}X_1) + V_2 B_{21} Y_{12} + V_3 B_{31} Y_{13} + V_2 B_{21} A_{12} X_2 + V_3 B_{31} A_{13} X_3 \\ &= VT_{1*} + V_1 \sum_{r\neq 1}^{3} B_{1r} Y_{r1} + V_1 \sum_{r\neq 1}^{3} B_{1r} A_{r1} X_1 + \sum_{r\neq 1}^{3} V_r B_{r1} Y_{1r} + \sum_{r\neq 1}^{3} V_r B_{r1} A_{1r} X_r \end{aligned}$$

Similar proof and decompositions can be performed for Country 2's and 3's total exports.

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

Figure 1

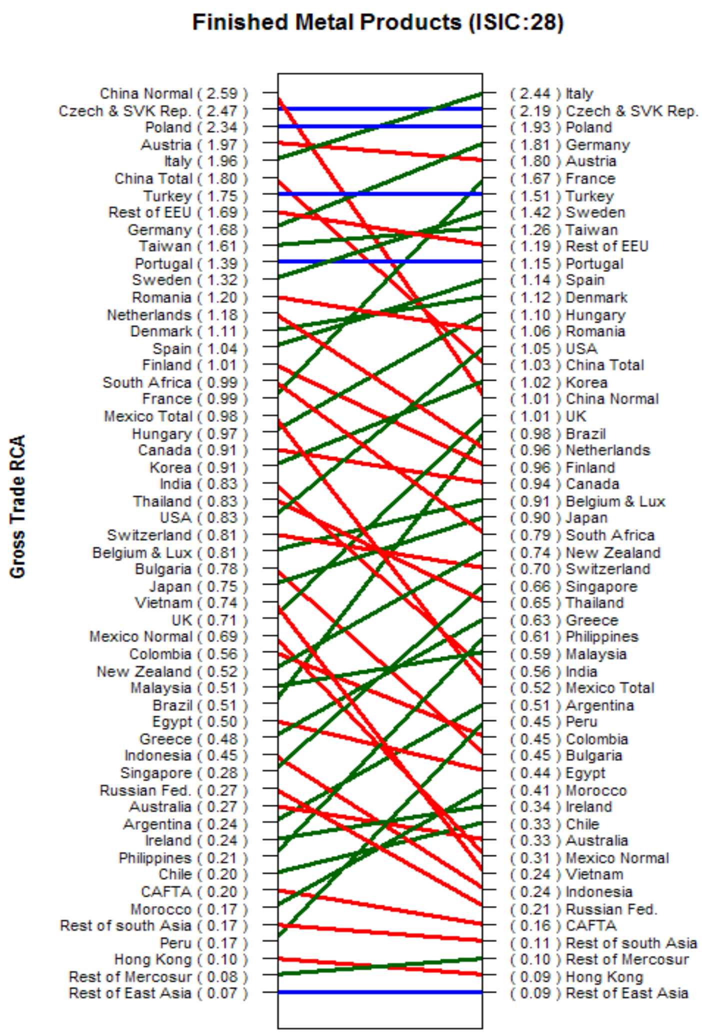
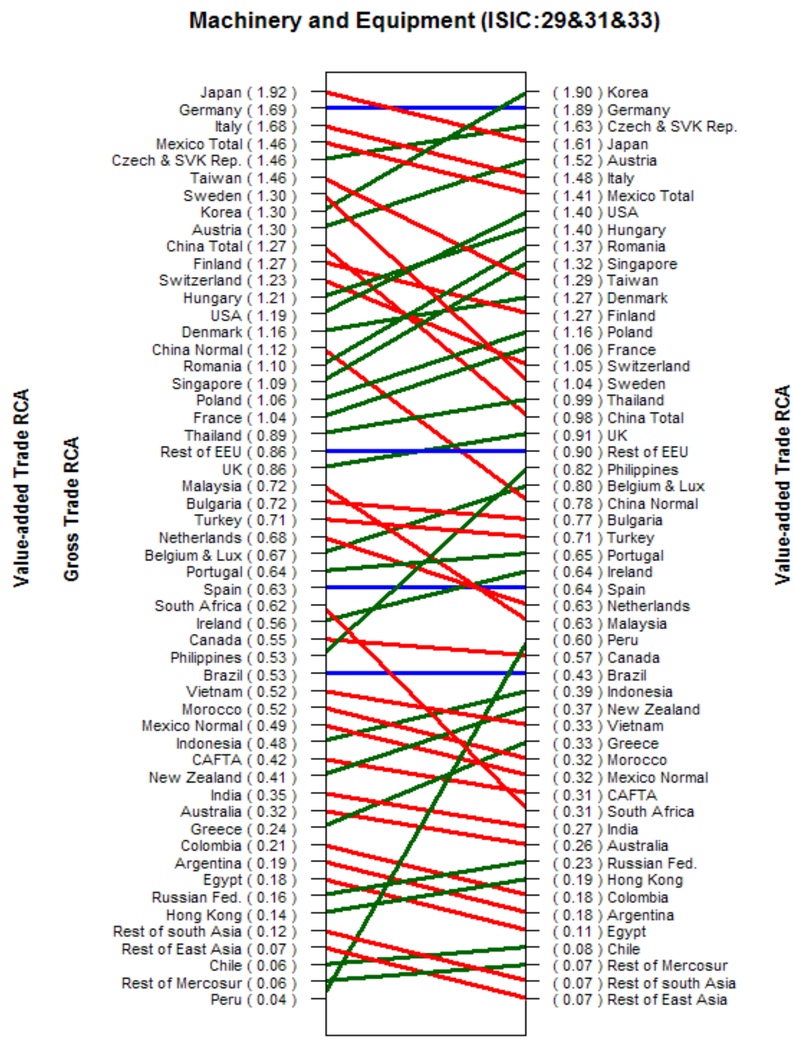


Figure 2



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

Figure 3

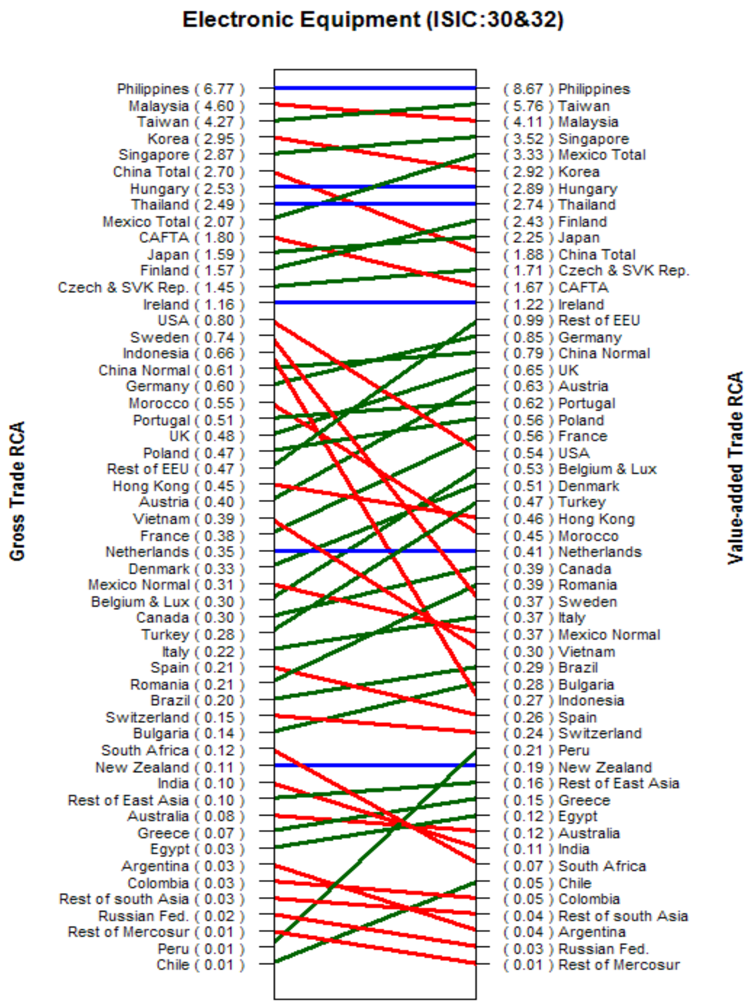
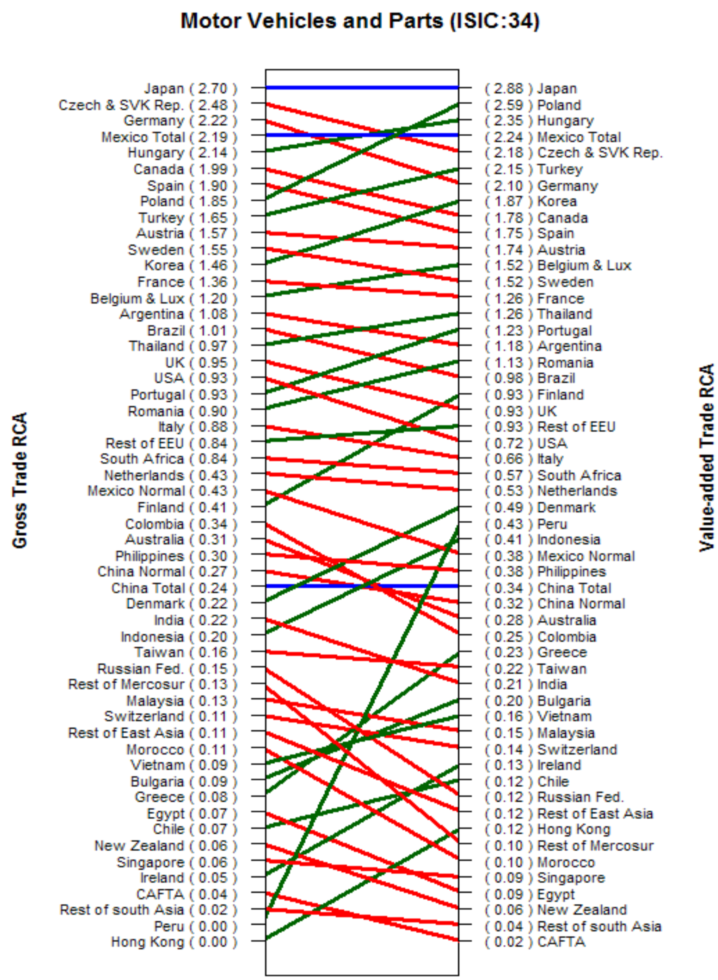


Figure 4



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

Figure 5

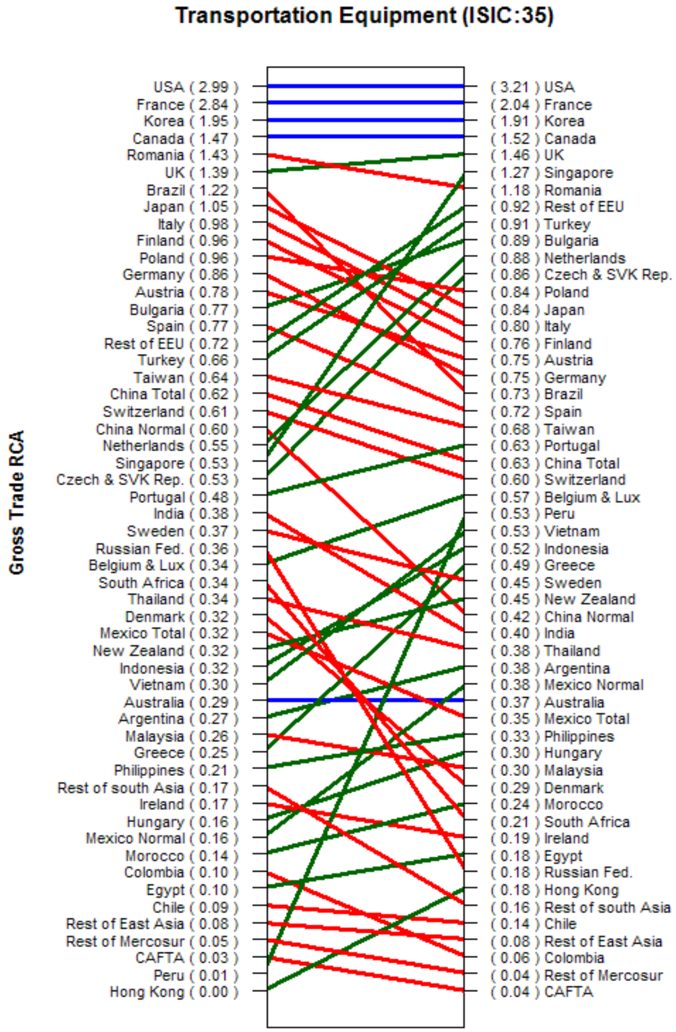
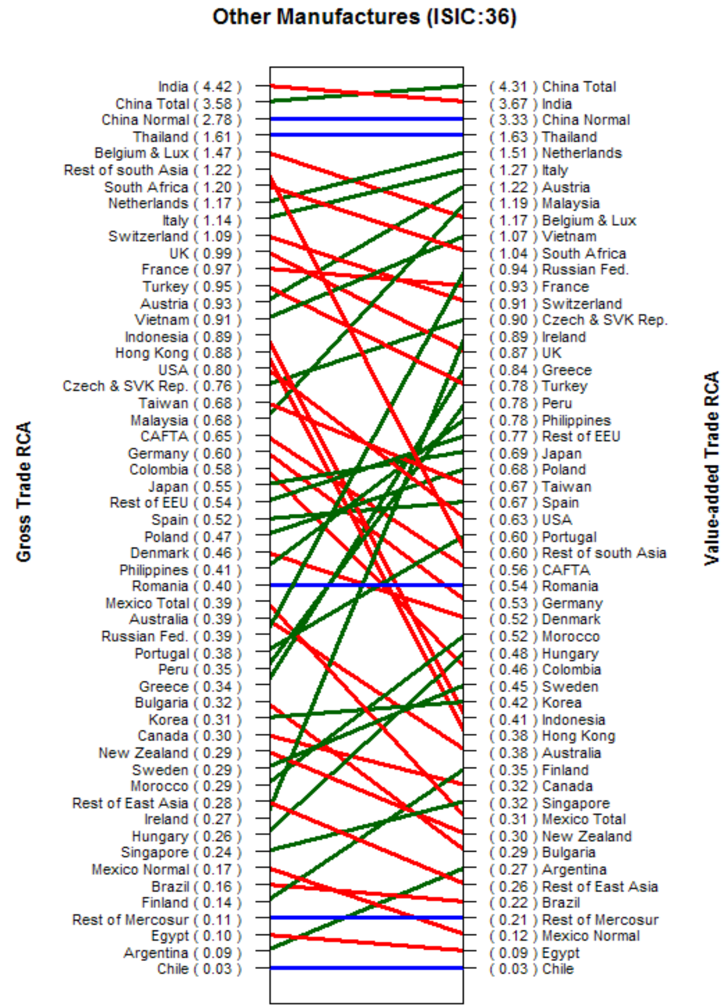


Figure 6



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

Figure 7

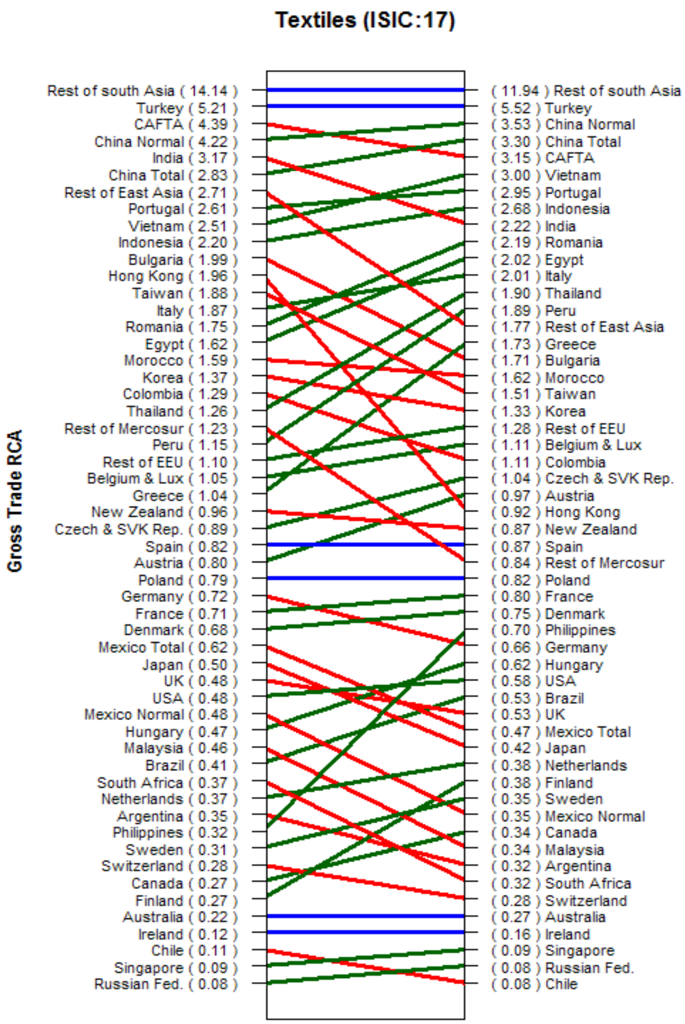
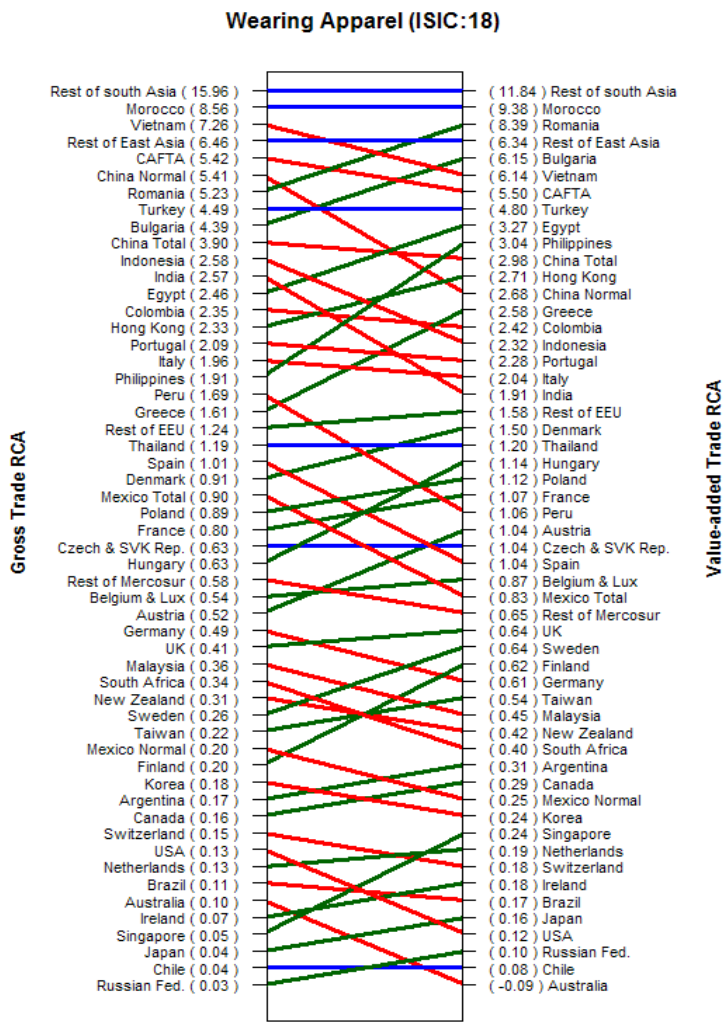


Figure 8



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

Figure 9

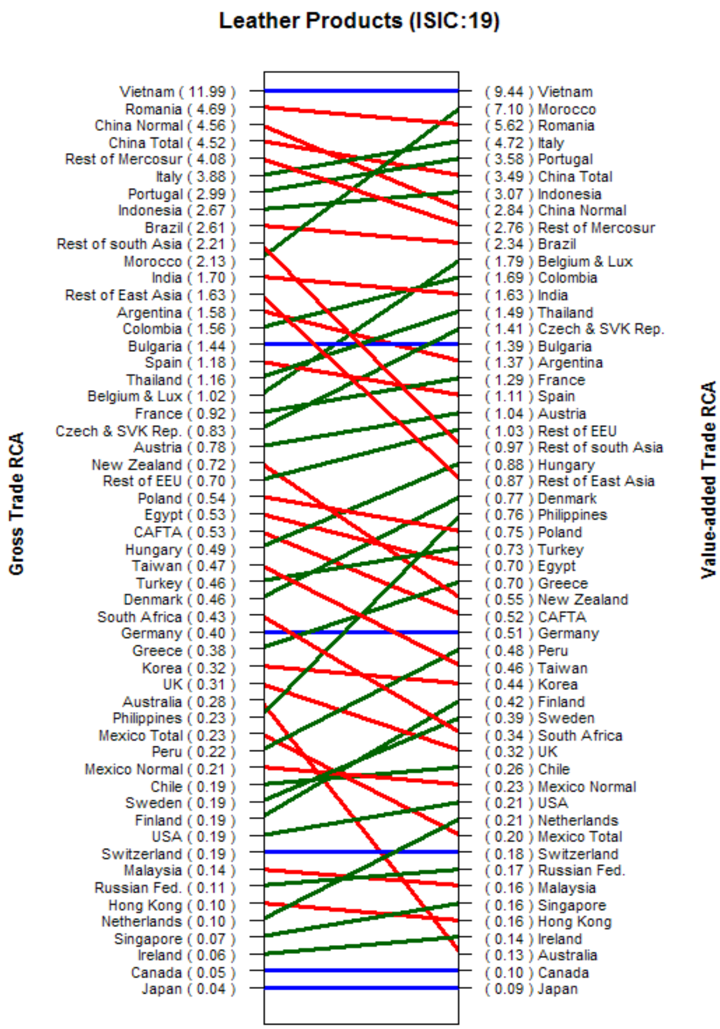
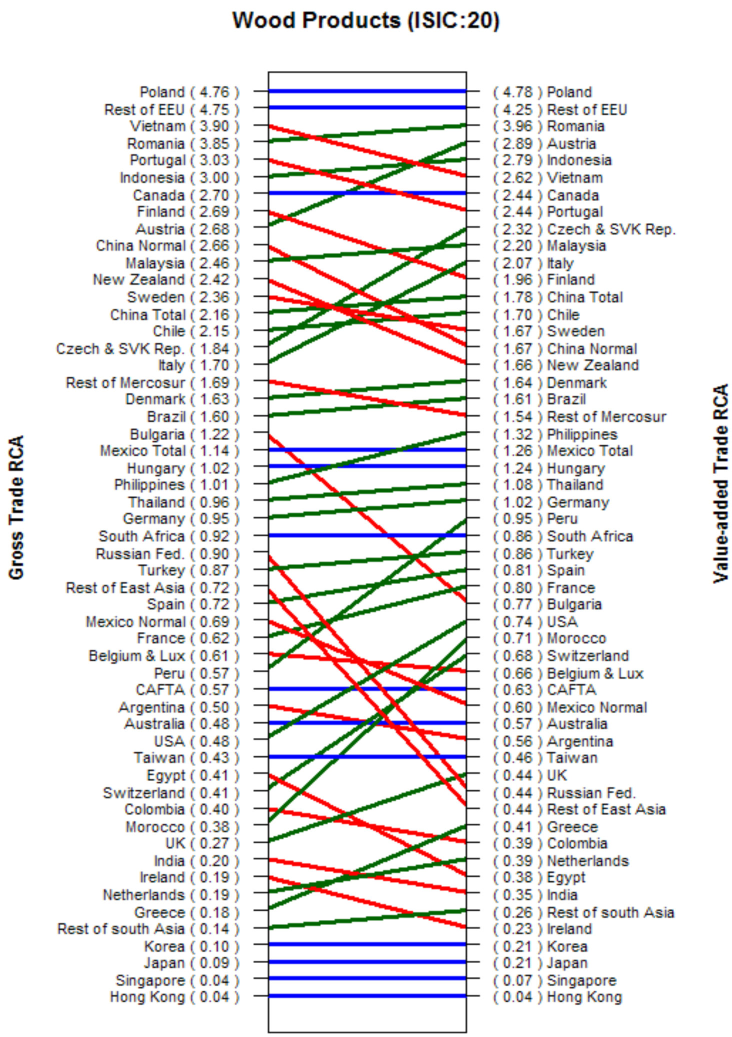


Figure 10



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

Figure 11

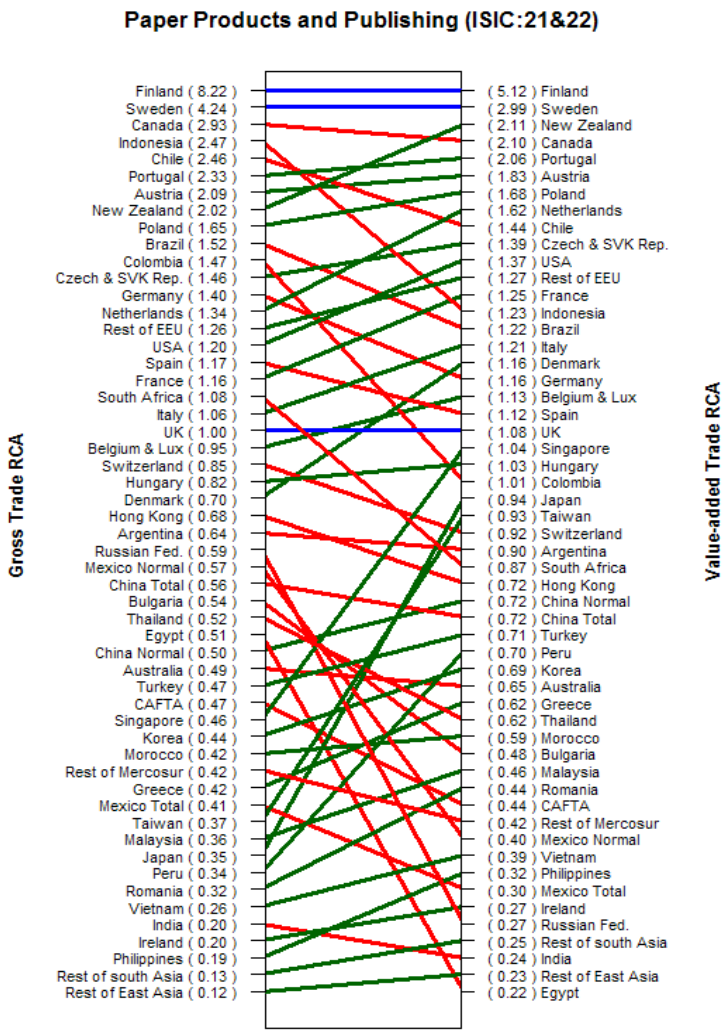
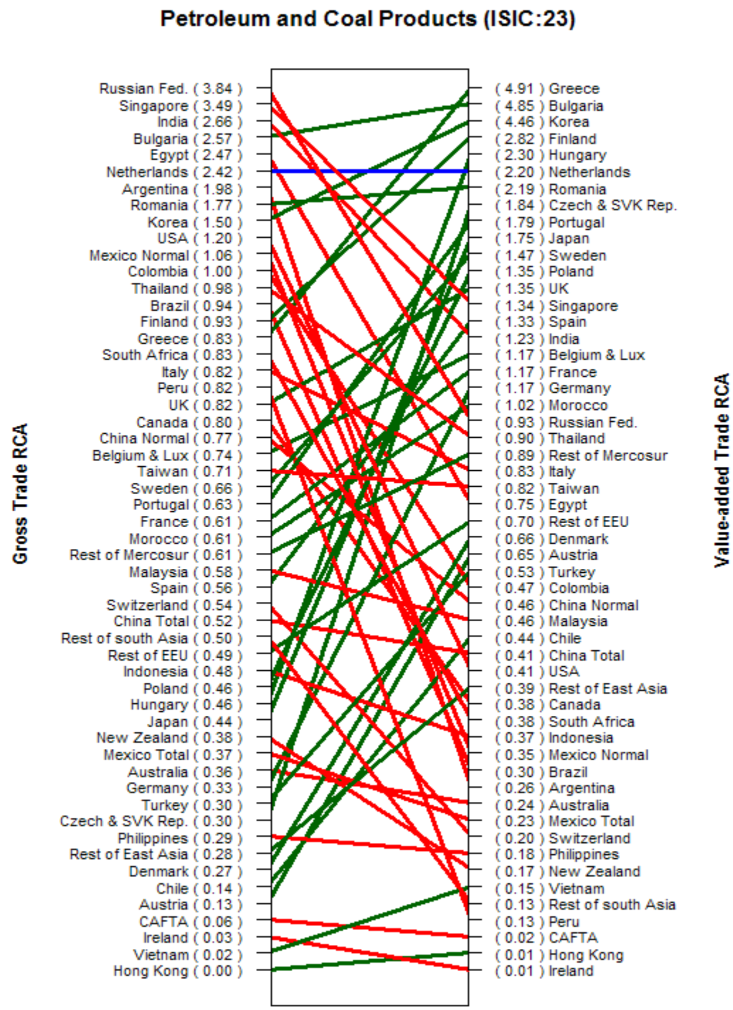


Figure 12



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

Figure 13

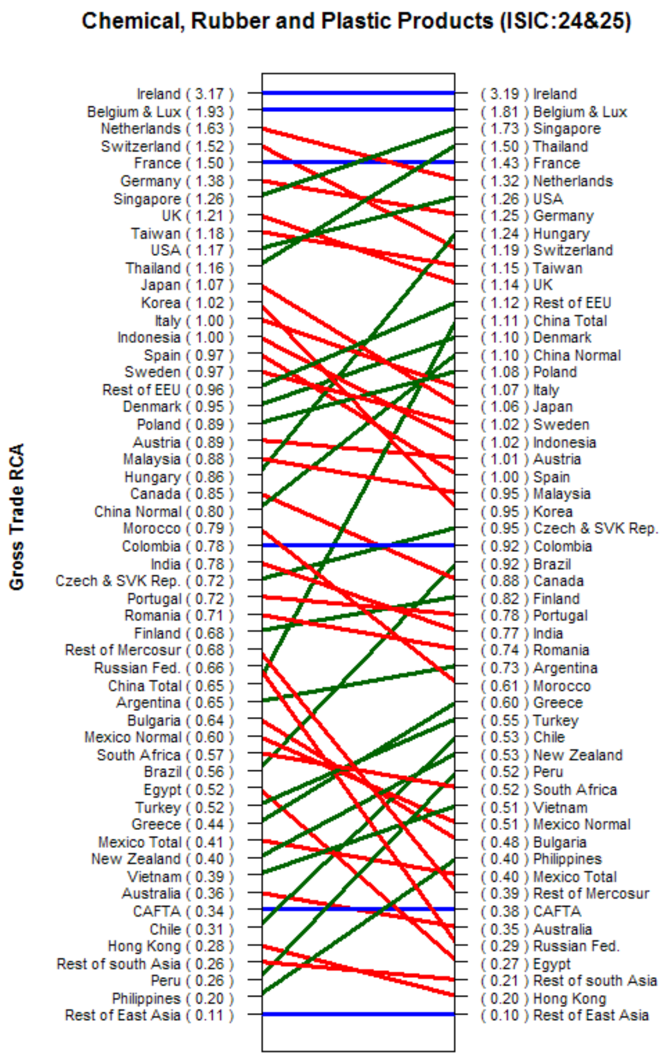
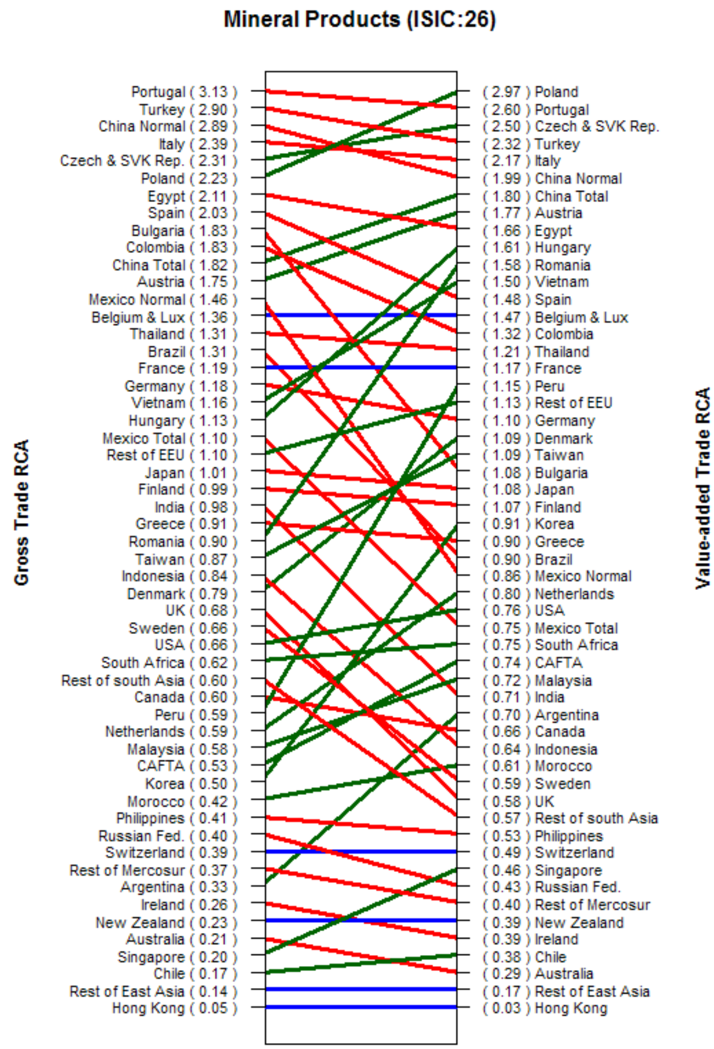


Figure 14



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

Figure 15

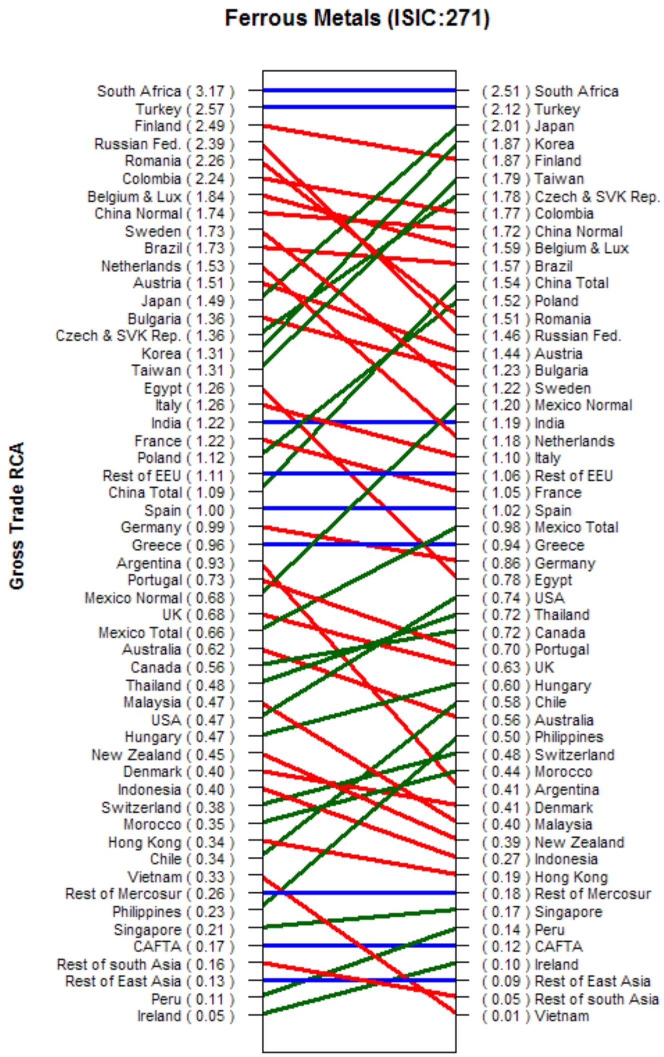


Figure 16