Global Value Chain Participation and Recent Global Business Cycle

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Abstract

In this paper, we propose a production activity decomposition framework to distinguish GVC and non-GVC activities in GDP and final goods production based on whether they cross national borders for production or not, and then redefine the measures of forward and backward industrial linkage based GVC participation indexes. We apply this decomposition framework to the newly available Global Input-Output Database (WIOD) that cover 44 countries and 56 industries to show the advantages of our new GVC participation measures, as well as to quantitatively characterize the cross-country production sharing patterns. The econometric analysis based on the numerical results contribute to a better understanding of the relationship between different types of value-added production activities and economic growth.

Key Words: Global Value Chain (GVC), Participation Index, Economic Growth

JEL Number: F1, F6

1. Introduction

The emergence of global value chains (GVCs) has changed the patterns of international trade in recent decades. Different stages of production now are often conducted by multiple producers located in several countries, with parts and components crossing national borders multiple times. While the deficiency (i.e., due to trade in intermediates) of official trade statistics as a description of true trade patterns has been well recognized, measures of global value chains based on sequential production are still under development.

As GVC involves products and services that will be used as inputs for production processes that cross national borders, the first major issue to be solved in GVC measurement is the missing information on final or intermediate usage in Customs trade statistics. However, hundreds and thousands of products are classified by Customs product codes (such as the 10-digit Harmonized Tariff Schedule (HS) in the US), and owing to the tremendous heterogeneity even within the 10-digit HS product groups. Properly identifying their final usage is not an easy task. Furthermore, supply chain trade or cross-border production-sharing measures in the literature, such as "vertical specialization" (VS) proposed by Hummels et al. (2001) or "import to produce" (I2P) and "import to export" (I2E) proposed by Baldwin and Lopez (2013), are recursive concepts and double counting is pervasive.

To overcome these difficulties in GVC measurement, "factor content," or "value-added" trade, is emerging as the mainstream measures of cross-border production-sharing activities as production factors are limited, such as land, labor, capital, etc., thus are easy to classify. Therefore, we can classify production activities based on factor content embodied in various products according to some uniform standard to make analytical work tractable. In the classical trade model, factors are not mobile across countries, but factor content embodied in final products does cross national borders, although it is only for consumption. In today's world economy dominated by regional and GVCs, some factors (e.g., capital) are more mobile internationally while some are less mobile (e.g., labor). Some factors directly cross national borders, such as FDI, but a large portion of production factors still do not directly cross national borders; instead, they continue to embody in both final and intermediate trade flows across national borders.

In this paper, we propose a production activity decomposition framework according to the System of National Accounts standard (SNA), classifying these embedded factor content into GVC and non-GVC activities based on whether they cross national borders for production or not (FDI was excluded for future work). Value-added creation is only classified as GVC activities when embodied factor content crosses national border for production purposes. Domestic input-output coefficient matrix and import input-output coefficient matrix in an inter-country input-output (ICIO) table are used to distinguish domestic and foreign factor content in various production activities.

We integrate the forward and backward cross-country, inter-industry linkages based decomposition into one unified mathematical framework. The forward linkage-based decomposition views a country/sector's engagement in GVC activities from the producer's perspective. It classifies the portion of GDP created in a country/sector by domestic production factor content that cross border at least once as GVC production activities, and the portion of GDP created by domestic factor content stay within the national border in the whole production process as domestic production activities. It decomposes values but not for particular products as any contemporary product is very likely to contain some foreign factor content or value added, directly or indirectly. However, these values are measured by GDP decomposition for foreign countries, or measured by backward-linkage based decomposition of a country/sector's final goods production, as one country's domestic value added embedded in its exports that are used by another country to produce exports will become foreign value added in that country's exports. In other words, the backward linkage-based decomposition considers a country/sector's engagement in GVC activities from the buyer's perspective. It traces all primary factor inputs embodied in the final products to its original country/sector sources and consistently classifies this embodied domestic or/and foreign factor content into GVC and non-GVC production activities based on whether they have crossed national borders for production or not.

We show the advantages of the GVC participation measures build on such a production activity accounting framework over these traditional GVC participation indexes based on gross exports, and conduct econometric analysis to establish the

empirical evidence that how economies to engage in different value-added creation activities to impact their economic performance first time in the literature.

Rest of the paper is organized as follows: Section 2 describe how GVC and Non-GVC activities are classified in our GDP and final goods production accounting framework and define the new GVC participation indexes; Section 3 presents numerical results when apply our decomposition to the newly available Global Input-output database that cover 44 countries and 56 industries and demonstrate the advantages of our newly defined GVC participation indexes over these indexes used in current literature; section 4 reports our econometric analysis that establish the relationship between different types of value-added production activities with economic growth and section 5 concludes.

2. Production Activity Accounting and Global Value Chain Participation Indexes

2.1 The setup of production activity accounting framework

Without loss generality, let's consider an Inter-Country Input-Output (ICIO) model for G countries and N sectors. Its structure can be described by Table 1:

Table 1 General Inter-Country Input-Output table

Outputs / Inputs		Intermediate Use				Final Demand				Total Output
		1	2	⋯	G	1	2	⋯	G	
Intermediate Inputs	1	Z^{11}	Z^{12}	⋯	Z^{1g}	Y^{11}	Y^{12}	⋯	Y^{1g}	X^1
	2	Z^{21}	Z^{22}	⋯	Z^{2g}	Y^{21}	Y^{22}	⋯	Y^{2g}	X^2
	⋮	⋮	⋮	⋱	⋮	⋮	⋮	⋱	⋮	⋮
	G	Z^{g1}	Z^{g2}	⋯	Z^{gg}	Y^{g1}	Y^{g2}	⋯	Y^{gg}	X^g
Value-added		Va^1	Va^2	⋯	Va^g					
Total input		$(X^1)'$	$(X^2)'$	⋯	$(X^g)'$					

where Z^{sr} is an $N \times N$ matrix of intermediate input flows that are produced in country s and used in country r; Y^{sr} is an $N \times 1$ vector giving final products produced in country s and consumed in country r; X^s is also an $N \times 1$ vector giving gross outputs in country s; and VA^s denotes a $1 \times N$ vector of direct value added in country s. In this ICIO model, the input

coefficient matrix can be defined as $A = Z\hat{X}^{-1}$, where $\hat{X}$ denotes a diagonal matrix with the output vector X in its diagonal. The value added coefficient vector can be defined as $V = Va\hat{X}^{-1}$. Gross outputs X can be split into intermediate and final products, $AX + Y = X$. Rearranging terms, we can reach the classical Leontief (1936) equation, $X = BY$, where $B = (I - A)^{-1}$ is the well-known (global) Leontief inverse matrix.

The gross output production and use balance, or the row balance condition of the ICIO table in Table 1 can be written as:

$$X = AX + Y = A^D X + Y^D + A^F X + Y^F = A^D X + Y^D + E \quad (1)$$

Where $A^D = \begin{bmatrix} A^{11} & 0 & \cdots & 0 \\ 0 & A^{22} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & A^{gg} \end{bmatrix}$ is a GN×GN diagonal block matrix of domestic input coefficient, A^F is a GN×GN off-diagonal block matrix of imported input coefficient, $A^F = A - A^D$, $Y = [\sum_r^G Y^{1r} \quad \sum_r^G Y^{2r} \quad \cdots \quad \sum_r^G Y^{gr}]'$ is a GN×1 vector of final goods and services production, $Y^D = [Y^{11} \quad Y^{22} \quad \ldots \quad Y^{gg}]'$ is a GN×1 vector of final goods and service production for domestic consumption, $Y^F = Y - Y^D$ is a GN×1 vector of final products exports, $E = [\sum_{r\neq 1}^G E^{1r} \quad \sum_{r\neq 2}^G E^{2r} \quad \cdots \quad \sum_{r\neq G}^G E^{gr}]'$ is a GN×1 vector of gross exports, $'$denotes transpose operation.

Rearranging equation (1) yields

$$X = (I - A^D)^{-1}Y^D + (I - A^D)^{-1}E = LY^D + LE$$
$$= LY^D + LY^F + LA^F X \quad (2)$$

where $L = (I - A^D)^{-1}$ is defined as local Leontief inverse, a GN by GN diagonal block matrix. Pre-multiplying with the GN by GN diagonal matrix $\hat{V}$ of direct value-added coefficients, replacing X as BY, and further converting the 3 final goods and service production vectors Y^D, Y^F and Y into GN by GN diagonal matrix $\hat{Y}$, $\hat{Y}^D$ and $\hat{Y}^F$, we can obtain the decomposition of value added and final products production simultaneously as following:

$$\hat{V}B\hat{Y} = \hat{V}L\hat{Y}^D + \hat{V}L\hat{Y}^F + \hat{V}LA^F B\hat{Y}$$
$$= \hat{V}L\hat{Y}^D + \hat{V}L\hat{Y}^F + \hat{V}LA^F L\hat{Y}^D + \hat{V}LA^F(B\hat{Y} - L\hat{Y}^D) \quad (3)$$

Each element in the $\hat{V}B\hat{Y}$ matrix represents the value added from a source country/sector directly or indirectly used in the production of final goods and services in a particular

country/sector. The element of row (*s, i)* and column (*r, j)* in the matrix, $v_i^s b_{ij}^{sr} y_j^r$, is the total value added (direct and indirect) of sector *i* in country s embodied in the final products produced by sector *j* of country r. Looking at the matrix along the row yields the distribution of value added created from one country/sector pair absorbed by final goods produced by all country/sectors pairs. Looking at the matrix along the column yields the contribution of value added from all source country /sectors pairs embodied in final goods and services produced by a particular country/sector.

The $\hat{V}B\hat{Y}$matrix can be decomposed into four GN by GN matrixes, each representing domestic value-added generated or foreign value-added used by the industry in its production of final products to satisfy different segments of the global market. The decomposition in equation (3) identifies three types of production activities in each country/sector pair as follows:

(1) Production of domestically produced and consumed value-added ($\hat{V}L\hat{Y}^D$). It is domestic value added embodied in domestic produced final products to satisfy domestic final demand without involving cross border trade such as haircut.

(2) Production of value-added embodied in final product exports ($\hat{V}L\hat{Y}^F$). It is domestic value added embodied in exports of final goods and services to satisfy foreign final demand. These embodied domestic factor content cross national borders for consumption only, so is similar to traditional "Ricardian" type trade such as "French wine in exchange for England cloth", in the term proposed by Borin and Mancini (2015) [1].

(3) Production of value-added embodied in exports/imports of intermediate goods and services ($\hat{V}LA^F B\hat{Y}^F$). It is domestic value-added used in production activities outside the source country, and is the contribution of source country's production factor to cross country production sharing activities. It can be further split into two categories[2]:

[1] In Ricard's time, exports were 100% domestically produced value added, whereas today, many final product exports from a country, foreign value added is always embodied and domestically produced value added is only a part of the exports. However, using decomposition method based on input-output statistics, we are still able to compute the portion of "Ricardian trade" analytically.

[2] The production of foreign affiliates may also be considered as a type of GVC activity since current residence-based national account rules treat all firms within national borders as domestic firms; therefore, they treat their value added creation as part of domestic GDP production. No inter-country input–output (ICIO) table currently exists to separate production activities between domestic firms and foreign affiliates. Thus, our GDP decomposition method may underestimate GVC production activities.

3a. Simple cross country production sharing activities ($\hat{V}LA^{F}L\hat{Y}^{D}$). Domestic or/and foreign value-added cross national border for production only once. Value-added embodied in intermediate exports/imports that is used by trading partner to produce its domestic products and absorbed in the direct importing country. It involves production activities in both the home and partner country, but only cross border for production once. There are no indirect exports via third countries or re-exports/re-imports of the source countries' factor contents. Such as Chinese value-added embodied in its steel exports to the US and used in US house construction.

3b. Complex cross country production sharing activities ($\hat{V}LA^{F}(B\hat{Y}-L\hat{Y}^{D})$). Domestic or/and foreign value-added embodied in intermediate exports/imports that is used by partner country to produce exports (intermediate or final) for other countries. Factor contents cross border at least twice. It is used by partner country to produce intermediate or final products either re-export to the home countries (such as Apple engineer's salary embodied in iPhone bought by an American consumer) or re-export to any other countries (such as Japanese value-added embodied in electronic chip installed in China made toy export to the US)[3].

To make equation (3) more intuitive, let us assume a two-country (home country s and foreign country r) world, in which each country produces products in N differentiated tradable industries. Then equation (3) can be rewritten as follows in block matrix notations:

$$\hat{V}B\hat{Y}=\begin{bmatrix}\hat{V}^{s}L^{ss}\hat{Y}^{ss} & 0\\ 0 & \hat{V}^{r}L^{rr}\hat{Y}^{rr}\end{bmatrix}+\begin{bmatrix}\hat{V}^{s}L^{ss}\hat{Y}^{sr} & 0\\ 0 & \hat{V}^{r}L^{rr}\hat{Y}^{rs}\end{bmatrix}+\begin{bmatrix}0 & \hat{V}^{s}L^{ss}A^{sr}L^{rr}\hat{Y}^{rr}\\ \hat{V}^{r}L^{rr}A^{rs}L^{ss}\hat{Y}^{ss} & 0\end{bmatrix} \quad (4)$$
$$+\begin{bmatrix}\hat{V}^{s}L^{ss}A^{sr}(B^{rs}\hat{Y}^{ss}+B^{rr}\hat{Y}^{rs}) & \hat{V}^{s}L^{ss}A^{sr}[(B^{rr}-L^{rr})\hat{Y}^{rr}+B^{rs}\hat{Y}^{sr}]\\ \hat{V}^{r}L^{rr}A^{rs}[(B^{ss}-L^{ss})\hat{Y}^{ss}+B^{sr}\hat{Y}^{rs}] & \hat{V}^{r}L^{rr}A^{rs}(B^{sr}\hat{Y}^{rr}+B^{ss}\hat{Y}^{sr})\end{bmatrix}$$

The first term of equation (4) is domestic value added production in country s and r directly absorbed by domestically produced final products to satisfy each country's domestic final demand, which are domestic production chains without involving cross border trade. The second term is domestic value added production in country s and r directly absorbed by exports of final goods and services to satisfy foreign final demand,

[3] This means that term 3b can be further divided into returned domestic value added and foreign value added based on their final destinations of absorption. A detailed mathematical derivation and their relation with measures exist in the literature is provided in Appendix A.

which are also part of domestic production chains without involving cross border trade for production. The third term is the domestic value added embodied in intermediate exports from Country s and r, or foreign value-added embodied in intermediate imports by country r and s, directly absorbed by importers' domestic final products, which are simple cross country production sharing activities. The last term is domestic/foreign value added embodied in intermediate trade flows between country s and r used by the importer to produce products absorbed at home or abroad, which are relatively complicated cross country production sharing activities. It can be further decomposed into complex cross country production ultimately absorbed by home country (domestic value-added return home, elements in the diagonal) and ultimately absorbed by foreign countries (foreign value-added re-exports, elements in the off-diagonal).

2.2 Decomposition value added and final goods production

Summing up equation (3) along the row direction, we can decompose value-added generated from each industry/country pair (GDP by industry) into four major components based on whether and how they are involved in cross country production sharing activities:

$$\mathrm{Va}' = \hat{\mathrm{V}}\mathrm{BY} = \underbrace{\hat{\mathrm{V}}\mathrm{LY}^{\mathrm{D}}}_{(1)-\mathrm{V\_D}} + \underbrace{\hat{\mathrm{V}}\mathrm{LY}^{\mathrm{F}}}_{(2)-\mathrm{V\_RT}} + \underbrace{\hat{\mathrm{V}}\mathrm{LA}^{\mathrm{F}}\mathrm{LY}^{\mathrm{D}}}_{(3\mathrm{a})-\mathrm{V\_GVC\_S}} + \underbrace{\hat{\mathrm{V}}\mathrm{LA}^{\mathrm{F}}(\mathrm{BY}-\mathrm{LY}^{\mathrm{D}})}_{(3\mathrm{b})-\mathrm{V\_GVC\_C}} \qquad (5)$$

Summing up equation (3) along the column direction, we can decompose country-sector final goods production into four major components based on whether and how their embodied factor content is involved in cross country production sharing activities.

$$Y' = VB\hat{Y} = \underbrace{VL\hat{Y}^{D}}_{(1)-Y\_D} + \underbrace{VL\hat{Y}^{F}}_{(2)-Y\_RT} + \underbrace{VLA^{F}L\hat{Y}^{D}}_{(3a)-Y\_GVC\_S} + \underbrace{VLA^{F}(B\hat{Y}-L\hat{Y}^{D})}_{(3b)-Y\_GVC\_C} \qquad (6)^{4}$$

The first term in equations (5) and (6) is domestic value-added embodied in domestically produced final products that satisfy domestic final demand without involving international trade; we label it as V_D and Y_D respectively. The second term is domestic value-added embodied in final product exports, we label it as domestic value added in traditional trade (V_RT and Y_RT). These two terms in both equations are Non-

[4] A detailed mathematical derivation of equation (5) and (6) and their relations are provided in Appendix B.

GVC activities, but the terms in equation (6) are sums of value added from all upstream country/industries embodied in the final products in a particular country/sector, the terms in equation (5) are sums of the same country/sector's domestic value-added used in all downstream country/industries. Numerically, they only equal each other at country aggregate, not at the country/sector level. The third term (3a) in both equations are simple cross country production sharing GVC activities, but the term in equation (5) is domestic value-added embodied in intermediate exports that is used by trading partner to produce its domestic products and consumed in the direct importing country, while the term in equation (6) is foreign value added from partner countries embodied in the intermediate imports to the home country used in its production of domestically consumed products. Both of them involve production activities in both the home and partner country, but only cross border for production once, we label them as V-GVC_S and Y_GVC_S respectively. The fourth term (3b) in both equations are complex GVC activities, but the term in equation (5) is domestic factor content embodied in intermediate exports that is used by partner country to produce exports (intermediate or final) for other countries, while the term in equation (6) is returned domestic value-added and/or foreign value-added embodied in intermediate imports used by the home country to produce its final products for domestic use or/and exports, we label them as V_GVC_C and Y_GVC_C respectively. Numerically, 3a and 3b in both equations only equals each other at the global level, not at the country/sector and country aggregate level due to indirect trade via other sectors or third countries.

The sum of (2) and (3) in equation (5) equals domestic value-added (GDP) in gross exports (DVA) proposed by Koopman, Wang and Wei (2014). The sum of (3a) and (3b) minus returned domestic value-added in equation (6) equal foreign value-added in the exporting country's final goods production (FVA) defined by Los, Timmer and Vries (2015). The downstream decomposition of GDP by industry based on forward linkage based cross country inter industry linkage can be illustrated as Figure 1a; and the backward-linkage based upstream decomposition of final goods production can be depicted as Figure 1b.

Figure 1a Decomposition of GDP by industry
— Which types of production and trade are Global Value Chain activities?

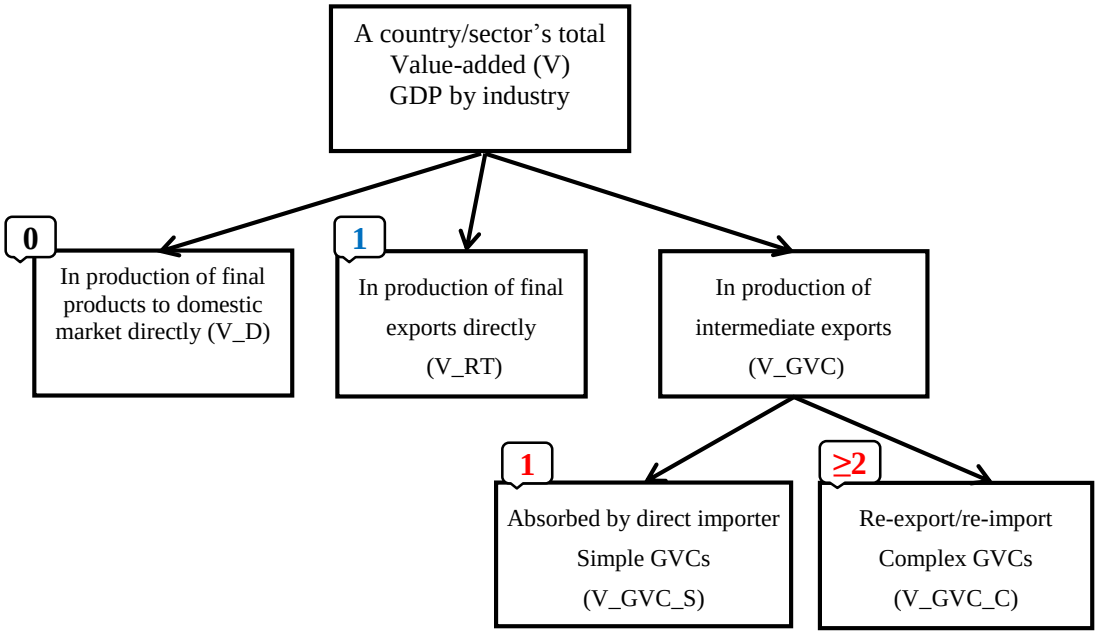
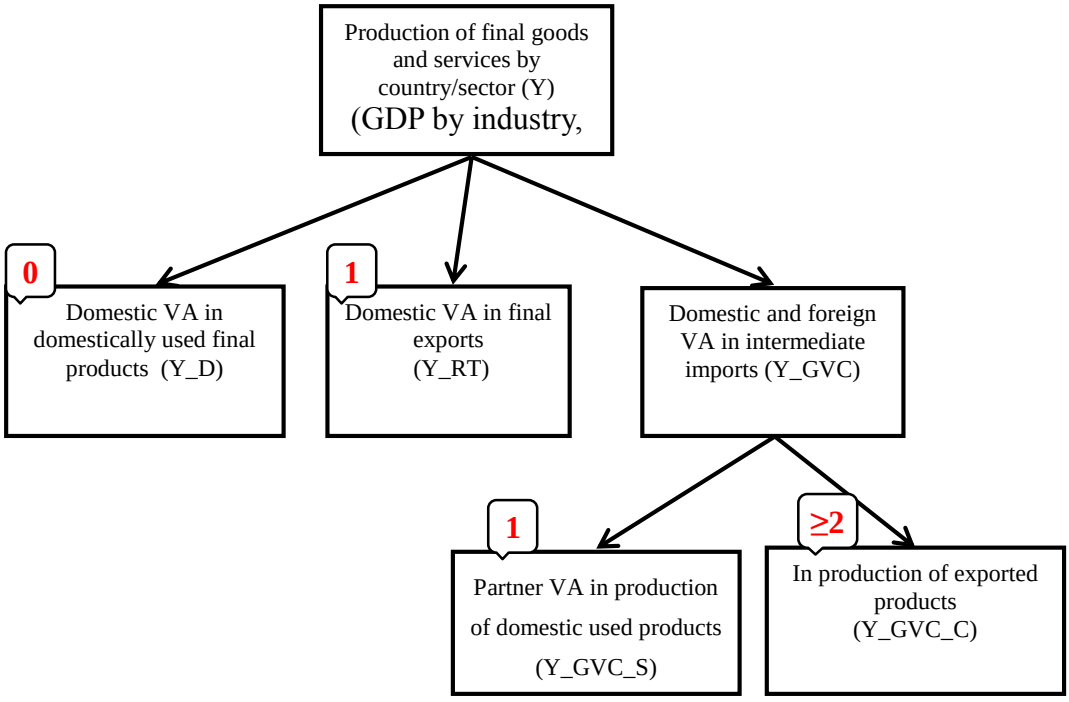


Figure 1b Decompose final goods production by country/sector
--Which part of final goods production and trade belong to GVCs?



Decomposition of value-added and final goods production into GVC and Non-GVC activities based on forward or backward cross-country, inter-industry linkage is the foundation of the GVC participation index we defined in this paper. Both way to decompose production activities in a country/sector pair include four parts: value-added in Parts 1 and 2 involve no cross country production sharing activities, satisfy domestic and foreign demand respectively. Value-added in Part 2 cross board once, but only for consumption activities, all value-added embodied in its intermediate inputs come from domestic sources, so it can be considered as Ricardo trade in value-added. Value added in Parts 3 and 4 are embodied in trade of intermediate products: 3a is value-added embed in intermediate products absorbed by direct importers, there is cross board production activities, but only within the direct importing country without further re-export/re-import activities; 3b is value-added cross board at least twice to satisfy domestic and/or foreign final demand. These two parts measure GVC production activities. It excludes domestic value-added measured by the first two terms in equations (5) and (6) because they are accomplished completely within the national boundaries, so both of them can be treated as pure domestic production activities. Equation (5) decomposes how and where a country's GDP by industry is used by all the downstream country/sectors and is consistent with the factor content method in international trade literature. Equation (6) traces out a particular sector's final products to all its upstream value-added sources, and is consistent with the GVC case studies in the literature.

2.3 Global Value-Chain participation indexes

The amount of Vertical Specialization (measured by both VS and VS1 as proposed by Hummels et al., 2001) as percent of gross exports have been used widely in the literature as the index to quantify the extent of a country's participation in global value chains (Koopman et al., 2010, 2014; OECD, 2013). However, it excludes production to satisfy domestic final demand (which includes both pure domestic and international trade related production activities), and by only considering export activities, may not cover all the possible ways a country could engage in the global production network.

Firms in a country/industry can participate in international production sharing in four ways:

(1) Exporting its domestic value-added in intermediate exports used by other countries to produce other countries' domestically consumed final products that shows up as foreign value-added in other countries' domestically produced final products used domestically;

(2) Exporting its domestic value-added in intermediate exports used by other countries to produce exports directly or indirectly; it is the source country's value-added that shows up as foreign value-added in other countries' gross exports;

(3) Using other countries' value-added to produce its gross exports directly or indirectly; it is the other countries' value-added that shows up as foreign value-added in the source countries' gross exports.

(4) Using other countries' value-added to produce its gross output for domestic use directly or indirectly; it is the other countries' value-added that shows up as foreign value-added in the source countries' gross output used domestically.

Global value chain participation indexes used in the literature, such as the VS and VS1 as percent of gross exports, only take channels 2 and 3 into consideration, thus exclude a large portion of production activities that satisfies source country's domestic final demand through international production sharing. In addition, using gross exports as the denominator, the share might be very high for some sectors since it has very little direct exports (e.g., Mining and Service). In such cases, we may not be able to determine whether a large index is due to the large numerator or the small denominator and whether it overestimates GVC participation for a country/sector pair. It is also not able to distinguish participation in simple or complex GVC activities. The former only involves production sharing activities between the exporting and importing country, while the later measures more complex sequential production activities across countries.

Using the downstream decomposition of value-added generated from each industry/country pair (GDP by industry) expressed in equation (5), and the upstream decomposition of final goods production expressed in equation (6), we can fully identify all the four possible ways a country can participant in the global production network and construct indexes that helps us to measure the full extent to which production factors are employed in a particular country-sector involved in the global production process. Such a

GVC participation index based on forward industrial linkage can be defined mathematically as follows:

$$GVCPt\_f = \frac{V\_GVC}{Va'} = \frac{V\_GVC\_S}{Va'} + \frac{V\_GVC\_C}{Va'} \quad (7)$$

The denominator of equation (7) is the value-added generated in production from a country/sector pair; the numerator is domestic value added of source country embodied in its intermediate exports to the world. So equation (7) gives domestic value-added generated from GVC production activities as a share of total sector value added. It measures the percentage of production factors employed in a country-sector has been cross national border at least once for production activities. It differs from the forward industrial linkage based GVC participation index defined in previous literature (VS1 as percent of gross exports) in two ways: (a) it is based on the value-added concept while both VS1 and gross exports are based on the gross concept; (b) it is a production concept, not only trade. It includes domestic value-added embodied in intermediate inputs from the exporting country that is directly and indirectly absorbed by its direct trading partners. Therefore, it completely reflects the degree of participation of domestic production factors employed in a particular country/sector in cross border production sharing activities.

Based on the upstream decomposition of final goods production we can define GVC participation index based on backward industrial linkage as

$$GVCPt\_B = \frac{Y\_GVC}{Y'} = \frac{Y\_GVC\_S}{Y'} + \frac{Y\_GVC\_C}{Y'} \quad (8)$$

The first term in (8) gives the portion of direct trading partners' value-added embodied in home country's intermediate imports used to produce final products consumed domestically as share of final goods produced in the home country. The second term in (8) gives the share of domestic and/or foreign value-added that cross national border at least twice in the total value of final products produced in the home country. The global sum of its numerator equals the global sum of the numerator in equation (7).[5] Therefore, at the global level, the forward and backward industrial linkage based GVC participation indexes equal each other, a similar property of VS and VS1 based GVC participation

[5] The mathematical proof is provided in Appendix C.

indexes. However, it also differs from the backward industrial linkage based GVC participation index defined in previous literature (VS as percent of gross exports) in two ways: (a) it is based on a net concept while both VS and gross exports are based on a gross concept; (b) it is a production concept, not only trade. It includes not only foreign value-added embodied in intermediate imports that is direct or indirectly absorbed by the importing country (production sharing activities with the source or third countries), so completely reflects the degree of foreign production factors' participation in the home country/sectors' production of final products, and measures international production sharing activities from another perspective: how a country's final goods production relies on other countries' production factors' contribution, but also reveal the role of domestic factor has played in deep cross country production sharing arrangement.

In summary, a complete picture of a country's participation in GVCs from the perspective of production factor contents needs to consider measures based on both forward and backward industrial linkages. The forward-linkage based GVCs participation measures domestic value-added generated from GVCs production and trade activities as a share of total sector value added (GDP). It views a country/sector's engagement in GVCs activities from the producer's perspective. The backward-linkage based GVCs participation measures the percentage of a country's final goods production contributed by both domestic and foreign factors that involve cross country production sharing activities. It views a country/sector's engagement in GVC activities from the buyer's perspective. The two indexes not only quantify the extent to which a country/sector integrated in GVCs, but also indicate a country/sector's position in the global production network. For instance, a higher degree of forward participation than backward participation implies that the country/sector is more actively engaged in upstream than downstream production activities in GVCs.

3. Numerical Results

In this section, we will apply the GVC participation measures developed in the previous section to the WIOD data (2016 version), which covers 44 countries and 56 industries over the time period 2000 to 2014. Since the indexes can be computed at both

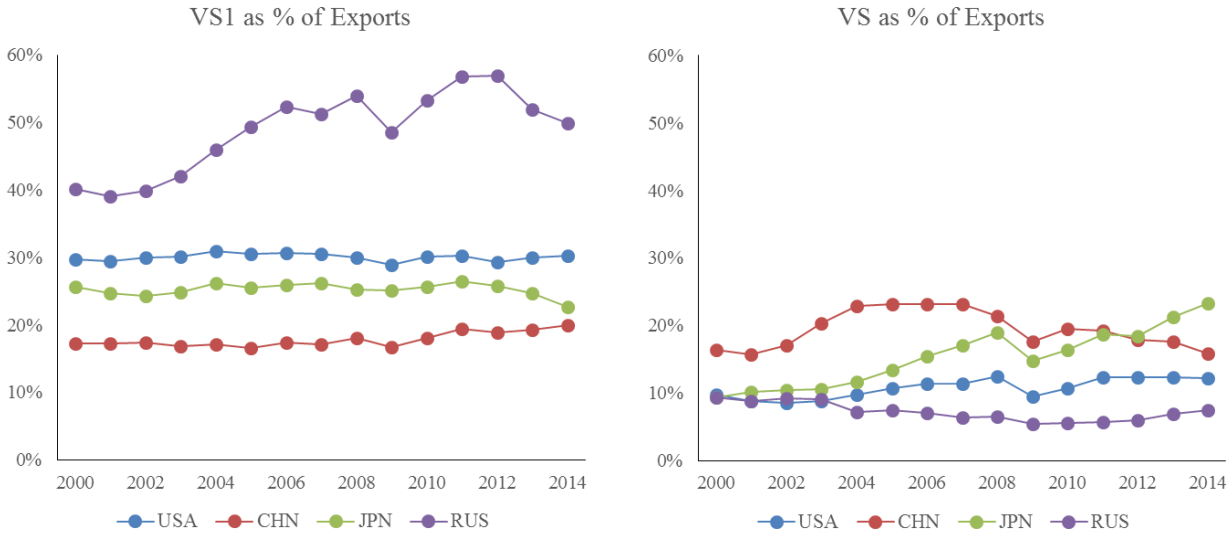
the most aggregated "world" and the more disaggregated "bilateral-sector" levels, we obtain a large amount of numerical results.

To illustrate the computation outcomes in a manageable manner, we first report a series of examples at various disaggregated levels to highlight the stylized facts and demonstrate their advantages compared to the existing indexes in the literature. Then in Section 4, we conduct econometric analysis on the role of GVCs in economic growth as an application of this newly developed GVC participation measure.

3.1 Traditional indexes

Hummels et al. (2001)'s Vertical Specification indexes, the share of VS and VS1 in gross exports, are widely used in the literature to measure the extent of GVC participation since they were first proposed by Koopman et al. (2010). Taking the top 3 countries in terms of GDP (United Statas, China and Japan) and a typical energy-exporting country (Russia) as examples, the VS and VS1 ratios shown in Figure 2 can provide us with useful information of GVC participation from at least two aspects: (1) Generally speaking, the degree of participation increase over the time period 2001 to 2011; (2) The upward trend of Vertical Specification has been temporarily interrupted by the global financial crisis (2009), and slowed down or reversed after the year 2012.

Figure 2 VS and VS1 ratios, 2000 to 2014



However, there are major shortcomings in those traditional participation indexes:

1) Using gross exports as the denominator. The share might be very high just because some sectors may have very little direct exports (e.g., Mining and Service). In such a case, the index value might become very large. In many empirical cases as we will show later, we may not be able to determine whether the index becoming larger is due to the large numerator or the small denominator (in math terms, the index goes to infinity when the denominator goes to zero) and whether such index actually overestimates GVC participation for a country/sector pair.

2) The fundamental characters of GVCs is cross country production sharing activities, VS and VS1 only consider export related activities, exclude a large portion of production activities that satisfies domestic final demand through international production sharing.

3) Not able to distinguish simple and complex GVC participation. The former only involve production sharing activities between the exporting and importing country, while the later measures more complex sequential production sharing activities across countries.

The GVC participation index proposed in this paper has overcome the above-mentioned shortcomings and is able to better measure the degree of GVC participation as the share of total value-added/final goods production for any country/sector pair and can be further decomposed into simple and complex parts based on number of border crossing. Such detailed GVC participation measure provides better indexes that are needed to conduct GVC related empirical analysis.

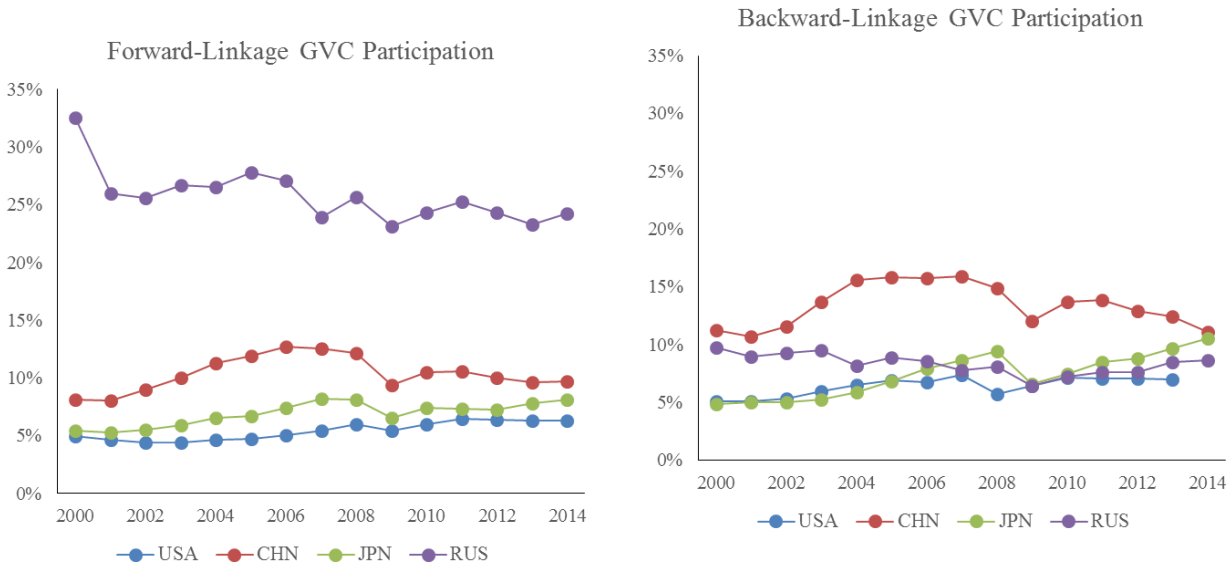
3.2 New GVC Participation indexes

The forward linkage based participation index proposed in this paper can be understood as "What is the percentage of production factors employed in a country-sector pair has been involved in cross country production sharing activities?" while the backward linkage based participation index can be understood as "What is the percentage of final products produced by a country-sector pair that comes from GVC related production and trade activities?"

(1) Country level

Continue using the US, China, Japan and Russia as examples, Figure 3 plots out the time trend of both forward/backward industrial linkage based participation indexes. The general patterns revealed are similar in both the traditional and the new indexes. For example, there is an upward trend of GVC participation in all four countries, and the negative impact of the global financial crisis on such trends can been clearly observed in both indexes. At country level, both the tradition VS/VS1 and our new GVC participation indexes show that Russia acts as an important energy supply country, its forward industrial linkage based participation index is significantly higher than its backward industrial linkage based participation index, indicating Russian participant GVCs mainly from the upstream. While China is just the opposite. As the "world factory", China's backward industrial linkage based index is higher than its forward industrial linkage based index, indicating China participants in GVCs relatively more from the downstream.

Figure 3 Forward/Backward Participation Indexes, 2000 to 2014

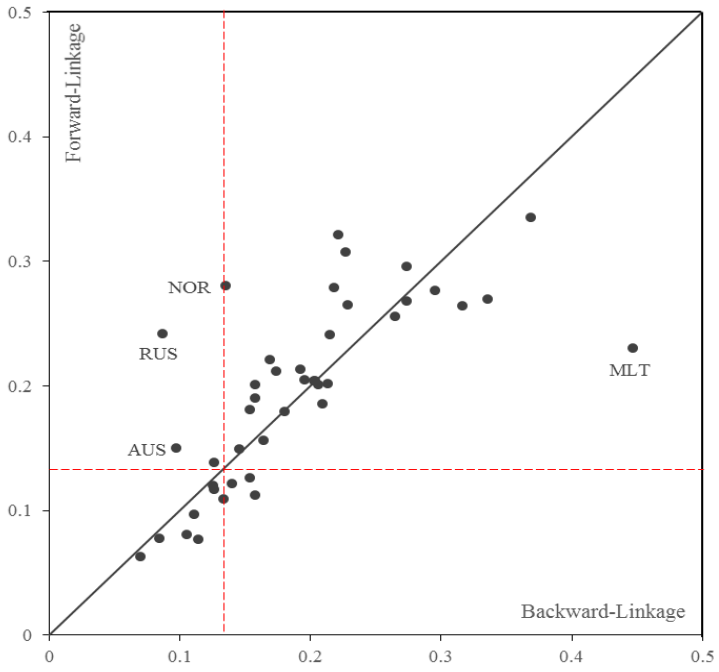


However, there are also clear difference between the new and traditional indexes. For instance, the traditional indexes show that there is an inconsistent time trend for Russia's GVC participation: there is an increasing trend for its forward participation but a decline trend for its backward participation. While our new indexes indicate there is a declined trend for Russia's GVC participation from both directions since 2000. Another

interest difference is that the U.S. and Japan have a much higher forward participation intensity than that of China based on the traditional index, while our new index indicate the opposite. This is largely due to Chinese economy is more depend on trade than the US and Japan (China's exports to GDP ratio is much higher than the US and Japan), therefore, using gross exports as denominator, traditional index will overestimate GVC participation intensity for the US and Japan.

We can also use a scatterplot matrix to describe the relations between our forward and backward GVC participation indexes. As shown in Figure 4, forward and backward GVC participation indexes are plotted on horizontal and vertical axes, respectively. The two red lines in the graph indicate the average forward and backward participation ratio. Most countries are scattered around the 45 degree line. Only several natural-resources-abundant countries, such as Australia, Russia and Norway, are positioned far above the 45 degree line on the upper left side.

Figure 4 GVC participation Matrix, Country Level，2014



(2) Sectoral level

The intensity of GVC participation varies by sector. Table 2a and 2b reports both forward and backward linkage based GVC participation indexes by four major industrial groups (Agriculture, Mining, Manufacturing and services) and their changes over 17 years. In the year 2014, among the four major industrial groups, Mining sector has the highest forward linkage based and lowest backward linkage based GVC participation ratio (48.1% over 11.3%), which is consistent with its upstream position in global production network. Manufacturing has the highest backward linkage based participation ratio (24.6%) and second highest forward linkage based index (24.1%), which is in line with the fact that the industry has been most complexly integrated into the global production network. As expected, service sector has the lowest GVC participation intensity, but its participation ratio has grown faster than agriculture in recent years. Further distinguish "complex" and "simple" participation, and analyze the time trend, we find that the increase of GVC participation intensity is mainly driven by the "complex" cross country production sharing activities.

Table 2a GVC Participation Index at sectoral level (Forward Linkage)

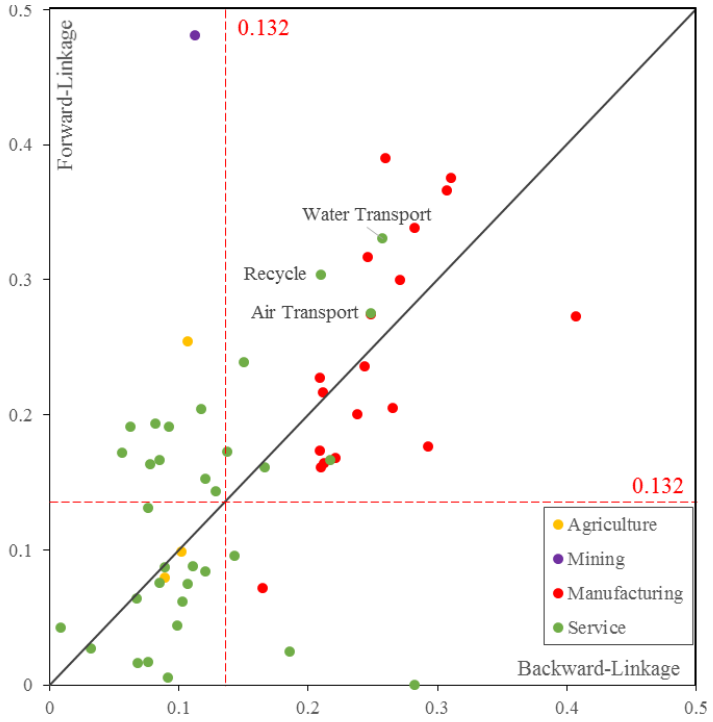
Sector	GVCPt_f			Simple GVC			Complex GVC		
	2000	2014	2014 over 2000	2000	2014	2014 over 2000	2000	2014	2014 over 2000
Agriculture	9.2%	10.7%	1.5%	6.8%	7.5%	0.7%	2.4%	3.3%	0.9%
Mining	50.3%	48.1%	-2.2%	35.2%	30.1%	-5.1%	15.1%	18.0%	2.9%
Manufacturing	20.4%	24.1%	3.7%	11.9%	14.0%	2.1%	8.5%	10.1%	1.7%
Service	6.7%	8.7%	2.0%	4.3%	5.4%	1.1%	2.3%	3.3%	0.9%

Table 2b GVC Participation Index at sectoral level (Backward Linkage)

Sector	GVCPt_b			Simple GVC			Complex GVC		
	2000	2014	2014 over 2000	2000	2014	2014 over 2000	2000	2014	2014 over 2000
Agriculture	9.5%	10.0%	0.6%	6.9%	6.7%	-0.3%	2.6%	3.4%	0.8%
Mining	10.9%	11.3%	0.4%	6.7%	8.2%	1.5%	4.3%	3.1%	-1.2%
Manufacturing	20.6%	24.6%	4.0%	9.5%	10.7%	1.2%	11.1%	13.9%	2.8%
Service	7.5%	10.3%	2.8%	5.7%	7.4%	1.7%	11.1%	13.9%	2.8%

Then we take the year 2014 as an example to show the sectoral level results in the GVC participation Matrix (Figure 5). There are significant differences in the GVC participation patterns observed among sectors. Most of the manufacturing industries (red data points) are located to the upper right, which reflects the fact that both the forward and the backward linkage GVC participation ratio are higher for those manufacturing industries. On the contrary, the level of GVC participation is relatively low in service sector. So the green data points are concentrated in the lower-left corner, except for three transportation-related industries. Besides that, mining sector and the forestry Industry of the agriculture sector are positioned on the upper left side, as the forward-linkage GVC participation ratio for these two industries are much higher than the backward ratio.

Figure 5 GVC participation Matrix, Sectoral Level, 2014



(3) Country-Sector level

Table 3 lists the forward and backward linkage based participation indexes in year 2014 for "Refined Petroleum" and "Machinery and Equipment" sectors in 6 countries, which shows the characteristics of different countries/sector pair when participating in GVC production.

For example, since Russia is the giant in energy, its mining sector's forward linkage based participation ratio is as high as 38.7%, while the backward ratio is only 6.2%. In contrast, due to the energy shortage, Japan's mining sector has the highest backward linkage based participation ratio (56.2%). Then for the typical manufacturing industry, "Machinery and Equipment", Germany is the global manufacturing power, so its forward and backward linkage based participation ratios are both higher than that of other countries. With a high forward linkage based participation ratio, a high proportion of production factors employed by German machinery and equipment sector has engaged into the network of Global Value Chains directly or indirectly. With a higher backward linkage based participation ratio, a high proportion of components and parts in the final products produced by Germany are produced by other countries in GVCs.

Table 3 Sectoral Level Participation Index, Forward/Backward Linkage

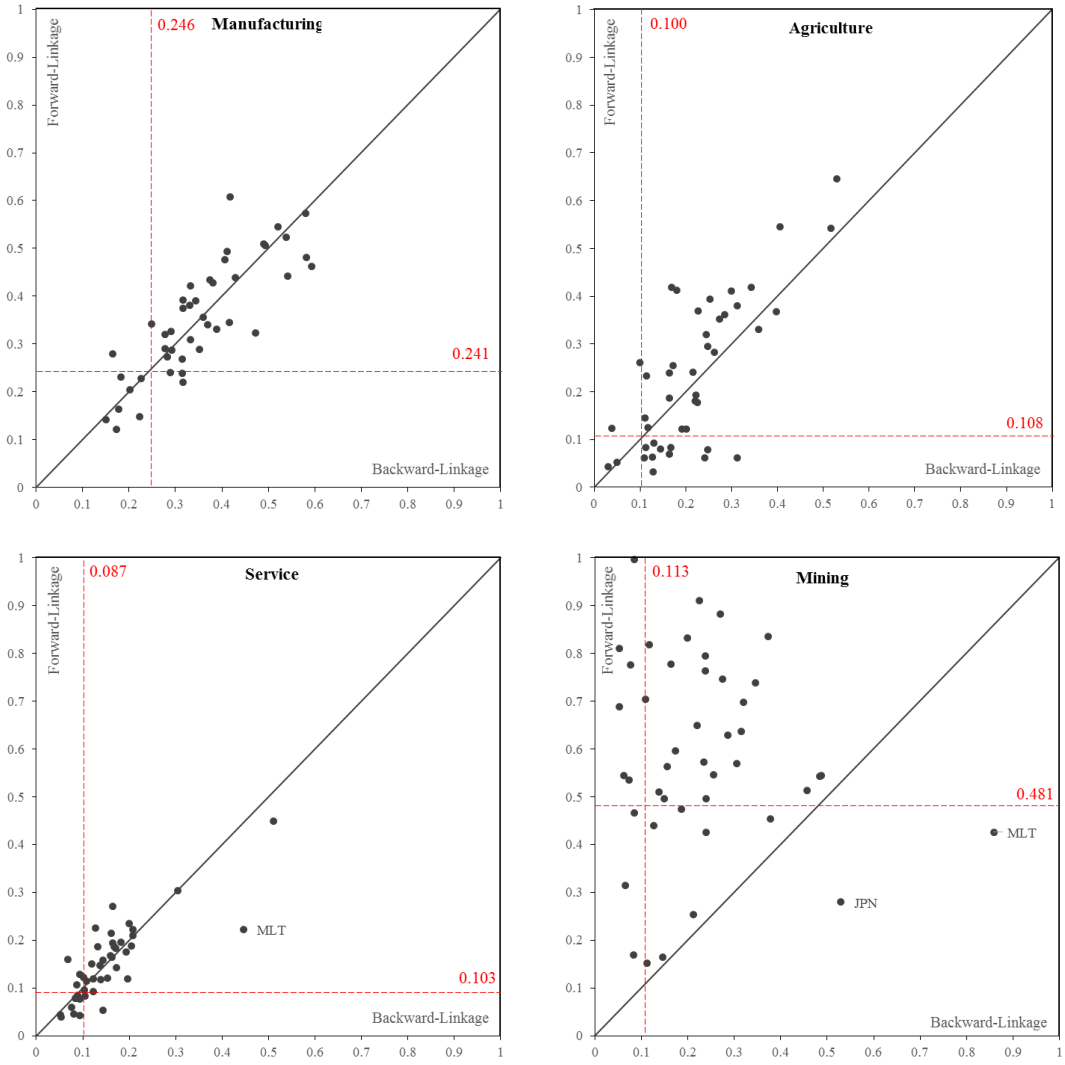
	Forward Linkage Based Participation Index (GVCPt_f)	
	Refined Petroleum	**Machinery and Equipment**
CHN	15.7%	13.1%
DEU	36.2%	**34.1%**
IND	26.8%	10.6%
JPN	19.9%	19.4%
RUS	**38.7%**	17.1%
USA	17.2%	16.4%
	Backward Linkage Based Participation Index (GVCPt_b)	
	Refined Petroleum	**Machinery and Equipment**
CHN	23.9%	16.9%
DEU	72.4%	**29.0%**
IND	57.7%	25.1%
JPN	56.2%	19.7%
RUS	**6.2%**	17.5%
USA	28.5%	18.9%

CHN=China; DEU=Germany; IDN=Indonesia; JPN=Japan; RUS=Russia; USA=United States

The four GVC participation matrices in Figure 6 indicate that, for manufacturing, service and agriculture sectors, countries are roughly distributed around the 45 degree line. But the average level of GVC participation across countries is higher in manufacturing sector

than in the service and agriculture sectors. Then for the mining sector, the forward linkage GVC participation ratio is higher for most countries except for Japan and Malta.

Figure 6 GVC participation Matrix, Country-Sector Level, 2014



3.3 Why do we need the new "GVC Participation Index"?

(1) Eliminate the sectoral level bias in traditional indexes

As mentioned previously, using gross exports as the denominator may lead to overvalue bias at the bilateral/sectoral level. For comparison, we use both gross exports and sector GDP as the denominator to compute the forward linkage based participation index, VS1 as share of gross exports and GVC_Pr_f, respectively. As shown in Table 4,

the VS1 share for 7 out of 56 industries are substantially larger than 100%. These industries have one thing in common: a great proportion of their value added is exported indirectly, which is embodied in other industries' exports.

Table 4 Comparison between Traditional and New Measures in US sectors, 2014

Sector (WIOD 2016)	Sector	GVCPt_F	VS1
23	Repair and installation	1.7%	1334.0%
24	Electricity and gas supply	3.6%	330.9%
25	Water supply	3.6%	322.7%
27	Construction	0.6%	1748.0%
28	Wholesale and retail trade	1.3%	248.1%
44	Real estate	1.2%	439.6%
45	Legal and accounting activities	9.4%	107.0%

The overvaluation problem is more pronounced for utility and service sectors, as a large proportion of their value added is exported indirectly. We choose three typical sectors to illustrate this point. Two of them belong to the utility and service industries ("Electricity, Gas and Water" and "Retail Trade"), while the third one, "Leather and Footwear," is a typical "direct" exporting sector. Table 5 lists 15 largest countries ranking by GDP to show the comparison between traditional VS1 ratio and our forward linkage based GVC participation index. As we have expected, the overvaluation problem is more serious in the utility and service industries.

Table 5 Comparison between Traditional and New Participation Indexes for Three Typical Sectors

	Electricity, Gas and Water		**Retail Trade**		**Leather and Footwear**	
	VS1	**GVCPt_F**	**VS1**	**GVCPt_F**	**VS1**	**GVCPt_F**
AUS	**630.2%**	14.4%	**635.6%**	11.9%	21.5%	32.8%
BRA	**3521.6%**	6.3%	**1131.2%**	4.0%	21.6%	8.6%
CAN	**101.9%**	19.5%	15.6%	18.0%	5.5%	37.5%
CHN	**396.2%**	12.0%	-	-	5.0%	12.3%
DEU	**101.8%**	18.6%	77.1%	15.9%	10.9%	42.4%
ESP	**306.4%**	15.0%	29.8%	7.8%	7.1%	22.3%
FRA	**148.6%**	14.6%	46.9%	7.2%	5.7%	25.2%
GBR	**273.1%**	10.9%	62.0%	13.7%	16.7%	20.8%

IND	**3419730.0%**	8.5%	73.2%	7.2%	6.5%	11.4%
ITA	**250.2%**	14.9%	58.6%	7.8%	11.0%	30.0%
JPN	**1082.2%**	9.2%	**3263.9%**	9.7%	31.8%	23.2%
KOR	**363.7%**	19.8%	45.3%	23.7%	17.2%	43.3%
MEX	**411.8%**	8.8%	33.4%	8.2%	3.7%	11.8%
RUS	**562.1%**	26.9%	**146.2%**	14.6%	20.6%	4.6%
USA	**330.6%**	3.6%	**248.1%**	1.3%	13.7%	12.3%

USA=United States; CHN=China; JPN=Japan; DEU=Germany; FRA=France; GBR=United Kingdom; BRA=Brazil; ITA=Italy; IND=India; RUS=Russia; CAN=Canada; ESP=Spain; AUS=Australia; MEX=Mexico; KOR=Korea;

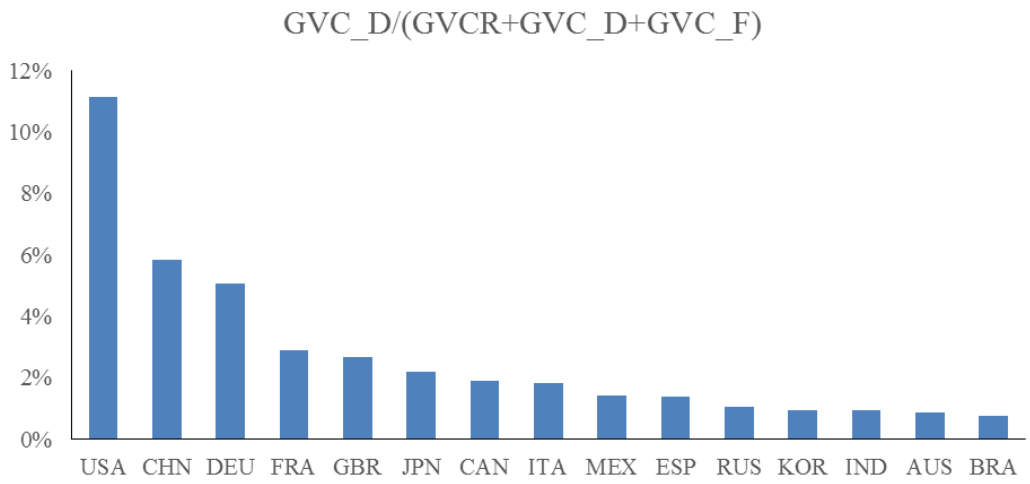
(2) Differentiate "simple" and "complex" GVC participation

As shown in our decomposition framework, the domestic value added in gross intermediate exports of a country can be decomposed into two major parts: DVA crossing the national border only once (GVC_R), representing the type of cross border specialization that is relatively simple; DVA cross border two or more times (GVC_D and GVC_F), representing the type of cross border specialization that is more complex. In our newly defined participation indexes, both way a country/sector pair to participant GVC can be identified and quantified.

We will show later in section 4.1 that the "simple" and "complex" parts of GVC participation are different in size and the trend of change. The simple part takes a relatively large proportion, but its relative importance is diminishing over time for almost all countries in the sample. Instead, the domestic value added exported via complex production sharing activities is increasing dramatically.

Besides that, the relative sizes of GVC_R, GVC_D, and GVC_F may reflect the differences of roles in the GVCs for different countries. Taking 10 countries with largest GDP in year 2014 as examples, as shown in Figure 7, GVC_D, "re-imported and absorbed domestically," accounts for a substantially larger proportion in the US, followed by China and Germany, as the US and Germany are controlling both ends (design and sales) of the value chain, and China serves as the "world's factory" and the world's largest consumption market.

Figure 7 The Share of Returned Value Added (GVC_D)



4. Application: Economic Growth and GVC Participation

4.1 stylized facts

Different from the pure domestic production and the traditional final goods trade, the international production fragmentation of the Global Value Chain has created a new path for world economic growth. The GDP decomposition results in our paper clearly demonstrate that the global production structure in different types of value added creation activities has changed dramatically during the past 15 years.

As the global economy recovered from the dotcom burst and China joined the WTO at the end of 2001, the world economy has experienced a rapid growth during the period 2002 to 2008. During this time period, three stylized facts in global production activities can be observed in our decomposition results at the global level:

First, the pure domestic activities still account for the largest portion of production activities, but its relative importance is decreasing over time (Figure 8); Second, among the three parts of a country/sector's GDP related to international trade, the relative importance of traditional trade in domestic value-added is increased relatively slow than cross country GVC production sharing activities, although such general trends have been temporarily interrupt by the 2009 global financial crisis (Figure 8); Finally, among GVC production activities, the percentage of factor content embodied in intermediate trade flows cross national border only once (Simple GVC) is higher than that of Deep GVC activities, but its relative importance is diminishing over time, while domestic factor

content exported via complex production sharing activities has been increased dramatically (Figure 9).

In contrary to the above mentioned two economic growth periods, the global financial crisis in the year 2009 has caused a significant setback in production globalization. There was an increase in the share of pure domestic production activities and a decrease in the share of all trade-related production activities, especially cross-border production-sharing activities of complex GVCs.

Rapid economic recovery was observed for two years following the Global Financial Crisis (2010 and 2011). The two portions of GVC production activities were observed to have experienced the fastest after-crisis recovery. However, after the year 2012, the economic growth rate significantly declined, with an obvious slowdown in cross-country production-sharing GVC activities.

Figure 8 Changing Trends of Different Types of Production Activities as a Share of Global GDP (2000–2014)

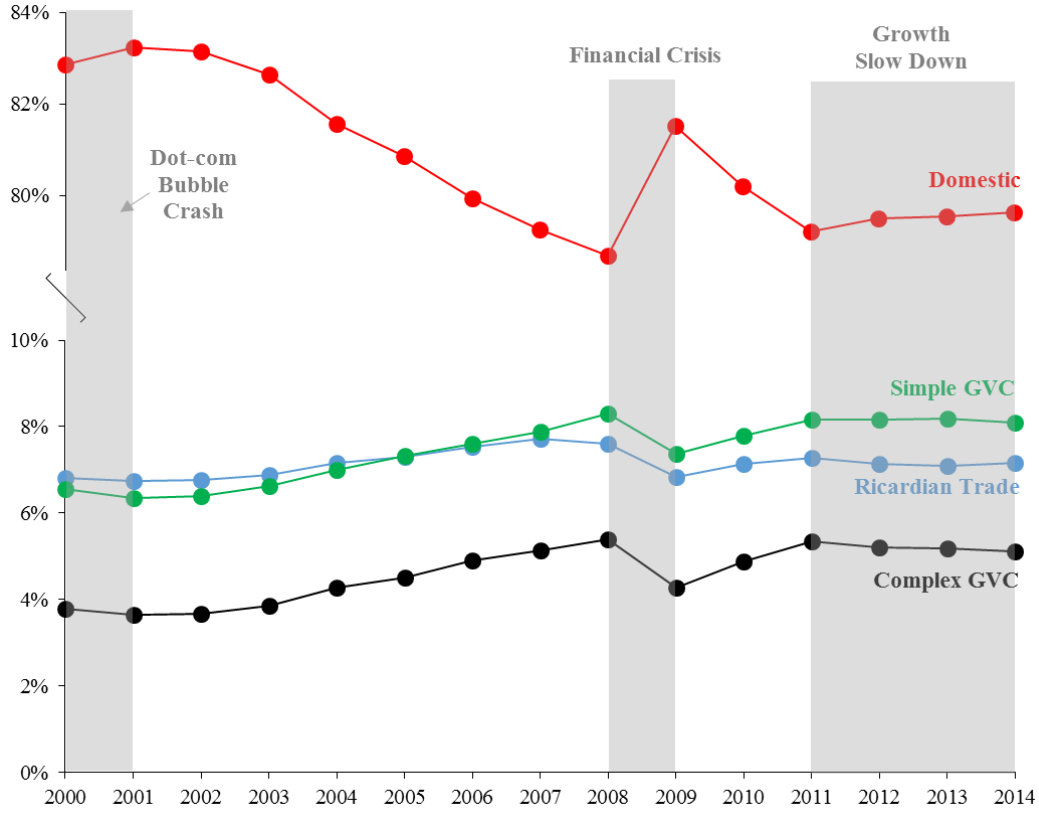
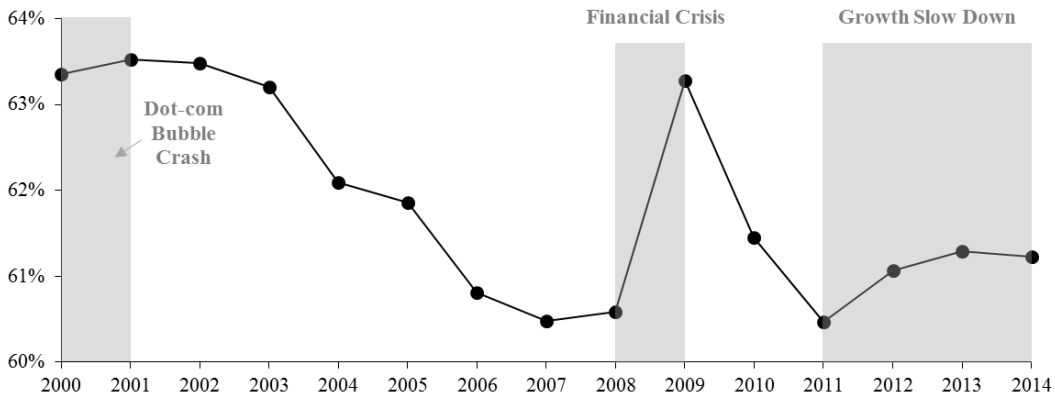
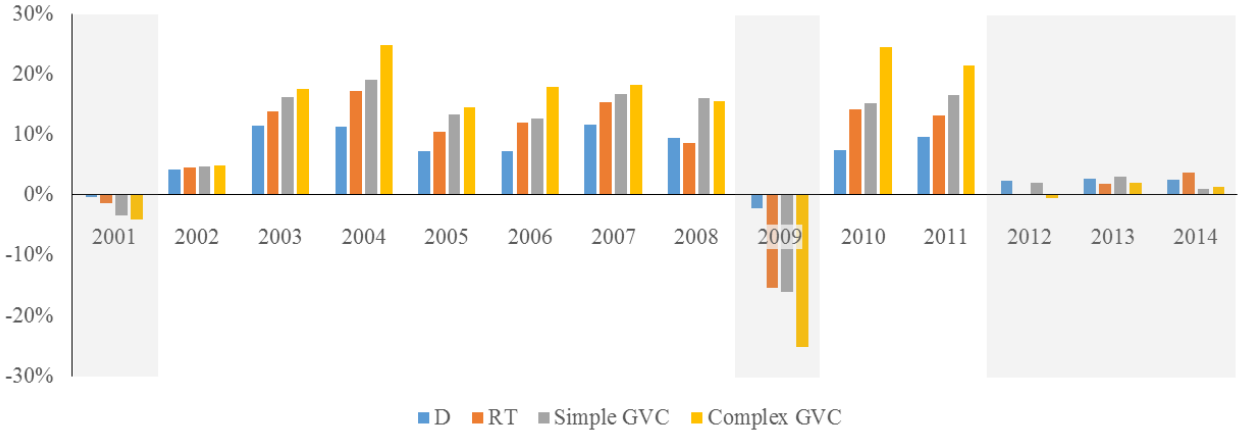


Figure 9 Simple GVC production activities as a share of total GVC production activities (1995–2014)



The importance of GVC production can also be observed if we look at the annual growth rate for different types of value added production activities (Figure 10). During the 7-year fast economic growth after the 2001 dotcom burst, there was a dramatic expansion of GVC, especially complex production-sharing GVC activities. Rapid economic recovery was also observed for two years following the global financial crisis (2010 and 2011).

Figure 10 Nominal growth rates of different value added creation activities during the global business cycle, global level (2000–2014)



However, the pattern is just the opposite during the financial crisis in 2009. Pure domestic production activities were least affected (in comparison with 2008, the fall was only 2.3%), the impact on production of traditional trade of domestic value-added (embodied in final goods exports) rank next, while the cross country GVC production activities were mostly affected, as the fall reached 16.1% in its simple portion and 25.1%

for its complex portion.

To minimize the impact of price fluctuation of the crude oil and bulk commodities (the so-called "commodity super-cycle") on the nominal GDP growth rate reported in Figure 10, we further examine the average annual growth rate and production structural changes at the sectoral level. As shown in Figure 11a and 11b, the growth patterns discussed above still hold for all sectors, and the changes in production structures reflect the increasing importance of GVC production activities.

Figure 11a Average Annual Growth Rates of Different Value Added Creation Activities during the Global Business Cycle, Sector Level

Figure 11b Structure changes in different types of value added creation activities as a Share of GDP, Sectoral Level

4.2 Empirical Results

The above stylized facts indicate that there is a clear link between economic growth (or recession) and GVC production activities, especially the complex cross country production sharing activities.

How does engage in different type value-added creation activities affect economic growth? Does participant in GVC production activities increase economic growth? To formally test this, we estimate the following regression for three sub-periods: fast growth period (2002 to 2008), global financial crisis (2009), after-crisis recovery period (2010 and 2011) and the growth slow down period (2012-2014).

$$\Delta lnVA_{ict} = \beta_0 + \beta_1 \times V\text{-}Share_{ict} + \beta_2 \times W_{ct} + \beta_3 \times Z_{it} + \gamma_t + \delta_c + u_{ict}$$

where

$\Delta lnVA_{ict}$ equals to the change of sectoral GDP, $\ln(VA_{ict})$ minus $\ln(VA_{ict-1})$, which quantifies the degree of economic growth (or recession) in industry *i* of Country *c*;

$V\text{-}Share_{ict}$ is the share of different types of value added creation activities in sectoral GDP (D and RT shares, Simple and Complex GVC Participation indexes), which are derived from the industry level GDP decomposition based on forward-cross country, inter-industrial linkages as we discussed in section 2;

W_{ct} and Z_{it} represent country and sectoral level control variables, including GDP per capita, hours worked by high and medium-skilled workers (share in total hours), and capital intensity defined as share of capital return in value added.

We also control for the year and country fixed effects by including a year dummy γ_t and a country dummy δ_c in the model.

Table 6 Benchmark Regression Results

($\Delta lnVA_{ict} = \beta_0 + \beta_1 \times X\text{-}Ratio_{ict} + u_{ict}$)

Time Period	Full Sample				
	D	RT	GVC	Simple GVC	Complex GVC
A. 2002-2008,2010-2011	-0.0106**	-0.00967	0.0236***	0.0318**	0.0678***
	(0.00509)	(0.0112)	(0.00856)	(0.0137)	(0.0191)
B. 2002-2008	-0.0136	-0.0191*	0.0382**	0.0465	0.104***
	(0.0104)	(0.0112)	(0.0156)	(0.0301)	(0.0262)
C. 2010-2011	-0.0120**	0.0105	0.0202**	0.0311**	0.0543**
	(0.00550)	(0.0190)	(0.00824)	(0.0129)	(0.0211)
D. 2009	0.232***	-0.175***	-0.309***	-0.439***	-0.720***
	(0.0281)	(0.0376)	(0.0391)	(0.0651)	(0.0795)
E. 2012-2014	-0.00625	0.0242	0.00610	0.0162	0.00626
	(0.0119)	(0.0263)	(0.0169)	(0.0335)	(0.0315)
Time Period	Manufacturing Only				
	D	RT	GVC	Simple GVC	Complex GVC
A. 2002-2008,2010-2011	-0.0127**	0.00357	0.0219**	0.0283*	0.0655***
	(0.00589)	(0.0118)	(0.00926)	(0.0148)	(0.0214)
B. 2002-2008	-0.0194	-0.00180	0.0349	0.0372	0.0967***
	(0.0154)	(0.0132)	(0.0225)	(0.0457)	(0.0338)
C. 2010-2011	-0.0125**	0.0155	0.0201**	0.0297**	0.0570**
	(0.00561)	(0.0190)	(0.00832)	(0.0125)	(0.0227)
D. 2009	0.222***	-0.0581	-0.323***	-0.430***	-0.743***
	(0.0394)	(0.0457)	(0.0526)	(0.0837)	(0.102)
E. 2012-2014	-0.0113	0.0385	0.0126	0.0275	0.0208
	(0.0144)	(0.0333)	(0.0199)	(0.0406)	(0.0365)

Note: Only the coefficients of *X-Ratio* (D, RT, GVC, Simple GVC and Complex GVC) are reported in the table. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

The benchmark regression results are shown in Table 6. For both the full sample and sub-sample of manufacturing sector, it clearly shows that there is a positive association between GVC participation and economic growth (Period A, B and C), and the estimated impact of complex GVC is larger and more significant than simple GVC, which suggests that participation in GVC production activities, especially the complex cross country production sharing activities, contributes to faster economic growth. On the contrary, a larger share of pure domestic production activities (D) has a negative effect on economic growth. Besides, there is no clear link between the production for traditional "Ricardian" type trade (RT) in value-added and economic growth during the sample period we investigated.

During the global financial crisis in the year 2009, all trade-related production activities, (both RT and GVC) have been negatively affected significantly by the global financial crisis. The higher the RT and GVC share in total GDP, the greater the degree of such negative impact. And similar to the period of economic growth, the impact of GVC participation on sectoral GDP during the financial crisis largely come from its complex portion.

However, during the period 2012-2015, the relationship between economic growth slow-down and different types of production activities is unclear. This phenomenon is a result of mixed reasons, such as weak domestic demand and the slowdown of production globalization, which need to be carefully investigated. We leave this in our future work.

Then we include year and country fixed effects (Table 7), as well as other country and sectoral level control variables (Table 8) in our regression. all major regression results still hold.

Table 7 Regression Results with Year and Country Fixed Effects

Time Period	Full Sample				
	D	RT	GVC	Simple GVC	Complex GVC
A. 2002-2008,2010-2011	-0.0155***	0.00279	0.0274***	0.0393***	0.0744***
	(0.00371)	(0.0133)	(0.00689)	(0.00940)	(0.0169)
B. 2002-2008	-0.0164**	-0.00989	0.0363***	0.0533***	0.0839***
	(0.00694)	(0.0107)	(0.00841)	(0.0141)	(0.0185)
C. 2010-2011	-0.0208***	0.0392**	0.0301***	0.0437***	0.0875***
	(0.00667)	(0.0168)	(0.00970)	(0.0126)	(0.0295)
D. 2009	0.186***	-0.0826**	-0.253***	-0.337***	-0.614***
	(0.0302)	(0.0384)	(0.0403)	(0.0667)	(0.0841)
E. 2012-2014	-0.00652	0.0237*	0.00667	0.0153	0.00991
	(0.00598)	(0.0138)	(0.00889)	(0.0167)	(0.0178)
Time Period	Manufacturing Only				
	D	RT	GVC	Simple GVC	Complex GVC
A. 2002-2008,2010-2011	-0.0162***	0.0109	0.0244***	0.0339***	0.0695***
	(0.00427)	(0.0139)	(0.00676)	(0.00858)	(0.0182)
B. 2002-2008	-0.0335***	0.00630	0.0419***	0.0617***	0.0905***
	(0.0118)	(0.0135)	(0.0117)	(0.0203)	(0.0236)
C. 2010-2011	-0.0138***	0.0221	0.0208***	0.0283***	0.0660**
	(0.00532)	(0.0171)	(0.00795)	(0.00983)	(0.0275)
D. 2009	0.126***	0.0805*	-0.236***	-0.253***	-0.605***
	(0.0454)	(0.0458)	(0.0558)	(0.0883)	(0.109)
E. 2012-2014	-0.0129*	0.0405**	0.0151*	0.0307*	0.0278
	(0.00665)	(0.0171)	(0.00915)	(0.0174)	(0.0183)

Note: *** p<0.01, ** p<0.05, * p<0.1. For time period A, B and C: Cluster standard errors (by country and sector) in parentheses. For time period D: Robust standard errors in parentheses, and only country fixed effects are included as there is only one year in the sample.

Table 8 Regression Results with Other Control Variables

	Full Sample					Manufacturing Only				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
D	-0.0134***					-0.0146***				
	(0.00334)					(0.00416)				
RT		7.07e-05					0.00962			
		(0.0120)					(0.0123)			
GVC			0.0248***					0.0221***		
			(0.00716)					(0.00712)		
Simple GVC				0.0335***					0.0301***	
				(0.00909)					(0.00861)	
Complex GVC					0.0718***					0.0643***
					(0.0187)					(0.0193)
GDP per Capita	0.0488	0.0492	0.0492	0.0490	0.0496	0.0227	0.0225	0.0236	0.0234	0.0239
	(0.0330)	(0.0330)	(0.0330)	(0.0330)	(0.0330)	(0.0463)	(0.0463)	(0.0463)	(0.0463)	(0.0463)
Capital Intensity	0.0133**	0.0121*	0.0130*	0.0129*	0.0130*	0.00385	0.00545	0.00129	0.00173	0.00108
	(0.00668)	(0.00682)	(0.00669)	(0.00670)	(0.00667)	(0.0114)	(0.0118)	(0.0117)	(0.0117)	(0.0116)
Skill	0.0309***	0.0298***	0.0313***	0.0311***	0.0315***	0.0340	0.0342	0.0412*	0.0428*	0.0372
	(0.0113)	(0.0112)	(0.0113)	(0.0112)	(0.0113)	(0.0252)	(0.0254)	(0.0249)	(0.0249)	(0.0249)
Constant	-0.420	-0.433	-0.438	-0.436	-0.442	-0.163	-0.173	-0.190	-0.188	-0.191
	(0.344)	(0.343)	(0.343)	(0.343)	(0.343)	(0.482)	(0.482)	(0.482)	(0.482)	(0.482)
Year Dummy	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Country Dummy	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	10,176	10,176	10,176	10,176	10,176	5,618	5,618	5,618	5,618	5,618
R-squared	0.106	0.105	0.106	0.106	0.107	0.105	0.104	0.105	0.105	0.105

Note: Cluster standard errors (by country and sector) in parentheses. *** p<0.01, ** p<0.05, * p<0.1

To further check the robustness of the positive link between GVC participation and economic growth, we estimate the regression for two sub-samples: mature economy (Table 9a) and Emerging Economy (Table 9b)[6]. All results still hold and a comparison between the two sets of regressions show that the positive effects of GVC participation on economic growth are more pronounced in mature economies.

Table 9a Sub-Sample Regression: Mature Economy

	Full Sample				Manufacturing Only			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Simple GVC	0.0693***	0.0498**			0.0584***	0.0437*		
	(0.0168)	(0.0200)			(0.0211)	(0.0223)		
Complex GVC			0.0886***	0.0914***			0.0836***	0.0760***
			(0.0212)	(0.0230)			(0.0256)	(0.0246)
GDP per Capita		-0.0830*		-0.0811		-0.133*		-0.131*
		(0.0504)		(0.0503)		(0.0709)		(0.0708)
Capital Intensity		-0.0106		-0.0106		-0.0304**		-0.0299**
		(0.00803)		(0.00802)		(0.0139)		(0.0134)
Skill		0.0577***		0.0593***		0.0168		0.00839
		(0.0189)		(0.0191)		(0.0418)		(0.0415)
Constant	0.0706***	0.935*	0.0725***	0.916*	0.0665***	1.468**	0.0666***	1.454**
	(0.00299)	(0.524)	(0.00264)	(0.523)	(0.00447)	(0.738)	(0.00397)	(0.738)
Year Dummy	YES	YES	YES	YES	YES	YES	YES	YES
Country Dummy	YES	YES	YES	YES	YES	YES	YES	YES
Observations	6,543	5,277	6,543	5,277	3,546	2,914	3,546	2,914
R-squared	0.004	0.164	0.004	0.165	0.003	0.159	0.004	0.160

Note: Cluster standard errors (by country and sector) in parentheses. *** p<0.01, ** p<0.05, * p<0.1

[6] Following the classification used in Timmer et al.(2012), Mature economies include Australia, Canada, Japan, South Korea, Taiwan, US, and 15 countries that joined the EU before 2004. Emerging economies include Brazil, China, Russia, India, Indonesia, Mexico and Turkey and 12 countries that joined the EU in 2004.

Table 9b Sub-Sample Regression: Emerging Economy

	Full Sample				Manufacturing Only			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Simple GVC	0.0269**	0.0291***			0.0277**	0.0279***		
	(0.0106)	(0.00764)			(0.0108)	(0.00755)		
Complex GVC			0.0636***	0.0646***			0.0636***	0.0608***
			(0.0218)	(0.0191)			(0.0234)	(0.0200)
GDP per Capita		0.0408		0.0422		-0.0123		-0.0107
		(0.0453)		(0.0453)		(0.0633)		(0.0633)
Capital Intensity		0.0413***		0.0412***		0.0400**		0.0389**
		(0.0110)		(0.0110)		(0.0192)		(0.0191)
Skill		0.0159		0.0157		0.0633**		0.0583*
		(0.0136)		(0.0135)		(0.0314)		(0.0314)
Constant	0.146***	-0.265	0.143***	-0.278	0.148***	0.208	0.144***	0.194
	(0.00291)	(0.411)	(0.00320)	(0.412)	(0.00384)	(0.575)	(0.00416)	(0.576)
Year Dummy	YES	YES	YES	YES	YES	YES	YES	YES
Country Dummy	YES	YES	YES	YES	YES	YES	YES	YES
Observations	5,752	4,899	5,752	4,899	3,135	2,704	3,135	2,704
R-squared	0.001	0.059	0.002	0.060	0.001	0.058	0.002	0.059

Note: Cluster standard errors (by country and sector) in parentheses. *** p<0.01, ** p<0.05, * p<0.1

5. Conclusion

The rise of GVCs has led to dramatic changes in world economy. However, considering the increasing complexity and sophistication in cross-border production-sharing activities, the significance and nature of the growth pattern changes in the global business cycle over the past 15 years cannot be revealed clearly by only using the official trade data (e.g., gross exports/imports) and GDP statistics. One important reason for this is that indicators based on official trade data cannot identify and distinguish which types of trade are GVC activities and which types are not, thus resulting in the difficulty of evaluating the relation between change in global trade and GDP growth.

This paper first showed the limitation of traditional GVC participation indictors when explaining the changing patterns of global GDP and trade growth. Then, we introduce a set of new GVC participation indexes based on our production activity accounting framework from the factor content perspective, which can clearly decompose a country/sector's GDP and final goods production into GVC and non-GVC activities. Using these new indicators, the production

position and degree of participation (simple vs. complex) in GVCs at country and sectoral levels can be easily identified.

Applying our new production accounting system to the most up-to-date inter-country input-output database (WIOD, 2016), our empirical results show that complex GVC was the most important driving force for globalization and the growth of global GDP during the fast economic growth period in past 15 years. However, during 2012–2015, complex GVC-related cross-border production-sharing activities showed a declining trend. This phenomenon is a result of mixed reasons, which need to be carefully investigated. We leave this in our future work.

Reference

Baldwin, Richard, and Javier Lopez-Gonzalez. "Supply-Chain Trade: A Portrait of Global Patterns and Several Testable Hypotheses." NBER Working Paper 18957. National Bureau of Economic Research. Washington, DC, 2013

Borin, Alessandro, and Michele Mancini. "Follow the value added: Bilateral gross exports accounting." No. 1026 Working paper of Banca D'Italia, July 2015.

Hummels, David, Jun Ishii, and Kei-Mu Yi. "The Nature and Growth of Vertical Specialization in World Trade." *Journal of International Economics 2001*, 54:75–96.

Hummels D, Ishii J, Yi K M. The Nature and Growth of Vertical Specialization in World Trade. Journal of International Economics, 2001, 54(1): 75-96.

Johnson R C, Noguera G. Accounting for Intermediates: Production Sharing and Trade in Value Added. Journal of International Economics, 2012, 86(2): 224-236.

Koopman R B, Wang Z, Wei S J. Estimating Domestic Content in Exports When Processing Trade is Pervasive. Journal of Development Economics, 2012, 99(1): 178-189.

Koopman R B, Wang Z, Wei S J. Tracing Value-Added and Double Counting in Gross Exports. The American Economic Review, 2014, 104(2): 459-494.

Leontief, W. "Quantitative Input and Output Relations in the Economic System of the United States." *Review of Economics and Statistics 1936*, 18: 105–125.

Miller, R. E., and P. D. Blair. *Input–output Analysis: Foundations and Extensions*. Cambridge: Cambridge University Press. 2009

Miller R E, Temurshoev U, Output Upstreamness and Input Downstreamness of Industries/Countries in World Production. International Regional Science Review, **November 5, 2015** 0160017615608095

Timmer, M., A. A. Erumban, J. Francois, A. Genty, R. Gouma, B. Los, F. Neuwahl, O. Pindyuk, J. Poeschl, J.M. Rueda-Cantuche, R. Stehrer, G. Streicher, U. Temurshoev, A. Villanueva, G.J. de Vries. "The World Input-Output Database (WIOD): Contents, Sources and Methods." 2012. WIOD Background document available at www.wiod.org.

Wang Z, Wei S J, Zhu K. Quantifying International Production Sharing at the Bilateral and Sector Level. NBER Working Paper Series, 2013.

Appendix

Appendix A. the detailed mathematical derivation of term 3b in equation (3)

The term 3b in equation (3) can be further divided into returned value added and foreign value added based on their final destinations of absorption.

$$\hat{V}LA^F\left(B\hat{Y} - L\hat{Y}^D\right) = \hat{V}LA^FB\hat{Y} - \hat{V}LA^FL\hat{Y}^D$$
$$= \hat{V}L(A^FB)^D\hat{Y} + \hat{V}L(A^FB)^F\hat{Y} - \hat{V}LA^FL\hat{Y}^D \quad \text{(A1)}$$
$$= \hat{V}L(A^FB)^D\hat{Y} + \hat{V}L\left[(A^FB)^F\hat{Y} - A^FL\hat{Y}^D\right]$$

Where $(A^FB)^D$ is a diagonal matrix of A^FB with sub-matrics, and $(A^FB)^F$ is a off-diagonal matrix of A^FB with sub-matrics. $\hat{V}L(A^FB)^D\hat{Y}$ is the returned value added embodied in intermediate exports and further returned home country for production of final goods and services, $\hat{V}L\left[(A^FB)^F\hat{Y} - A^FL\hat{Y}^D\right]$ is the value added embodied in intermediate exports that is used by partner country to produce exports of final products or intermediate inputs for other countries' production of final goods and services that are eventually re-exported and consumed abroad.

Appendix B Detailed mathematical proof of equation (5) and (6)

As equation (2) in main text, the gross input production can be written as:

$$X = (I - A^D)^{-1}Y^D + (I - A^D)^{-1}E = LY^D + LE$$
$$= LY^D + LY^F + LA^FBY \quad \text{(B1)}$$

Pre-multiplying with the GN by GN direct value-added diagonal matrix $\hat{V}$,

$$Va' = \hat{V}X = \hat{V}LY^D + \hat{V}LY^F + \hat{V}LA^FBY$$
$$= \underbrace{\hat{\mathrm{V}}\mathrm{LY}^{\mathrm{D}}}_{(1)-\mathrm{V\_D}} + \underbrace{\hat{\mathrm{V}}\mathrm{LY}^{\mathrm{F}}}_{(2)-\mathrm{V\_RT}} + \underbrace{\hat{\mathrm{V}}\mathrm{LA}^{\mathrm{F}}\mathrm{LY}^{\mathrm{D}}}_{(3a)-\mathrm{V\_GVC\_S}} + \underbrace{\hat{\mathrm{V}}\mathrm{LA}^{\mathrm{F}}(\mathrm{BY} - \mathrm{LY}^{\mathrm{D}})}_{(3b)-\mathrm{V\_GVC\_C}} \quad \text{(B2)}$$

The gross input production and use balance, or the column balance condition of the ICIO table in Table 1 can be written as:

$$u\hat{X} = uA\hat{X} + V\hat{X} \quad \text{(B3)}$$

Rearranging the equation (B1) yields

$$u = V(I - A)^{-1} = VB \quad \text{(B4)}$$

Inserting the final products production as a diagonal matrix into equation (B4), the decomposition of final products production based on the Leontief model can be expressed as follows:

$$Y' = VB\hat{Y} \tag{B5}$$

Expanding equation (B5), final products production at each country/sector pair can be decomposed into five different parts as follows:

$$Y' = VB\hat{Y} = \underbrace{VL\hat{Y}^D}_{(1)-Y\_D} + \underbrace{VL\hat{Y}^F}_{(2)-Y\_RT} + \underbrace{VLA^F L\hat{Y}^D}_{(3a)-Y\_GVC\_S} + \underbrace{VLA^F(B\hat{Y} - L\hat{Y}^D)}_{(3b)-Y\_GVC\_C} \tag{B6}$$

Appendix C Forward and backward linkage based GVC participation indexes at global level

As shown in equations (6) and (7), GVC participation indexes based on forward and backward industrial linkage can be defined as

$$GVC\_PAT\_f = \frac{V\_GVC}{\hat{V}X} = \frac{\hat{V}LA^F BY}{\hat{V}X} \tag{C1}$$

$$GVC\_PAT\_b = \frac{Y\_GVC}{Y'} = \frac{VBA^F L\hat{Y}\mu}{Y'} \tag{C2}$$

Aggregating to the world level

$$GVC\_PAT\_f^w = \frac{uV\_GVC}{u\hat{V}X} = \frac{u\hat{V}LA^F BY}{uGDP} = \frac{VLA^F BY\mu}{uGDP} = 1 - \frac{VLY}{uGDP} \tag{C3}$$

$$GVC\_PAT\_b^w = \frac{Y\_GVCu'}{uY} = \frac{VBA^F LY}{uGDP} = 1 - \frac{VLY\mu}{uGDP} \tag{C4}$$

Obviously, the numerators in equations (C3) and (C4) are the same. Therefore, GVC participation indexes based on forward and backward industrial linkage equal each other at the global level.