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Compilation of a Regionally-extended Inter-country Input–Output Table and Its Application to Global Value Chain Analysis

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Abstract: Studies on the rise of global value chains (GVCs) have attracted a great deal of interest in the recent economics literature. However, due to statistical and methodological challenges, most existing research ignores domestic regional heterogeneity in assessing the impact of joining GVCs. GVCs are supported not only directly by domestic regions that export goods and services to the world market, but also indirectly by other domestic regions that provide parts, components, and intermediate services to final exporting regions. To better understand the nature of a country's position and degree of participation in GVCs, we need to fully examine the role of individual domestic regions. Understanding the domestic components of GVCs is especially important for larger economies such as China, the US, India and Japan, where there may be large variations in economic scale, geography of manufacturing, and development stages at the domestic regional level. This paper proposes a new framework for measuring domestic linkages to global value chains. This framework measures domestic linkages by endogenously embedding a target country's (e.g. China and Japan) domestic interregional input–output tables into the OECD inter-country input–output model. Using this framework, we can more clearly understand how global production is fragmented and extended internationally and domestically.

Keywords: trade in value-added, global value chain, input-output, regional heterogeneity
JEL classification: R15; C65; Q56

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Abstract

Studies on the rise of global value chains (GVCs) have attracted a great deal of interest in the recent economics literature. However, due to statistical and methodological challenges, most existing research ignores domestic regional heterogeneity in assessing the impact of joining GVCs. GVCs are supported not only directly by domestic regions that export goods and services to the world market, but also indirectly by other domestic regions that provide parts, components, and intermediate services to final exporting regions. To better understand the nature of a country's position and degree of participation in GVCs, we need to fully examine the role of individual domestic regions. Understanding the domestic components of GVCs is especially important for larger economies such as China, the US, India and Japan, where there may be large variations in economic scale, geography of manufacturing, and development stages at the domestic regional level. This paper proposes a new framework for measuring domestic linkages to global value chains. This framework measures domestic linkages by endogenously embedding a target country's (e.g. China and Japan) domestic interregional input–output tables into the OECD inter-country input–output model. Using this framework, we can more clearly understand how global production is fragmented and extended internationally and domestically.

Keyword: input–output, global value chains, regional heterogeneity

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1 Introduction

As one of the most useful tools for studying international production networks, inter-country input–output (ICIO) tables provide detailed information and thus have been widely used in both economic and environmental analyses (see Miller and Blair, 2009; Murray and Wood, 2010), especially in areas related to today's global value chains (GVCs) (see WTO-IDE, 2011; OECD-WTO-World Bank, 2014; Koopman et al., 2014 (KWW); and Meng et al., 2015).

If the focus of analysis is at only the country or inter-country level, the existing ICIO tables may be sufficient. In practice, however, many economic policy needs are at a country's domestic regional level, while linking with the world market. For example, questions like how the 2008 financial crisis damaged the economy of Chinese Guandong province through various channels of GVCs[1] or how the 2011 Great East Japan Earthquake impacted Korea's semiconductor industry through GVCs[2] significantly challenge the existing ICIO approach. The conventional way of using ICIO-based economic models (including computable general equilibrium models) to answer the first question is to first evaluate the inter-country impact and then to conduct a top-down analysis at the domestic regional level. The response to the second question is to first conduct a bottom-up analysis to evaluate the impact of a specific region on the whole country and then to measure the inter-country impact. For both approaches, in the process of evaluating the inter-country impact based on the ICIO table, the target country is treated as a single entry (an economic point), without any information about its domestic regional heterogeneity. Namely, there is implicitly a strong assumption that all domestic regions have the same production function as the national average. This may potentially lead to a large estimation bias in economic analyses for the target country if it has domestic regions with various heterogeneities in terms of regional economic endowments, geographic locations, developmental stages, industrial structures, and foreign independency.

Another example is that, in the U.S., much of the chemical industry is concentrated in the South with large amounts of relatively clean natural gas-fired power plants. What remains of the steel industry is largely concentrated in the Upper Midwestern states, where coal-fired power plants dominate. If we use ICIO to estimate embodied emissions in U.S. exports through domestic supply chains, an overestimation will likely occur for chemical exports, and an underestimation may occur for steel exports if more chemical exports are from the South and more steel exports are from the Upper Midwestern states. This is a crucial issue with the ICIO-type approach, which needs to be carefully treated in both economic and environmental analyses.

One option to overcome this problem is to construct a regionally-extended Inter-country Input–Output Table (REXICIO) table containing the target country's domestic regional information. This can directly provide information about linkages between a target country's domestic production networks and international production networks. Some efforts have been reported in the literature. For example, Meng et al. (2013a) embedded China's domestic inter-regional IO (IRIO) table into the World Input-Output Table (WIOT) using a linear programing method. Their empirical results show that using the newly extended WIOT can both reduce the estimation discrepancy of China's bilateral trade in value added and also elucidate the position and the degree of participation of China's domestic regions in global value chains which cannot be explicitly measured by using China's domestic IO table or the WIOT in isolation. This new WIOT has also been applied to environmental analysis (see Pei et al., 2015). Similar works can also be found in Cherubini and Los (2013), who link Italy's IRIO table to the WIOT, and then illustrate Italy's regional employment patterns in a globalizing world. Also, Dietzenbacher et al. (2013) linked Brazil's IRIO IO table into the WIOT and evaluated the role of Brazilian regions in the global value chain. Another ambitious attempt is to

[1] "An estimated 600,000 migrant workers have left China's southern Guangdong Province due to unemployment in 2008 after the worldwide financial crisis hit the region" (China Daily, www.chinadaily.com.cn/business/2009-01/08/content_7379756.htm).
[2] "Japan earthquake to affect several major IT industries of Korea" (DIGITIMES, by Betty Shyu, (http://www.digitimes.com/news/a20110322VL203.html)

link more countries' domestic IRIO IO tables to existing ICIO tables (see Meng et al. (2013b) and Inomata and Meng (2015), who links Japan, China, and Korea's domestic IRIO tables into the Asian International IO tables).

The aim of this paper is to develop a more consistent and flexible method for embedding a target country's domestic IRIO table into an existing ICIO table. The existing efforts mentioned above can be considered a good starting point. However, some important problems in the existing works remain unsolved. One is consistency of terms used for valuation in the IO tables. For example, the official WIOT uses basic prices, while China's IRIO table uses producer prices. Without appropriately adjusting China's IRIO from producer's prices to basic prices in advance, potential discrepancies may arise to some extent in the process of linking these two tables. This is mainly because taxation and transportation margin at the product level may be different across domestic regions or sectors. In addition, the import data in China's IRIO table are at CIF prices, which also should be adjusted before linking with an ICIO table since tariff, import duty, and international transportation margins and insurance may vary across countries of origin at the product level. The other challenge is how to improve the reliability of the target country's regional customs data. These data provide very important information to be used in allocating the international trade flow between the target country's domestic regions and other countries. However, domestic regional customs data may not provide true domestic destination information of imported goods and domestic origin information of exported goods. For example, officially published Japanese regional customs data are based on the reporter's location information rather than that of producer and user locations. Therefore, when using a target country's domestic regional customs data, careful treatment and adjustment should be done in advance. Another problem is the control and evaluation of estimation errors. Meng et al. (2013b) and Satoshi and Meng (2015) use the so-called split method to link target countries' domestic IRIO table with an ICIO table. This method keeps the balance of the existing ICIO column-wise, but without detailed treatments of row-wise estimation discrepancies. Meng et al. (2013a) use a linear programing method to do similar linking work resulting in a balanced ICIO table with a target country's IRIO table embedded. However, the selection of constraint equations in the linear programing method is not unique. In order to get a converged result with the smallest discrepancy level, personal experiences play a very important role in their estimation.

In order to overcome the above limitations, this paper introduces some new variables for adjusting the valuation format between different tables to be linked. We also propose a gravity-type model for improving the reliability of a target country's domestic regional customs data. Furthermore, we suggest using the so-called grid search method to automatically get the best combination of constraints in the linear programing.

2 How to embed a specific country's domestic interregional IO table into an existing inter-country IO table

2.1 Framework of the regionally-extended inter-country IO table and data configuration

For ease of explanation, we consider a two-country case where the target country has two domestic regions and two sectors for each region. The existing data that can be used to construct the REXICIO table for a target country are shown below:

1) The target country's domestic IRIO table with separate import row vector (or matrix) and export column vector (Table 1).
2) A closed ICIO table including the target country as an endogenous part at basic prices (Table 2).
3) Domestic regional export data by sector and by country of destination at FOB prices and domestic regional import data by sector and by country of origin at the CIF prices from the target country's customs statistics.
4) If the table of item 1) is not at basic prices, then relevant tax, domestic and international transportation margins (including insurance), and tariff information (including import duty and commodity tax) for the target country at both the regional and product level should be available

or can be estimated.

For simplicity, three final demand items (household consumption, government consumption, and capital formation including change of inventory) and one value-added item are considered in the format. The format of the REXICIO table is shown in Table 3. We can see that the domestic IRIO table of the target country (country 1), has been embedded in an ICIO framework.

The notation used to specify IO-related variables in the paper is given in Table 4. The country, region, and sector dimension configuration used in this paper are shown below.

For sector: $i, j \in \{1,2, \dots, ns\}$,
where i and j respectively represent the sectors allocated row-wise and column-wise in an IO table, and ns represents the number of sectors.
For country: $R, S \in \{1, 2, \dots, T, \dots, G\}$,
where T represents the target country that needs to be embedded in the ICIO table, R and S respectively represent the countries of origin and destination, and G represents the number of countries.
For domestic region: $r, s \in T\{1, 2, \dots, g\}$,
where r and s respectively represent the target country T's domestic regions of origin and destination, and g represents the number of regions.
For final demand item: $k \in \{1,2, \dots, nf\}$,
where nf represents the number of final demand items.
For simplicity, we consider only one value-added item.

Table 1 Layout of the target country's domestic IRIO table

<table>
<tr><td colspan="2" rowspan="3">A target country's domestic IRIO table</td><td colspan="4">Intermediate demand</td><td colspan="6">Final demand</td><td rowspan="3">Export outside target cuntry</td><td rowspan="3">Total output</td></tr>
<tr><td colspan="2">Region 1</td><td colspan="2">Region 2</td><td colspan="3">Region 1</td><td colspan="3">Region 2</td></tr>
<tr><td>sector 1</td><td>sector 2</td><td>sector 1</td><td>sector 2</td><td>Household consumption</td><td>Government consumption</td><td>Capital formatino</td><td>Household consumption</td><td>Government consumption</td><td>Capital formatino</td></tr>
<tr><td rowspan="2">Region 1</td><td>sector 1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>sector 2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Region 2</td><td>sector 1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>sector 2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Import outside target cuntry</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Value added</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Total input</td><td></td><td></td><td></td><td></td></tr>
</table>

Table 2 Layout of an ICIO table

An ICIO table		Intermediate demand				Final demand						Total output
		Country 1		Country 2		Country 1			Country 2			
		sector 1	sector 2	sector 1	sector 2	Household consumption	Government consumption	Capital formatino	Household consumption	Government consumption	Capital formatino	
Country 1	sector 1											
	sector 2											
Country 2	sector 1											
	sector 2											
Value added												
Total input												

Table 3 Layout of an REXICIO table

An Regionally-extended ICIO table		Intermediate demand						Final demand									Total output
		Country 1's Region 1		Country 1's Region 2		Country 2		Country 1's Region 1			Country 1's Region 2			Country 2			
		sector 1	sector 2	sector 1	sector 2	sector 1	sector 2	Household consumption	Government consumption	Capital formatino	Household consumption	Government consumption	Capital formatino	Household consumption	Government consumption	Capital formatino	
Country 1's Region 1	sector 1																
	sector 2		Block A1			Block C1				Block A2					Block C2		
Country 1's Region 2	sector 1																
	sector 2																
Country 2	sector 1		Block B1							Block B2							
	sector 2																
Value added																	
Total input																	

Table 4 Variable and parameter definitions

	ICIO table (known)	Domestic IRIO table (known)	REXICIO table $(R, S \neq T)$ (unknown)
Transaction of intermediate products	$\bar{x}_{ij}^{RS}$	xd_{ij}^{rs}	$x_{ij}^{RS} = \bar{x}_{ij}^{RS}, x_{ij}^{rS}, x_{ij}^{Rs}, x_{ij}^{rs}$
Transaction of final demand products	$\bar{y}_{ik}^{RS}$	yd_{ik}^{rs}	$y_{ik}^{RS} = \bar{y}_{ik}^{RS}, y_{ik}^{rS}, y_{ik}^{Rs}, y_{ik}^{rs}$
Import row-vector (or matrix)		MX_j^s, MY_k^s (mx_{ij}^s, my_{ik}^s)	
Export column-vector		EX_i^r	
Output	$\bar{X}_i^R$	XD_i^r	$X_i^R = \bar{X}_i^R, X_i^r$
Value-added	$\bar{V}_j^S$	VD_j^s	$V_j^S = \bar{V}_j^S, V_j^s$
Column-sum of final demand	$\bar{Y}_k^S$	YD_k^s	$Y_k^S = \bar{Y}_k^S, Y_k^s$

In addition, the regional export and import data taken from the customs statistics for trade in goods are further separated into three main categories (intermediate goods, household consumption goods, and capital goods) using the OECD end-use categories (mainly based on the Broad Economic Categories (BEC) defined by the United Nations Statistics Division). The regional export data for services without information about destination country can be obtained from the domestic IRIO table. If the import matrix is not available in the domestic IRIO table, regional import data for services are better obtained from other official statistics (while there is no relevant way to separate trade in services into end-use categories). The notation used to express regional export and import data is shown below.

mx_i^{Rs}: Region s's imports of the target country from country R for intermediate good i.
my_{ik}^{Rs}: Region s's imports in the target country from country R for final good i.
ex_i^{rS}: Region r's exports from the target country to country S for intermediate good i.
ey_{ik}^{rS}: Region r's exports from the target country to country S for final good i.
m_i^s: Region s's imports of service i.

If the domestic IRIO table for the target country is at the producer's price (e.g. China and Japan's cases), the following supplementary information will be helpful for more reliable estimation of the REXICIO table.

$\alpha_{ij(k)}^{rs}$: Adjustment item (rate) for transferring the domestic IRIO table from producer's price to basic price. The first approximation is to assume that $\alpha_{ij(k)}^{rs} = \alpha_{ij(k)}^{T}$, where j is intermediate use and k is final use.
β_i^{Rs}: Adjustment item of international transportation freight and insurance for transferring the target country's regional imports from CIF price to FOB price (as a percentage share of CIF price). The first approximation is to assume that $\beta_i^{Rs} = \beta_i^{RT}$.
τ_i^{RT}: Target country's import duty and commodity tax (as a percentage share of CIF price).
γ_i^R: Target country's trade partner's domestic transportation and trade margin on exports (as a percentage share of FOB price).
For simplicity in transferring the CIF price of the target country's imports to basic price, we can

assume that $\sigma_i^{Rs} = \left[1 - \left(\beta_i^{Rs} + \tau_i^{RT}\right) \cdot \gamma_i^{R}\right]$.
γ_i^r: Target country's domestic regional transportation and trade margin on exports (as a percentage share of FOB price). The first approximation is to assume that $\gamma_i^r = \gamma_i^T$.

2.2 Determination of initial values for endogenous variables

One important principle in the process of constructing the REXICIO table is use of the existing ICIO table as a control total[3]. Constants in the REXICIO table include $\bar{x}_{ij}^{RS}$, $\bar{y}_{ik}^{RS}$,$\bar{X}_i^R$,$\bar{V}_j^S$, and $\bar{Y}_k^S$. For the other parts, we conduct an estimation based on both the structure of the existing IO tables and the regional import-export data from customs statistics.

The initial values for domestic regions of the target country in estimating the REXICIO table can be given from the following equations:

$$\hat{x}_{ij}^{rs} = \sum_i \sum_j \bar{x}_{ij}^{TT} \cdot \frac{xd_{ij}^{rs} \cdot \alpha_{ij}^{rs}}{\sum_r \sum_s \sum_i \sum_j xd_{ij}^{rs} \cdot \alpha_{ij}^{rs}}, \tag{1}$$

$$\hat{y}_{ik}^{rs} = \sum_i \sum_k \bar{y}_{ik}^{TT} \cdot \frac{yd_{ik}^{rs} \cdot \alpha_{ik}^{rs}}{\sum_r \sum_s \sum_i \sum_k yd_{ik}^{rs} \cdot \alpha_{ik}^{rs}}, \tag{2}$$

$$\hat{X}_i^r = \bar{X}_i^T \cdot \frac{XD_i^r}{\sum_r XD_i^r}, \tag{3}$$

$$\hat{V}_j^r = \bar{V}_j^T \cdot \frac{VD_j^r}{\sum_r VD_j^r}, \tag{4}$$

$$\hat{Y}_k^s = \bar{Y}_k^T \cdot \frac{YD_k^r}{\sum_r YD_k^r}. \tag{5}$$

These equations give initial values for the target country's domestic interregional trade in intermediate products (Eq. 1's left side: region r's product i used to produce region s's product j), trade in final products (Eq. 2's left side: region r's product i used to fulfill region s's final demand item k), regional output (Eq. 3), regional value added (Eq. 4), and regional final demand (Eq. 5) in the REXICIO table by using the structure of the existing domestic interregional IO table to distribute the target country's corresponding total value as obtained from the ICIO table.

The initial values for regional imports of the target country by country of origin in the REXICIO table can be tentatively given as follows $(R \neq T, \text{p for goods}, \text{q for service})$:

$$\hat{x}_{pj}^{Rs} = \left(\sum_j \bar{x}_{pj}^{RT} \cdot \frac{mx_p^{Rs} \cdot \sigma_p^{Rs}}{\sum_s mx_p^{Rs} \cdot \sigma_p^{Rs}}\right) \cdot \frac{\sum_r xd_{pj}^{rs} \cdot \alpha_{ij}^{rs}}{\sum_r \sum_j xd_{pj}^{rs} \cdot \alpha_{ij}^{rs}}, \tag{6) or (}$$

$$\hat{x}_{pj}^{Rs} = \left(\sum_j \bar{x}_{pj}^{RT} \cdot \frac{mx_p^{Rs} \cdot \sigma_p^{Rs}}{\sum_s mx_p^{Rs} \cdot \sigma_p^{Rs}}\right) \cdot \frac{mx_{pj}^{s}}{\sum_j mx_{pj}^{s}}, \tag{6*) or (}$$

$$\hat{x}_{pj}^{Rs} = \left(\sum_j \bar{x}_{pj}^{RT} \cdot \frac{mx_p^{Rs} \cdot \sigma_p^{Rs}}{\sum_s mx_p^{Rs} \cdot \sigma_p^{Rs}}\right) \cdot \frac{\bar{x}_{pj}^{RT}}{\sum_j \bar{x}_{pj}^{RT}}, \tag{6**}$$

$$\hat{x}_{qj}^{Rs} = \left(\sum_j \bar{x}_{qj}^{RT} \cdot \frac{\sum_p mx_p^{Rs} \cdot \sigma_p^{Rs}}{\sum_s \sum_p mx_p^{Rs} \cdot \sigma_p^{Rs}}\right) \cdot \frac{\sum_r xd_{pj}^{rs} \cdot \alpha_{ij}^{rs}}{\sum_r \sum_j xd_{pj}^{rs} \cdot \alpha_{ij}^{rs}}, \tag{6a) or (}$$

$$\hat{x}_{qj}^{Rs} = \left(\sum_j \bar{x}_{qj}^{RT} \cdot \frac{\sum_p mx_p^{Rs} \cdot \sigma_p^{Rs}}{\sum_s \sum_p mx_p^{Rs} \cdot \sigma_p^{Rs}}\right) \cdot \frac{mx_{qj}^{s}}{\sum_j mx_{qj}^{s}}, \tag{6a*) or (}$$

$$\hat{x}_{qj}^{Rs} = \left(\sum_j \bar{x}_{qj}^{RT} \cdot \frac{mx_p^{Rs} \cdot \sigma_p^{Rs}}{\sum_s mx_p^{Rs} \cdot \sigma_p^{Rs}}\right) \cdot \frac{\bar{x}_{qj}^{RT}}{\sum_j \bar{x}_{qj}^{RT}}, \tag{6a**) or (}$$

$$\hat{x}_{qj}^{Rs} = \left(\sum_j \bar{x}_{qj}^{RT} \cdot \frac{m_q^{s}}{\sum_s m_q^{s}}\right) \cdot \frac{\sum_r xd_{pj}^{rs} \cdot \alpha_{ij}^{rs}}{\sum_r \sum_j xd_{pj}^{rs} \cdot \alpha_{ij}^{rs}}, \tag{6a***}$$

[3] The "control total" is a widely used terminology in the IO field, especially when we need to balance a matrix in which the values for all elements in the matrix are tentatively given, but their row-sum and column-sum are not consistent to the expected (fixed) values. These fixed values for row-sum and column-sum are usually called the "control total". During the balancing procedure, these values always need to be kept constant.

$$\hat{y}_{pk}^{Rs} = (\sum_k \bar{y}_{pk}^{RT} \cdot \frac{mx_p^{Rs} \cdot \sigma_p^{Rs}}{\sum_s mx_p^{Rs} \cdot \sigma_p^{Rs}}) \cdot \frac{\sum_r yd_{pk}^{rs} \cdot \alpha_{ik}^{rs}}{\sum_r \sum_k yd_{pk}^{rs} \cdot \alpha_{ik}^{rs}}, \tag{7) or (}$$

$$\hat{y}_{pk}^{Rs} = (\sum_k \bar{y}_{pk}^{RT} \cdot \frac{mx_p^{Rs} \cdot \sigma_p^{Rs}}{\sum_s mx_p^{Rs} \cdot \sigma_p^{Rs}}) \cdot \frac{my_{pk}^{s}}{\sum_j my_{pk}^{s}}, \tag{7*}$$

$$\hat{y}_{q,k}^{Rs} = \left(\sum_k \bar{y}_{qk}^{RT} \cdot \frac{\sum_p mx_p^{Rs} \cdot \sigma_p^{Rs}}{\sum_s \sum_p mx_p^{Rs} \cdot \sigma_p^{Rs}}\right) \cdot \frac{\sum_r yd_{pk}^{rs} \cdot \alpha_{ik}^{rs}}{\sum_r \sum_k yd_{pk}^{rs} \cdot \alpha_{ik}^{rs}}, \tag{7a) or (}$$

$$\hat{y}_{q,k}^{Rs} = \left(\sum_k \bar{y}_{qk}^{RT} \cdot \frac{mx_p^{Rs} \cdot \sigma_p^{Rs}}{\sum_s mx_p^{Rs} \cdot \sigma_p^{Rs}}\right) \cdot \frac{my_{qk}^{s}}{\sum_j my_{qk}^{s}}, \tag{7a*) or (}$$

$$\hat{y}_{q,k}^{Rs} = \left(\sum_k \bar{y}_{qk}^{RT} \cdot \frac{\sum_p mx_p^{Rs} \cdot \sigma_p^{Rs}}{\sum_s \sum_p mx_p^{Rs} \cdot \sigma_p^{Rs}}\right) \cdot \frac{\bar{x}_{qj}^{RT}}{\sum_j \bar{x}_{qj}^{RT}}, \tag{7a**) or (}$$

$$\hat{y}_{q,k}^{Rs} = \left(\sum_k \bar{y}_{qk}^{RT} \cdot \frac{m_q^{s}}{\sum_s m_q^{s}}\right) \cdot \frac{\sum_r yd_{pk}^{rs} \cdot \alpha_{ik}^{rs}}{\sum_r \sum_k yd_{pk}^{rs} \cdot \alpha_{ik}^{rs}}, \tag{7a***}$$

These equations give initial values for the target country's regional imports of intermediate goods (Eq. 6) and services (Eq. 6a) and regional imports of final goods (Eq. 7) and services (Eq. 7a) by country of origin in the REXICIO table by using the structure of the existing customs regional import data and domestic interregional IO table to distribute the target country's corresponding total import value as obtained from the ICIO table. It should be noted that Eqs. 6 and 7 are based on the following respective assumptions: a domestic region's sector that uses more domestic inputs of a specific good may use more of the same type of imported good as well, and a domestic region's final demand item that consumes more of a specific good produced domestically may use more of the same type of imported good as well. In addition, due to the lack of regional import statistics on services by country of origin, we use the structure of regional import statistics on goods as a proxy to estimate the initial value for services (Eqs. 6a and 7a). This means we assume that if more goods are shipped from country R to region s, more services may also imported by region s from country R. In addition, the superscript * gives a proxy when an import matrix is available in the domestic IRIO table, the superscript ** gives a proxy when the assumption used in Eqs. 6 and 7 is supposed to be unreliable and no regional import matrix is available, and the superscript *** gives a proxy when the assumption used in Eqs. 6a* and 7a* is unreliable and only information about regional imports of services are available.

The initial values for regional exports of the target country by country of destination in the REXICIO table are first estimated using the following equations ($S \neq T, \text{p for goods}, \text{q for services}$):

$$\hat{x}_{pj}^{rS} = \bar{x}_{pj}^{TS} \cdot \frac{ex_p^{rS} \cdot (1-\gamma_p^r)}{\sum_r ex_p^{rS} \cdot (1-\gamma_p^r)}, \tag{8) or (}$$

$$\hat{x}_{qj}^{rS} = \bar{x}_{qj}^{TS} \cdot \frac{\sum_p ex_p^{rS} \cdot (1-\gamma_p^r)}{\sum_r \sum_p ex_p^{rS} \cdot (1-\gamma_p^r)}, \tag{8a) or (}$$

$$\hat{x}_{qj}^{rS} = \bar{x}_{qj}^{TS} \cdot \frac{EX_q^r}{\sum_r EX_q^r}, \tag{8a*}$$

$$\hat{y}_{pk}^{rS} = \bar{y}_{pk}^{TS} \cdot \frac{ey_{pk}^{rS} \cdot (1-\gamma_p^r)}{\sum_r ey_{pk}^{rS} \cdot (1-\gamma_p^r)}, \tag{9) or (}$$

$$\hat{y}_{qk}^{rS} = \bar{y}_{qk}^{TS} \cdot \frac{\sum_p \sum_k ey_{pk}^{rS} \cdot (1-\gamma_p^r)}{\sum_r \sum_p \sum_k ey_{pk}^{rS} \cdot (1-\gamma_p^r)}, \tag{9a) or (}$$

$$\hat{y}_{qk}^{rS} = \bar{y}_{qk}^{TS} \cdot \frac{EX_q^r}{\sum_r EX_q^r}, \tag{9a*}$$

These equations give initial values for the target country's regional exports of intermediate goods (Eq. 8) and services (Eq. 8a or 8a*) and regional exports of final goods (Eq. 9) and services (Eq. 9a or 9a*) by country of destination in the REXICIO table by using the structure of the existing customs regional export data to distribute the target country's corresponding total export value as obtained from the IRIO table. When we lack regional export statistics on services by country of destination, we again use the structure of regional export statistics on goods as a proxy to estimate the initial value for services (Eqs. 8a and 9a). This means we assume that if a region exports more goods to a foreign country, it may also export more services to that same country. Another option for this estimation is to use the regional total export of services taken from the existing domestic IRIO table as a proxy (see Eqs. 8a* and 9a*).

2.3 Estimation methodology and reconciliation procedure

For ease of estimation, we separate the whole REXICIO table into several blocks (see Table 3). The blocks A1 and A2 concerning the domestic interregional transaction of the target country are estimated and balanced by using the following linear programming model. The objective function (F1) in the model is given as

$$\text{Minimize F1} = \frac{1}{2}\begin{cases} \sum_r \sum_s \sum_i \sum_j \frac{(x_{ij}^{rs} - \hat{x}_{ij}^{rs})^2}{\hat{x}_{ij}^{rs}} + \sum_r \sum_s \sum_i \sum_k \frac{(y_{ik}^{rs} - \hat{y}_{ik}^{rs})^2}{\hat{y}_{ik}^{rs}} \\ + \sum_r \sum_i \frac{(X_i^r - \hat{X}_i^r)^2}{\hat{X}_i^r} + \sum_r \sum_j \frac{(V_j^r - \hat{V}_j^r)^2}{\hat{V}_j^r} + \sum_r \sum_k \frac{(Y_k^r - \hat{Y}_k^r)^2}{\hat{Y}_k^r}, \end{cases} \tag{10}$$

subject to

$$\sum_s \sum_j x_{ij}^{rs} = \sum_j \bar{x}_{ij}^{TT} \cdot \frac{\sum_s \sum_j xd_{ij}^{rs} \cdot \alpha_{ij}^{rs}}{\sum_r \sum_s \sum_j xd_{ij}^{rs} \cdot \alpha_{ij}^{rs}}, \tag{11}$$

$$\sum_r \sum_i x_{ij}^{rs} = \sum_i \bar{x}_{ij}^{TT} \cdot \frac{\sum_r \sum_i xd_{ij}^{rs} \cdot \alpha_{ij}^{rs}}{\sum_s \sum_r \sum_i xd_{ij}^{rs} \cdot \alpha_{ij}^{rs}}, \tag{12}$$

$$\sum_r \sum_s x_{ij}^{rs} = \bar{x}_{ij}^{TT}, \tag{13}$$

$$\sum_i \sum_j x_{ij}^{rs} = \sum_i \sum_j \bar{x}_{ij}^{TT} \cdot \frac{\sum_i \sum_j xd_{ij}^{rs} \cdot \alpha_{ij}^{rs}}{\sum_r \sum_s \sum_i \sum_j xd_{ij}^{rs} \cdot \alpha_{ij}^{rs}}, \tag{14}$$

$$\sum_s \sum_k y_{ik}^{rs} = \sum_k \bar{y}_{ik}^{TT} \cdot \frac{\sum_s \sum_k |yd_{ik}^{rs}| \cdot \alpha_{ik}^{rs}}{\sum_r \sum_s \sum_k |yd_{ik}^{rs}| \cdot \alpha_{ik}^{rs}}, \tag{15}$$

$$\sum_r \sum_i y_{ik}^{rs} = \sum_i \bar{y}_{ik}^{TT} \cdot \frac{\sum_r \sum_i |yd_{ik}^{rs}| \cdot \alpha_{ik}^{rs}}{\sum_s \sum_r \sum_i |yd_{ik}^{rs}| \cdot \alpha_{ik}^{rs}}, \tag{16}$$

$$\sum_r \sum_s y_{ik}^{rs} = \bar{y}_{ik}^{TT}, \tag{17}$$

$$\sum_i \sum_k y_{ik}^{rs} = \sum_i \sum_k \bar{y}_{ik}^{TT} \cdot \frac{\sum_i \sum_k |yd_{ik}^{rs}| \cdot \alpha_{ik}^{rs}}{\sum_r \sum_s \sum_i \sum_k |yd_{ik}^{rs}| \cdot \alpha_{ik}^{rs}}, \tag{18}$$

$$\sum_r X_i^r = \bar{X}_i^T, \tag{19}$$

$$\sum_r V_j^r = \bar{V}_j^T, \tag{20}$$

$$\sum_r YE_k^r = Y_k^T. \tag{21}$$

The balancing conditions row-wise (row control totals) are given by Eq. 11 for intermediate product transactions and by Eq. 15 for final product transactions. The balancing conditions column-wise (column control totals) are given by Eq. 12 for intermediate product transactions and by Eq. 16 for final product transactions. Equations 13 and 17 represent the control totals for inter-industrial intermediate and final product transactions, respectively. Equations 14 and 18 give the control for inter-regional intermediate and final product transactions, respectively. Equations 19, 20, and 21 give the control for sectoral output, value added, and final demand.

Based on this minimization process, the domestic interregional transactions can be estimated with balanced row, column, inter-regional, and inter-industry relationships. The estimation results can then help us to calculate control total figures for other blocks.

The regional imports of the target country by industry and by country of origin in the REXICIO table (Blocks B1 and B2) can be estimated as

$$\text{Minimize F2} = \frac{1}{2}\left[\sum_R \sum_s \sum_i \sum_j \frac{(x_{ij}^{Rs} - \hat{x}_{ij}^{Rs})^2}{\hat{x}_{ij}^{Rs}} + \sum_R \sum_s \sum_i \sum_k \frac{(y_{ik}^{Rs} - \hat{y}_{ik}^{Rs})^2}{\hat{y}_{ik}^{Rs}}\right], \tag{22}$$

subject to

$$\sum_s \sum_j x_{ij}^{Rs} = \sum_j \bar{x}_{ij}^{RT}, \tag{23}$$

$$\sum_R \sum_i x_{ij}^{Rs} = X_j^s - V_j^s - \sum_r \sum_i x_{ij}^{rs} \quad , \tag{24}$$

$$\sum_s \sum_k y_{ik}^{Rs} = \sum_k \bar{y}_{ik}^{RT}, \tag{25}$$

$$\sum_R \sum_i y_{ik}^{Rs} = Y_k^s - \sum_r \sum_i y_{ik}^{rs}, \tag{26}$$

$$\sum_s x_{ij}^{Rs} = \bar{x}_{ij}^{RT}, \tag{27}$$

$$\sum_s \sum_i x_{ij}^{Rs} = \sum_i \bar{x}_{ij}^{RT}, \tag{27a}$$

$$\sum_s y_{ik}^{Rs} = \bar{y}_{ik}^{RT}, \tag{28}$$

$$\sum_s \sum_i y_{ik}^{Rs} = \sum_i \bar{y}_{ik}^{RT}. \tag{28a}$$

The demand-supply balancing conditions row-wise (row control totals) in terms of the target country's regional imports are given by Eq. 23 for intermediate products, and by Eq. 25 for final products. Equations 24 and 26 represent the balancing conditions column-wise (column control total) for the same block. Equations 27 and 28 give the individual cell control inside the transaction blocks for intermediate and final products, respectively. Equations 27a and 28a are the relaxed balancing conditions from Eq. 27 and 28. Note that for Eqs. 22–28a, $R \neq Ct$.

Using a method similar to the one above, the regional exports of the target country by sector and by country of destination in the REXICIO table can be estimated as

$$\text{Minimize F3} = \frac{1}{2}\left[\sum_r \sum_S \sum_i \sum_j \frac{(x_{ij}^{rS} - \hat{x}_{ij}^{rS})^2}{\hat{x}_{ij}^{rS}} + \sum_r \sum_S \sum_i \sum_k \frac{(y_{ik}^{rS} - \hat{y}_{ik}^{rS})^2}{\hat{y}_{ik}^{rS}}\right], \tag{29}$$

subject to

$$\sum_S \sum_j x_{pj}^{rS} = \sum_S \sum_j \bar{x}_{pj}^{TS} \cdot \frac{\sum_S ex_p^{rS} \cdot (1-\gamma_p^r)}{\sum_r \sum_S ex_p^{rS} \cdot (1-\gamma_p^r)}, \tag{30}$$

$$\sum_S \sum_j x_{qj}^{rS} = \sum_S \sum_j \bar{x}_{qj}^{TS} \cdot \frac{EX_q^r}{\sum_r EX_q^r}, \tag{30a}$$

$$\sum_r \sum_i x_{ij}^{rS} = \sum_i \bar{x}_{ij}^{TS}, \tag{31}$$

$$\sum_S \sum_k y_{pk}^{rS} = \sum_S \sum_k \bar{y}_{pk}^{TS} \cdot \frac{\sum_S \sum_k ey_{pk}^{rS} \cdot (1-\gamma_p^r)}{\sum_r \sum_S \sum_k ey_{pk}^{rS} \cdot (1-\gamma_p^r)}, \tag{32}$$

$$\sum_S \sum_k y_{qk}^{rS} = \sum_S \sum_k \bar{y}_{qk}^{TS} \cdot \frac{EX_q^r}{\sum_r EX_q^r}, \tag{32a}$$

$$\sum_r \sum_i y_{ik}^{rS} = \sum_i \bar{y}_{ik}^{TS}, \tag{33}$$

$$\sum_r x_{ij}^{rS} = \bar{x}_{ij}^{TS}, \tag{34}$$

$$\sum_j \sum_r x_{ij}^{rS} = \sum_j \bar{x}_{ij}^{TS}, \tag{34a}$$

$$\sum_r y_{ik}^{rS} = \bar{y}_{ik}^{TS}, \tag{35}$$

$$\sum_r \sum_k y_{ik}^{rS} = \sum_k \bar{y}_{ik}^{TS}, \tag{35a}$$

$$\sum_S \sum_j x_{ij}^{rS} + \sum_S \sum_k y_{ik}^{rS} + \sum_s \sum_j x_{ij}^{rs} + \sum_s \sum_k y_{ik}^{rs} = X_i^r. \tag{36}$$

The balancing conditions row-wise (row control totals) in terms of the target country's regional exports are given by Eqs. 30 and 30a for intermediate goods and services respectively, and by Eqs. 32 and 32a for final goods and services respectively. Equations 31 and 33 represent the balancing conditions column-wise (column control total) for the same block. Equations 34 and 35 give the individual cell control inside the transaction blocks for intermediate and final products, respectively. Equations 34a and 35a are the relaxed balancing conditions from Eqs. 34 and 35. There is no need to give a column-balancing condition for the whole REXICIO table in terms of the target country, since according to Eqs. 12, 24, and 31, the column balance has been guaranteed (self-evidenced). However, there is no guarantee for row balance across the whole table in terms of the target country. For this reason, we use Eq. 36 to provide the row-balancing condition. Note that for Eqs. 30–36, $S \neq T$.

Up to this point, we have shown how a country's domestic IRIO table can be consistently embedded into an ICIO framework by using linear programming models for different blocks, one by one. With sufficient calculation capacity for more systematic work, we can aggregate all blocks together and solve the linear programming problems at the same time. To maintain the consistency of bilateral trade balance, we must add the following constraints on the entire linear programming problem.

$$\sum_r \sum_j x_{ij}^{rS} - \sum_r \sum_j x_{ij}^{Sr} = \sum_j \bar{x}_{ij}^{TS} - \sum_j \bar{x}_{ij}^{ST}, \qquad (S \neq T), \tag{37}$$
$$\sum_r \sum_k y_{ik}^{rS} - \sum_r \sum_k y_{ik}^{Sr} = \sum_k \bar{y}_{ik}^{TS} - \sum_k \bar{y}_{ik}^{ST}, \qquad (S \neq T). \tag{38}$$

Thus, we have the following linear programming problem for estimating the REXICIO table:

$$\text{Minimize } F = F1 + F2 + F3, \tag{39}$$
subject to the equation set A (Eqs. 11, 12, 15, 16, 19-21, 23–26, 30–33, 36–38) and
subject to all possible combinations in the equation set B (13, 14, 17, 18, 27, 27a, 28, 28a, 34, 34a, 35, 35a) using a grid-search method.

The equation set A gives the minimum necessary constrains that can guarantee a solution of the above linear programing with demand–supply equilibria for all rows and columns in the REXICIO table. In other words, when aggregating the target country's interregional parts of the REXICIO table, we can get an ICIO table which is just the original ICIO table under these constrains. However, when just using the equation set A, there is no guarantee that the target function F (Eq. 39) can get the best solution since there are many additional constraints (set B) remaining. Here, we propose a kind of grid-search method to add all possible combinations in set B to solve the above linear programing problem and obtain the minimum F. Note that there are 12 equations in set B, so the possible number of combinations is $C_{12}^1 + C_{12}^2 + \cdots + C_{12}^{12} = 4095$.

3 An application of the regionally-extended ICIO table in tracing value added in gross exports for both domestic and global value chains

3.1 Measuring bilateral trade in value added

In a closed international IO framework (for simplicity, number of countries = G, number of sectors = N, number of final demand items = 1, number of value added items = 1), the world's total GDP can be given as

$$\begin{aligned} GDP &= \mathrm{diag}(V) \cdot (I - A)^{-1} \cdot Y \\ &= \mathrm{diag}(V) \cdot B \cdot Y, \end{aligned} \tag{40}$$

where $GDP = (GDP^1, GDP^2, \ldots, GDP^G)^t$, $V = (V^1, V^2, \ldots, V^G)$, $A = \begin{pmatrix} A^{11} & \cdots & A^{1G} \\ \vdots & \ddots & \vdots \\ A^{G1} & \cdots & A^{GG} \end{pmatrix}$, and $B = \begin{pmatrix} B^{11} & \cdots & B^{1G} \\ \vdots & \ddots & \vdots \\ B^{G1} & \cdots & B^{GG} \end{pmatrix}$, $Y = \begin{pmatrix} Y^{11} \\ \vdots \\ Y^{G1} \end{pmatrix} + \cdots + \begin{pmatrix} Y^{1G} \\ \vdots \\ Y^{GG} \end{pmatrix}$. GDP^R is a N*1 column vector representing country R's GDP by sector; V^R is a 1*N row vector representing country R's value-added ratio (the share of value added in total input) by sector; A^{RS} is a N*N matrix showing intermediate input coefficients (the share of intermediate imports coming from country R in country S's total input); B^{RS} is a N*N sub-matrix of the international Leontief inverse; and Y^{RS} is a N*1 column vector representing country S's final demand on products produced in country R. Following the concept proposed by Johnson and Noguera (2012), country R's value-added export to country S ($TiVA^{RS}$) is defined as the value added induced in country R by country S's final demand:

$$(0, \ldots, TiVA^{RS}, \ldots 0)^t = \mathrm{diag}(0, \ldots, V^R, \ldots 0) \begin{pmatrix} B^{11} & \cdots & B^{1G} \\ \vdots & \ddots & \vdots \\ B^{G1} & \cdots & B^{GG} \end{pmatrix} \begin{pmatrix} Y^{1S} \\ \vdots \\ Y^{GS} \end{pmatrix}$$

$$\mathrm{TiVA}^{RS} = \mathrm{diag}(V^{R})(B^{R1}Y^{1S} + B^{R2}Y^{2S} + \cdots + B^{RG}Y^{GS}). \quad (41)$$

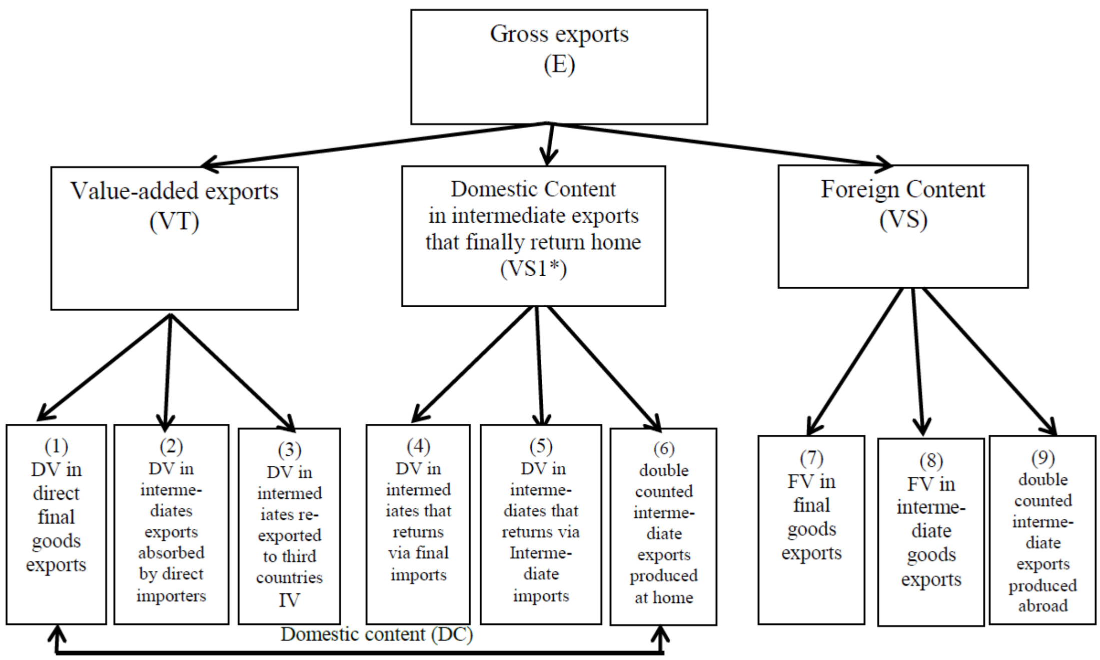
When applying the above TiVA concept to our REXICIO table, the region-by-region, region-by-country, and country-by-region value-added exports can be easily measured. This can help us understand how value added is created across both regional and national borders.

3.2 Tracing value added in gross exports for both domestic and global value chains

To illustrate the performance of a country's domestic regions in GVCs, we apply the KWW gross export decomposition method to our REXICIO system. Using this method, we can see how GVCs are fragmented and extended inside a specific country.

The KWW decomposition method is shown in Figure 1. A country's total exports in gross terms can be decomposed into three parts: value-added exports (VT), domestic content in intermediate exports that ultimately return home (VS1*), and foreign content (VS). Every part at this stage can be further decomposed into three more parts. VT yields (1) domestic value added (DV) in direct final goods exports, (2) DV in intermediate exports absorbed by direct importers, and (3) DV in intermediates re-exported to third countries. VS1* is separated into (4) DV in intermediates that return via final imports, (5) DV in intermediates that return via intermediate imports, and (6) double-counted intermediate exports produced at home. VS is further decomposed into (7) foreign value added (FV) in final goods exports, (8) FV in intermediate goods exports and (9) double-counted intermediate exports produced abroad.

Figure 1 KWW's gross export accounting system



Source: Koopman et al. (KWW 2014)

When using the notation in terms of IO techniques, the KWW decomposition method in an international IO system with n sectors and G countries can be given as follows:

$$
\begin{aligned}
uE_{S*} &= VT_{S*} + VS1_{S*} + VS_{S*} \\
&= \{V_S \sum_{R \neq S}^{G} B_{SS} Y_{SR} + V_S \sum_{R \neq S}^{G} B_{SR} Y_{RR} + V_S \sum_{R \neq S}^{G} \sum_{T \neq S,R}^{G} B_{SR} Y_{RT}\} \\
&+ \{V_S \sum_{R \neq S}^{G} B_{SR} Y_{RS} + V_S \sum_{R \neq S}^{G} B_{SR} A_{RS} (I - A_{SS})^{-1} Y_{SS}\} + V_S \sum_{R \neq S}^{G} B_{SR} A_{RS} (I - A_{SS})^{-1} E_{S*} \\
&+ \{\sum_{T \neq S}^{G} \sum_{R \neq S}^{G} V_T B_{TS} Y_{TS} + \sum_{T \neq S}^{G} \sum_{R \neq S}^{G} V_T B_{TS} A_{SR} (I - A_{RR})^{-1} Y_{RR}\} + \sum_{T \neq S}^{G} V_T B_{TS} A_{SR} \sum_{R \neq S}^{G} (I - A_{RR})^{-1} E_{R*}
\end{aligned}
\tag{42}
$$

Here, u is a row vector of 1's, E_s represents country S's export by sector, and V_s is the diagonal matrix as constructed by country S's sectoral value-added rate (non-diagonal elements are given by 0). B_{SR} is the submatrix of the international Leontief inverse representing the induced output by way of international production networks in country S when there is a single-unit increase in final demand in country R. Y_{SR} represents country R's final demand for goods and services produced in country S. A_{RS} is the international intermediate input coefficient representing the amount, by sector, of intermediate inputs (imports) coming from country R when country S produces one unit of output.

Since the REXICIO table includes both domestic regions and foreign countries, we must distinguish between these dimensions in our notation. For simplicity we use R, S, and T to represent countries and r, s, and t to represent domestic regions. In the REXICIO system the number of countries is given by G and the number of regions by g. When focusing on the decomposition of VT as shown above and using the notation shown for country and region, the extended decomposition incorporating a country's domestic regions into an inter-country IO system can be given as follows:

$$
\begin{aligned}
VT_{s*} &= \left[V_s \sum_{r \neq s}^{g} B_{ss} Y_{sr} + V_s \sum_{r \neq s}^{g} B_{sr} Y_{rr} + V_s \sum_{r \neq s}^{g} \sum_{t \neq s,r}^{g} B_{sr} Y_{rt} \right] + \left[V_s \sum_{R}^{G} \sum_{t \neq s}^{g} B_{sR} Y_{Rt} \right] \\
&+ \left[V_s \sum_{R}^{G} B_{sR} Y_{RR} + V_s \sum_{R}^{G} \sum_{T \neq R}^{G} B_{sR} Y_{RT} \right] + \left[V_s \sum_{R}^{G} B_{ss} Y_{sR} + V_s \sum_{r \neq s}^{g} \sum_{T}^{G} B_{sr} Y_{rT} \right] .
\end{aligned}
\tag{43}
$$

Here, VT_{s*} represents region s's value-added exports and outflows. In particular, outflows mean domestic trade flows across regions. The first term on the right side of Eq. 43 represents region s's value-added outflow in GVCs by domestic segment. This term includes three parts. The first represents region s's value added in direct final goods outflow; the second shows region s's value added in intermediate outflows absorbed by direct domestic demander, and the third is region s's value added in intermediates re-shipped to third domestic regions. The second term on the right side of Eq. 43 represents region s's value added in intermediates re-shipped to third domestic regions by way of international segments of GVCs. The third term represents region s's value-added exports by way of international segments of GVCs. This term can be further separated into two parts. The first is region s's value added in intermediates exports absorbed by direct international importers, and the second is region s's value added in intermediates re-exported to third countries. The final term on the right side of Eq. 43 shows region s's value-added exports by way of domestic segments of GVCs. The first part in this term represents region s's value added in direct final goods exports, and the second represents region s's value added in intermediates re-exported to third countries.

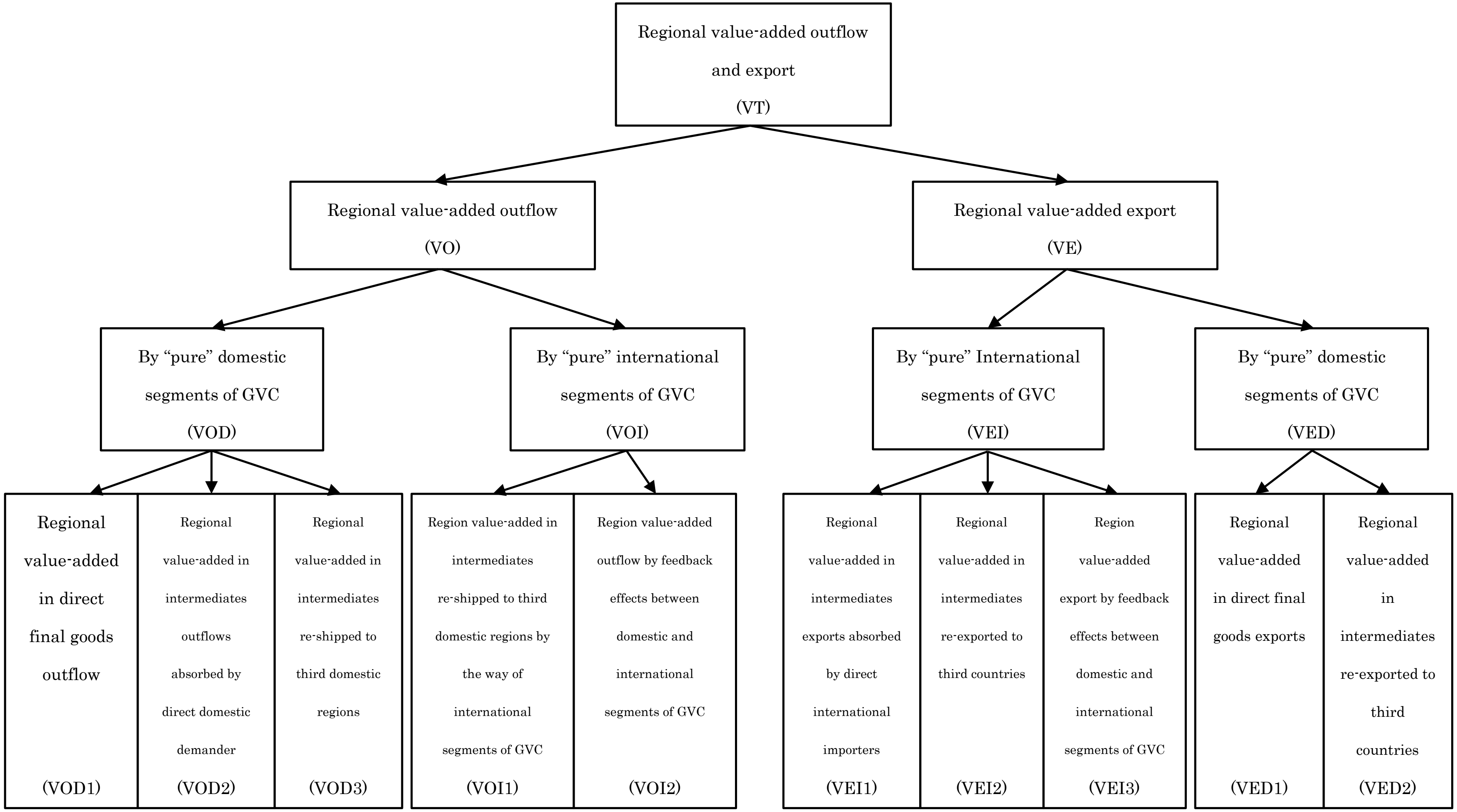
Using the extended KWW decomposition technique in an REXICIO framework, the measurement of GVCs can be divided into international and domestic segments. This framework can help us understand how, and by what routes, a country's domestic regions engage in GVCs. The method used to distinguish the domestic and international segments in the above decomposition method is based on block matrixes in the Leontief inverse used. If the notation in the block matrix involves only domestic regions, we consider the value added induced by this block matrix to be achieved by the domestic segment of GVCs. For the other block matrices in which a country notation such as R, S, or T are involved, we consider the value added induced by these block matrices to come through the international segment of GVCs.

However, B_{sr} may not exactly represent a pure domestic segment of GVCs, since this inter-regional block matrix (B_{sr}) is obtained from the large matrix of the Leontief inverse based on the extended table. If there are no international segments in the REXICIO table, we cannot have B_{sr}. To more clearly define the pure domestic and pure international segments, we introduce a block matrix of B_{sr}^d to the above extended KWW decomposition form. This block matrix is from the large matrix of the Leontief inverse based on the domestic interregional IO table. The difference between B_{sr} and B_{sr}^d is the international feedback effect (see Miller and Blair, 1985) between the domestic and international segments in GVCs. Using this definition, we can rewrite Eq. 43 in the following form:

$$
\begin{aligned}
VT_{s*} &= \left[V_s \sum_{r \neq s}^{g} B_{ss}^d Y_{sr} + V_s \sum_{r \neq s}^{g} B_{sr}^d Y_{rr} + V_s \sum_{r \neq s}^{g} \sum_{t \neq s,r}^{g} B_{sr}^d Y_{rt} \right] \\
&+ \left[V_s \sum_{r \neq s}^{g} (B_{ss} - B_{ss}^d) Y_{sr} + V_s \sum_{r \neq s}^{g} (B_{sr} - B_{sr}^d) Y_{rr} + V_s \sum_{r \neq s}^{g} \sum_{t \neq s,r}^{g} (B_{sr} - B_{sr}^d) Y_{rt} \right] + \left[V_s \sum_{R}^{G} \sum_{t \neq s}^{g} B_{sR} Y_{Rt} \right] \\
&+ \left[V_s \sum_{R}^{G} B_{sR} Y_{RR} + V_s \sum_{R}^{G} \sum_{T \neq R}^{G} B_{sR} Y_{RT} \right] + \left[V_s \sum_{R}^{G} (B_{ss} - B_{ss}^d) Y_{sR} + V_s \sum_{r \neq s}^{g} \sum_{T}^{G} (B_{sr} - B_{sr}^d) Y_{rT} \right] \\
&+ \left[V_s \sum_{R}^{G} B_{ss}^d Y_{sR} + V_s \sum_{r \neq s}^{g} \sum_{T}^{G} B_{sr}^d Y_{rT} \right]
\end{aligned} \tag{44}
$$

The first row of the equation shows the value-added outflow achieved by the pure domestic segment of GVCs (VOD) in region s. The second row shows region s's value-added outflow by way of the pure international segment of GVCs (VOI). The third row represents region s's value-added exports through the pure international segment of GVCs (VED), while the final row shows region s's value-added exports by way of the pure domestic segment of GVCs (VEI). A detailed description of each part is given in Figure 2.

Figure 2 Decomposition of regional value-added outflow and export by GVC routes



4 Data used

We use the following data to embed China and Japan's domestic IRIO data into the OECD ICIO framework:

1) China's domestic interregional IO (CIRIO) table for 2007.
2) Japan's domestic interregional IO (JIRIO) table for 2005.
3) The OECD inter-country input–output table (ICIO) for 2005 and 2007.
4) China and Japan's customs import and export statistics at the provincial level for 2007 and 2005, respectively.
5) China and Japan's domestic transportation margin and insurance from the by-product information obtained from IDE-JETRO's 2005 Asian International Input–output Table project.
6) International transportation freight and insurance rate estimated by using the CEPII's 2005 and 2007 BACI database (including international trade data at both CIF and FOB prices)

The 2007 CIRIO tables are compiled by China's State Information Center (see Zhang and Qi, 2012). The most detailed table has 8 domestic regions and 29 sectors at the producer's price with a stand-alone row vector for imports. The main data source when compiling CIRIO tables is from every province's regional IO table. One problem is that Tibet has no original IO table for 2007. Fortunately, the value-added data and final demand data by industry for Tibet can be obtained from officially published statistics. This information has been added to the southwest region in order to keep consistency with the officially published national value added and final demand information when doing the final balancing work (total inputs should equal total outputs by sector) for the whole inter-regional IO table. In addition, this treatment for Tibet causes very limited bias on the analytical results, since Tibet's GRP as a share in China's total GDP is just 0.137% for 2007.

The 2005 JIRIO table is from the Ministry of Economy, Trade and Industry, Japan (METI)[4]. This table covers 9 domestic regions with 53 sector classifications at the producer's price. Note that the import information is a stand-alone column vector in the JIRIO table, not a separate matrix (the information of imports by product is available, but no information about how many imported products are used in which industry). To get the transaction flow of pure domestic products across sectors and regions, we use the following method to remove the imported parts from current transaction flows in the JIRIO table. In practice, when converting a competitive-type national IO table (an IO table without a separated import matrix) into non-competitive-type IO table (an IO table with a separated import matrix), a useful but sometimes rough "same proportion assumption" is always conducted. Distributing the total import row-wise by using the proportion (intermediate input/row sum of intermediate inputs) in a competitive-type IO table allows the import matrix to be easily estimated. The assumption is that there is no difference between the distribution share of domestic intermediate goods and imported intermediate goods across sectors.

The OECD ICIO tables consist of a time series of international IO data for 62 countries and regions and 34 industries at the basic price. In our exercise, we use the 2005 and 2007 OECD table as our control total for Japan and China, respectively. Again, for simplicity in this exercise, we aggregate the OECD ICIO table from a 62-country, 34-industry table to a table with 5 country groups (China, Japan, U.S., EU, and the rest of the world) and 8 industries.

The Chinese regional customs data cover 31 domestic provinces (based on the statistics from more than 400 regional customs offices). The Japanese regional customs data cover 148 customs offices located in different provinces[5]. We use the OECD end-use category for commodity classification to rearrange the Harmonized System eight-digit customs import and export data into three categories: intermediate products, consumption products, and capital products. This information will help to more reliably split China and Japan's regional import and export data by country of origin and

[4] http://www.meti.go.jp/english/statistics/tyo/tiikiio/

[5] http://www.customs.go.jp/toukei/info/tsdl.htm

destination in the estimation process of the REXICIO tables. For detailed country, region, and sector classifications used in this paper, please refer to Appendices 1 and 2.

5 Application examples

5.1 China and Japan's regional value-added export by country/region of destination

To investigate details of the bilateral structure of China and Japan's regional export of value added respectively, we calculate the share of value-added exports of a specific destination by country/region using both gross exports and value-added-based measures. From Figure 3.1, we can see a significant difference for China's central region. This result implies that the central region does not directly export a great deal to foreign countries in terms of gross exports, but that it can participate in GVCs by providing intermediate products to coastal regions, thereby exporting more value added overseas. Thus, China's coastal regions have been an important bridge linking GVCs and China's domestic value chains. Through this linkage, the inland regions can take part in GVCs indirectly by providing support to the coastal regions' domestic value chains, even though the inland regions may not have an advantage in accessibility to overseas markets when compared with the coastal regions. A similar situation can be observed for Japan's Tohoku region, as shown in Figure 3.2. Namely, the degree of Japan Tohoku's participation in GVCs is much higher than commonly thought since Tohoku's value added may be indirectly exported to foreign countries through providing parts and components to one of its downstream region (e.g. Kanto), which further performs processing and exports.

Figure 3.1 Gross vs. value-added term measure on China's regional exports (Center, 2007)

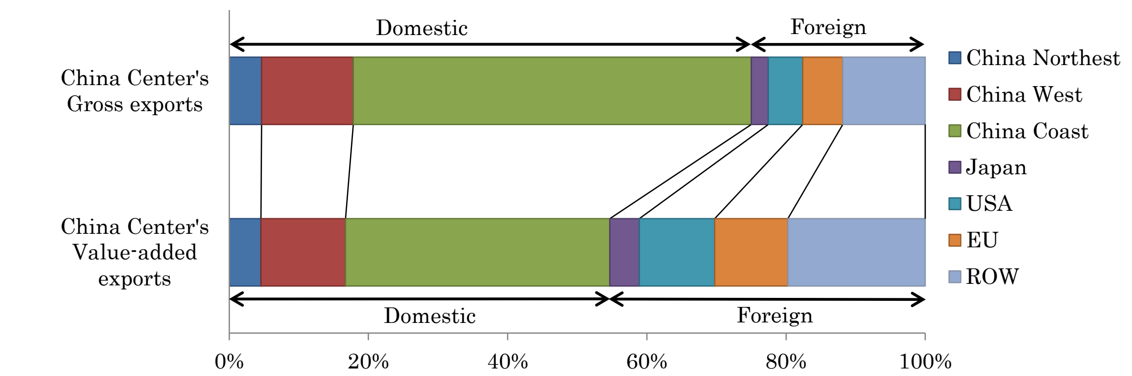
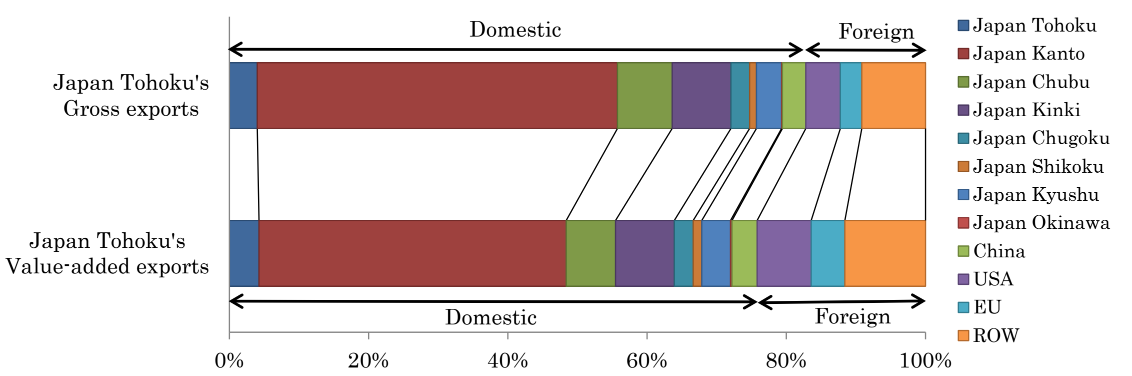


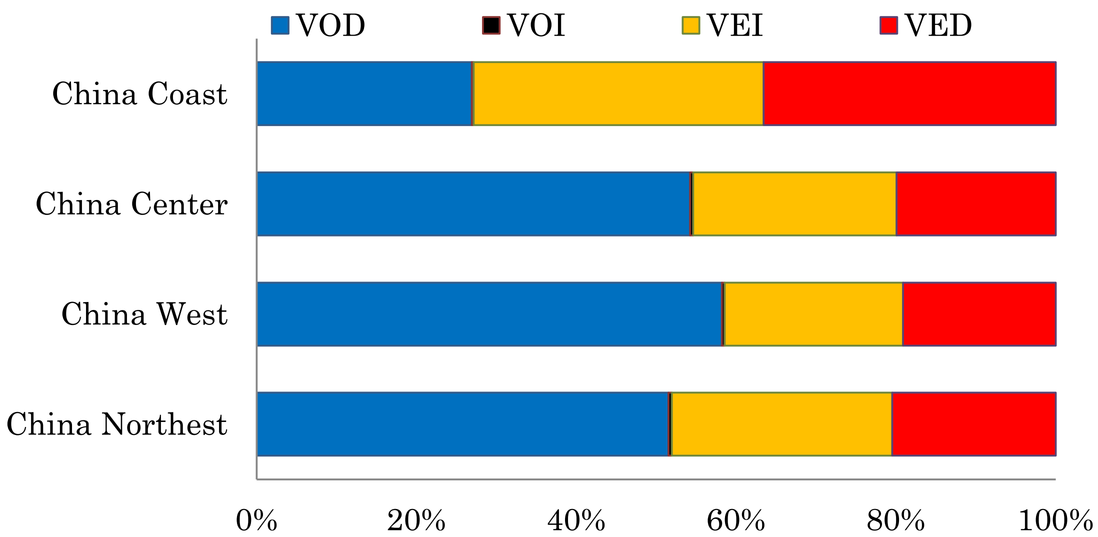
Figure 3.2 Gross vs. value-added term measure on Japan's regional exports (Tohoku, 2005)



5.2 GVC participation by various routes

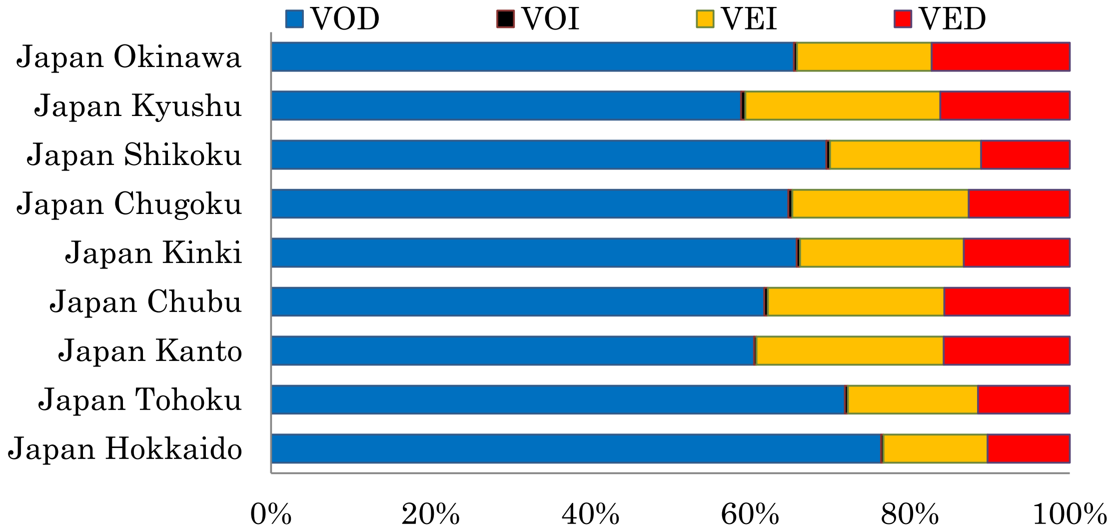
As shown in Fig. 2, regional outflows and exports of value added can be further decomposed into four parts according to the route, or segment, of GVCs. Based on calculations using the newly constructed REXICIO table, we show these four parts in Figure 4.1 for the Chinese case. Clearly China's regional outflows of value added are mainly achieved through the domestic segment of GVCs (VOD), especially for inland regions. Because of the export-oriented nature of the China Coast region, its domestic segment accounts for just 27% of its total GVCs. Regional outflows of value added created in the international segment of GVCs (VOI) are extremely small for all regions. For example, the value added induced in China's Guandong province when a household in Shanghai consumes final products produced in the United States should be very small. The main reasons are 1) Chinese regional demand for foreign final products is still low; 2) given the large domestic production capacity and the relatively low price of final goods, most final demand can be satisfied through domestic supply; and 3) China's regional (Guandong) demand for foreign (U.S.) products can induce foreign (U.S.) production to some extent. However, when foreign countries (U.S.) produce final goods to satisfy Chinese regional demand, they may not require intermediate goods from other Chinese regions (Shanghai). The feedback effect caused by domestic demand for foreign goods that return to other Chinese regions through the international segment of GVCs is therefore very small. However, when looking at regional value-added exports, we can see that there is not a large difference between the international (VEI) and domestic (VED) segment for all regions in comparison with the difference between VOD and VOI. China's inland regions seem to export value added mainly through the international segment of GVCs, while China Coast exports value added through the domestic segment of GVCs. This is not surprising if we recall the definition of VED (Eq. 44). China Coast participates in GVCs mainly by providing final products directly to the world market, whereas China's inland regions join GVCs mainly by providing intermediate products to foreign suppliers.

Figure 4.1 Domestic region's GVC participation by route (China, 2007)



VOD: Regional value-added outflow through the pure domestic segment of GVCs
VOI: Regional value-added outflow through the pure international segment of GVCs
VEI: Regional value-added exports through the pure domestic segment of GVCs
VED: Regional value-added exports through the pure international segment of GVCs

Figure 7.2 Domestic region’s GVC participation by route (Japan, 2005)



VOD: Regional value-added outflow through the pure domestic segment of GVCs
VOI: Regional value-added outflow through the pure international segment of GVCs
VEI: Regional value-added exports through the pure domestic segment of GVCs
VED: Regional value-added exports through the pure international segment of GVCs

Compared to the above Chinese case, the majority of Japan’s regional value-added flow goes to other domestic regions rather than to foreign countries (see Fig. 4.2). A similar phenomenon is that the participation of Japanese regions in GVCs also highly relies on the domestic routes. In addition, following Fig. 2, the above four parts can be further separated into more detailed descriptions, as shown in Appendix 3.

6 Conclusion and discussion

The existing IO-based measurements for GVCs treat countries as the minimum unit or target. This is sufficient only if we are studying the country-to-country relationship in GVCs. However, given rapid deepening and spreading of globalization in terms of reduction of various trade costs, a country’s territory has become less and less relevant for firms that take part in GVCs. The difference between one country and another in terms of territory has become less important, since GVCs can be fragmented and extended not only at the international level, but also at the domestic regional level. In fact, even if a domestic region does not engage in much direct trade with foreign countries, it can nonetheless be an important supporting player of global production networks by providing parts, components, and intermediate services to more export-oriented regions.

To better understand the linkage between domestic value chains and GVCs, the information provided by the conventional inter-country IO tables is insufficient, as these tables completely ignore the regional heterogeneity inside a target country. This paper proposed a new IO framework, the regionally-extended inter-country IO table in which a country’s domestic interregional IO table is consistently embedded into an inter-country IO table. As an exercise, we used China and Japan’s interregional IO tables, the OECD inter-country IO tables, and China and Japan’s regional customs statistics to compile the regionally-extended inter-country IO table.

To examine the validity and usefulness of this new approach, we applied an extension of the KWW gross export decomposition method to the extended tables. Most empirical results shown in the previous section helped us better understand how global production is fragmented and extended across China and Japan’s domestic regions, as well as how value added is created and distributed in both domestic and international segments of GVCs.

It should be noted, however, that customs statistics at the detailed regional level provide the most important information for compiling the extended table. Statistics from different sources, such as national IO tables, domestic regional IO tables, and customs data, may have their own uses. However, when combining these data systematically and consistently, some information that cannot be obtained directly can be estimated. Since the performance of the extended table with China and Japan's regional information has been demonstrated in this paper, future work will include the use of a similar method to embed both China and Japan's interregional IO tables together into an inter-country IO framework. In addition, there are many possible applications based on the extended IO table, such as computable general equilibrium models and environmental analyses.

Appendix 1 Sector classification

A 1.1 Concordance between China's IRIO sectors and REXICIO sectors

Sector name (Chinese IRIO table)	Code	s1	s2	s3	s4	s5	s6	s7	s8
		Agriculture	Mining and quarrying	Life-related industry	Process industry	Assembly Industry	Electricity, Gas and Water Supply	Construction	Other services
Agriculture	c1	1							
Mining and quarrying	c2		1						
Food products and tobacco	c3			1					
Textile and garment	c4			1					
Wooden products and furniture	c5				1				
Pulp, paper and printing	c6				1				
Chemical	c7				1				
Non-metallic mineral products	c8				1				
Metal products	c9				1				
General mechinary	c10					1			
Transport equipment	c11					1			
Electric apparatus, electronic and telecommunications equipment	c12					1			
Other manufacturing products	c13			1					
Electricity, gas, and water supply	c14						1		
Construction	c15							1	
Trade and transportation	c16								1
Other services	c17								1

A 1.2 Concordance between Japan’s IRIO sectors and REXICIO sectors

Sector name (Japan IRIO table)	code	s1	s2	s3	s4	s5	s6	s7	s8
		Agriculture	Mining and quarrying	Life-related industry	Process industry	Assembly Industry	Electricity, Gas and Water Supply	Construction	Other services
Agriculture, forestry and fishery	10	1							
Mining	20		1						
Coal mining , crude petroleum and natural gas	30		1						
Beverages and Foods	40			1					
Textile products	50			1					
Wearing apparel and other textile products	60			1					
Timber, wooden products and furniture	70				1				
Pulp, paper, paperboard, building paper	80				1				
Printing, plate making and book binding	90				1				
Chemical basic product	100				1				
Synthetic resins	110				1				
Final chemical products	120				1				
Medicaments	130				1				
Petroleum and coal products	140				1				
Plastic products	150				1				
Ceramic, stone and clay products	160				1				
Iron and steel	170				1				
Non-ferrous metals	180				1				
Metal products	190				1				
General machinery	200					1			
Machinery for office and service industry	210					1			
Electrical devices and parts	220					1			
Other electrical machinery	230					1			
Household electric appliances	240					1			
Household electronics equipment	250					1			
Electronic computing equipment and accessory equipment of electronic computing equipment	260					1			
Electronic components	270					1			
Passenger motor cars	280					1			
Other cars	290					1			
Motor vehicle parts and accessories	300					1			
Other transport equipment	310					1			
Precision instruments	320					1			
Miscellaneous manufacturing products	330			1					
Reuse and recycling	340			1					
Construction	350							1	
Electricity	360						1		
Gas and heat supply	370						1		
Water supply and waste disposal business	380						1		
Commerce	390								1
Finance and insurance	400								1
Real estate	410								1
House rent (imputed house rent)	420								1
Transport	430								1
Other information and communications	440								1
Information services	450								1
Public administration	460								1
Education and research	470								1
Medical service, health, social security and nursing care	480								1
Advertising services	490								1
Goods rental and leasing services	500								1
Other business services	510								1
Personal services	520								1
Others	530								1

A 1.3 Concordance between the OECD ICIO sectors and REXICIO sectors

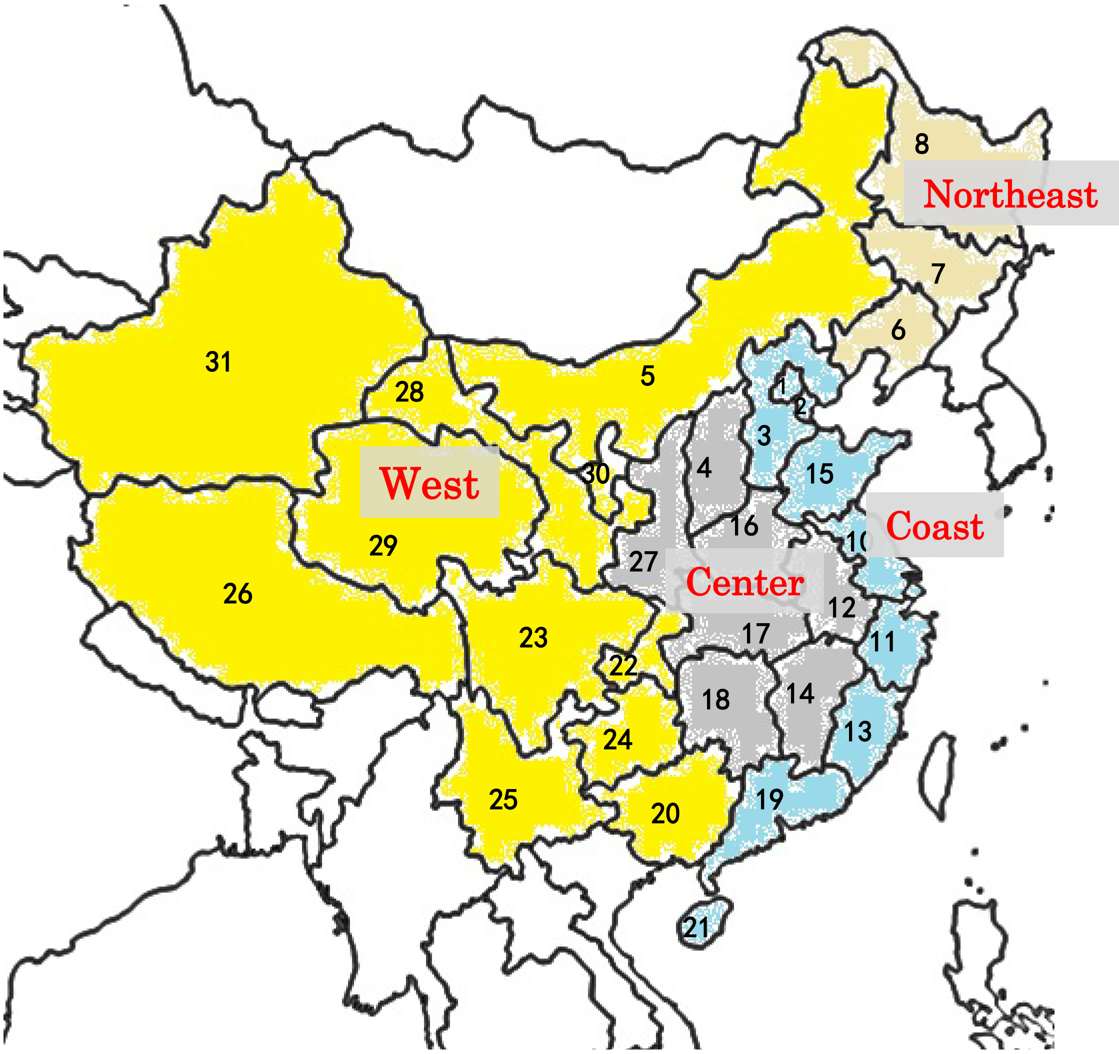
Sector name (OECD ICIO)	Code	s1 Agriculture	s2 Mining and quarrying	s3 Life-related industry	s4 Process industry	s5 Assembly Industry	s6 Electricity, Gas and Water Supply	s7 Construction	s8 Other services
Agriculture, hunting, forestry and fishing	C01T05AGR	1							
Mining and quarrying	C10T14MIN		1						
Food products, beverages and tobacco	C15T16FOD			1					
Textiles, textile products, leather and footwear	C17T19TEX			1					
Wood and products of wood and cork	C20WOD				1				
Pulp, paper, paper products, printing and publishing	C21T22PAP				1				
Coke, refined petroleum products and nuclear fuel	C23PET				1				
Chemicals and chemical products	C24CHM				1				
Rubber and plastics products	C25RBP				1				
Other non-metallic mineral products	C26NMM				1				
Basic metals	C27MET				1				
Fabricated metal products	C28FBM				1				
Machinery and equipment, nec	C29MEQ					1			
Computer, Electronic and optical equipment	C30.32.33CEQ					1			
Electrical machinery and apparatus, nec	C31ELQ					1			
Motor vehicles, trailers and semi-trailers	C34MTR					1			
Other transport equipment	C35TRQ					1			
Manufacturing nec; recycling	C36T37OTM			1					
Electricity, gas and water supply	C40T41EGW						1		
Construction	C45CON							1	
Wholesale and retail trade; repairs	C50T52WRT								1
Hotels and restaurants	C55HTR								1
Transport and storage	C60T63TRN								1
Post and telecommunications	C64PTL								1
Financial intermediation	C65T67FIN								1
Real estate activities	C70REA								1
Renting of machinery and equipment	C71RMQ								1
Computer and related activities	C72ITS								1
R&D and other business activities	C73T74BZS								1
Public admin. and defence; compulsory social security	C75GOV								1
Education	C80EDU								1
Health and social work	C85HTH								1
Other community, social and personal services	C90T93OTS								1
Private households with employed persons	C95PVH								1

Appendix 2 China and Japan’s domestic regions

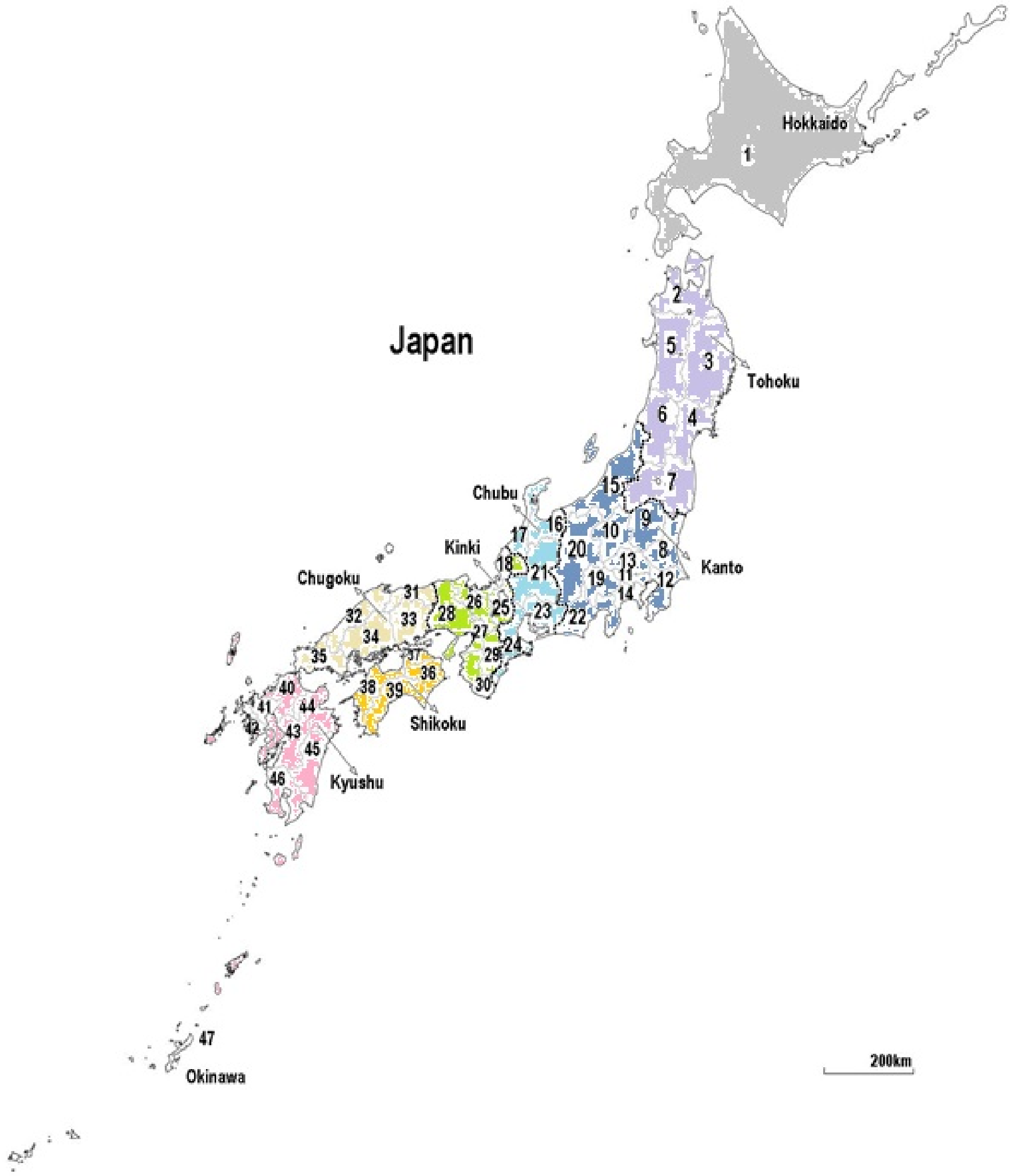
A2.1 Region coverage

Region	Description (The numbers in the parenthesis correspond to regional numbers in the maps)
CHINA	
1. Northeast	Liaoning(6), Jilin(7), Heilongjiang(8)
2. West	Inner Mongolia(5), Guangxi(20), Chongqing(22), Sichuan(23), Guizhou(24), Yunnan(25), Tibet(26), Shaanxi,(27), Gansu(28), Qinghai(29), Ningxia(30), Xinjiang(31)
3. Center	Shanxi(4), Anhui(12), Jiangxi(14), Henan(16), Hubei(17), Hunan(18)
4. Coast	Beijing(1), Tianjin(2), Hebei(3), Shanghai(9), Jiangsu(10), Zhejiang(11), Fujian(13), Shandong(15), Guangdong(19), Hainan(21)
JAPAN	
1. Hokkaido	Hokkaido(1)
2. Tohoku	Aomori(2), Iwate(3), Miyagi(4), Akita(5), Yamagata(6), Fukushima(7)
3. Kanto	Ibaraki(8), Tochigi(9), Gunma(10), Saitama(11), Chiba(12), Tokyo(13), Kanagawa(14), Niigata(15), Yamanashi(19), Nagano(20), Shizuoka(22)
4. Chubu	Toyama(16), Ishikawa(17), Gifu(21), Aichi(23), Mie(24)
5. Kinki	Fukui(18), Shiga(25), Kyoto(26), Osaka(27), Hyogo(28), Nara(29), Wakayama(30)
6. Chugoku	Tottori(31), Shimane(32), Okayama(33), Hiroshima(34), Yamaguchi(35)
7. Shikoku	Tokushima(36), Kagawa(37), Ehime(38), Kochi(39)
8. Kyushu	Fukuoka(40), Saga(41), Nagasaki(42), Kumamoto(43), Oita(44), Miyazaki(45), Kagoshima(46)
9.Okinawa	Okinawa(47)

A2.2 Regions in mainland China



A2.3 Regions in Japan



Appendix 3 Decomposition results of China and Japan's value-added exports and outflow

2007	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Million US$	VOD1	VOD2	VOD3	VOD=(1)+(2)+(3)	VOI1	VOI2	VOI=(5)+(6)	VO=(4)+(7)	VEI1	VEI2	VEI3	VEI=(9)+(10)+(11)	VED1	VED2	VED=(13)+(14)	VE=(12)+(15)	Total=(8)+(16)
China Northest	27,174	46,098	6,959	80,231	20	675	695	80,926	38,644	4,050	251	42,945	20,885	10,988	74,818	117,763	236,639
Share	11%	19%	3%	34%	0.0%	0.3%	0%	34%	16%	1.7%	0.1%	18%	9%	5%	32%	50%	100%
China West	84,528	85,292	8,735	178,554	33	996	1,029	179,584	61,662	6,391	394	68,447	35,758	22,894	127,099	195,546	435,762
Share	19%	20%	2%	41%	0.0%	0.2%	0%	41%	14%	1.5%	0.1%	16%	8%	5%	29%	45%	100%
China Center	73,251	95,596	7,881	176,728	43	1,166	1,208	177,937	74,777	7,752	471	83,000	37,440	27,420	147,860	230,861	482,367
Share	15%	20%	2%	37%	0.0%	0.2%	0%	37%	16%	1.6%	0.1%	17%	8%	6%	31%	48%	100%
China Coast	120,262	89,625	11,168	221,055	239	1,491	1,730	222,786	266,147	30,066	1,825	298,038	292,576	7,774	598,388	896,426	1,383,628
Share	9%	6%	1%	16%	0.0%	0.1%	0%	16%	19%	2.2%	0.1%	22%	21%	1%	43%	65%	100%

2005	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Million US$	VOD1	VOD2	VOD3	VOD=(1)+(2)+(3)	VOI1	VOI2	VOI=(5)+(6)	VO=(4)+(7)	VEI1	VEI2	VEI3	VEI=(9)+(10)+(11)	VED1	VED2	VED=(13)+(14)	VE=(12)+(15)	Total=(8)+(16)
Japan Hokkaido	15,870	14,875	3,612	34,357	68	64	132	34,489	5,148	714	9	5,871	3,315	1,311	10,497	16,368	55,873
Share	28%	27%	6%	61%	0.1%	0.1%	0%	62%	9%	1.3%	0.0%	11%	6%	2%	19%	29%	100%
Japan Tohoku	39,326	29,136	6,559	75,021	206	185	391	75,412	14,761	2,236	30	17,026	8,669	3,318	29,013	46,039	135,821
Share	29%	21%	5%	55%	0.2%	0.1%	0%	56%	11%	1.6%	0.0%	13%	6%	2%	21%	34%	100%
Japan Kanto	194,684	142,852	24,644	362,180	966	947	1,913	364,093	121,764	18,351	247	140,362	76,273	18,422	235,057	375,419	859,363
Share	23%	17%	3%	42%	0.1%	0.1%	0%	42%	14%	2.1%	0.0%	16.3%	9%	2%	27%	44%	100%
Japan Chubu	83,516	61,713	14,238	159,468	676	602	1,278	160,746	49,122	7,824	105	57,051	32,064	8,510	97,626	154,677	363,267
Share	23%	17%	4%	44%	0.2%	0.2%	0%	44%	14%	2.2%	0.0%	16%	9%	2%	27%	43%	100%
Japan Kinki	93,733	71,814	15,649	181,196	614	575	1,189	182,384	48,980	7,372	100	56,451	26,882	9,632	92,965	149,416	379,591
Share	25%	19%	4%	48%	0.2%	0.2%	0%	48%	13%	1.9%	0.0%	15%	7%	3%	24%	39%	100%
Japan Chugoku	34,390	32,831	8,373	75,594	312	301	613	76,207	22,382	3,343	46	25,771	10,559	4,214	40,543	66,314	164,290
Share	21%	20%	5%	46%	0.2%	0.2%	0%	46%	14%	2.0%	0.0%	16%	6%	3%	25%	40%	100%
Japan Shikoku	14,298	14,635	3,594	32,527	108	105	213	32,740	7,699	1,129	15	8,844	3,680	1,524	14,048	22,892	63,119
Share	23%	23%	6%	52%	0.2%	0.2%	0%	52%	12%	1.8%	0.0%	14%	6%	2%	22%	36%	100%
Japan Kyushu	35,227	26,421	6,443	68,092	332	307	638	68,730	24,552	3,690	50	28,291	15,873	2,882	47,046	75,337	167,981
Share	21%	16%	4%	41%	0.2%	0.2%	0%	41%	15%	2.2%	0.0%	17%	9%	2%	28%	45%	100%
Japan Okinawa	2,051	1,567	316	3,935	12	11	23	3,958	895	119	2	1,015	931	109	2,054	3,070	7,900
Share	26%	20%	4%	50%	0.1%	0.1%	0%	50%	11%	1.5%	0.0%	13%	12%	1%	26%	39%	100%

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