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ABSTRACT

A World Factory in Global Production Chains: Estimating Imported Value Added in Chinese Exports

The rise of the People's Republic of China (PRC) in world trade has brought both benefits and anxiety to other economies. For many policy questions, it is crucial to know the extent of foreign value added (FVA) in exports. We review a general formula in Koopman, Wang and Wei (2008) for computing domestic and foreign contents when processing exports are pervasive. In addition, we develop another formula for slicing up foreign content to allocate it among key individual economy's supply chains, including sourcing from Japan and the United States. By our estimation, the share of foreign content in exports by the PRC is about 50%. There are also interesting variations across sectors. Those sectors that are likely labeled as relatively sophisticated such as electronic devices have particularly high foreign content (about 80%). By our estimation, Japan; the United States; Hong Kong, China; and the European Union are the major sources of foreign content in the PRC's exports of computers and consumer electronics, two of its largest and fastest growing export categories.

JEL Classification: C67, C82 and F1
Keywords: domestic content, foreign value added and processing trade

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1. Introduction

Walking into any shopping mall in the United States (US), one is rarely surprised to see a product with a “made in China” label. Increasingly, many products that are supposed to be technically sophisticated and therefore likely to be associated with exports from high-income countries, such as digital cameras and computers, also carry that label. Since the most salient characteristic of the factor endowment in the People’s Republic of China (PRC) is a vast supply of unskilled labor relative to either physical or human capital, is the country’s actual export structure inconsistent with the predictions from the international trade theory based on its endowment? A possible resolution to the puzzle is that the PRC is simply the last section of a long global production chain that ends up assembling components from various countries into a final product before it is exported to the US market. Indeed, a MacBook computer carries a label at its back (in small type) that reads “Designed by Apple in California; Assembled in China.” This label is likely to be oversimplified already, as it reports only the head and the tail of a global production chain, but skips many other countries that supply other components that go into the product.

The PRC is the archetype of a national economy that is well integrated into a global production chain. It imports raw material, equipment, and intermediate inputs, and then exports a big fraction of its output **(**on the order of 37% of GDP in 2006**)** to the world market. The PRC is not the only country whose production and exports are a part of a global chain; Japan, the Republic of Korea (Korea), Singapore, and Malaysia are some other examples of countries that participate actively in the international divisions of labor. However, the PRC is noteworthy due to its sheer size. In addition, its export/GDP ratio, at 35% or higher in recent years, is extraordinarily high for a large economy, when compared with 8% for the US and 13% for India. With a reputation as a “world factory,” the PRC is a top supplier of manufacturing outsourcing for many global companies.

Imported inputs used in production for exports reduce the share of value added generated by domestic producers. Consider the example of iPod, which the PRC assembles for Apple and exports to the US and other countries. In its trade statistics, the export value for a unit of a 30GB video model in 2006 was about $150. However, the best estimate of the value added attributable to producers in the PRC was only $4, with the remaining value added coming from the US, Japan, and other countries (Linden, Kraemer, and Dedrick, 2007; and Varian, 2007).

For many policy issues, it is important to assess the extent of domestic content in exports. For example, what is the effect of a currency appreciation on a country's exports? The answer depends crucially on the share of domestic content in the exports. Other things being equal, the lower the share of domestic content in the exports, the smaller the effect on trade volume a given exchange rate appreciation would have As another example, what is the effect of trading with the PRC on US income inequality? The answer depends in part on whether the PRC simply exports products that are intensive in low-skilled labor or whether its exports are more sophisticated. Rodrik (2006) notes that the per capita income typically associated with the kind of goods bundle that the PRC exports is much higher than the country's actual income. He interprets this as evidence that the skill content of its exports is likely to be much higher than its endowment may imply. Schott (2008) documents an apparent rapid increase in the similarity between the PRC's export structure and that of high-income countries, and interprets it as evidence of a rise in the level of sophistication embedded in the country's exports. Indeed, many other observers have expressed fear that the PRC is increasingly producing and exporting sophisticated products and may be providing wage competition for mid- to high-skilled workers in the US and Europe. However, the calculations by Rodrik (2006) and Schott (2008) do not take into account the imported content in the country's exports. If the domestic content in exports from the PRC is low, especially in sectors that would have been considered sophisticated or high-skilled in the US, then imports from the PRC may still generate a large downward pressure on the wage of the low-skilled Americans after all (as pointed out by Krugman, 2008). These are important policy questions and have implications for both developing and developed countries. A good understanding of the nature and extent of global supply chains can provide important insights for economists and policy makers.

How would one assess foreign versus domestic content in a country's exports? Hummels, Ishii, and Yi (2001) (HIY in subsequent discussion) propose a concept of vertical specialization (VS) in a country's trade, defined as "the imported input content of exports, or equivalently, foreign value added embodied in exports," and provide a formula to compute VS share based exclusively on a country's input-output table. For a sample of 14 countries (not including the

PRC), they calculate that the average share of foreign value added in exports was about 21% in 1990. Yi (2003) shows that a dramatic increase in vertical specialization after the Second World War is likely to have been responsible for a faster growth of world trade relative to world GDP over the last five decades. Other recent applications of the vertical specialization concept include Goh and Olivier (2004), Chinn (2005), National Research Council (2006), Dean, Fung, and Wang (2007), and Koopman, Wang, and Wei (2008).

A key assumption needed for the HIY formula to work is that the intensity in the use of imported inputs is the same between production for exports and production for domestic sales. This assumption is violated in the presence of processing exports. Processing exports are characterized by imports for exports with favorable tariff treatment: firms import parts and other intermediate materials from abroad, with tariff exemptions on the imported inputs and other tax preferences from local or central governments, and, after processing or assembling, export the finished products. The policy preferences for processing exports usually lead to a significant difference in the intensity of imported intermediate inputs in the production of processing exports and that in other demand sources (for domestic final sales and normal exports). Since processing exports have accounted for more than 50% of exports from the PRC every year at least since 1996 (see Column 1 of Table 1 for detail), the HIY formula is likely to lead to a significant under-estimation of the share of foreign value added in its exports. In fact, most economies offer tariff reductions or exemptions on imported intermediate inputs used in production for exports. Ignoring processing exports (or duty drawbacks) is likely to lead to estimation errors, especially for economies that engage in a massive amount of tariff/tax-favored processing trade, such as the PRC, Mexico and Viet Nam.

In this paper, we aim to make three points. First, we review a formula in Koopman, Wang and Wei (2008) for computing shares of foreign and domestic value added in a country's exports when processing exports are pervasive. We develop this formula because the production technology and input sourcing differs between goods produced for general domestic consumption and general exports compared to those produced under export processing regimes. The HIY formula is a special case of this general formula. Second, we apply our methodology to the PRC using data for 1997, 2002, and 2006[1]. We estimate that the share of foreign value added in its manufactured exports is about 50%, almost twice as high as that implied by the HIY formula. There are also interesting variations across sectors. Those sectors that are likely labeled as relatively sophisticated such as computers, telecommunication equipments, and electronic devices have particularly high foreign content (about 80%). Third, we develop a method that estimates the amount of foreign content that originates in key individual foreign supplying countries by taking advantage of an international I/O table. Computers and home electronics (such as TVs, radios, and cell phones), two of the country's largest export categories in recent years, account for 17% of manufacturing exports; our estimates suggest that Japan; the US; Hong Kong, China; and the EU supplied about 60% of their foreign input content.

By our estimation, the imported content in total merchandise exports of the PRC experienced a modest increase in recent years (from 47.7% in 1997 to 49.3 in 2006). The imported content in manufactured goods exports experienced a modest decline (from 52.4% in 1997 to 50.6% in 2006). However, the average imported content in exports masks an interesting divergence between normal versus processing exports. For processing exports, there was a decline in imported content (or an increase in domestic content) from 1997 to 2002 (though this is reversed in more recent years). As domestic input suppliers increase both number of varieties and qualities over time, processing trade producers may decide to increase local sourcing of their inputs. This is consistent with the conjecture in Aziz and Li (2007) of a rising domestic content in processing trade based on an increase in their estimated price elasticity over time. However, for normal exports, the imported content has been increasing. This is because the PRC has progressively lowered import barriers on foreign inputs, largely in association with its accession to the World Trade Organization in 2001, which has encouraged producers to buy more imported inputs. In addition, the reductions in the country's trade barriers also reduced the tariff advantage associated with the processing trade. As a result, processing exports as a share of total exports declined steadily from 60.2% in 1997 to 54.5% in 2006. These two opposing forces balance each other out and result in a relatively stable overall share of imported content in PRC exports. Looking ahead, the share of imported content in exports could fall or rise, depending on the

[1] Note that the 2002 Input-Output (I/O) Table is the latest such table available; the next table — the 2007 benchmark I/O table — is scheduled to be released in 2010. Our 2006 estimates make use of the 2006 trade statistics but use the 2002 I/O table.

relative speed with which domestic input suppliers can step up their quality and variety versus the extent of additional reductions in the cost of using imported inputs.

In addition to discussions on vertical specialization in the international trade literature, this paper is also related to the I/O analyses. In particular, Chen et al. (2004) and Lau et al (2007) are the first to develop a "non-competitive" type I/O model for the PRC (i.e., one in which imported and domestically produced inputs are accounted for separately) and to incorporate processing exports explicitly. However, these papers do not describe a systematic way to compute separate input-output coefficients for production of processing exports versus those for other final demands. It is therefore difficult for others to replicate their estimates or apply their methodology to other countries. In addition, they use an aggregated version of the PRC's 1995 and 2002 input-output tables to perform their analysis, with 20-some goods-producing industries. We provide a more up-to-date and more disaggregated assessment of foreign and domestic values added in the country's exports with 83 goods-producing industries. Finally, they impose an assumption in estimating the import use matrix from the competitive type I/O table published by the PRC National Statistical Bureau: within each industry, the mix of the imported and domestic inputs is the same in capital formation, intermediate inputs, and final consumption. We relax this assumption by refining a method proposed in Dean, Fung, and Wang (2007) that combines the PRC's processing imports statistics with the United Nations Broad Economic Categories (UNBEC) classification.

The rest of the paper is organized as follows: Section 2 reviews a conceptual framework in Koopman, Wang and Wei (2008) for estimating shares of domestic and foreign value added in a country's exports when processing exports are pervasive. Section 3 presents the estimation results for the PRC's exports. Section 4 develops a method to further slice up foreign content to account for supplies from individual foreign countries, while Section 5 applies it to the country's exports. Finally, Section 6 offers concluding remarks.

2. Conceptual Framework and Estimation Method

2.1 When special features of processing exports are not taken into account

We first discuss how domestic and foreign contents in a country's exports can be computed when it does not engage in any processing trade. The discussion follows the input-output literature, and is the approach adopted (implicitly) by Hummels, Ishii, and Yi (2001) and Yi (2003). Along the way, we will point out a clear connection between the domestic content concept and the concept of vertical specialization[2].

When imported and domestically produced intermediate inputs are accounted separately, an input-output model can be specified as follows[3]:

$$A^D X + Y^D = X \tag{1}$$

$$A^M X + Y^M = M \tag{2}$$

$$uA^D + uA^M + A_v = u \tag{3}$$

where $A^D = [a^D_{ij}]$ is an nxn matrix of direct input coefficients of domestic products; $A^M = [a^M_{ij}]$ is an nxn matrix of direct inputs of imported goods; Y^D is an $nx1$ vector of final demands for domestically produced products, including usage in gross capital formation, private and public final consumption, and gross exports; Y^M is an $nx1$ vector of final demands for imported products, including usages in gross capital formation, private and public final consumption; X is a $nx1$ vector of gross output; M is a $nx1$ vector of imports; $A_v = [a^v_j]$ is a $1xn$ vector of each sector j's ratio of value added to gross output; $\hat{A}_V$ is an nxn diagonal matrix with a^v_j as its diagonal elements; finally, u is a $1xn$ unity vector. Subscripts i and j indicate sectors, and superscripts D and M represent domestically produced and imported products, respectively.

Equations (1) and (2) define two horizontal balance conditions for domestically produced and imported products, respectively. A typical row k in Equation (1) specifies that total domestic production of product k should be equal to the sum of the sales of product k to all users in the economy (to be used as intermediate inputs or for final sales to these users); the final sales include domestic consumption and capital formation, plus exports of product k. A typical row h in Equation (2) specifies that the total imports of product h should be equal to the sum of the sales of product h to all users in the economy, including intermediate inputs for all sectors, plus final domestic consumption and capital formation. Equation (3) is both a vertical balance

[2] We use the terms "domestic value added" and "domestic content" interchangeably. Similarly, we use the terms "foreign value added," "foreign content," and "vertical specialization," to mean the same thing.
[3] Such a model is called a "non-competitive" model in the I/O literature. HIY (2001) do not specify this system explicitly but go straight to the implied Leontief inverse while Chen et al. (2004) specify only the first two equations. A fully specified model facilitates better understanding of the connection between vertical specialization and domestic content, and a comparison with the model in the next sub-section that features processing exports.

condition, and an adding-up constraint for the input-output coefficients. It implies that the total output (X) in any sector *k* has to be equal to the sum of direct value added in sector *k*, and the cost of intermediate inputs from all domestically produced and imported products.

From equation (1) we have

$$X = (I - A^D)^{-1} Y^D \tag{4}$$

$(I - A^D)^{-1}$ is the well-known Leontief Inverse, a matrix of coefficients for the total domestic intermediate product requirement. Define a vector of share of domestic content, or domestic value added, in a unit of domestically produced products, $DVS = \{dvs_j\}$, a $1xn$ vector, as the additional domestic value added generated by one additional unit of final demand of domestic products ($\Delta Y^D = u'$).

$$DVS = \hat{A}_v \, \Delta X / \Delta Y^D = \hat{A}_v (I - A^D)^{-1} = A_v (I - A^D)^{-1} \tag{5}$$

Equation (5) indicates that the domestic content for an I/O industry is the corresponding column sum of the coefficient matrix for total domestic intermediate goods requirement, weighted by the direct value-added coefficient of each industry.

Under the condition that all exports and domestic sale have the same input-output coefficients, the share of domestic content in final demand and the share of domestic content in total exports should be the same. So Equation (5) is also the formula for the share of domestic content in total exports for each industry. As Chen et al (2004) point out, there is good intuition behind the *DVS* formula. When one extra unit of product for final demand is produced at home, both direct and indirect values added are generated. The indirect value added comes from the domestic value added that is embedded in all the domestically produced intermediate inputs. Each of them is produced with direct and indirect value added involved. Therefore, the *total* domestic value added induced by one extra unit of domestic product is equal to the sum of direct domestic value added and multiple rounds of indirect domestic value added. Expressing this process mathematically, we have:

$$\begin{aligned} DVS &= A_v + A_v A^D + A_v A^D A^D + A_v A^D A^D A^D + \ldots. \\ &= A_v (I - A^D)^{-1} \end{aligned} \tag{6}$$

The last step invokes the formula for the convergence of matrix power series of A^D.

Define a vector of share of foreign content (or foreign value added) in final demand for domestically produced products by $FVS = u - DVS$. By making use of Equation (3), it can be verified that

$$FVS = u - A_v (I - A^D)^{-1} = uA^M (I - A^D)^{-1} \tag{7}$$

For each industry, this is the column sum of the coefficient matrix for total intermediate import requirement. This turns out to be the *same* formula used to compute vertical specialization by HIY (2001). In other words, the concepts of vertical specialization and of foreign content are identical.

2.2 Domestic Content in Exports When Processing Trade is Prevalent

We now turn to the case in which tariff-favored processing exports are prevalent; these exports have a different intensity in the use of imported inputs than do domestic final sales (and normal exports). Conceptually, we wish to keep track separately of the I/O coefficients of the processing exports and those of domestic final sales and normal exports. For now, we ignore the fact that these I/O coefficients may not be directly available, and will discuss a formal approach to estimate them in the next subsection.

The expanded I/O table with a separate account for processing exports is represented by Figure 1. We use superscript P and D, respectively, to represent processing exports on one hand, and domestic sales and normal exports on the other. Define z_{ij}^{dd} = Domestically produced intermediate good i used by sector j for domestic sales and normal exports; z_{ij}^{dp} = Domestically produced intermediate good i used by sector j for processing exports; z_{ij}^{md} = Imported intermediate good i used by sector j for domestic sales and normal exports; z_{ij}^{mp} = Imported intermediate good i used by sector j for processing exports; v_j^d = Direct value added by domestic and normal export production in industry j ; v_j^p = Direct value added by processing export production in industry j. Then direct I/O coefficients for this expanded model can be written:

$$A^{DD} = [a_{ij}^{dd}] = [\frac{z_{ij}^{dd}}{x_j - e_j^p}],\ A^{MD} = [a_{ij}^{md}] = [\frac{z_{ij}^{md}}{x_j - e_j^p}],\ A_v^D = [a_j^{vd}] = [\frac{v_j^d}{x_j - e_j^p}]$$

$$A^{DP} = [a_{ij}^{dp}] = [\frac{z_{ij}^{dp}}{e_j^p}], A^{MP} = [a_{ij}^{mp}] = [\frac{z_{ij}^{mp}}{e_j^p}], A_v^P = [a_j^{vp}] = [\frac{v_j^p}{e_j^p}]$$

where i represents a row and j represents a column. This expanded I/O model can be formally described by the following system of equations:

$$\begin{bmatrix} I - A^{DD} & -A^{DP} \\ 0 & I \end{bmatrix} \begin{bmatrix} X - E^P \\ E^P \end{bmatrix} = \begin{bmatrix} Y^D \\ E^P \end{bmatrix} \tag{8}$$

$$A^{MD}(X - E^P) + A^{MP}E^P + Y^M = M \tag{9}$$

$$uA^{DD} + uA^{MD} + A_v^D = u \tag{10}$$

$$uA^{DP} + uA^{MP} + A_v^P = u \tag{11}$$

This is a generalization of the model discussed in the previous subsection. Equations (8)-(9) are a generalization of Equations (1)-(2), and Equations (10)-(11) are a generalization of Equation (3), with a separate account for processing exports. In a slight abuse of notation, we now re-define Y^D to be final domestic sales plus normal exports while excluding processing exports. Equations (10) and (11) are also the new adding-up constraint for the I/O coefficients.

The analytical solution of the system is

$$\begin{bmatrix} X - E^P \\ E^P \end{bmatrix} = \begin{bmatrix} I - A^{DD} & -A^{DP} \\ 0 & I \end{bmatrix}^{-1} \begin{bmatrix} Y^D \\ E^P \end{bmatrix} \tag{12}$$

The generalized Leontief inverse for this expanded model can be computed as follows:

$$B = \begin{bmatrix} I - A^{DD} & -A^{DP} \\ 0 & I \end{bmatrix}^{-1} = \begin{bmatrix} B^{DD} & B^{DP} \\ B^{PD} & B^{PP} \end{bmatrix} = \begin{bmatrix} (I - A^{DD})^{-1} & (I - A^{DD})^{-1} A^{DP} \\ 0 & I \end{bmatrix} \tag{13}$$

Substituting equation (13) into equation (12), we have:

$$X - E^P = (I - A^{DD})^{-1} Y^D + (1 - A^{DD})^{-1} A^{DP} E^p \tag{14}$$

Substituting equation (14) into equation (9), the total demand for imported intermediate inputs is:

$$M - Y^M = A^{MD}(I - A^{DD})^{-1} Y^D + A^{MD}(1 - A^{DD})^{-1} A^{DP} E^P + A^{MP} E^p \tag{15}$$

It has three components: the first term is total imported content in final domestic sale and normal exports, and the second and the third terms are indirect and direct imported content in processing exports, respectively.

We can compute vertical specialization (VS) or foreign content share in processing and normal exports in each industry separately:

$$\begin{vmatrix} VSS^D \\ VSS^P \end{vmatrix}^T = \begin{vmatrix} uA^{MD}(I-A^{DD})^{-1} \\ uA^{MD}(1-A^{DD})^{-1}A^{DP}+uA^{MP} \end{vmatrix}^T \tag{16}$$

The total foreign content share in a particular industry is the sum of the two weighted by the share of processing and non-processing exports s^p and u-s^p, where both s and u are a 1 by n vector:

$$\overline{VSS} = (u-s^P, s^P)\begin{vmatrix} VSS^D \\ VSS^P \end{vmatrix} \tag{17}$$

The foreign content (or foreign value-added) share in a country's total exports is:

$$TVSS = uA^{MD}(I-A^{DD})^{-1}\frac{E-E^P}{te} + u(A^{MD}(1-A^{DD})^{-1}A^{DP}+A^{MP})\frac{E^P}{te} \tag{18}$$

Where *te* is a scalar, the country's total exports. Equation (17) is a generalization of Equation (7), the formula to compute industry-level share of vertical specialization. Equation (18) is a generalization of the formula for country-level share of vertical specialization proposed by HIY (2001, page 80). In particular, either when $A^{DD} = A^{DP}$ and $A^{MD} = A^{MP}$, or when $E^P/te = 0$, Equation (18) reduces to the HIY formula for VS.

Similarly, the domestic content share for processing and normal exports at the industry level can be computed separately:

$$\begin{aligned} \begin{vmatrix} DVS^D \\ DVS^P \end{vmatrix}^T &= \bar{A}_v B = (A_v^D \quad A_v^P)\begin{bmatrix} (I-A^{DD})^{-1} & (I-A^{DD})^{-1}A^{DP} \\ 0 & I \end{bmatrix} \\ &= \begin{vmatrix} A_v^D(I-A^{DD})^{-1} \\ A_v^D(I-A^{DD})^{-1}A^{DP}+A_v^P \end{vmatrix}^T \end{aligned} \tag{19}$$

The total domestic content share in a particular industry is a weighted sum of the two:

$$\overline{DVS} = (u-s^P, s^P)\begin{vmatrix} DVS^D \\ DVS^P \end{vmatrix} \tag{20}$$

The domestic content share in a country's total exports is:

$$TDVS = A_V^D (I - A^{DD})^{-1} \frac{E - E^P}{te} + (A_V^D (1 - A^{DD})^{-1} A^{DP} + A_V^P) \frac{E^P}{te} \qquad (21)$$

Either when A^{DD} = A^{DP} and $A_v^D = A_v^P$, or when $E^P/te = 0$, Equation (20) reduces to the HIY formula in Equation (5). Note we can easily verify that for both processing and normal exports, the sum of domestic and foreign content shares is unity.

2.3 Estimation Issues

Equations (19-21) allow us to compute the shares of domestic content in processing and normal exports for each industry as well as in a country's total exports. However, statistical agencies typically only report a traditional I/O matrix, A^D, and sometimes A^M, but not A^{DP}, A^{DD}, A^{MP} and A^{MD} separately. Koopman, Wang, and Wei (2008) present a mathematical programming procedure to estimate these matrices that utilizes both detailed trade data that separate processing and normal trade and a conventional I/O table.

3. Estimation Results on Domestic and Foreign Content in Exports of the PRC

After describing the data sources, we report and discuss the estimation results for shares of domestic and foreign content in both normal and processing exports by the PRC and compare our estimation with results from HIY formula at the aggregate level.

3.1 Data

Inter-industry transaction and (direct) value-added data are from 1997 and 2002 benchmark I/O tables for the PRC published by the National Bureau of Statistics (NBS). We use detailed exports and imports data from 1997, 2002, and 2006 from the General Customs Administration to help differentiate the processing and normal trade in each sector. The trade statistics are first aggregated from the 8-digit HS level to the I/O industry level, and then used to compute the share of processing exports in each I/O industry. Modifying a method from Dean, Fung and Wang (2007), we partition all imports in a given industry into three parts based on the distinction between processing and normal imports in the trade statistics, and on the UN BEC classification scheme: (a) intermediate inputs in producing processing exports; (b) intermediate inputs for normal exports and other domestic final sales; and (c) those used in gross capital formation and final consumption. A summary of these trade statistics as a share of the PRC's total imports during 1996-2006 is reported in Table 2, which shows a downward trend for the use of imported inputs in producing processing exports, but a moderately upward trend in their use in producing normal trade and domestic final sales.

3.2 Domestic and foreign contents in total exports

Table 3 shows decomposition results for foreign and domestic value-added shares in 1997 and 2002. Preliminary estimates for 2006 are also included[4]. For comparison, the results from the HIY formula that ignore processing trade are also reported. The aggregate domestic value added share in PRC's merchandise exports was 52.3% in 1997, and 50.7% in 2006. For manufacturing products, these shares are slightly lower in levels but trending upward moderately at 47.6% in 1997 and 49.4% in 2006, respectively, indicating that the country uses more imported intermediate inputs to produce manufacturing goods than other exports. In general, the direct domestic value-added shares are less than half of the total domestic value-added shares. However, the indirect foreign value-added share was relatively small; most of the foreign content comes from directly imported foreign inputs.

Relative to the numbers from the HIY's method, our procedure produces a much higher share of foreign value added in the country's gross exports (approximately double) and shows a different trend over time. To be more precise, estimates from the HIY method show that the foreign content share (total VS share) increased steadily from 17.6% in 1997 to 26.3% in 2006 for all merchandise exports, and from 19.0% to 27.1% for manufacturing goods only during the same period. In contrast, our estimates reveal no clear trend for foreign content (with the share of foreign value added in all merchandise exports falling from 47.7% in 1997 to 46.1% in 2002, and bouncing back to 49.3% in 2006, and a similar fluctuation for the share in manufacturing exports, falling from 52.4% in 1997 to 48.7% in 2002 but bouncing back to 50.6% in 2006. Overall, the HIY method appears to incorrectly estimate both the level and the trend in domestic versus foreign content in the PRC's exports.

[4] We consider the estimates preliminary because the calculation relies on the trade statistics from 2006 but the I/O table from 2002. The 2002 I/O table is the most recent benchmark table currently available. The next benchmark table — the 2007 table — is scheduled to be released in 2010.Therefore, 2006 estimates are not directly comparable to 1997 and 2002 estimates.

Table 4 reports our estimates of the shares of domestic and foreign value added in normal and processing exports, separately. Clearly, the share of domestic valued added is high in normal exports (between 88%-95%), but low in processing exports (between 18%-26%). This is true for both manufacturing exports and all merchandise exports.

4. Slicing Up the Value Chains along Multiple Countries: Methodology

In this and the next sections, we attempt to disaggregate foreign value added (FVA) in the PRC's exports into that which originates from selected key economies and the rest of the world. We also separate PRC's indirect domestic value added (DVA) via third countries that use PRC-made intermediate inputs themselves to produce their exports from the PRC's total DVA. This exercise is made possible by taking advantage of a rare international input-output table that records the source of input use in a sector in any one of nine East Asian economies plus the United States from each sector in each of the other countries in the group and the rest of the world. We first explain the conceptual framework in this section, following Wang and Wei (2008b) and then report the empirical results in the next section.

While VS measures the imported content in a country's exports, a separate indicator (called VS1 in Hummels et al, 2001) measures the extent of a country's exports used by other countries as inputs in their exports. The primary conceptual contribution of this section is to extend both measures of vertical specialization into a framework that includes many countries based on an international input-output model. This extended measure allows us to estimate each country's net contribution of value added in the East Asia production network at industry level.

It is relatively rare to use an international IO table to evaluate the growth of vertical specialization and to slice up value-added along an industrial supply chain across countries. We know of only related paper, Pula and Peltonen (2008), entitled "Has Emerging Asia Decoupled? An analysis of Production and Trade Linkage Using the Asian International Input-Output Table." They estimate the dependence of each country's GDP on domestic, intra-East Asia and extra-regional demand based on an aggregate Asia IO table, and conclude that there is no support for the "decoupling" view. These authors do not connect their exercise with HIY measure of vertical specialization and do not conduct any analysis at the industry level.

Recall that two key (but implicit) assumptions are needed for the HIY measure to work. First, the intensity in the use of imported inputs is the same between production for export and production for domestic final demand. Second, the foreign value added in all imported intermediate inputs is 100%. That is, there is no indirect domestic content in a country's imports. The first assumption is violated when processing exports are pervasive. The second assumption is violated because the essence of a global production chain is that any country's exports could contain inputs coming from many other countries. By this logic, imported inputs (e.g., imported computer parts by the PRC) could very well contain domestic value added that is embedded in the country's intermediate goods exports.

When data on processing trade are utilized, one can relax the first assumption. Koopman et al. (2008) provide a methodology to re-compute domestic and foreign value added in this case, and the first part of this paper summarizes the empirical results for the PRC's exports. An inter-regional input-output (IRIO) table permits the relaxation of the second assumption. In particular, such a table would have information on (a) transaction flows of intermediate products and final goods within and between each country in the world at industry level; (b) the direct value-added of each industry in all countries; and (c) the gross output for each industry in all countries. In the next two sub-sections, we will use an international input-output model to illustrate how value added along a multi-country production chain can be decomposed into the sum of each participating country's net contributions.

4.1 When a World Input-Output Table (That Covers All Countries) Is Available

Assume there are G countries, with N sectors in each country. Production in each sector in any country can potentially use intermediate inputs from any sector (including its own) in any country. Products in the same sector from two countries are imperfect substitutes. A world IO table is a comprehensive account of annual product and payment flows within and between countries. With a slight abuse of notations, we will recycle the symbols in Section 2; in most instances, a given notation in this section is a multi-country generalization of the same object for a single country case in Section 2. To be precise, we use the following notations to describe the elements of the world IO table (expressed in annual values): x_i^r = Gross output of industry i in country r; v_j^s = Direct value added by production of industry j in country s; z_{ij}^{sr} = Delivery of good i produced by country s and used as an intermediate by sector j in country r; and y_{ik}^{sr} = Delivery of good i produced in country s for final use in final demand type k in country r (the total number of final demand types is H). Then the following two accounting identities describe the relationship among elements of each row (i,r) and column (j,s) of the international IO table:

$$\sum_{s=1}^{G}\sum_{j=1}^{N} z_{ij}^{sr} + \sum_{s=1}^{G}\sum_{k=1}^{H} y_{ik}^{sr} = x_i^r \quad . \tag{22}$$

$$\sum_{r=1}^{G}\sum_{i=1}^{N} z_{ij}^{rs} + v_j^s = x_j^s \quad . \tag{23}$$

The economic meanings of the two equations are straightforward. A typical row in Equation (22) states that total gross output of commodity i in country r is equal to the sum of all deliveries to intermediate and final users in all countries (including itself) in the world. Equation (23) defines the value of gross output for commodity j in production country s as the sum of the values from all of its (domestic plus imported) intermediate and primary factor inputs. Equations (22) and (23) must hold for all $i,j \in N$, $k \in H$ and $s,r \in G$ in each year. In addition, this World IO account has to be consistent with each country's national IO account and official trade statistics, which requires the following accounting identities to be satisfied each year:

$$\sum_{k=1}^{H}\sum_{s=1}^{G} y_{ik}^{sr} = y_i^{\bullet r} \,, \tag{24}$$

$$\sum_{s=1}^{G} z_{ij}^{sr} = z_{ij}^{\bullet r} \,, \tag{25}$$

$$\sum_{s\neq r}^{G}\sum_{j=1}^{N} z_{ij}^{sr} + \sum_{s\neq r}^{G}\sum_{k=1}^{H} y_{ik}^{sr} = e_i^{s} \,, \tag{26}$$

$$\sum_{s\neq r}^{G}\sum_{j=1}^{N} z_{ij}^{sr} + \sum_{s\neq r}^{G}\sum_{k=1}^{H} y_{kj}^{sr} = m_j^{r} \,, \tag{27}$$

where $y_i^{\bullet r}$ = total final domestic demand of product i of destination country r; $z_{ij}^{\bullet r \cdot}$ = total intermediate demand of product i by sector j in destination country r; e_i^s = exports of sector i of production country s ; and m_j^r = imports of product j of destination country r.

Equation (24) indicates that each country's total final demand for commodity i must be met by final goods and services shipped from all nations, including its own. Equation (25) states that each country's total intermediate use of product i in sector j must be equal to the total input-output flow from sector i to sector j in the IO table of the destination country r. Equations (26) and (27) represent the fact that all intermediate and final goods and services exported to and imported from all foreign countries have to equal the country's total exports to and imports from the world market.

Define $a_{ij}^{rr} = \frac{z_{ij}^{rr}}{x_j^{rr}}$ as the direct input coefficients of the domestic products of country r,

$a_{ij}^{sr} = \frac{z_{ij}^{sr}}{x_j^{rr}}$ $s \neq r$ as intermediate input-output coefficients of good i produced in source country s for

use in sector j by destination country r; and $av_j^r = \frac{v_j^r}{x_j^r}$ as each sector j's ratio of value added to

gross output for each country r; then Equations (22) and (23) could be re-written as:

$$AX + Y = X, \tag{28}$$

$$A^T X + \hat{A}_v X = X, \tag{29}$$

where A is a NG by NG square matrix with G^2 number of N by N block sub matrices. It shows input-output coefficients not only within each country, but also across all countries.

$$A = \begin{bmatrix} A^{11} & \cdots & A^{1G} \\ \vdots & \ddots & \vdots \\ A^{G1} & \cdots & A^{GG} \end{bmatrix}$$

$A^{rr} = [a^{rr}{}_{ij}]$ are $n \times n$ matrices at the diagonal, $A^{sr} = [a^{sr}{}_{ij}]$ $s \neq r$ are also $n x n$ matrices but at the off-diagonal. $\hat{A}_V$ is a diagonal block matrix of NG by NG whose diagonal elements are row vectors of the corresponding country's ratio of value added to gross output (value-added coefficients).

$$\hat{A}_v = \begin{bmatrix} AV^1 & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & AV^G \end{bmatrix},$$

where $AV^r = [av^r{}_j]$ is an n by n diagonal block matrix and X is an RG by one output vector

$$X = \begin{bmatrix} x_1^1 & \cdots & x_n^1 & \cdots & x_1^r \cdots & x_n^r & \cdots & x_1^G \cdots & x_n^G \end{bmatrix}^T.$$

The adding up condition on the input-output coefficients in Equations (30) and (31) can be written as

$$uA + A_v = u, \tag{30}$$

where u and A_v are a one by NG unit vector and a value-added coefficient vector respectively. Equation (30) implies that the direct value-added coefficients and intermediate input-output coefficients from all domestically produced and imported products in any sector j and country r must sum to unity.

As in Section 2, from Equation (28) we have

$$X = (I - A)^{-1} Y. \tag{31}$$

where $B = (I - A)^{-1} = [b_{ij}^{sr}]$ is the Leontief inverse. Its j^{th} column in the r^{th} block states how much the production of each industry in all countries is induced when the final demand for j^{th} industry in country r increases by one unit (total requirement coefficient). Y is a NG by H final demand matrix, usually including private and government consumption, capital formation and inventory changes. Based on the definition of the value-added coefficient, the incremental increase in value added induced by a one unit increase in final demand is given by

$$\Delta V = \hat{A}_v \, \Delta X = \hat{A}_v (I - A)^{-1} \Delta Y = \hat{A}_v (I - A)^{-1}. \tag{32}$$

Define a G by NG matrix VAS as the value added share distribution in a unit of final product. Each row r represents the value-added share contributed to industry i by corresponding country r. It can be computed by summing across rows of the NG by NG matrix ΔV:

$$VAS = V_0 (I - A)^{-1} = V_0 B \qquad V_0 = S \cdot \hat{A}_v, \tag{33}$$

where S is a G by NG block diagonal summation matrix with G one by N unit vectors as its diagonal block. Its elements are the column sum of products between value-added coefficients and total requirement coefficients:

$$VAS = [vas_i^{sr}] = \left[\sum_{j=1}^{N} av_j^s b_{ji}^{sr} \right] \tag{34}$$

Intuitively, this equals pre-multiplying the Leontief inverse by the value-added ratio and summing them over the column (industries) for each bilateral transaction in every country and industry, so we obtain the amount of value added generated directly and indirectly in one unit of final product for each industry in each country. The contributed value-share from all countries for a particular industry equals unity. The VAS matrix can be written as G as follows,

$$VAS = \begin{bmatrix} VAS_1^1 & \cdots & VAS_i^r & \cdots & VAS_N^G \end{bmatrix}, \tag{35}$$

where $VASi^r = [vas^{sr}{}_i]$ is a G by G matrix . For each VAS_i^s the off-diagonal elements (for all $s \neq r$) of source country s and destination country r (hold production country s constant) are the terms capturing exported intermediate inputs from source country s used in the output of destination country r at the 2nd,3rd,4th, … stages before becoming embodied in final goods delivered to other countries. Therefore the sum over destination country r weighted by the corresponding final goods from all G countries consumed in country r will be similar to the VS1 measure proposed by HIY, but without the restrictive assumption that the exported intermediates are 100% domestically sourced. This revised VS1 measures how much of source country s domestic value-added is embodied in its indirect intermediate exports to third countries that then export final goods consumed in the destination countries. It can be computed at each sector i as

$$vs1_i^s = \sum_r^G vas_i^{sr} y_i^{sr} = \sum_r^G \sum_{j=1}^N \sum_k^H av_j^s b_{ij}^{sr} y_{ik}^{sr}. \tag{36}$$

The off-diagonal elements of destination country r and source country s (holding the destination country r constant) in the VAS matrix are the terms capturing imported intermediate inputs from source country s in the output of destination country r at the 2nd, 3rd, 4th, … stages before becoming embodied in the final goods imported by destination country r. Therefore, the sum over source country s is similar to the VS measure proposed by HIY without the assumption that the imported intermediates be 100% foreign-sourced. This revised VS measure decomposes the foreign value added embodied in direct exports of the exporting country s to its destination country r into its original value-added sources and can be computed at sector level as

$$vs_i^r = \sum_s^G vas_i^{sr} y_i^{sr} = \sum_s^G \sum_{j=1}^N \sum_k^H av_j^s b_{ij}^{sr} y_{ik}^{sr}. \tag{37}$$

For the destination country r, $vs^r{}_i$ is the domestic content of its imports, that is, its own domestic content that was previously exported and has come back into the country through its imports from other countries. The diagonal elements of each VAS_i^s matrix captures the domestic intermediate inputs in domestic output of country r at the 2nd,3rd,4th, … stages before it becomes embodied in final goods delivered to other countries plus the revised VS1, the domestic value added embodied in its exports used by any third country to produce exports to a destination for final consumption. Therefore, the domestic value-added share derived from HIY VS share measure (one minus HIY VS share) will under-estimate domestic value added by neglecting both the domestic value added embodied in the imports of the home country and indirect exports to the destination country via indirect intermediate exports to third countries. It can be computed at sector *i* for each country as follows:

$$dv_i^r = \sum_s^G vas_i^{rr} y_i^{sr} = \sum_s^G \sum_{j=1}^N \sum_k^H av_j^r b_{ij}^{rr} y_{ik}^{sr}. \tag{38}$$

The aggregate measure of revised VS, VS1 and domestic value-added DV at each country or each sector level can be obtained by sum over sector (country) weighted by final consumption. For example,

$$VS^r = \sum_s^G \sum_i^N vas_i^{sr} y_i^{sr} = \sum_s^G \sum_i^N \sum_{j=1}^N \sum_k^H av_j^s b_{ij}^{sr} y_{ik}^{sr} \tag{39}$$

$$VS_i = \sum_s^G \sum_r^G vas_i^{sr} y_i^{sr} = \sum_s^G \sum_r^G \sum_{j=1}^N \sum_k^H av_j^s b_{ij}^{sr} y_{ik}^{sr} \tag{40}$$

Just as our revised VS measure provides a way to further decompose VS to all its original source countries, our revised VS1 measure provides a way to further decompose domestic value added into that which is embodied in a country's direct exports to its consumption destination and that which is embodied in its indirect intermediate exports via third countries to its final destination. When all the off-diagonal block matrices in *A* are equal to zero, our *VAS* matrix reduces to HIY's VS measure. Our measure also allows us to relax the assumption that HIY made for their computations that each country's imports are of 100% foreign content.

Obviously, our total value chain measure, *VAS*, is an extension of the vertical specialization measure (VS and VS1) proposal by HIY into as many as *G* countries. It includes both domestic value-added share (in the diagonal) and foreign value-added share from all other countries, and a country's exports of intermediates embodied in all other countries' exports, and thus combines VS and VS1 in a consistent framework. The detailed distribution of foreign value added in both a source country's direct and indirect exports to a destination country revealed by this systematic measure will enable us to quantify the “length” (how many participating countries) and “thickness” (value added share for each participating country) of the regional or global production chain. In addition, it relaxes the unrealistic assumption that a country’s imported intermediate inputs have to be 100% foreign content and the first country’s exports have to be 100% domestic content. Our revised VS measure takes all the back-and forth trade of intermediates across borders into account, something that cannot be captured with only single country IO tables.

4.2 Working with an Inter-Regional Input-Output Table (for a Subset of Countries)

International IO tables are rare because of the tremendous amount of data required to compile them, as well as differences in statistical classifications across countries. Available inter-regional IO tables, such the Asian international IO table, usually cover only a select set of economies and treat other countries in the rest of the world (without IO accounts) as exogenous blocks. To estimate total value chains based on such tables, our model specified in the previous section has to be modified.

Dividing the G countries into a set of M endogenous and another set of G–M exogenous countries, the model specified by Equations (24) and (25) becomes:

$$\sum_{s=1}^{M} \sum_{j=1}^{N} z_{ij}^{sr} + \sum_{s=1}^{M} \sum_{k=1}^{H} y_{ik}^{sr} + \sum_{s=G-M}^{G} e_i^{sr} = x_i^r \ , \tag{41}$$

$$\sum_{s=1}^{M}\sum_{i=1}^{N} z_{ij}^{sr} + \sum_{s=G-M}^{G} \sum_{i=1}^{N} m_{ij}^{sr} + v_j^r = x_j^r \ , \tag{42}$$

where e_i^{sr} = exports of product i from country s to country r; m_{ij}^{sr} = imports of product i used in sector j in an endogenous country r from an exogenous country s.

This is a modified international IO model. , The computation of VAS in such a model is similar to Equation (33) but with different dimensionality for the related matrices. (Matrix A reduces to NM with M^2 number of N by N blocks. $\hat{A}_V$ reduces to a diagonal block matrix of NM by NM, and the block diagonal summation matrix S reduces to M by NM).

To estimate the value-added contribution from exogenous countries in the rest of the world (which does not have an input-output account), we need to assume imported intermediate inputs from the *G-M* exogenous countries are 100% foreign sourced, similar to HIY. Then the contribution of value-added share from the *G-M* exogenous countries in each of the *N* industries is computed as follows:

$$VSS = M_0 (I - A)^{-1}, \qquad (43)$$

where *VSS* is a *G–M* by *N*(*G–M*) matrix, with each row *i* giving the contribution of value-added share from a corresponding exogenous country to each of the *N* industries.

$$M_0 = \begin{bmatrix} M_0^{M+1} & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & M_0^G \end{bmatrix}$$

M_0 is also a diagonal block matrix of *G–M* by *N*(*G–M*) whose diagonal block are 1×*n* row vectors $M_0^r = [m_{0j}^r]$, and each element m_{0j}^r is the column sum of the direct import coefficients of the corresponding exogenous country. In other words, $M_0^r = uM^r$ where $M^r = [m^{sr}_{ij}]$ is an *n* by *n* import coefficient matrix and *u* is a 1×*n* vector of ones. Intuitively, the amount of imports from the rest of the world required directly and indirectly by one unit of final demand (including exports to the rest of the world) can be obtained by pre-multiplying the Leontief inverse by the imported intermediate IO coefficient matrix.

The column sum of *VAS* and *VSS* is always equal to one by using the adding up condition of the international IO model. In other words, the column sum of domestic input/output coefficients, import input/output coefficients, and the value-added ratio for each industry in each endogenous country has to equal unity.

5. Empirical Estimates on Value Added Along Production Chains

5.1 Data Source

The Asian international Input-Output tables (AIO) are the main source of data. These table are compiled by the Institute of Development Economies (IDE) affiliated with Japan’s Ministry of Economics, Trade and Industry in collaboration with national statistical institutions in eight other economies in Asia (Indonesia; Korea; Malaysia; the PRC; Philippines; Singapore;

Taipei,China; and Thailand) plus the US. The AIO provides the origin and destination of all transaction flows within and across these the economies at the industry level, and reports trade flows with Hong Kong, China and the rest of the world. It specifies intermediate and/or final use for all such flows. The table is available for 1990 and 2000. The 2000 table separates the EU15 from the rest of the world.

Sixty-four sectors, including 36 non-food-processing manufactures sectors, appear in both the 1990 and 2000 tables after careful concordance. Final demand in the AIO has four components (i.e. H=4): private consumption, government consumption, gross domestic fixed capital formation, and changes in inventories. Direct value added in the AIO includes wages and salary, operating surplus, gross fixed capital formation, and indirect taxes less subsidies.

5.2 Comparing the PRC with Other Asian Economies in Production Chain

Table 5 provides a comparison of the PRC vis-à-vis other major economies in East Asia. Columns (2) and (3) report the current dollar value of final and intermediate goods exports by each of the nine economies in 1990 and 2000, relying on BEC classifications. Column (4) gives the estimated share of intermediate exports in total manufacturing exports (4) = (3)/[(2)+(3)]. In 2000, the median value of this share is 52.9% (Malaysia). Four economies that exported a greater portion of intermediate goods that year are Korea (63.5%), the Philippines (61.2%), Singapore (59.9%), and Taipei,China (61.6%). It is noteworthy that in 2000 the PRC's intermediate export share is the lowest of the economies in our Asian sample. Indeed, comparing 2000 with 1990, it stands out as the only economy that experienced a decline in the share of intermediates in exports. All other economies experienced an increase, with the increment exceeding 10 percentage points for five of them. By this metric, it seems that the PRC's participation in the Asian (plus the US and EU) production chains declined, but it may indicate that the PRC is located at the end of this production chain, with a significant portion of its exports consisting of final goods exports to the US and EU markets.

However, the share of intermediate goods in a country's total exports can be a misleading yardstick to judge international integration. We suggest a more informative statistic might be the shares of domestic and foreign content in a country's exports; these are reported in Columns (5) and (6) in Table 5. The foreign content share exceeds 40% for Malaysia; Philippines; Singapore; Taipei,China; and Thailand in 2000. This suggests that these economies are heavy users of imported intermediates in the production of their exports. On the other end of the spectrum is Japan, whose foreign content is less than 10% of its exports. This indicates that Japan primarily specializes in producing intermediate inputs for other countries' exports, but uses relatively few foreign-sourced inputs in its own final goods exports. In comparison, the foreign content share for the PRC's exports is estimated to be 23.6%, which is on the low end of the spectrum when compared with most other East Asian economies.

It is important to note that the estimates reported in Table 5 do not distinguish between processing and normal exports; they underestimate the true extent of foreign content in exports. For the PRC, as the first part of the paper shows, the foreign content share is on the order of 50% once the higher reliance on imported inputs by processing exports is taken into account. As the use of processing exports is more intensive in the PRC than in many other Asian economies, it is likely that the adjustment needed is smaller for those economies. For example, for both Japan and Singapore, since their tariff rates on manufactured inputs are already low, the estimation errors are probably small, and the estimated foreign content shares reported in Table 5 are likely to be reliable.

5.3 Slicing Up Production Chains Across Countries

A major advantage of the international I/O tables is that they allow for further breakdown of the foreign content in a country's exports according to the origins of countries that supply intermediate goods. This is done with the help of the formulas in equations (39) and (43)[5], and reported in Table 6.

Each row represents a breakdown of the supply chain, for a given county's exports to the US, of all foreign countries that contribute value added to its production. For example, the first row shows that in 1990 Indonesia contributed 1.1% to the foreign content of PRC's exports to the US. Hong Kong, China; Japan; and the US are the most significant suppliers of intermediate inputs for the PRC's exports to the US, accounting for 51.3%, 13.0% and 6.8% of the foreign content, respectively. Comparing 2000 with 1990, we can see the share of Hong Kong, China in the foreign content in PRC's exports has declined substantially (to 10.5% in 2000). On the other hand, the shares by Japan, Korea, Taipei,China and the US in the foreign content in PRC's

[5] In columns 2-11, the shares of the 10 endogenous countries are computed using equation (39), while in columns 12 and 15, the shares for Hong Kong, China and the rest of the world are computed according to equation (43). These shares are then treated equally when re-scaled (to ensure that they sum to 100%).

exports have each increased by more than two percentage points during the same period. The biggest increase in the contribution to the foreign content comes from the rest of the world, including Europe. In other words, sourcing of inputs by companies in the PRC to be used in production for exports has become more dispersed geographically and there is significantly less reliance on inputs from Hong Kong, China. These countries increasingly export value added to the US indirectly by exporting intermediate inputs to the PRC to be used in its exports to the US market.

Across the rows in Table 6, we can compare the geographic sourcing patterns in exports for nine major economies in East Asia. A number of interesting patterns emerge. First, Japan is the dominant supplier of inputs used in the production of other Asian economies' exports to the US market, accounting for 20% of foreign content in nearly all other Asian exporters' goods. This role by Japan has declined only moderately over time. Second, the US itself is often a major input supplier to Asian countries' exports to the US market. Its role is relatively stable over time, though with some fluctuations for individual exporters. Third, Korea and Taipei,China are the next two most significant Asian suppliers of inputs in other Asian economies' exports.

5.4 Multinational Value-Added Chains in the PRC for Disaggregated Export Categories

The extent of participation in a global production chain varies by sectors. One of the findings in Koopman, Wang and Wei (2008) is that for the PRC's exports those sectors that are considered relatively sophisticated, such us consumer electronics and computers, often have a relatively high foreign content. In this subsection, we apply the methodology in Section 4 to sector-level exports data of the PRC, and report the estimation results in Table 7.

The sectors are listed in descending order by the value of the PRC's exports in 2002, reported in Column 2 of Table 7. The top three sectors in absolute value are "television, radios, audios and communication equipments" (or "electronics" for short), "electronic computing equipment" (or "computers" for short), and "wearing apparel." Columns 3 and 4 report the share of a sector's exports in the country's total manufacturing exports, and the share of processing exports in that sector's exports, respectively. The top three sectors (out of 64 manufacturing sectors) account for about one-quarter of total manufacturing exports. The degree of processing trade differs across sectors. For example, 90% of electronics exports are in the processing trade category, and virtually all computer exports (99%) are processing exports. In comparison, about 45% of wearing apparel exports are processing exports.

Columns 5 and 6 report an estimated breakdown between domestic and foreign content (as a share of a sector's exports) according to the KWW (2008) method, as summarized in Section 2, (i.e., taking into account the difference between processing and normal exports). The numbers reported in these two columns are the sector level counterpart for national aggregate estimates reported in the second to the last Column (i.e., for 2002) of Table 3 for manufacturing goods only. The foreign content share is 65% for electronics and 83% for computers, but only 33% for wearing apparel. These examples illustrate the more general pattern that Chinese exports from relatively sophisticated sectors are more likely to have a high foreign content share.

The remaining columns (Columns 7-15 of Table 7) list the contribution of key foreign economies as a percentage of foreign content in PRC's exports using the KWW methodology described in Section 4. These estimates are the sector-level counterparts to the national aggregate estimates reported in the first row of Table 6 It is useful to note the maintained assumptions in the construction of this paper. First, when it comes to partitioning a sector's exports into domestic and foreign content share, the KWW method is feasible and preferred, therefore we report the estimates using the KWW method in Columns 5-6. Second, when it comes to slicing up the foreign content across different foreign sources, we do not have information on a breakdown between processing and normal trade for these economies except the PRC. Consequently, we assume that the distribution of foreign content across the source countries as estimated in Table 7 is not affected by the estimated share of foreign content in a country's total exports.

In any case, for both electronics and computers (two major sectors with a low share of local content), Japan; Hong Kong, China; EU15; and the US are the primary sources for the foreign content in the PRC's exports, collectively accounting for about 60% of it. For wearing apparel, domestic content share is high (67%), and the foreign content comes from a diverse set of countries. Japan; Korea; and Taipei,China are the main supplies of foreign content in East Asia, but account for only 40% of the total foreign content; another 40% come from EU15 and rest of the world.

6. Concluding Remarks

Segmentation of production across countries allows for reductions in production costs and more efficient allocation of resources. The opening-up of the PRC has likely facilitated this process. A quantitative assessment of the extent of its participation in global production chains allows us to get a better grasp of many policy questions, including the effect of an exchange rate change on bilateral trade balances. This paper reviews and extends a conceptual framework that allows one to estimate domestic and foreign content in a country's exports, and to further assign foreign content into contributions from individual foreign economies. This framework is then applied to the data for the PRC.

We find several interesting patterns. First, we report from KWW 2008 that the estimated level of foreign content in exports from the PRC is close to 50%, almost twice as high as that calculated using the HIY formula. Second, we report interesting heterogeneity across sectors: those sectors that are likely to be labeled as sophisticated or high-skilled, such as computers, electronic devices, and telecommunication equipment, tend to have notably low shares of domestic content. Conversely, many sectors that are relatively intensive in low-skilled labor, such as apparel, are likely to exhibit a high share of domestic content in the country's exports. Finally, we find that Japan; the US; and Hong Kong, China are the primary suppliers of foreign content in the PRC's exports in several top export categories that may be considered relatively sophisticated. In other export sectors that are relatively less sophisticated, Korea and Taipei,China become more important, in addition to Japan.

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Figure 1: Input-Output Table with Separate Production Account for Processing Trade

			Intermediate use			
			Production for domestic use and normal exports	Production for processing exports	Final use (C+I+G+E)	Gross Output or Imports
		Dimension	1,2,…, N	1,2,…, N	1	1
Domestic Intermediate Inputs	Production for domestic use and normal exports (D)	1 . . . N	Z^{DD}	Z^{DP}	Y^{D}	$X - E^{P}$
	Processing Exports (P)	1 . . . N	0	0	E^{P}	E^{P}
Intermediate Inputs from Imports		1 . . . N	Z^{MD}	Z^{MP}	Y^{M}	M
Value-added		1	V^{D}	V^{P}		
Gross output		1	$X - E^{P}$	E^{P}		

Source: Authors' construction.

Table 1: Processing Manufacturing Exports (excluding HS Chapters 1-27), 1996-2006

Year	*Share of processing exports in total exports (100*PE/TE)*	*Share of Processing and assembling*	*Share of Processing with imported materials*	*Share of processing imports in total imports*	*Ratio of processing imports to processing exports(100*PM/PE)*	*Processing trade surplus as share of processing exports (100*[PE-PM]/PE)*
1996	62.1	18.0	44.1	47.6	71.1	28.9
1997	**60.2**	**17.9**	**42.3**	**53.1**	**67.0**	**33.0**
1998	62.0	18.3	43.7	52.0	63.3	36.7
1999	61.2	19.9	41.3	47.9	64.7	35.3
2000	59.6	17.9	41.7	46.6	65.9	34.1
2001	59.7	17.2	42.5	43.0	62.7	37.3
2002	**58.8**	**15.6**	**43.2**	**45.6**	**67.4**	**32.6**
2003	58.5	13.2	45.4	44.0	66.7	33.3
2004	58.0	12.0	46.0	45.3	66.6	33.4
2005	57.0	11.3	45.7	48.3	64.6	35.4
2006	**54.5**	**9.9**	**44.6**	**47.9**	**61.7**	**38.3**

Source: Customs Trade statistics, General Customs Administration, the People's Republic of China.

Table 2: Final Use of Imports by Producers in the People's Republic of China (in percent of total imports),1996-2006

Year	Share of Intermediates		Share of Capital goods		Share of final Consumption
	For processing exports	for normal use	for processing exports	for normal use	
1996	46.2	26.8	8.1	16.7	2.2
1997	51.2	28.2	12.1	7.3	1.2
1998	50.8	28.2	10.0	9.8	1.3
1999	43.7	34.9	11.2	8.3	1.9
2000	39.4	41.2	9.1	8.5	1.7
2001	36.6	41.2	11.6	8.7	1.8
2002	38.3	38.5	10.3	11.1	1.8
2003	35.4	41.2	11.0	10.8	1.6
2004	35.1	42.3	9.1	12.0	1.5
2005	36.6	42.9	8.2	10.8	1.5
2006	35.7	43.5	10.0	9.1	1.7

Source: Authors' calculations based on the United Nation Broad Economic Categories (UNBEC) classification scheme, and trade statistics on normal and processing imports.

Table 3 Shares of Domestic and Foreign Value Added in Total Exports by the People's Republic of China (%)

	The HIY Method			The KWW Method		
	1997	**2002**	**2006***	**1997**	**2002**	**2006***
All Merchandise						
Total Foreign value-added	17.6	25.1	26.3	47.7	46.1	49.3
Direct foreign value-added	*8.9*	*14.7*	*15.7*	*46.1*	*42.4*	*45.7*
Total Domestic Value-added	82.4	74.9	73.7	52.3	53.9	50.7
Direct domestic value-added	*29.4*	*26.0*	*25.3*	*23.7*	*20.1*	*19.2*
Manufacturing Goods Only						
Total Foreign value-added	19.0	26.4	27.1	52.4	48.7	50.6
Direct foreign value-added	*9.7*	*15.6*	*16.3*	*50.9*	*45.0*	*47.0*
Total Domestic Value-added	81.1	73.6	72.9	47.6	51.3	49.4
Direct domestic value-added	*27.5*	*24.6*	*24.6*	*21.2*	*18.5*	*18.4*

Notes: The HIY method refers to estimates from using the approach in Hummels, Ishii, and Yi (2001). The KWW method refers to estimates from using the approach developed in this paper that takes into account special features of processing exports. The estimates for 2006 are preliminary as they use the trade statistics in 2006 but the I/O table in 2002, which is the latest available. The next benchmark table (2007) is scheduled to be released in 2010.

Source: Authors' calcuation

Table 4: Domestic and Foreign Value Added: Processing and Normal Exports

(in percent of total exports)

	Normal Exports			Processing Exports		
	1997	**2002**	**2006***	**1997**	**2002**	**2006***
All Merchandise						
Total Foreign value-added	5.3	10.8	11.3	81.9	74.3	81.9
Direct foreign value-added	*1.9*	*4.5*	*4.6*	*81.7*	*72.5*	*80.9*
Total Domestic Value-added	94.7	89.2	88.7	18.1	25.7	18.1
Direct domestic value-added	*34.4*	*31.0*	*29.3*	*15.0*	*11.4*	*10.5*
Manufacturing Goods Only						
Total Foreign value-added	5.7	11.6	11.7	82.3	74.9	82.3
Direct foreign value-added	*2.1*	*4.9*	*4.8*	*82.2*	*73.0*	*81.4*
Total Domestic Value-added	94.3	88.4	88.3	17.7	25.1	17.7
Direct domestic value-added	*30.9*	*28.5*	*28.3*	*15.0*	*9.5*	*10.4*

The estimates for 2006 are preliminary as they use the trade statistics in 2006 but the I/O table in 2002, which is the latest available. The next benchmark I/O table — the 2007 table — is scheduled to be released in 2010.
Source:Authors' calculations.

Table 5: Foreign and Domestic Value Added in East Asia Manufacturing Exports to the United States (in millions of US dollars)

Source Country (1)	Final goods exports (2)	Interme-diate goods exports (3)	Int. share in gross exports (4)	Total domestic value added(%) (5)	Total foreign value added (%) (6)
1990					
China	3,870	2,672	40.8	81.2	18.8
Indonesia	886	538	37.8	76.9	23.1
Japan	53,446	28,473	34.8	91.6	8.4
Korea	11,298	5,450	32.5	68.3	31.8
Malaysia	2,051	2,091	50.5	52.8	47.2
Philippines	1,361	596	30.5	55	45.0
Singapore	5,306	3,599	40.4	39.9	60.1
Thailand	2,641	1,189	31	56.9	43.2
Taiwan	13,280	8,411	38.8	63.6	36.4
Total	94,139	53,019	36	86	14.0
2000					
China	37,991	22,060	36.7	76.5	23.6
Indonesia	3,730	2,424	39.4	75.4	24.6
Japan	66,680	53,438	44.5	90.5	9.5
Korea	16,661	19,260	53.6	66.2	33.8
Malaysia	9,681	10,860	52.9	35.1	64.8
Philippines	3,674	5,785	61.2	55.4	44.5
Singapore	6,074	9,072	59.9	41.8	58.1
Thailand	5,909	5,912	50	54.9	45.0
Taiwan	12,300	19,761	61.6	54.5	45.5
Total	162,700	148,571	47.7	84.5	15.5

Data Source: Authors calculations based on the Asia Input-Output Table, originally compiled by the Institute of Development Economics, Ministry of Economics, Trade and Industry, Japan.

Table-6 Tracing Sources of Foreign Value Added in Exports for Exports to the United States for Individual Exporting Countries

Source country (1)	China, People's Republic of (2)	Indo-nesia (3)	Japan (4)	Korea, Republic of (5)	Malay-sia (6)	Taipei,China (7)	Philip-pines (8)	Singa-pore (9)	Thai-land (10)	United States (11)	Hong Kong, China (12)	Rest of World (13)	To (1
						1990, in percent							
China, People's Rep. of	-	1.1	13	1.4	1.7	3.5	0.1	0.4	0.9	6.7	51.3	20	10
Indonesia	3.2	-	12.2	8.2	1.6	5.9	0.3	1.7	0.7	11.3	3.3	51.6	10
Japan	2.6	3.7	-	2.9	1.7	2.6	0.8	0.7	1.5	18.6	1.2	63.6	10
Korea, Rep. of	0.2	1.5	26.5	-	2.8	2.2	0.3	0.5	0.6	20.7	1.5	43.2	10
Malaysia	2.1	1.3	21.1	2.3	-	5.8	0.5	7.2	1	12.3	3.8	42.5	10
Taipei,China	0.2	1.2	28.2	2	1.4	-	0.4	1	0.5	17.7	3.3	44.1	10
Philippines	1.3	1.1	16.4	3.9	1.1	10.8	-	1.9	0.5	18.1	10.4	34.4	10
Singapore	1.6	1.3	32.8	2.7	5.6	4	0.9	-	1.6	19.6	4.4	25.4	10
Thailand	2.4	0.8	22.4	2.5	2	3.3	0.3	3.8	-	17.5	2.3	42.6	10
Total[a]	**3.6**	**1.1**	**56.3**	**8.6**	**1.7**	**9.5**	**0.9**	**2.5**	**1.8**	**3.8**	**1**	**9.2**	10
						2000, in percent							
China, People's Rep. of	-	1.6	15.5	8.4	1.6	7.9	0.5	1.2	1	8.9	10.5	42.9	10
Indonesia	5.4	-	11.5	6.3	2.3	4.2	0.2	1.4	1.6	8.4	2.3	56.4	10
Japan	6.1	3.6	-	4.6	2.5	4.5	1.3	1.1	2.7	18.4	2.3	52.8	10
Korea, Rep. of	6	1.7	21.5	-	1.7	2.7	0.7	1.3	0.8	17.5	3.2	42.9	10
Malaysia	3.4	1.8	21.1	3.8	-	4.6	1.5	6.8	2.6	17.9	5.1	31.3	10
Taipei,China	3.8	1.7	26	5.3	2.4	-	1.4	1.9	1.2	13.8	3.2	39.3	10
Philippines	5	2.5	17	6.2	2	8.9	-	2	2.9	13.5	9.8	30.2	10
Singapore	4.3	1.4	23.6	3.3	7.1	2.8	0.5	-	1.7	15	2.9	37.6	10
Thailand	6.2	2.1	22.1	4.2	3.4	4	0.8	3.3	-	13.2	3.2	37.5	10
Total[a]	**18.8**	**2.2**	**41.5**	**8**	**2.7**	**5.2**	**1.5**	**2.1**	**2.4**	**3.7**	**1.3**	**10.5**	10

Data Source: Authors calculations.

Note. The first column lists individual exporting countries. Each row reports estimated percentage contributions to the foreign content embedded in that country's exports to the United States by individual economies and the rest of the world.

Table 7: Slicing Up Value-added Chains in Manufacturing Exports by Sector (2002)

Industries	Export Value in 2002 (in million dollars)	Share in PRC's Manuf. Exports (%)	Share of processing exports (%)	Domestic Content Share (%)	Foreign Content Share (%)	Sources of Foreign Value Added in PRC's Exports to the U.S. in 2000								
						Japan	Korea Rep. of	Taipei, China	Singa-pore	Other ASEAN	United States	Hong Kong, China	EU15	Rest of the world
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Television, radios, audios & communication equipment	32,713	10.2	89.8	35.0	65.0	16.2	7.2	7.8	1.8	4.6	11.1	16.9	16.5	17.8
Electronic computing equipment	22,450	7.0	99.1	16.9	83.1	15.9	7	8.3	2.6	6.5	12.6	16.5	13	17.6
Wearing apparel	22,450	7.0	45.1	67.0	33.0	19.4	10.6	10.3	0.6	3.9	6.1	7.3	9.7	32.1
Knitting	18,601	5.8	31.6	72.9	27.1	17	10.3	10	0.4	4.1	5.5	8.5	8.9	35.4
Lighting fixtures, batteries, wiring and others	17,960	5.6	66.8	46.1	53.9	14.1	5.8	6.1	0.7	3.5	7.8	5.6	12.1	44.3
Other manufacturing products	16,036	5.0	64.2	55.0	45.0	15.3	8.4	8	0.7	4.7	7.1	6.9	11.6	37.3
Leather and leather products	14,432	4.5	54.3	48.8	51.2	9.6	15.6	9.8	0.4	3.1	10	6.8	16.6	28.1
Metal products	14,111	4.4	43.2	57.9	42.1	16.6	6.7	7.4	0.5	3.3	5.7	3.6	11.2	45.1
Other electronics and electronic products	13,791	4.3	93.4	19.2	80.8	18.6	7.3	7.4	1.1	4.2	8.7	9.8	14.2	28.7
General machinery	11,225	3.5	43.7	58.5	41.5	17.6	6.5	7	0.7	3.6	7.2	5.1	14	38.3
Semiconductors and integrated circuits	10,904	3.4	89.7	22.2	77.8	16.2	7.6	8.4	1.7	5	10.3	13.9	14	23
Wooden furniture	8,980	2.8	36.7	76.3	23.7	13.5	7.6	6.8	0.4	10.5	6.8	5.1	13.5	35.9
Plastic products	7,697	2.4	64.5	37.6	62.4	16	8.7	9.3	1.3	4.2	9	4.8	13.6	33.2
Basic industrial chemicals	6,414	2.0	11.7	80.2	19.8	14.6	7.6	5.1	0.5	4.5	7.6	3	13.1	43.9
Household electrical equipment	6,094	1.9	79.1	37.2	62.8	16.9	7	7.5	1	4.1	8.4	7.3	14	33.8
Other chemical products	6,094	1.9	42.7	60.2	39.8	13.3	7	6	1	5.5	8.3	3.5	13.3	42
Precision machines	5,773	1.8	68.6	42.2	57.8	18.5	6.2	6.7	1	3.8	10.2	9.5	14.5	29.4
Tires and tubes	5,131	1.6	53.1	61.0	39	14.4	7.4	7.4	0.8	6.2	6.2	4.9	12.6	40.3
Other food products	4,811	1.5	26.7	74.9	25.1	10	4.4	4	0.8	7.6	11.2	3.2	12.7	46.2
Specialized machinery	4,490	1.4	38.5	63.4	36.6	18.9	6.3	7.1	0.8	3.3	7.4	4.4	16.1	35.8
Other transport equipment	4,169	1.3	40.2	61.0	39	17.7	6.7	7.2	0.8	3.6	6.7	4.4	13.3	39.7
Fish products	4,169	1.3	41.6	82.9	17.1	12.9	5.8	4.7	0.6	5.8	7.6	3.5	13.5	45.6
Non-metallic ore and quarrying	4,169	1.3	16.4	85.0	15	14	5.3	5.3	0.7	4.7	6.7	4.7	16.7	42

Non-ferrous metal	3,849	1.2	45.6	61.8	38.2	9.9	4.2	4.5	0.5	3.1	6.3	3.4	9.4	58.6
Refined petroleum and its products	3,528	1.1	24.2	65.3	34.7	4	1.7	1.4	0.3	6.6	2	1.2	5.5	77.2
Other non-metallic mineral products	3,528	1.1	12.9	84.5	15.5	12.3	5.8	5.8	0.6	5.2	7.1	3.9	13.5	45.8
Heavy Electrical equipment	2,886	0.9	76.8	39.6	60.4	17.9	6	6.3	0.7	3.3	7.5	5.6	15.2	37.6
Motor vehicles	2,566	0.8	35.2	67.8	32.2	23	5.3	5.6	0.6	2.8	6.5	3.1	21.7	31.4
Iron and steel	2,245	0.7	26.3	79.9	20.1	13.9	6	6	0.5	3.5	4.5	3	9.5	53.2
Drugs and medicine	2,245	0.7	16.9	81.4	18.6	14	6.5	5.4	0.5	4.8	9.1	4.3	16.7	38.7
Shipbuilding	1,924	0.6	95.8	56.7	43.3	18.7	5.8	6.2	0.7	3.2	7.9	4.4	18.2	34.9
Slaughtering, meat products and dairy products	1,924	0.6	17.5	88.9	11.1	11.7	4.5	4.5	0.9	5.4	11.7	4.5	13.5	43.2
Pulp and paper	1,604	0.5	50.7	58.9	41.1	10.9	7.5	5.1	0.5	8.5	12.2	5.1	12.9	37.2
Glass and glass products	1,604	0.5	33	71.1	28.9	14.5	6.6	5.2	0.7	5.2	7.3	3.8	12.5	44.3
Crude petroleum and natural gas	1,604	0.5	3.4	93.6	6.4	15.6	6.3	6.3	1.6	4.7	7.8	4.7	14.1	39.1
Boilers, Engines and turbines	1,283	0.4	26.6	75.8	24.2	18.2	5.8	5.8	0.4	2.9	7.9	3.7	18.6	36.8
Printing and publishing	962	0.3	83	43.1	56.9	11.2	7.6	5.3	0.5	8.3	12.3	5.4	13.2	36.2
Chemical fertilizers and pesticides	962	0.3	5.6	78.7	21.3	14.6	6.6	6.1	0.9	4.2	8.5	4.2	14.1	40.8
Beverage	641	0.2	16.9	80.8	19.2	13.5	5.7	5.7	0.5	5.7	10.9	4.2	13.5	40.1
Metal working machinery	641	0.2	13.3	83.5	16.5	18.2	6.1	7.3	0.6	3.6	7.3	4.8	14.5	37.6
Livestock and poultry	641	0.2	2.8	94.8	5.2	11.5	3.8	3.8	0	5.8	11.5	3.8	13.5	46.2
Other metallic ore	321	0.1	7.2	85.4	14.6	15.1	6.2	6.2	0.7	4.1	7.5	4.8	13.7	41.8
Cement and cement products	321	0.1	7	86.5	13.5	16.3	6.7	6.7	0.7	4.4	7.4	4.4	13.3	40
Fishery	321	0.1	1.2	94.4	5.6	12.5	5.4	5.4	0	5.4	7.1	3.6	14.3	46.4
Tobacco	321	0.1	5	95.7	4.3	11.6	7	7	0	7	11.6	4.7	14	37.2

Source: Authors' calculations.