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Estimating domestic content in exports when processing trade is pervasive☆

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ABSTRACT

For many questions, it is crucial to know the extent of domestic value added (DVA) in a country's exports, but the computation is more complicated when processing trade is pervasive. We propose a method for computing domestic and foreign contents that allows for processing trade. By applying our framework to Chinese data, we estimate that the share of domestic content in its manufactured exports was about 50% before China's WTO membership, and has risen to nearly 60% since then. There are also interesting variations across sectors. Those sectors that are likely labeled as relatively sophisticated such as electronic devices have particularly low domestic content (about 30% or less).

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1. Introduction

This paper proposes an accounting framework for estimating the domestic/foreign content share in a country's exports when processing trade is prevalent. We then apply the framework to China's exports, one of the world's best known processing exporters. While the application is to China, the underlying methodology is relevant for all countries that use a processing trade scheme, such as Mexico and Vietnam. Indeed, the World Trade Organization has identified more than 130 countries that use some form of processing exports (WTO and IDE_JETRO, 2011). Processing trade can take on other names in some countries, such as a duty drawback scheme, which means a rebate of tariffs paid on imported inputs if they are used for exports.

Of course, the choice of China as an illustration of the general methodology is not random. “Made in China” is one of the most common labels one encounters in a shopping mall in the United States and Europe. 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 China 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 China 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 and EU 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.

China is the archetype of a national economy that is well integrated into a global production chain. It imports raw material, equipment, and manufactured intermediate inputs, and then exports a big fraction

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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, 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 about 8% for the US and 13% for India. With a reputation as a "world factory," China is a top supplier of manufacturing outsourcing for many global companies.

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 its 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. Wang and Wei (2008) use disaggregated regional data to investigate the determinants of the rise in export sophistication. 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, Xu (2007) points out that the calculation of Rodrik (2006) and Schott (2008) did not take into account possible quality differences between Chinese varieties and those of other countries, and also did not take into account diverse production capabilities and income level in different Chinese regions. Our study further indicates that the calculations by Rodrik (2006) and Schott (2008) do not take into account the imported content in the country's exports. Therefore, Rodrik's (2006) and Schott (2008)'s assessments on China's exports sophistications are very likely exaggerated. 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 et al. (2001) (HIY in subsequent discussion) propose a method to decompose a country's exports into domestic and foreign value added share based on a country's input–output (I/O) table. They make a key assumption 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. It is important to stress that processing exporters may also use different technologies from normal exporters that call for different usages of imported inputs. They 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 China's exports every year at least since 1996, the HIY formula is likely to lead to a significant under-estimation of the share of foreign value added in its exports.

Since processing exports are widespread,[1] ignoring processing exports is likely to lead to estimation errors, especially for economies that engage in a massive amount of processing trade.

In this paper, we aim to make two contributions to the literature. First, we develop a formula for computing shares of foreign and domestic value added in a country's exports when processing exports are pervasive. The formula allows for potential differences in the use of imported inputs between normal and processing exports. We illustrate mathematically that the HIY formula is a special case of this general formula. The differences between the two types of exports could come from differences in the technology used, responses to different tariff or tax treatments, or some other reasons. This paper does not formally investigate the sources of these differences, and our formula is invariant to the relative importance of the underlying factors. Second, we apply our methodology to China using data for 1997, 2002, and 2007. We estimate that the share of foreign value added in China's manufactured exports was about 50% in both 1997 and 2002, almost twice as high as that implied by the HIY formula, but fell to about 40% in 2007 after 5 years of its WTO membership. 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 low domestic content (about 30% or less).

By design, this paper presents an accounting framework and conducts an accounting exercise. As such, it does not examine determinants and consequences of changes in the domestic content share in China's gross exports. However, a solid methodology to estimate foreign value added share in a country's exports is a necessary first step toward a better understanding of these issues.

Besides the papers on vertical specialization in the international trade literature, this paper is also related to the I/O literature. In particular, Chen et al. (2004) and Lau et al. (2007) are the first to develop a "non-competitive" type I/O model for China (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 infer 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. They focus on estimating U.S.–China bilateral trade balance and make no connection with vertical specialization in the international trade literature. In addition, they use an aggregated version of China's 1995 and 2002 input–output tables, respectively, to perform their analysis, with only 21 goods producing industries. We provide a more up-to-date and more disaggregated assessment of foreign and domestic values added in Chinese exports with more than 80 goods producing industries. Finally, they impose an assumption in estimating the import use matrix from the competitive type I/O table published by China's 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 et al. (2011) that combines China's processing imports statistics with United Nations Broad Economic Categories (UNBEC) classification.

The rest of the paper is organized as follows. Section 2 presents a conceptual framework for estimating shares of domestic and foreign value added in a country's exports when processing exports are

[1] About 3500 export processing zones (EPZs) operated in 130 countries (WTO and IDE_JETRO, 2011).

pervasive. It also describes a mathematical programming procedure to systematically infer a set of I/O coefficients called for by the new formula but not typically available from a conventional I/O table. Section 3 presents the estimation results for Chinese exports. Section 4 concludes.

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 et al. (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, a value-based input–output table 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 $n \times n$ matrix of direct input coefficients of domestic products; $A^M = [a^M{}_{ij}]$ is an $n \times n$ matrix of direct inputs of imported goods; Y^D is an $n \times 1$ 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 $n \times 1$ vector of final demands for imported products, including usages in gross capital formation, private and public final consumption; X is a $n \times 1$ vector of gross output; M is a $n \times 1$ vector of imports; $A_v = [a^v{}_j]$ is a $1 \times n$ vector of each sector j's ratio of value added to gross output, and u is a $1 \times n$ unity vector. Subscripts i and j indicate sectors, and superscripts D and M represent domestically produced and imported products, respectively.

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

[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 IO literature. Hummels et al. (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.

From Eq. (1) we have

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

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

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

where $\hat{A}_V$ an $n \times n$ diagonal matrix with $a^v{}_j$ as its diagonal elements. Eq. (5) indicates that the domestic content for an I/O industry is the corresponding column sum of the coefficient matrix for total domestic output requirement, weighted by the direct value-added coefficient of each industry. Because the standard model assumes that exports and domestic sales are produced by the same technology, the share of domestic content in final demand and the share of domestic content in total exports are the same. So Eq. (5) is also the formula for the share of domestic content in total exports for each industry.

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 Eq. (3), it can be verified that

$$FVS = u - A_v \left(I - A^D\right)^{-1} = uA^M \left(I - A^D\right)^{-1} \tag{6}$$

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 Hummels et al. (2001). In other words, the concepts of vertical specialization and of foreign in gross exports are identical.

2.2. Domestic content in exports when processing trade is prevalent

We now turn to the case in which processing exports are prevalent, and importantly, these exports could 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 Fig. 1.

We use superscript P and D, respectively, to represent processing exports on the one hand, and domestic sales and normal exports on the other. This expanded I/O model can be formally described by the following system of equations:

$$\begin{bmatrix} I - A^{DD} & -A^{DP} \\ 0 & I \end{bmatrix} \begin{bmatrix} X - E^P \\ E^P \end{bmatrix} = \begin{bmatrix} Y^D - E^P \\ E^P \end{bmatrix} \tag{7}$$

$$A^{MD}\left(X - E^P\right) + A^{MP} E^P + Y^M = M \tag{8}$$

$$uA^{DD} + uA^{MD} + A_v^D = u \tag{9}$$

$$uA^{DP} + uA^{MP} + A_v^P = u \tag{10}$$

This is a generalization of the model discussed in the previous subsection. Eqs. (7) and (8) are a generalization of Eqs. (1)–(2), and

[4] $(I - A^D)$ has to be full rank.

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			Intermediate use			
			Production for domestic use & normal exports	Production of processing exports	Final use (C+I+G+E)	Gross Output or Imports
		DIM	1,2,…, N	1,2,…, N	1	1
Domestic Intermediate Inputs	Production for domestic use & normal exports (D)	1 . . . N	Z^{DD}	Z^{DP}	$Y^{D}-E^{P}$	$X-E^{P}$
	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}		

Fig. 1. Input–output table with separate production account for processing trade.

Eqs. (9)–(10) are a generalization of Eq. (3), with a separate account for processing exports. Eqs. (9) and (10) are also the new adding-up constraint for the I/O coefficients.

The analytical solution of the system is

$$\begin{bmatrix} X-E^P \\ E^P \end{bmatrix} = \begin{bmatrix} I-A^{DD} & -A^{DP} \\ 0 & I \end{bmatrix}^{-1} \begin{bmatrix} Y^D-E^P \\ E^P \end{bmatrix} \tag{11}$$

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

$$B = \begin{bmatrix} I-A^{DD} & -A^{DP} \\ 0 & I \end{bmatrix}^{-1} = \begin{bmatrix} B^{DD} & B^{DP} \\ B^{PD} & B^{PP} \end{bmatrix} = \begin{bmatrix} \left(I-A^{DD}\right)^{-1} & \left(I-A^{DD}\right)^{-1}A^{DP} \\ 0 & I \end{bmatrix} \tag{12}$$

Substituting Eq. (12) into Eq. (11), we have:

$$X-E^P = \left(I-A^{DD}\right)^{-1}\left(Y^D-E^P\right) + \left(1-A^{DD}\right)^{-1}A^{DP}E^P \tag{13}$$

Substituting Eq. (13) into Eq. (8), the total demand for imported intermediate inputs is

$$M-Y^M = A^{MD}\left(I-A^{DD}\right)^{-1}\left(Y^D-E^P\right) + A^{MD}\left(1-A^{DD}\right)^{-1}A^{DP}E^P + A^{MP}E^P \tag{14}$$

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:

$$\begin{vmatrix} VSS^D \\ VSS^P \end{vmatrix}^T = \begin{vmatrix} uA^{MD}\left(I-A^{DD}\right)^{-1} \\ uA^{MD}\left(1-A^{DD}\right)^{-1}A^{DP} + uA^{MP} \end{vmatrix}^T \tag{15}$$

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:

$$\overline{VSS} = \left(u-s^P, s^P\right)\begin{vmatrix} VSS^D \\ VSS^P \end{vmatrix} \tag{16}$$

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

$$TVSS = uA^{MD}\left(I-A^{DD}\right)^{-1}\frac{E-E^P}{te} + u\left(A^{MD}\left(1-A^{DD}\right)^{-1}A^{DP} + A^{MP}\right)\frac{E^P}{te} \tag{17}$$

where te is a scalar, the country's total exports. Eq. (16) is a generalization of Eq. (7), the formula to compute industry-level share of vertical specialization. Eq. (17) is a generalization of the formula for country-level share of vertical specialization proposed by Hummels et al. (2001, page 80). In particular, either when $A^{DD}=A^{DP}$ and $A^{MD}=A^{MP}$, or when $E^P/te=0$, Eq. (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:

$$\begin{aligned} \begin{vmatrix} DVS^D \\ DVS^P \end{vmatrix}^T &= \bar{A}_v B = \left(A_v^D \quad A_v^P\right)\begin{bmatrix} \left(I-A^{DD}\right)^{-1} & \left(I-A^{DD}\right)^{-1}A^{DP} \\ 0 & I \end{bmatrix} \\ &= \begin{vmatrix} A_v^D\left(I-A^{DD}\right)^{-1} \\ A_v^D\left(I-A^{DD}\right)^{-1}A^{DP} + A_v^P \end{vmatrix}^T \end{aligned} \tag{18}$$

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

$$\overline{DVS} = \left(u-s^P, s^P\right)\begin{vmatrix} DVS^D \\ DVS^P \end{vmatrix} \tag{19}$$

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

$$TDVS = A_V^D\left(I-A^{DD}\right)^{-1}\frac{E-E^P}{te} + \left(A_V^D\left(1-A^{DD}\right)^{-1}A^{DP} + A_V^P\right)\frac{E^P}{te} \tag{20}$$

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Either when $A^{DD}=A^{DP}$ and $A_v^D=A_v^P$, or when $E^P/te=0$, Eq. (20) reduces to the HIY formula in Eq. (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

Eqs. (18)–(20) 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, and sometimes A^M, but not A^{DP}, A^{DD}, A^{MP} and A^{MD} separately. Therefore, a method to estimate these matrices, based on available information, has to be developed. In this subsection, we propose to do this via a quadratic programming model by combining information from trade statistics and conventional I/O tables.

The basic idea is to use information from the standard I/O table to determine sector-level total imports/exports, and information from trade statistics to determine the relative proportion of processing and normal exports within each sector, thus use up all available data to split the national economy into processing and non-processing blocks, each with its own I/O structure. The first step (using the data from the I/O table to determine sector-level total imports/exports) helps to ensure that the balance conditions in the official I/O account are always satisfied, and that the I/O table with separate processing and non-processing accounts are consistent with the published official table. The second step (using data from trade statistics to determine the relative proportion of processing and normal exports within each sector) helps to ensure that the estimated new I/O table is consistent with the trade structures implied by official trade statistics.

The following data are observable from a standard I/O table and enter the model as constants:

x_i = Gross output of sector i;
z_{ij} = Goods i used as intermediate inputs in sector j;
v_j = Value-added in sector j;
m_i = Total imports of sector i goods; and
y_i = Total final demand except for exports of goods i.

We combine those observed data from the I/O table and processing trade shares[5] observed from trade statistics to determine the values for:

m_i^p = Imports of sector i good used as intermediate inputs to produce processing exports;
m_i^d = Imports of sector i goods used as intermediate inputs for domestic production and normal exports;
e_i^n = Normal exports of sector i; and
e_i^p = Processing exports of sector i.

The partition of imports into intermediate and final use is based on a combination of China custom import statistics and UN BEC classification, as described in Dean et al. (2011). The results of such partition and the actual numbers used in our empirical estimation are reported and discussed in the data source subsection later. Parameters on domestic and imported final demand can be inferred from the observed data discussed above:

y_i^m = Final demand of goods i from imports (residuals of $m_i - m_i^p - m_i^d$);
y_i^d = Final demand of goods i provided by domestic production (residual of $y_i - y_i^m$).

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 the IO coefficients for the expanded I/O model can be written as:

$$A^{DD}=\left[a_{ij}^{dd}\right]=\left[\frac{z_{ij}^{dd}}{x_j-e_j^p}\right],A^{MD}=\left[a_{ij}^{md}\right]=\left[\frac{z_{ij}^{md}}{x_j-e_j^p}\right],A_v^D=\left[a_j^{vd}\right]=\left[\frac{v_j^d}{x_j-e_j^p}\right],$$
$$A^{DP}=\left[a_{ij}^{dp}\right]=\left[\frac{z_{ij}^{dp}}{e_j^p}\right],A^{MP}=\left[a_{ij}^{mp}\right]=\left[\frac{z_{ij}^{mp}}{e_j^p}\right],A_v^P=\left[a_j^{vp}\right]=\left[\frac{v_j^p}{e_j^p}\right],$$

To obtain these unobservable IO coefficients, we need to estimate within-industry transactions $[z_{ij}^{dd}]$, $[z_{ij}^{dp}]$, $[z_{ij}^{md}]$, and $[z_{ij}^{mp}]$, as well as sector-level value added $[v_j^d]$, and $[v_j^p]$, subject to the flowing I/O accounting identities and adding up constraints:

$$\sum_{j=1}^{K}\left(z_{ij}^{dd}+z_{ij}^{dp}\right)=x_i-e_i^p-e_i^n-y_i^d \tag{21}$$

$$\sum_{j=1}^{K}\left(z_{ij}^{md}+z_{ij}^{mp}\right)=m_i-y_i^m \tag{22}$$

$$\sum_{i=1}^{K}\left(z_{ij}^{dd}+z_{ij}^{md}\right)+v_j^d=x_j-e_j^p \tag{23}$$

$$\sum_{i=1}^{K}\left(z_{ij}^{dp}+z_{ij}^{mp}\right)+v_j^p=e_j^p \tag{24}$$

$$\sum_{j=1}^{K}z_{ij}^{md}=m_i^d \tag{25}$$

$$\sum_{j=1}^{K}z_{ij}^{mp}=m_i^p \tag{26}$$

$$\sum_{j=1}^{K}\left(z_{ij}^{dd}+z_{ij}^{dp}\right)=\sum_{j=1}^{K}z_{ij}-\left(m_i^d+m_i^p\right) \tag{27}$$

$$z_{ij}^{dd}+z_{ij}^{dp}+z_{ij}^{md}+z_{ij}^{mp}=z_{ij} \tag{28}$$

$$v_j^d+v_j^p=v_j \tag{29}$$

The economic meanings of these 9 groups of constraints are straightforward. Eqs. (21) and (22) are row sum identities for the expanded I/O account. They state that total gross output of sector i has to equal to the sum of domestic intermediaries, final demand and exports (both processing and normal exports) in that sector. Similarly, total imports have to equal imported intermediate inputs plus imports delivered to final users. Eqs. (23) and (24) are column sum identities for the expanded I/O account. The later defines the value of processing exports in sector j as the sum of domestic and imported intermediate inputs as well as primary factors used in producing processing exports; these four groups of constraints correspond to Eqs. (7)–(10) in the extended I/O model respectively. Eqs. (25)–(29) are a set of adding up constraints to ensure that the solution from the model is

[5] China Customs officially report processing and normal exports at the HS-8 digit level based Chinese customs records. Processing trade are defined by China Customs, which include trade regime "Process & assembling" and "Process with imported materials" in China Customs statistics. These statistics are relatively accurate because they involve duty exemption and value-added tax rebates which under intensive Customs monitoring.

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consistent with official statistics on sector-level trade and within-industry transactions.

We can make initial guesses about the values of the unobserved within-industry transactions and sector-level value added using a combination of official statistics and some proportional assumptions (to be made precise later). These initial values may not satisfy all the adding-up constraints and need to be modified. We cast the estimation problem as a constrained optimization procedure to minimize following objective functions:

$$\text{Min}S = \sum_{i=1}^{K}\sum_{j=1}^{K}\frac{\left(z_{ij}^{dd}-z0_{ij}^{dd}\right)^2}{z0_{ij}^{dd}} + \sum_{i=1}^{K}\sum_{j=1}^{K}\frac{\left(z_{ij}^{dp}-z0_{ij}^{dp}\right)^2}{z0_{ij}^{dp}} + \sum_{i=1}^{K}\sum_{j=1}^{K}\frac{\left(z_{ij}^{md}-z0_{ij}^{md}\right)^2}{z_{ij}^{md}} + \sum_{i=1}^{K}\sum_{i=1}^{K}\frac{\left(z_{ij}^{mp}-z0_{ij}^{mp}\right)^2}{z0_{ij}^{mp}} + \sum_{j=1}^{K}\frac{\left(v_j^d-v0_j^d\right)^2}{v0_j^d} + \sum_{j=1}^{K}\frac{\left(v_j^p-v0_j^p\right)^2}{v0_j^p} \quad (30)$$

Where z's and v's are variables to be estimated, those variables with a 0 in the suffix denote initial values. Because all parameters in the 9 groups of linear constraints (right hand side of Eqs. (21)–(29)) were directly or indirectly obtained from observable official statistical sources, model solutions thus are restricted into a convex set and will be relatively stable respect to variations in these initial values as long as all the parameters in these linear constraints are kept as constants.

The initial value of z_{ij}^{md} and z_{ij}^{md}, are generated by allocating m_i^d and m_i^p in proportion to input i's usage in sector j as Eq. (31):

$$z0_{ij}^{mp} = \frac{z_{ij}\left(e_j^p/x_j\right)}{\sum_k^N z_{ik}\left(e_k^p/x_k\right)} m_i^p \qquad z0_{ij}^{md} = \frac{z_{ij}\left(x_j-e_j^p\right)/x_j}{\sum_k^N z_{ik}\left(x_k-e_k^p\right)/x_k} m_i^d \quad (31)$$

The split of total inter-sector intermediate inputs flow from sector i to sector j between normal and processing use are based on their proportion in gross output. The residuals of the total intermediate inputs and the imported intermediate inputs estimated from Eq. (31) are taken as the initial values for domestically produced intermediate inputs as Eqs. (32) and (33):

$$z0_{ij}^{dd} = z_{ij}\frac{\left(x_j-e_j^p\right)}{x_j} - z0_{ij}^{md} \quad (32)$$

$$z0_{ij}^{dp} = z_{ij}\frac{e_j^p}{x_j} - z0_{ij}^{mp} \quad (33)$$

The initial values for direct value added in the production for processing exports in sector j ($v0_j^p$), are generally set to be the residuals implied by Eq. (24). However, we set a minimum value at the sum of labor compensation and depreciation in a sector multiplied by the share of processing exports in that sector's total output. In other words, the initial value $v0_j^p$ is set to equal the greater of the residuals from Eq. (24) or the minimum value. The initial value for direct value added in the production for domestic sales and normal exports ($v0_j^d$) is set as the difference between v_j (from the I/O table) and $v0_j^p$.

We conduct some sensitivity checks using alternative initial values. It turns out that they do not materially alter our basic conclusions. We implement this quadratic programming model in GAMS (Brooke et al., 2005), related computer programs and data files will be available at the authors' websites for downloading.

3. Estimation results

After describing the data sources, we report and discuss the estimation results for shares of domestic and foreign content in Chinese exports at the aggregate level, and by sector, firm ownership and major destination countries.

3.1. Data

Inter-industry transaction and (direct) value-added data are from China's 1997, 2002 and 2007 benchmark I/O tables published by the National Bureau of Statistics of China (NBS), while detailed exports and imports data of 1997, 2002, and 2007 are from the General Customs Administration of China. The trade statistics are first aggregated from the 8-digit HS level to China's I/O industry, and then used to compute the share of processing exports in each I/O industry. Modifying a method from Dean et al. (2011), we partition all imports in a given commodity classification 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 percentage of China's total imports along with share of processing exports during 1996–2008 is reported in Table 1, which shows a downward trend for the use of imported inputs in producing processing exports, and an upward trend in their use in producing normal exports and domestic final sales.[6]

We report detailed trade share parameters for each I/O industry in the three benchmark year (1997, 2002, and 2007) in Appendix Tables A–C. (The tables are to be posted online rather in published in the print version.) These data computed directly from detailed Chinese official trade statistics (at 8 digit HS) are important to understand our estimates of domestic and imported content in Chinese gross exports, especially cross sector heterogeneity and their changes over time. Our estimation results reflect these parameters.

3.2. Domestic and foreign contents in total exports

Table 2 presents the results for the decomposition of aggregate foreign and domestic value-added shares in 1997, 2002 and 2007. For comparison, the results from the HIY method that ignores processing trade are also reported. The estimated aggregate domestic value added share in China's merchandise exports was 54% in 1997, and 60.6% in 2007. For manufacturing products, these estimated shares are slightly lower in levels but trending upward more significantly from 50.0% in 1997 to 59.7% in 2007. In general, the estimated direct domestic value-added shares are less than half of the total domestic value-added shares. However, the estimated indirect foreign value-added share was relatively small; most of the foreign content comes from directly imported foreign inputs, especially in 1997 and 2002. The indirect foreign value-added increase over time, and reach about a quarter of China's directly imported foreign inputs in 2007, indicating the share of simple processing and assembling of foreign parts is declining, while more imported intermediates are being used in the production of other intermediate inputs that are then used in the production process of exported goods.

Relative to the estimates from the HIY method, our procedure produces estimates of a much higher share of foreign value added in Chinese gross exports and with a different trend over time. To be more precise, estimates from the HIY method would show that the foreign content share (total VS share) increased steadily from 17.6% in 1997 to 28.7% in 2007 for all merchandise exports, and from 19.0% to 27.1% for manufacturing only during the same period. In contrast, our estimates suggest a trend in the opposite direction, with the share of foreign value added in all merchandise exports falling from

[6] Sector level counterparts of the data in Table 1 are used to determine the parameters in Eqs. (21)–(26). Additional parameters in Eqs. (27)–(29) are directly obtained from China's official benchmark IO tables.

Table 1
Major trade share parameters used in estimation, 1997–2008.

Year	Imported intermediates %		Imported capital goods %		Imported final consumption %	Processing exports as % of total exports
	For processing exports	For normal use	For processing exports	For normal use		
	(1)	(2)	(3)	(4)	(5)	(6)
1996	46.2	26.8	16.7	8.1	2.2	56.0
1997	51.2	28.2	12.1	7.3	1.3	55.1
1998	50.7	28.2	9.7	10.0	1.4	57.4
1999	43.6	35.0	8.2	11.2	2.0	57.3
2000	39.4	41.2	8.5	9.1	1.8	55.7
2001	36.6	41.2	8.7	11.6	1.9	55.9
2002	38.0	39.1	10.2	11.0	1.8	55.9
2003	35.0	41.8	10.7	10.8	1.6	56.0
2004	34.7	43.0	11.8	8.9	1.5	56.3
2005	36.1	43.6	10.6	8.1	1.5	55.6
2006	35.3	44.2	9.8	8.9	1.7	53.6
2007	32.7	47.3	9.0	7.6	3.3	50.1
2008	27.5	53.5	8.1	7.2	3.7	48.1

Source: Authors' calculations based on official China Custom trade statistics and the United Nation Broad Economic Categories (UNBEC) classification scheme.
Note: "Normal use" refers to "normal exports and domestic sales." The UNBEC scheme classifies each HS 6-digit product into one of three categories: "intermediate inputs," "capital goods," and "final consumption." For the first two categories, we further decompose the imports into two subcategories: "processing imports" by customs declaration are classified as used for producing processing exports and cannot be sold to any domestic users by regulation, and the remaining imports are classified as for normal use. Capital goods are part of the final demand in a conventional I/O model (Column (1) to (5) sum to 100%). However, this classification may under-estimate the import content of exports. We therefore also experiment with classifying a fraction of the capital goods as inputs used in current year of production. This is discussed in Section 3.2.

46% in 1997 to 39.4% in 2007, and a somewhat more dramatic decline for the share in manufacturing exports from 50% in 1997 to 40.3% in 2007. The decline occurred mainly during the 2002–2007 period, which corresponds to the first 5 years of China's entry to the WTO. Our estimates indicate that the HIY method appears to incorrectly estimate both the level and the trend in domestic versus foreign content in the PRC's exports. These striking differences indicate the importance of taking account of differences between processing and normal exports.

What accounts for the difference between ours and HIY approaches? There are at least three factors that drive the change of foreign content of the country's gross exports: (1) the relative proportions of imported intermediate inputs in producing processing exports and normal exports and domestic sales; (2) the share of processing exports in its total exports; and (3) the sector composition of its exports. Because processing exports tend to use substantially more imported inputs, and processing exports account for a major share of China's total exports, the HIY indicator substantially underestimates the true degree of foreign content in China's exports. This explains why the level of domestic content by our measure is much lower than that of the HIY indicator. On the other hand, as exporting firms (both those producing for normal exports and those for processing exports) gradually increase their intermediate inputs sourcing from firms within China including multinationals that have moved their upstream production to China, the extent of domestic content in exports rises over time. This process is likely aided by China's accession to the WTO. However, because exports from industries with relatively lower domestic content often grow faster, the composition of a country's total exports may play as an offsetting role to slow down the increase of domestic value-added share in the country's total exports. As the Chinese government started to narrow the gap in policy treatments for both foreign invested firms relative to domestic firms and processing exports relative to normal exports since the end of 2006, the domestic content share of Chinese exports could continue its rise in the future.

Table 2
Shares of domestic and foreign value added in total exports (%).

	The HIY method			The KWW method		
	1997	2002	2007	1997	2002	2007
All merchandise						
Total foreign value-added	17.6	25.1	28.7	46.0	46.1	39.4
Direct foreign value-added	8.9	14.7	13.7	44.4	42.5	31.6
Total domestic value-added	82.4	74.9	71.3	54.0	53.9	60.6
Direct domestic value-added	29.4	26.0	20.3	22.2	19.7	17.1
Manufacturing goods only						
Total foreign value-added	19.0	26.4	27.1	50.0	48.7	40.3
Direct foreign value-added	9.7	15.6	16.3	48.3	45.1	32.4
Total domestic value-added	81.1	73.6	72.9	50.0	51.3	59.7
Direct domestic value-added	27.5	24.6	24.6	19.6	18.1	16.5

Source: Authors' estimates based on China's 1997, 2002 and 2007 Benchmark input–output table published by Bureau of National Statistics and Official China trade statistics from China Customs.
Note: The HIY method refers to estimates from using the approach in Hummels et al. (2001). The KWW method refers to estimates from using the approach developed in this paper that takes into account special features of processing exports.

Our interpretation is confirmed by DVA shares for processing and normal exports estimated separately (Table 3). There is an increase by more than 10 percentage points in the total foreign value-added share for domestic sales and normal exports between 1997 and 2007. However, in processing exports, as we see that more domestically produced inputs were used, the domestic value-added share increased from 20.7% in 1997 to 37.0% in 2007, up by more than 16 percentage points. Because processing exports still constitute more than 50% of China's total exports in 2007, the domestic value-added share in total exports climbed up during the decades. Because the gap in the domestic content shares is large between the two types of exports, it is unlikely to disappear any time soon.

We perform a number of robustness checks on the sensitivity of our main results to alternative ways of setting the initial values of the variables and the share parameters of import use. First, we initialize $v0_j^p$ and $v0_j^d$ by apportioning the observed direct value added in a sector to processing exports and other final demands based on their respective portions in the sector's total output. Second, we initialize $v0_j^p$ either at the residuals implied by Eq. (24) if the residuals are positive, or by following the previous alternative if the residuals are nonpositive. Third, when we partition imports into different users, we use the average of a three-year period (previous, current, and following years) rather than just one year's statistics. Fourth, we experiment with 0% versus 10% annual depreciation rate for capital goods. These

Table 3
Domestic and foreign values added: processing vs. normal exports (in percent of total exports).

	Normal exports			Processing exports		
	1997	2002	2007	1997	2002	2007
All merchandise						
Total foreign value-added	5.2	10.4	16.0	79.0	74.6	62.7
Direct foreign value-added	2.0	4.2	5.0	78.6	73.0	58.0
Total domestic value-added	94.8	89.6	84.0	21.0	25.4	37.3
Direct domestic value-added	35.1	31.9	23.4	11.7	10.1	10.9
Manufacturing goods only						
Total foreign value-added	5.5	11.0	16.4	79.4	75.2	63.0
Direct foreign value-added	2.1	4.5	5.2	79.0	73.6	58.3
Total domestic value-added	94.5	89.0	83.6	20.7	24.8	37.0
Direct domestic value-added	31.5	29.5	22.4	11.7	10.0	10.9

Source: Authors' estimates based on China's 1997, 2002 and 2007 Benchmark input–output table published by Bureau of National Statistics and Official China trade statistics from China Customs.
Note: The HIY method refers to estimates from using the approach in Hummels et al. (2001). The KWW method refers to estimates from using the approach developed in this paper that takes into account special features of processing exports.

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variations produce relatively little change in the main results. In particular, the pattern of a trend increase in the domestic content share in total exports is robust to these variations.

3.3. Domestic content in exports by firm ownership

Since foreign-invested firms account for over half of China's exports, one may be interested in the domestic content share in their exports. However, since there is no information on separate input–output coefficients by firm ownership, we cannot meaningfully distinguish foreign versus local firms within a sector and trade regime (processing or normal exports). Instead, we provide an estimate of the domestic content share of aggregate exports by foreign invested firms. By construction, the differences across firms of different ownership are driven entirely by different degrees of their reliance on processing exports within a sector, and differences in the sector composition of their total exports (both are observed directly from the customs trade statistics).

Estimates of the domestic content shares by firm ownership are presented in Table 4. The results show that exports by wholly foreign owned enterprises exhibit the lowest share of domestic valued-added but rose relatively quickly (from 33.4% in 2002 to 44.1% in 2007), followed by Sino-foreign joint venture companies (at about 44% in both 2002 and 2007). Exports from Chinese private enterprises embodied the highest domestic content shares (83.9% and 80.8% in 2002 and 2007, respectively), while those from the state-owned firms were in the middle (about 70% in both years). Note that these estimates represent the best guesses based on currently available information; better estimates can be derived once information on I/O coefficients by firm ownership becomes available.

The most noticeable feature of this table is the rising domestic content shares in exports produced by foreign invested firms by more than 10 percentage points from 2002 to 2007. This suggests that the increase in the domestic content share is mainly due to foreign invested processing exporters sourcing more of their intermediate inputs from within China. This is presumably also linked to more multinationals moving their upstream production to China.

3.4. Domestic content by sector

To see if there are interesting patterns at the sector level, Tables 5 and 6 report, in ascending order of the domestic content share, the value-added decomposition in Chinese manufacturing exports by industry in 2002 and 2007, respectively, together with the shares of processing trade and foreign invested firms in each sector's exports and the sector's share in China's total merchandise exports. Because the sector classifications are consistent between 2002 and 2007 (but less so between 1997 and 2002), we choose to report the sector-level results only for 2002 and 2007.

Among the 57 manufacturing industries in the table, 15 have a share of domestic value-added in their exports less than 50% in 2002; they collectively account for nearly 35% of China's merchandise exports that year. It is interesting to note that many low-DVA industries are likely to be labeled as relatively sophisticated, such as telecommunication equipment, electronic computer, measuring instruments, and electronic devices. A common feature of these industries is that processing exports account for over two-thirds of their exports (and foreign invested enterprises played an overwhelming role). In 2007, the number of industry with less than 50% domestic contents in their exports declined to 10, and their collective share in China's total exports also declined to 32%.

The next 18 industries in Table 6 have their shares of domestic value-added in the range of 51 to 65%; they collectively accounted for 28% of China's total merchandise exports in 2002. Several labor-intensive sectors are in this group, such as furniture, toys and sports products, Leather, fur, down and related products.

The remaining 24 industries have relatively high shares of domestic value-added. They as a group produced slightly less than 30% of China's total merchandise exports in 2002. Apparel, the country's largest labor intensive exporting industry, which by itself was responsible for 7% of the country's total merchandise exports in 2002, is at the top of this group with a share of domestic content at 66%. The 12 industries at the bottom of Table 6 with DVA share more than 75% collectively produced only 10% of China's total merchandise exports in 2002.

The high-DVA industries have seen their weights in the country's total exports to rise significantly from 2002 to 2007. The number of industries with DVA share of more than 75% increased from 12 in 2002 to 25 in 2007 (comparing the bottoms of Tables 5 and 6), and their exports as a share of the country's total exports also rose from 10% in 2002 to more than 30% in 2007. Among these high-DVA industries, besides the traditional labor-intensive industries such as furniture, textiles and apparel, we start to see capital and skill intensive industries such as automobile, industrial machinery and rolling steel

Table 4
Shares of domestic value added in exports by firm ownership (%), 2002 and 2007.

	Share of processing exports in total exports	Non processing		Processing		Weighted-sum		Share of exports by firm ownership in China's total exports
		Direct domestic value-added	Total domestic value-added	Direct domestic value-added	Total domestic value-added	Direct domestic value-added	Total domestic value-added	
2002								
Wholly foreign owned	87.5	34.9	90.1	9.8	25.3	13.0	33.4	28.9
Joint venture firms	70.5	31.2	89.4	9.9	24.5	16.2	43.6	22.9
State owned firms	32.2	32.1	89.6	10.7	26.4	25.2	69.3	38.1
Collectively owned firms	27.4	29.9	89.6	10.8	28.2	24.7	72.8	5.8
Private firms	9.0	30.7	89.6	10.7	26.3	28.9	83.9	4.3
All firms	**55.7**	31.8	89.3	10.1	26.1	19.7	**53.9**	**100.0**
2007								
Wholly foreign owned	83.0	23.8	83.8	11.4	36.0	13.5	44.1	38.1
Joint venture firms	59.5	23.0	83.6	10.4	38.7	15.5	56.9	17.7
State owned firms	25.8	23.4	83.4	10.0	39.5	20.0	72.1	18.9
Collectively owned firms	24.0	22.4	83.1	8.9	42.0	19.1	73.3	4.0
Private firms	9.6	23.5	84.9	9.8	42.0	22.2	80.8	21.3
All firms	50	23.5	83.9	10.5	38.7	17.1	60.6	100.0

Source: Authors' estimates based on China's 2002 and 2007 Benchmark input–output table published by Bureau of National Statistics and Official China trade statistics from China Customs. Input/output structure is assumed to be the same for a given export regime within a sector across all type firms. The variation of domestic value-added by firm types is due solely to variation in sector composition and the relative reliance on processing exports. The numbers reported in the row "All firms" are shares for China's total merchandise exports. Some of them may slightly differ from numbers reported in the up penal of table 3 due to rounding errors.

Table 5
Domestic value-added share in manufacturing exports by sector, 2002.

IO industry description	Value-added decomposition %			% of processing exports	% of FIE exports	% of merchandise exports
	Non-processing	Processing	Weighted sum			
Telecommunication equipment	87.5	5.3	12.5	91.2	88.4	3.2
Ship building	82.3	14.7	17.5	95.8	21	0.6
Electronic computer	83.6	18.7	19.3	99.1	89.7	7
Cultural and office equipment	79.7	19.3	23.3	93.4	71.6	4.3
Household electric appliances	88.2	6.8	23.9	79.1	56.9	1.9
Household audiovisual apparatus	82.5	21.3	27	90.6	62.3	5.2
Printing, reproduction of recording media	91.1	19.7	31.9	83	62.7	0.3
Plastic	84.4	10.3	36.6	64.5	51.2	2.4
Electronic component	84.6	32.8	38.1	89.7	87.5	3.4
Steelmaking	89	12.8	44.3	58.8	86.1	0
Generators	85.2	32	44.3	76.8	55.8	0.9
Other electronic and communication equipment	97.8	36	45.3	84.9	84.9	1.8
Rubber	90.6	12.2	48.9	53.1	44.4	1.6
Nonferrous metal pressing	86.2	7.5	49.3	46.9	48.7	0.4
Measuring instruments	85.8	32.9	49.5	68.6	51.8	1.8
Paper and paper products	90.8	12.4	51.1	50.7	57	0.5
Furniture	88.3	12.5	52.5	47.2	56.8	1.7
Articles for culture, education and sports activities	87.5	38.2	52.7	70.6	56.3	3.3
Nonferrous metal smelting	88.9	10.6	53.6	45	17.4	0.8
Smelting of ferroalloy	83.6	13	54.8	40.8	13.1	0.2
Synthetic materials	80.5	37.1	55.2	58.3	65.4	0.3
Petroleum refine and nuclear fuel	79.4	5.5	55.7	32.1	24.9	0.8
Metal products	90.3	10.2	55.7	43.2	45.6	4.4
Other transport equipment	86	12.7	55.8	41.2	50.5	1.2
Other electric machinery and equipment	88.4	40.1	56.2	66.8	60.1	5.6
Special chemical products	82.9	31.4	58.7	46.9	48.4	0.8
Other manufacturing products	89.2	31.3	59	52.2	37.6	1.7
Woolen textiles	91.1	8.8	60.1	37.8	42.6	0.3
Paints, printing inks, pigments and similar products	83.5	8.3	61.6	29.1	44.4	0.4
Motor vehicles	89.6	10	61.6	35.2	48.2	0.8
Glass and its products	86.8	16.5	63.6	33	48.8	0.5
Leather, fur, down and related products	91.9	40.4	63.9	54.3	50.3	4.5
Chemical products for daily use	85.3	26.8	64.1	36.3	43.6	0.4
Wearing apparel	91.3	34.3	65.6	45.1	39.2	7
Chemical fiber	80.2	9.2	65.7	20.5	29.2	0
Other special industrial equipment	89.3	32	66.4	39.9	44	1.3
Boiler, engines and turbine	85.9	13.1	66.5	26.7	28.4	0.4
Other industrial machinery	90.1	38.6	67.6	43.7	43.7	3.5
Iron-smelting	86.8	11	68.8	23.7	3	0.1
Railroad transport equipment	83.9	14.6	70.1	19.9	5.9	0.1
Wood, bamboo, rattan, palm and straw products	87.8	11.3	72.8	19.6	45.6	1
Knitted and crocheted fabrics and articles	90.6	34.7	72.9	31.6	34.2	5.8
Agriculture, forestry, animal husbandry and fishing machinery	85.7	13.9	72.9	17.8	20.8	0.1
Pesticides	77	11.5	72.9	6.3	14.4	0.2
Hemp textiles	89.5	11.7	74.3	19.5	19.5	0.3
Textiles productions	90.1	28.9	75.5	24	31.8	1.4
Cotton textiles	91.8	35.6	75.7	28.7	28.8	3.3
Fire-resistant materials	90.5	15.4	76.2	19.1	49.8	0.1
Metalworking machinery	87.2	18.8	78.1	13.3	27	0.2
Medicines	90.2	24.3	79.1	16.9	28.7	0.7
Pottery and porcelain	88.2	14.8	79.8	11.4	33.1	0.7
Other non-metallic mineral products	90.4	16.7	80.1	14	35.7	0.4
Fertilizers	84.4	9.7	81.1	4.5	21.7	0.1
Basic chemical raw materials	87.1	43.7	82	11.7	18.8	2
Rolling of steel	90.2	40.5	82.3	16	16.8	0.3
Cement, lime and plaster	91	20.3	86	7	77.7	0.1
Coking	91.4	13.2	89.4	2.6	5.3	0.3
Total merchandise	89.6	25.4	53.9	55.7	51.8	92.5

Data source: Authors' estimates. China 2002 and 2007 benchmark I/O table have 84 and 90 goods producing sector respectively, they both concord to China's 4 digit classification of economic activities (GB/T 4754-2002). This concordance enable us aggregate both year's estimates to 77 consistent goods producing industries reported in this table.

(accounting for nearly one third of these high-DVA sector's exports). This likely reflects industrial upgrading in the Chinese economy.

3.5. DVA shares in Chinese exports by trading partners

By assuming domestic value added shares within a given sector and export regime are the same for all destination countries, we can further estimate the domestic value-added share in China's exports to each of its major trading partners. Note, however, the variation by destination in this method is driven solely by China's export structure (sector composition) to each of its trading partners. The decomposition results for China's total merchandise exports to each of its major trading partners are reported in Table 7 in increasing order of the estimated domestic value-added share in 2002.

Hong Kong, the United States, Singapore, Taiwan and Malaysia are at the top of the table in both 2002 and 2007, with less than or about 60% of China's domestic value-added embodied in its exports. The noteworthy pattern is that China's exports to developing countries tend to embody much higher domestic valued added than its exports to OECD countries. While this pattern appears to mirror the finding by

Table 6
Domestic value-added share in manufacturing exports by sector, 2007.

IO industry description	Value-added decomposition %			% of processing exports	% of FIE exports	% of merchandise exports
	Non-processing	Processing	Weighted sum			
Household audiovisual apparatus	75.9	29.6	32.6	93.4	79.1	2.5
Electronic computer	75.7	33	33.9	97.9	93.3	11.3
Cultural and office equipment	74.1	33.1	36.5	91.7	86.4	1.6
Other electronic and communication equipment	68	34.7	39.7	84.8	81.6	1.4
Telecommunication equipment	75.2	35.3	43.6	79.3	83.6	5.9
Ship building	83.9	39.1	43.8	89.4	16.5	1.1
Petroleum feline and nuclear fuel	68.7	20.1	44.4	50.1	27.3	0.7
Measuring instruments	80	37.8	45.8	81.2	73.3	2.5
Synthetic materials	76.4	34	47.7	67.7	66.1	0.6
Household electric appliances	82	35.6	51.8	65.1	61.7	2.7
Other electric machinery and equipment	80.3	33.7	52.1	60.5	65.9	4.9
Rubber	81.8	27	53.4	51.8	41.9	1.7
Plastic	80.8	31.1	55.1	51.7	54.7	1.7
Articles for culture, education and sports activities	83	45.6	58.4	66	64.9	2.1
Special chemical products	76.7	34	61.6	35.3	51.2	0.8
Chemical fiber	76.4	51.9	62.6	56.2	48.7	0.3
Other special industrial equipment	82.5	43	65.2	43.8	54.7	2.7
Generators	80.3	51.2	66.6	47.2	50.3	0.7
Railroad transport equipment	77.7	54.1	69	37.0	12.2	0.1
Leather, fur, down and related products	90.4	40.4	69.2	42.5	46.0	2.4
Paper and paper products	85.5	57.6	69.2	58.4	62.8	0.4
Metal products	85.1	39.7	70.1	32.9	49.5	4.4
Boiler, engines and turbine	81.6	38.7	70.6	25.6	37.8	0.5
Nonferrous metal pressing	78.6	56.1	71.2	32.7	41.4	1
Other manufacturing products	86.5	48.1	72.3	36.8	41.5	1.6
Paints, printing inks, pigments and similar products	76.5	56.8	72.6	20.1	47.3	0.3
Pesticides	73.9	53.6	72.9	4.8	19.5	0.1
Chemical products for daily use	80.8	58.4	73.3	33.5	55.5	0.3
Nonferrous metal smelting	76.2	56.4	73.3	14.6	19.6	0.8
Other transport equipment	81	54.9	73.8	27.8	46.5	0.9
Basic chemical raw materials	80.8	42.5	74.9	15.6	26.4	1.9
Motor vehicles	84	47.4	75.3	23.7	42.0	2
Agriculture, forestry, animal husbandry and fishing machinery	80.6	57.7	75.6	21.9	32.7	0.1
Other industrial machinery	83.6	56.2	75.6	29.0	49.9	3.4
Iron-smelting	75.9	50.6	75.6	1.1	24.3	0.1
Smelting of ferroalloy	75.7	53.3	75.6	0.4	8.8	0.4
Furniture	86.7	56.1	76.2	34.2	56.0	2
Printing, reproduction of recording media	86.4	61	76.5	39.0	44.4	0.2
Glass and its products	83.3	59	76.7	27.2	46.4	0.6
Woolen textiles	89.4	57.9	76.9	39.8	46.8	0.2
Metalworking machinery	81.2	56.8	77.3	16.0	36.4	0.3
Rolling of steel	80	52.9	77.8	8.3	22.6	3.8
Fertilizers	81	57.3	77.9	13.2	9.5	0.3
Cotton textiles	88	45.8	78.9	21.5	26.1	2.1
Wearing apparel	89.5	53.9	79	29.7	36.9	4.6
Medicines	87.6	37.5	80.3	14.5	32.3	0.8
Wood, bamboo, rattan, palm and straw products	84.6	58.4	80.4	16.1	33.1	1
Steelmaking	80.8	51.7	80.8	0.2	7.1	0.3
Pottery and porcelain	83.4	58.2	82	5.2	29.9	0.5
Textiles productions	88.4	54.9	82.4	18.1	35.1	1.8
Knitted and crocheted fabrics and articles	88.2	51.6	82.5	15.6	25.7	5.7
Other non-metallic mineral products	86	56.6	83	10.1	25.1	0.5
Hemp textiles	86.6	56.8	83.9	9.0	14.7	0.2
Fire-resistant materials	86.6	55.1	84.7	5.8	51.6	0.1
Cement, lime and plaster	89	52.9	88.4	1.7	29.6	0.1
Coking	89.6		89.6	0	11.4	0.3
Total merchandise	84	37.3	60.6	50.1	55.7	96

Data source: Authors' estimates. China 2002 and 2007 benchmark I/O table have 84 and 90 goods producing sector respectively, they both concord to China's 4 digit classification of economic activities (GB/T 4754-2002). This concordance enable us aggregate both year's estimates to 77 consistent goods producing industries reported in this table.

Manova and Zhang (2009) that China's export prices tend to be lower in lower income countries, our data and method do not allow us to estimate destination-specific domestic value share within a product.

Interestingly, the domestic value-added share in China's exports to high income country increased between 2002 and 2007, while it declined for exports to developing countries. This suggests that progressively more locally supplied inputs are used in making exports to high income countries while the opposite may be true for exports to developing countries.

4. Concluding remarks

Segmentation of production across countries allows for reductions in production costs and more efficient allocation of resources, but also creates a wedge between the gross export value and the domestic value added that is embedded in the exports. Because processing exports may have a different tendency to use imported inputs from normal exports, it is important to account for such differences in estimating the share of domestic value added in a country's exports.

Table 7
Total domestic value-added share in chinese gross merchandise exports to its major trading partners, in percent, 2002 and 2007.

Region description	Share of processing exports in total exports		*Non processing*		*Processing*		*Weighted-sum*		Share in total exports to the world	
Year	2002	2007	2002	2007	2002	2007	2002	2007	2002	2007
Hong Kong	74.0	77.4	89.8	83.0	26.3	35.3	42.8	46.0	17.5	14.3
United States	67.2	61.7	89.2	84.6	24.3	38.2	45.5	56.0	21.6	19.1
Singapore	62.7	59.7	88.7	83.4	24.3	33.0	48.3	53.3	2.1	2.4
Taiwan province	59.6	50.7	89.3	81.9	27.1	34.9	52.2	58.0	2.0	1.9
Malaysia	57.6	52.0	90.4	84.0	25.5	33.5	53.0	57.7	1.5	1.5
Japan	59.2	56.4	90.7	85.4	27.6	40.5	53.3	60.1	15.0	8.4
EU15	54.8	50.9	89.4	84.0	23.6	37.2	53.4	60.2	14.9	18.3
Thailand	48.1	38.8	88.3	82.0	22.9	38.7	56.8	65.2	0.9	1.0
Rest of OECD	46.9	38.5	89.7	85.4	25.4	40.3	59.5	68.0	1.7	2.1
Korea Rep	45.4	43.2	90.4	83.5	27.1	37.0	61.6	63.4	4.8	4.7
Australia/NZ	41.6	42.8	89.3	84.4	23.0	38.6	61.7	64.8	1.6	1.7
Mexico	42.1	49.1	89.6	84.2	26.6	35.8	63.1	60.4	0.9	0.9
Philippines	37.6	38.2	89.1	83.5	25.2	33.8	65.1	64.5	0.6	0.6
EU12	36.5	50.8	90.2	83.4	22.9	35.8	65.7	59.2	1.5	1.9
Brazil	35.0	36.7	89.4	83.2	27.1	37.7	67.6	66.5	0.5	0.9
India	24.0	27.0	89.3	81.7	21.5	38.6	73.1	70.1	0.8	2.0
Rest of Latin Am/Caribbean	20.3	24.2	89.2	83.4	23.1	38.1	75.8	72.5	1.6	2.4
Indonesia	20.7	23.4	89.4	83.3	25.8	36.1	76.2	72.2	1.1	1.1
Middle East/North Africa	19.4	18.2	89.3	83.9	21.9	38.8	76.3	75.6	3.6	4.8
Eastern Europe/Central Asia	18.9	16.6	89.4	85.0	26.3	39.2	77.5	77.4	0.9	2.8
Rest Asia	17.2	18.9	88.6	83.5	27.0	41.6	77.9	75.6	2.2	2.6
Sub-Saharan Africa	15.5	16.1	89.6	83.9	22.1	38.8	79.2	76.6	1.4	2.1
Russia	15.5	16.9	90.9	85.6	30.4	39.3	81.5	77.8	1.1	2.4
World	55.7	50.0	89.6	84.0	25.4	37.3	53.9	60.6	100.0	99.9

Source: Authors' estimates based on China's 2002 and 2007 Benchmark input–output table published by Bureau of National Statistics and Official China trade statistics from China Customs. Input/output structure is assumed to be the same for a given export regime within a sector across all trading partners. The variation of domestic value-added by destination is due solely to variations in sector composition and the relative reliance on processing exports.

In this paper, we present a general framework in assessing the shares of domestic and foreign value added in a country's exports when processing exports are explicitly accounted for. This formula nests the existing best known approach (Hummels et al.,, 2001) as a special case. If separate input–output coefficients for processing and normal exports are available, our formula can be applied in a straightforward way.

Because some of the I/O coefficients called for by the new formula are not readily available from conventional I/O tables, we propose an easy-to-replicate mathematical programming procedure to estimate these coefficients by combining information from detailed trade statistics (which records processing and normal exports/imports separately) with conventional input–output tables. This methodology should be applicable to Vietnam, Mexico, and many other developing countries that engage in a significant amount of processing exports.

By applying our methodology to the Chinese data, we find several interesting patterns. First, the share of foreign content in China's manufacturing exports was close to 50% during 1997–2002, almost twice as high as that calculated using the HIY formula. Second, the share of domestic content increased from 51% to 60% for China's manufacturing exports during 2002–2007, which corresponds to the first five years of China's membership in the WTO. We also 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 lower 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 foreign invested firms (including both wholly-owned foreign firms and Sino-foreign joint venture firms) tend to have a relatively low share of domestic content in their exports as they tend to use more processing exports and take large shares in sectors that have a relatively low domestic value added share.

There are several areas in which future research can improve upon the estimation in this paper. First, we assign initial values of the direct domestic value added for processing exports at the industry level based on the information in a conventional I/O table and proportion assumptions. If firm-level survey data becomes available that tracks separately the direct value added for processing and normal exports, and provide information on how the imported intermediate inputs are allocated across sector users, we can improve the accuracy of our estimates. Second, as an inherent limitation of an I/O table, the input–output coefficients are assumed to be fixed—that is the nature of the assumed Leontief technology—rather than be allowed to respond to price changes. If the relevant I/O tables are available every year, then the variations in the I/O coefficients would be recorded. If I/O tables are available only sparsely (e.g. once every five years), which tend to be the case for developing countries, then estimating domestic value shares in exports based on past I/O tables could be problematic, especially in years when large shocks could induce large (but unobserved) changes in the I/O coefficients.

This paper does not directly investigate causes and consequences of changes in the domestic content share in exports. These can be fruitful areas for future research.

Appendix A. Supplementary data

Supplementary data to this article can be found online at doi:10.1016/j.jdeveco.2011.12.004.

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