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Abstract

Two recent phenomena have transformed the nature of world trade: the explosive growth of Chinese trade, and the growth of vertically specialized trade due to international production fragmentation. While vertical specialization may explain much of the growth and unique features of Chinese trade, few papers have quantitatively assessed these two phenomena together. In part, this is because it is difficult to measure just how vertically specialized Chinese trade is. The unique features of China's extensive processing trade cause both the identification of imported intermediate goods, and their allocation across sectors, to depend upon the Chinese trade regime. In this paper, we estimate the vertical specialization of Chinese exports, addressing these two challenges. Using two Chinese benchmark input-output tables, and a detailed Chinese trade dataset which distinguishes processing trade from other forms of trade, we develop a new method of identifying intermediate goods imported into China. Vertical specialization is then estimated using two methods. The first method uses the Hummels, Ishii and Yi (2001) measure, the official benchmark IO tables, and incorporates our identification correction. The second method follows the first, but also incorporates the Koopman, Wang and Wei (2008) method of splitting the benchmark IO tables into separate tables for processing and normal exports, in order to address the allocation problem. Results show strong evidence of an Asian network of intermediate suppliers to China, and the two methods provide a range of estimates for the foreign content of Chinese exports. For 2002, we find the vertical specialization of China's aggregate exports ranged between 25% and 46%, with some individual sectors as high as 52%-95%. Across destinations, under both methods, vertical specialization declined with the income level of the trading partner.

JEL Codes: F10, F14
Key Words: China, fragmentation, vertical specialization, trade growth

1. Introduction

In recent years, two interrelated important phenomena have occurred that transform the nature of global trade. The first phenomenon is the international fragmentation of production. Production processes are sliced thinner and thinner into many stages, and the resulting production fragments are carried out in many countries, each specializing in different stages of the vertical production chain. The second phenomenon is the explosive growth of Chinese trade, and China's increasing importance in these global production chains. In current dollars, the value of China's exports plus imports rose from $280.9 billion in 1995 to $1760.4 billion in 2006--a growth of about 527%. In that year, 42 percent of China's imports and 53 percent of China's exports were processing trade--imports of intermediate goods which are further processed or finished, and are made solely for export. This trade is concentrated in fragments within relatively high-tech products, and is carried out largely by foreign-invested enterprises.

China's prominence in trade has raised numerous questions. How is it that China's trade can grow so rapidly? Has China's comparative advantage really shifted to production of high-tech goods? How does this rapid growth and new composition of trade affect China's gains from trade? Increasingly, it appears that the answers to these questions may be found by studying the impact of international production fragmentation on China's trade. Because the splitting of the production process leads to products crossing borders many more times than in ordinary trade, production fragmentation across borders could account for rapid growth in trade (Yi, 2003). While China's final good exports may appear far more high-tech than traditional comparative advantage would predict (Rodrik, 2006; Schott, 2006), fragmentation theory suggests that the fragments which make up the production chain are likely to be allocated across countries in a way that reflects traditional comparative advantage (Jones and Kierzkowski, 2001). Finally, the global gains from trade may be enlarged because international production fragmentation allows more finely defined production processes to be allocated across countries more efficiently (Yi, 2003).[1] Unlike intra-industry trade, this "intra-product" trade might particularly foster the growth of trade between industrial and developing countries (Jones, et al., 2005).

But to what extent has China's trade been influenced by international production fragmentation? Recent literature studying the pattern and growth of Chinese trade has focused on foreign direct investment, trade liberalization, WTO accession, and government incentives, with little discussion of fragmentation.[2] Similarly the literature on fragmentation has largely focused on developing and testing various theories of the firm's decision to fragment production across borders, with little application to China.[3] A few studies have attempted to measure the importance of trade in parts and components in global, East Asian, and Chinese trade (Yeats, 2001; Ng and Yeats 2001, 2003; Athukorala, 2006; Athukorala and Yamashita, 2006), or document the growing importance of China in East Asian trade in parts and components (Baldwin, 2006; Athukorala, 2006). But little work has been done exploring the degree to which China's trade has become vertically specialized due to production fragmentation. One exception is Ping (2005), who uses the Hummels, Ishii, and Yi (2001) (HIY) measure of vertical specialization, and finds the foreign content of Chinese exports to be only 15% in 1997, growing to only 21% in 2002.[4]

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[1] An individual country's gains from trade might also be enlarged if fragmentation lowers adjustment costs to trade liberalization, by allowing displaced workers to find new employment in a different stage of production within the same sector (Deardorff, 2001; Jones and Kierzkowski, 2001). Deardorff (2005) argues that in a world of fragmentation, the gains from trade result will likely hold. However, it is unclear if all factors of production will benefit from fragmentation. See also Markusen (2005).

[2] Some recent examples include Bhattasali, et al. (2004), Dean, Lovely and Wang (2008), Wang (2003), Schott (2006), Rodrik (2006), Hammer (2006), Amiti and Javorcik (2008). One exception is Dean and Lovely (2008), who investigate the impact of fragmentation and trade growth on China's environment.

[3] See the survey by Spencer (2005). An exception is Feenstra and Hanson (2005), who test different versions of property rights and incomplete contract theories using detailed Chinese trade data.

[4] Ping calculates vertical specialization for 1997-2002, for 40 Chinese sectors. But his analysis is limited by access to only the 1997 benchmark input-output table. Chen, Cheng, Fung and Lau (2004) estimate the "domestic value added" in Chinese exports for a single year and 33 sectors. This concept is related to the HIY VS measure, but is not explored in that paper (see Koopman, et al., 2008 for a discussion). We discuss these studies more below.

China's processing trade regime raises two challenges to the measuring of the vertical specialization in Chinese exports. The first challenge is *identification.* Identification of imported inputs is dependent upon the trade regime. China's processing imports are only intermediate goods, while China's ordinary imports are a mixture of intermediate, final and capital goods. The second challenge is *allocation*. The allocation of imported intermediates across sectors is also dependent on the trade regime. China's processing imports are only used in processing exports, not for goods sold locally or exported as ordinary (or normal) exports. China's processing exports are highly concentrated by sector, with more than two-thirds in three key sectors: Electrical Machinery (HS85), Machinery (HS84), and Optical, Medical and Precision Instruments (HS90). Thus, the imported input intensity of these industries is much higher than exports of other types of goods.

This study quantifies the vertical specialization (VS) in Chinese trade, using the measure developed by Hummels, Ishii, and Yi (2001) (HIY), and addresses these two challenges. To address the identification challenge, we use a new detailed Chinese trade dataset which distinguishes processing and ordinary imports, as well as the United Nations Broad Economic Categories (BEC) classification, to more accurately identify Chinese imports of intermediate goods. These data allow us to examine in detail the sources of China's inputs in the global supply chain. We then combine these newly identified intermediate import data with the unified (Non-Split) 1997 and 2002 Chinese benchmark input-output (IO) tables, and the HIY method, to measure the vertical specialization of Chinese merchandise exports. We quantify the foreign content in Chinese exports for 1997 and 2002, by sector and by trading partners.

Addressing the allocation challenge requires separate input-output data for processing and normal exports--data which are unavailable. However, in a related paper, Koopman, Wang, and Wei (KWW, 2008), develop a methodology to split the Chinese input-output table.

Incorporating the identification method developed by Dean, Fung and Wang,[5] KWW use their methodology to generate separate (Split) input-output tables for China's processing and normal exports, in order to measure the domestic content of China's trade. Making use of KWW's Split method, we can incorporate the unique features of imported intermediate use in processing trade into our VS estimation process. The results from the separate input-output tables (Split method) are contrasted with those generated from the unified input-output tables (Non-Split method).

Our results show strong evidence of vertical specialization in Chinese trade. The foreign content of China's 2002 aggregate merchandise exports ranges from 25% using the Non-Split approach to 46% using the Split approach. This suggests that imported intermediate inputs made up between 25 cents and 46 cents of every dollar's worth of Chinese merchandise exports to the world in 2002. Both approaches identify electronic computers, telecommunications equipment, computer peripheral equipment, electronic elements and devices, radio/TV/other communications equipment, and plastics as among China's ten most vertically specialized exports. For these sectors, foreign content ranges from 28% - 57% (Non-Split) to 63% - 95% (Split).

There is strong evidence of an Asian network of suppliers to China, with Japan and the Four Tigers accounting for more than half of the value of China's imported inputs, both in 1997 and in 2002. This Asian network is much stronger for China's processing than for normal trade. Both approaches identify Hong Kong, the US, and Singapore as being the most vertically specialized among China's export destinations, with foreign content ranging from 27%-29% (Non-Split) to 50%-59% (Split). However, China's exports to transition and developing economies (e.g., India) are far less vertically specialized. These results suggest very different trading patterns: more traditional exports to developing country partners, and more non-traditional, fragmented exports to richer trading partners.

[5]This concept was first developed in an earlier version of this paper (Dean, Fung and Wang (2007).

Both approaches to estimating VS have their strengths and weaknesses. The Non-Split approach uses the official unified input-output table. In some sense these data are more authoritative, but the Non-Split estimates cannot capture the differences in imported input intensity between processing and normal exports. As a result, Non-Split estimates are essentially an average of the VS share for all types of Chinese production. The Split approach captures the distinctions between imported input intensity for processing and normal exports, by relying on a reasonable and interesting method to compute input coefficients in the split tables. However, some may argue that alternative iterative processes could be used to computationally generate alternative input coefficients. Both sets of estimates contribute to our overall understanding of how vertically specialized China's trade is.

Comparing the two approaches in a given year, we find that differences in VS share estimates are strongly positively correlated with the share of processing exports, across sectors and destinations. Thus, the Non-Split and Split estimates might be viewed as lower and upper bound measures of vertical specialization, which converge as the share of processing exports decreases. With only two years of data, no conclusions can be drawn regarding general trends in vertical specialization over time. In fact, between 1997 and 2002, the Non-Split estimates generally show growing foreign content, while the Split estimates show the opposite. This difference in direction is interesting, and may reflect both the different assumptions underlying the two methods, and the interplay of two opposing forces. One force would be the growing global fragmentation in production technologies across and within most sectors, which would tend to increase China's vertical specialization. The other would be the increasing sophistication or widening range of fragments produced in China, which would tend to reduce vertical specialization.

2. Identifying China's Imported Inputs

Hummels, Ishii and Yi (2001) proposed their VS measure as one indicator of the impact of international production fragmentation on a country's trade. A high VS share indicates that imported intermediate goods make up a large proportion of the value of a country's exports. High VS shares might, therefore, indicate a country's greater degree of involvement in global production chains--importing intermediates from one set of countries, supplying further processing locally, and then exporting the semi-finished or finished products to another (perhaps overlapping) set of countries. For example, China might import laptop components from Singapore or Malaysia that were initially designed in Japan. These components might then be assembled and packaged using Chinese labor and capital, and then exported to Japan, the EU, the US and other countries.

HIY used input-output tables to calculate VS share as:

$$\text{VS share} = \mathbf{u}\mathbf{A}^{\mathbf{M}}[\mathbf{I} - \mathbf{A}^{\mathbf{D}}]^{-1}\mathbf{X} / x_k \qquad (1)$$

where u is a 1 x n vector of 1's, A^M is an n x n imported coefficients matrix, I is the identity matrix, A^D is the n x n domestic coefficient matrix, X is the n x 1 export vector and x_k is a scalar that denotes the amount of exports from country k. The numerator of equation (1) measures all the imported inputs, iterated over the economy's production structure, that are needed to produce the exports of a country from all n sectors. Dividing this by the value of total exports yields the total (both direct and indirect) share of a country's exports attributable to imported inputs (VS share).[6]

Estimation of VS share first requires identification of imported intermediate use. A standard approach used in the literature (Ping (2005) and Chen, Cheng, Fung and Lau (2004)) is

[6] There are at least two concepts used in the literature which are related to VS share. One is the domestic content share, which is the gross value of exports minus the value of all imported intermediate goods used in their production divided by export value. A second term used is "domestic value added share", which is not often used in the academic literature, but is identical in definition to the domestic content share. See Chen, Cheng, Fung and Lau (2004) and Koopman, Wang and Wei (2008) for proofs relating these concepts.

to assume that the ratio of imported intermediate inputs to total imports--which is unknown--is the same as the ratio of total intermediate inputs to total absorption--which can be computed from a country's I-O table.[7]

This "I-O approach" to identification is problematic for China, due to its extensive processing trade. The Chinese government provides special incentives for enterprises engaged in both types of processing trade, allowing them to import raw materials and other inputs duty free as long as these inputs are used to produce final goods or further processed inputs solely for export.[8] A priori, therefore, we expect China's processing imports to be only intermediate goods, whereas ordinary imports are likely to be a mixture of intermediate, final and capital goods.

We incorporate these important features of Chinese trade into our identification of imported Chinese inputs. First, we classify all processing imports as imported intermediate goods. Second, we then recognize that within ordinary Chinese imports there may also be some amount of imported intermediate goods used for the production of exports. This is particularly true for information technology products, as China joined the Information Technology Agreement (ITA) in 2003, which provides importers with duty free imports in this category. To capture these imported intermediate goods, we apply the United Nations BEC (Broad Economic Categories) classification to all Chinese ordinary imports, and include as intermediates any goods labeled as such by the BEC. We denote this two-part approach to identification as the DFW (Dean-Fung-Wang) approach.

All data on processing and ordinary imports and exports are from China Customs.[9] The two unified Chinese benchmark input-output tables used are for 1997 and 2002,[10] and include 124

[7] Hummels et al. (2001) also appears to use this method, but the exact method is not stated explicitly in the paper.
[8] In China's customs statistics, processing trade consists of two types—trade classified as processing and assembly and trade associated with processing with imported inputs. Under the first type of trade, ownership of the imported inputs is retained by the foreign exporting firm, while under the second, ownership is transferred to a local presence.
[9] These data are from a new USITC Chinese trade database, obtained from China Customs, and containing official Chinese export and import data from 1995-2007 at the HS 8-digit level, differentiated by customs regime, region, source, destination, firm ownership, incentives, port, and transport mode.

and 122 sectors, respectively.[11] In 2002, 87 of these are merchandise sectors, and the others are service sectors. The DFW approach to identification is general, and can be applied to either the unified I-O table or to the two computationally split processing and non-processing tables. To illustrate the importance of our identification correction, we calculate the shares of imported intermediates identified in the *unified* 2002 benchmark I-O table, using the DFW and the conventional I-O approach, as well as the shares that would result using the BEC identification alone. These shares are plotted for the merchandise sectors in Figure 1. These three methods yield significantly different estimates. Using the DFW approach, the median imported intermediate share is 96%, and the minimum is 57%. In contrast, the median share using the I-O approach is 82% and the minimum is 38%. As can be seen in Figure 1, there is very little discernible relationship between the DFW and I-O distributions of imported intermediate shares. As expected, the DFW approach yields shares that are greater than or equal to the BEC method. Thus, a comparison of BEC shares with I-O shares shows a similar lack of discernible relationship.

We believe that the general DFW identification approach introduced here is conceptually and economically an improvement over the alternative methods of identifying intermediate imports. Fundamental economic principles teach us that economic agents do respond to incentives. When Chinese firms or foreign firms import intermediate goods into the country for processing, there is every incentive for these economic agents to declare that these inputs are used for processing. For sectors such as information technology, agreements like the ITA may have reduced these incentives. But it seems that there is relatively little cost for these processing firms to still declare them as such. Furthermore, even if they do not declare these imported inputs as

[10] The Chinese input-output tables are of the competitive import type, which means that the tables do not differentiate between domestic intermediate goods and imported intermediate goods. To achieve the objective of our project, we need to convert the input-output tables into the non-competitive type, i.e. to separate out imported inputs and domestic inputs. As discussed earlier, the main method we used is the DFW approach.

[11] These sectors are listed in Dean, et al. (2007)..

used for processing purposes, the BEC method should still be able to catch these outliers. At worst, it seems to us that the general DFW approach is no better than the BEC method.[12] In contrast, the I-O method uses a very strong assumption. While this may be necessary when detailed data on processing trade are not available, it is easy to see why the two alternative methods should yield better results.

Figure 2 shows China's imported intermediate inputs by source for 1997 and 2002. Evidence of an Asian network of suppliers is strong. In 1997, the share of China's total intermediate inputs from Japan and the Four Tigers alone was 54%. With the addition of other East and Southeast Asian suppliers, this share rises to about 61%. [13] The US and EU15 together accounted for just under 20% of China's total imported inputs. It is also clear that this Asian network of suppliers is even more important to China's processing trade. While Japan's share was a little higher for 1997 processing intermediate imports, the Four Tigers alone accounted for more than 40% of China's processing intermediate imports. The share of all East and Southeast Asian suppliers was nearly 75%. In contrast, only 15% of processing intermediates were sourced from the US or the EU15.

In 2002, the Asian network continued to account for 60% of China's supply of imported intermediates, but with a somewhat decreased reliance on Japan and the Tigers. While these large suppliers still accounted for half of China's total imported intermediates in 2002, the share supplied by other East and Southeast Asian countries rose to 10.3% (an increase of nearly 50%). A closer look shows an increasing share of China's inputs coming from Taiwan and Southeast Asia, but decreasing shares from Japan, the other Tigers and other East Asian countries.

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[12] Because of these incentives, it is possible that producers will report more imports as processing imports than is actually true, implying that China official customs statistics will overstate the amount of processing imports. This may be one of the reasons that only about 85 percent of processing imports were identified by UN BEC classification as intermediate inputs. On the other hand, the BEC method may underestimate the portion of imported intermediates in processing trade for some double end use commodities which are entered as processing trade in Chinese Custom statistics.

[13] Other Southeast Asian suppliers includes all of ASEAN, excluding Singapore, plus East Timor. Other East Asian suppliers include Mongolia, Macau and North Korea.

Reliance on the US (EU15) falls (rises) slightly. A similar trend emerges for processing intermediate imports, with the Asian network's share rising to nearly 80%, and the US and EU15 shares falling to 12%.

China's top five intermediate imports in 2002 were in electronic elements and devices, man-made chemicals, extraction of petroleum and natural gas, basic chemicals and steel pressing. Electronic elements and devices alone account for 18% of China's total imported intermediates, and nearly 30% of China's processing imported intermediates. The Asian network described above was the source of about 69% of these five intermediates, and 86% of electronic elements and devices alone.

Part of the increasingly reliance of China on imported intermediate goods coming from Taiwan and Southeast Asia may be due to both the increasing importance of China's computer- and electronics-related industries and also the rising costs of inputs from East Asia. Taiwan has a long history of an offshoring relationship with Silicon Valley, dating all the way back to the seventies. The move of Taiwanese computer-related industries to Shanghai and subsequently other cities in Mainland China no doubt contributed to the amazingly rapid rise of China as a manufacturing hub of computer-related and electronics-related products. With Taiwanese factories increasingly migrating to China in the late nineties, sourcing of inputs from Taiwan increased. At the same time, the cutthroat competition in Silicon Valley puts intense pressure on the Taiwanese companies, including Taiwan-owned factories and businesses in China. This also necessitates sourcing of components and parts from cheaper locations such as economies in Southeast Asia.

3. Measuring vertical specialization: Non-Split Method

Having met the identification challenge, the next step is to incorporate these newly identified imported inputs into the HIY measure of vertical specialization. Here we work with the original benchmark tables which do not distinguish processing from ordinary exports. To identify the coefficients in the A^M matrix in equation (1), we use our new DFW estimates of total sectoral imported intermediates, and assume that these imported inputs are used in each industry in the same proportion as indicated in the original input-output table. The coefficients in the A^D matrix are then obtained as residuals by subtracting the coefficients in the A^M matrix from the coefficients in the original input-output table. This assumes that the coefficients contained in the original Chinese input-output tables are constructed accurately based on the requirements of both imported and domestically produced inputs. Thus, if we subtract the imported input coefficients from the A^M matrix from the published input-output table, the residuals are the coefficients for inputs that are domestically produced, i.e. coefficients contained in the A^D matrix.

One potential weakness with this approach is that typically input-output tables are constructed based mostly on information provided by firms located within the country. While there are a large number of foreign firms located in China, the large number of domestic firms using mainly domestically produced inputs may skew the I-O coefficients towards input-output relationships based mostly on domestically produced inputs. This could lead to an underestimation of VS share. Perhaps a more important weakness is that this procedure does not address the allocation challenge discussed earlier. It maintains the assumption that the relative proportions in which imported intermediates are used are the same, regardless of whether the product is sold locally, exported under ordinary trade, or exported under processing trade. As a result, the Non-Split estimates can only show an average VS share across all Chinese production. To the extent that processing exports are actually more intensive in their use of imported inputs, the Non-Split results will be biased downwards.

The results for both direct VS shares and total VS shares for each year, using this Non-Split method of measurement are shown in Table 1. The aggregate intermediate import content (total VS share) of China's exports, incorporating the DFW identification method was 17.8 % in 1997, and 25.4 % in 2002. In general, the direct shares are about half of the total VS shares, but they show a similar increase during this period. While these results suggest that the fragmentation of China's exports to the world has risen significantly, it would be premature to conclude a steady rising trend over the period with only two years of observations. Non-Split estimates using the BEC or I-O identification methods were generally similar, though somewhat smaller than those incorporating DFW identification.

Across sectors, average VS share for 2002 merchandise exports was 18 %. Figure 3 shows a large number of sectors with above average VS share in that year. Of these, two sectors had total VS shares exceeding 50% of exports (cultural and office equipment (56.8 %) and electronic computers (51.5 %). An additional three sectors had foreign content ranging between 40% and 50% of the value of exports. In most cases, sectoral VS shares have also grown significantly. While imported inputs constituted 36.7 cents of every US dollar worth of electronic computer products exported by China in 1997, this grew to 56.8 cents by 2002. Total VS more than doubled in cultural and office equipment.

China appears to be increasingly enmeshed in the global network of production fragmentation, whether we consider its trade with the world or its trade with individual trading partners. Figure 4 shows the foreign content of China's merchandise exports to a number of trading partners for 1997 and 2002, using the Non-Split measure. China's exports to Singapore, Hong Kong, the US, Mexico, and the EU15 are the most vertically specialized, with foreign content ranging from 26.3 to 28.6%. VS shares for merchandise exports to Taiwan and Japan are just under 25%. To the extent that production fragmentation is more prevalent in high tech goods such as computers, we might expect the foreign content of China's exports to fall as the income level of the partner country falls. The Non-Split VS share estimates do show some evidence for this idea. VS shares are lower for Eastern European and Latin American countries than for the US, Europe, Japan, or the Asian Tigers. For India and Sub-Saharan Africa, the VS share estimates are a full third below that for the US and the EU15. As with the aggregate and sectoral results, the Non-Split estimates show an upward trend.

4. Measuring vertical specialization: Split Method

The second challenge we identified in calculating the vertical specialization of China's exports, was the allocation of imported intermediates across sectors. We know that the use of intermediates is actually inter-related with the trade regime. Processing imports are only used in processing exports (by definition). Thus, they are not used for goods sold locally or goods exported as ordinary exports. Processing exports are highly concentrated by sector. Thus, exports in these industries will likely use a much higher ratio of imported inputs than exports of other types of goods. Ideally, we would like to modify the HIY measure to capture these characteristics. This would require a split I-O table, showing the input-output requirements for processing exports separately from the input-output requirements for normal or ordinary exports. If this were available, the VS measure would be modified to:

$$\text{VS share*} = \mathbf{uA^{MD}[I - A^{DD}]^{-1}X^{N} + u\ (A^{MD}(I - A^{DD})^{-1}A^{DP} + A^{MP})\ X^{P}}\,]/x_k \qquad (2)$$

where D refers to domestic sales, N refers to normal exports, P refers to processing exports. As before, u is a 1x n vector of 1's, I is the identity matrix and x_k is a scalar that denotes the total amount of exports from country k, which in our case is China. The n x 1 export vector is now split into X^N and $X^{P,}$ which are normal exports and processing exports, respectively. The n x n domestic coefficient matrix A^D is now subdivided into the domestic coefficient matrix associated with domestic sales A^{DD} and the domestic coefficient matrix associated with processing exports A^{DP}.

Equation (2) thus captures all the imported intermediate goods used for the two types of Chinese exports. The first part is the imported intermediate goods, iterated over the entire economy, used for the Chinese normal exports X^N and for goods sold domestically. The second part of equation (2) highlights the two channels through which imported intermediate goods can be used in processing exports. First, imported inputs used for goods for domestic sales can be channeled indirectly into domestic inputs used for processing exports. Secondly, intermediate goods are also directly imported to be used in processing exports, as captured by the matrix A^{MP}.

In their recent paper, Koopman, Wang and Wei (2008) (KWW) propose a method to split the I-O table. They use a mathematical programming method to infer an input-output table with a processing export production account. The idea is to minimize the sum of squared errors in separating the input-output relationships associated with processing exports from an existing I-O table, while maintaining all the logical resource flows constraints.[14] To meet the allocation challenge (above), we continue to use the DFW method to identify imported intermediates, but in addition, adopt the KWW methodology to split the I-O table, and generate VS shares for processing trade and normal trade separately. VS shares for total trade are then a weighted average of those for processing and normal trade, using trade shares as weights.

The KWW methodology involves several key assumptions: (1) that sectors use imported intermediates in the same proportion, for goods destined for normal exports or for domestic sales; (2) that processing exports can and will only be sold abroad and never domestically; (3) that processing exports are more intensive in the use of imported intermediates than normal exports or goods produced for domestic sales; (4) that all processing imports are used only for processed exports; (5) that the coefficients of use associated with domestically produced inputs are accurately measured as the residuals between the original input-output table and our A^M matrix.; (6) that processing export production uses no domestic intermediate goods. Data on direct payments to capital and labor (value-added) and on use of domestic intermediate

[14] The method is to first guess a reasonable value of the needed coefficients, e.g. an initial vale of the imported intermediate good i used by sector j for processing exports. Then to get to the estimated "true" value, a computer program is created such that the square of the difference between the "true" value of the coefficient and the initial value is minimized, subject to all the resource flow constraints. These constraints include, for example, the fact that the value of processing exports in a sector is the sum of the domestically produced inputs, imported intermediate inputs as well as all the primary factors (such as land, labor and capital) used in the production of such processed exports. The program is run until the conjectured coefficients converge to the final estimated values. This approach is very similar to a standard approach of formalizing learning in some macroeconomics models as well as in some learning models used in the computer science literature.

goods are not available by trade regime. Thus, the initial values of direct payments to capital and labor are the same, regardless of destination, while the initial values for domestic intermediates use are the same for normal exports and domestic sales.

Though these assumptions are not unreasonable, they may have consequences for our results. For example, if the use of imported intermediates in goods for normal exports is actually higher than that of goods for domestic sales, then assumption (1) is violated and the VS measure should be a weighted sum of three components rather than two. In this case, the Split method would underestimate VS share. If direct payments to capital and labor for exports exceed those for goods sold locally, then equal starting values might skew the iterative results toward overestimating VS share. Despite these limitations, the split I-O table allows us to incorporate the distinct features of the allocation of processing imports across sectors, and should give a good indication of how important this is for estimating the imported input content of Chinese trade.

Results using the Split method (Table 1) show that the aggregate estimates of the foreign content of Chinese exports in 2002 was about 46 percent, nearly 21 percentage points more than the Non-Split estimate. This divergence in estimates is due in part to the divergence in VS shares between the processing exports and normal exports. At 74 %, the foreign content of processing exports was far higher than that of the normal exports (11%). This wide difference, coupled with the large share of exports classified under the processing regime in 2002, yields an overall weighted average foreign content which is significantly higher than the estimate based on the Non-Split method.

Figure 5a shows both similarities and distinctions between the merchandise sectors identified by the two approaches as those with high vertical specialization. Both approaches identify electronic computers, cultural and office equipment, telecommunications equipment, computer peripheral equipment, electronic elements and devices, radio/TV/other communications equipment, and plastics as among China's ten most vertically specialized exports. Though magnitudes and ranks differ across approaches, the foreign content in these sectors ranges from

28%-57% (Non-Split) to 63%-95% (Split). Many of the sectors identified by the Non-Split method as above average VS share are also classified as above average using the Split method. However, the Split approach yields a wider range of VS share estimates (4.3 % to 95.4 %), and again a higher average VS share (32%) than the Non-Split approach.

Perhaps not surprisingly, there is a very strong positive correlation (0.89) between the shares of processing exports in these sectors and the Split estimates of foreign content. The expected but striking contrast between VS shares for processing and for normal exports in these sectors can be seen in figure 5b. What may be more interesting is the fact that the differences between the Split and Non-Split VS share estimates are also strongly positively correlated (0.79) with the ratio of processing exports to total sectoral exports.

Figure 6 highlights and contrasts the 2002 Non-Split and Split estimates of VS shares of Chinese exports by destination. Both approaches identify Hong Kong, the US, and Singapore as being the most vertically specialized among China's export destinations, with foreign content ranging from 27%-29% (Non-Split) to 50%-59% (Split). In fact, of the top ten vertically specialized destinations ranked by the Non-Split method, eight are also ranked in the top ten by the alternative Split method. Once again Split estimates indicate a higher average and broader range of VS shares (18% - 60%) than estimates based on the Non-Split method (18% - 29%). The differences between the two estimates are highly correlated with processing share, and are negligible for destinations where processing exports account for less than a fifth of Chinese total merchandise exports. As with the Non-Split method, the Split method shows a strong positive correlation between VS share and income of the trading partner.

Comparing the two approaches in a given year, we find that differences in VS share estimates are strongly positively correlated with the share of processing exports, across sectors and destinations. Thus, the Non-Split and Split estimates might be viewed as lower and upper bound measures of vertical specialization, which converge as the share of processing exports decreases. In sectors where imported input intensities differ little for exports or domestic sales, we would expect the magnitudes of the two measures to be very similar. Despite the differences in magnitudes, the two measures yield similar rankings for VS share by sector and by destination.

Over time, however, the Non-Split and Split approaches tell opposite stories. As table 1 shows, in contrast to the Non-Split results, Split total VS share of Chinese exports falls over time. Although the VS share for normal exports grows, it falls for processing exports, which account for a larger share of China's total exports. As KWW discuss in detail, this decline also appears in most sectors between 1997 and 2002. These differences in the Non-Split and Split results over time may reflect both the differing assumptions of the two methods and the interplay of two opposite forces. On the one hand, increasing global fragmentation in production technologies across and within sectors would likely increase China's vertical specialization for all exports and domestic sales. This trend would be reflected in both the Non-Split and Split estimates. On the other hand, increasing sophistication or a widening range of fragments produced in China, would likely decrease the vertical specialization of China's exports. Such a downward trend might affect processing exports relatively more than normal or domestic sales. If so, this might affect the Split estimates disproportionately, since only the Split method captures processing exports' higher imported intermediate intensity, and higher weight in total exports.

5. Conclusion

While production fragmentation and China’s rapidly growing trade have been recognized as important economic phenomena, the importance of such fragmentation in China’s trade growth has been left unexamined until recently. In part, this has been due to two key difficulties arising from the importance of processing trade in China: the identification of imported inputs and the allocation of those inputs across sectors. Both identification and allocation are related to the customs regime under which Chinese exports are classified. In this paper, we develop measures of the vertical specialization in China's exports, based on Hummels, Ishii and Yi (2001), addressing these two critical problems.

The combined use of a new detailed Chinese dataset, the United Nations Broad Economic Categories (BEC) system, and the 1997 and 2002 benchmark Chinese I-O tables, allow us to more accurately identify imported inputs and provide evidence of an extensive Asian network of intermediate input suppliers to China,. Incorporating these newly identified imported inputs into the HIY measure of vertical specialization yields estimates of the foreign content of exports for 122 Chinese sectors over time. Adopting the Koopman, Wang and Wei (2008) method of splitting the benchmark I-O table allows us to improve the allocation of these imported inputs across sectors, incorporating different imported-input intensities for processing and normal exports. We then compare estimates of vertical specialization from both the Non-Split and Split approaches.

We find strong evidence of an Asian network of suppliers to China, with Japan and the Four Tigers accounted for more than half of the value of China's imported inputs, both in 1997 and in 2002. Estimates from the Non-Split and Split approaches show the foreign content of China's aggregate exports in 2002 between 25% and 46%, respectively. While the Non-Split method nearly always yields estimates that are lower than the Split method, the two methods identify a very similar list of sectors and trading partners which are characterized by high levels of vertical specialization. Both sets of estimates also show the foreign content of China's exports declining with the income level of its trading partner.

Comparing the two approaches in a given year, we find that differences in VS share estimates are strongly positively correlated with the share of processing exports, across sectors and destinations. To some extent this is anticipated, since the Non-Split estimates reflect the average share of vertical specialization across all Chinese production, and cannot capture the relatively higher imported input intensity of processing exports. Thus, we can view these two methods as yielding lower and upper bound estimates of VS share. Comparing the two approaches over time, we find the Non-Split and Split estimates disagree on the change in China's vertical specialization. These differences may illustrate the importance of addressing both the identification and the allocation challenges in measuring vertical specialization. They may also illustrate differences in the sensitivity of the Non-Split and Split measures to two trends: growing vertical specialization, as production technologies become more internationally fragmented, and declining vertical specialization as a country moves along a global supply chain and produces an increasingly sophisticated or a wider range of fragments.

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Table 1. Aggregate VS Share Estimates for China's Exports to the World

Method	Exports	Imported Input Identification	VS Share		
				1997	2002
Non-Split	All	DFW	Direct	9.0	15.0
	All	DFW	Total	17.9	25.4
Split	All	DFW	Direct	46.1	42.4
	All	DFW	Total	47.7	46.1
	Processing	DFW	*Direct*	*81.7*	*72.5*
	Processing	DFW	*Total*	*81.9*	*74.3*
	Ordinary	DFW	*Direct*	*1.9*	*4.5*
	Ordinary	DFW	*Total*	*5.3*	*10.8*
Ping (2005)	All	IO	Direct		
	All	IO	Total	15.2	21.0
Chen et al. (2006) (implicit)	All	IO	Direct		
	All	IO	Total		54.4

Figure 1. Comparing Intermediate Shares Calculated by the Three Methods for 2002

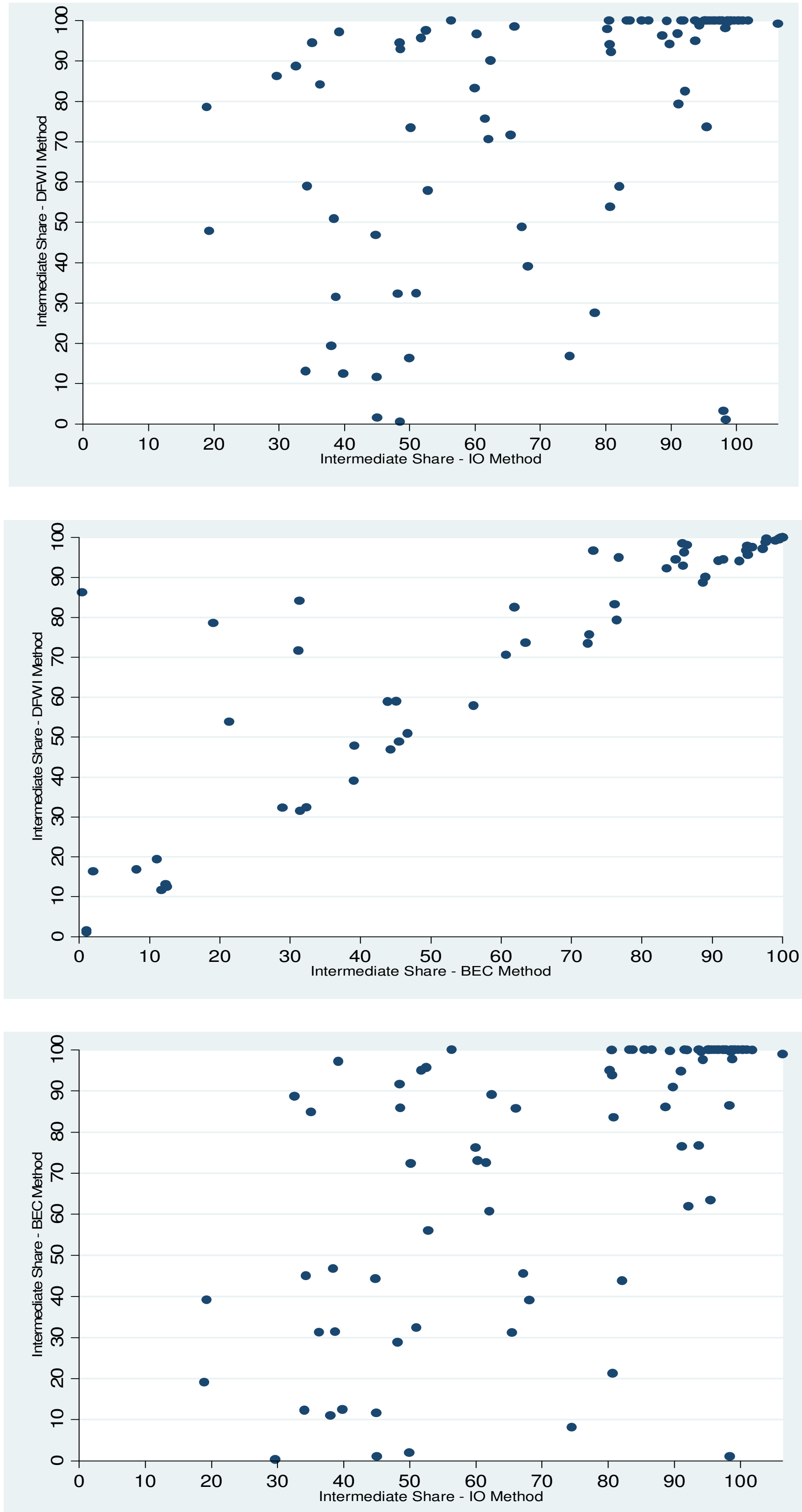

Figure 2.

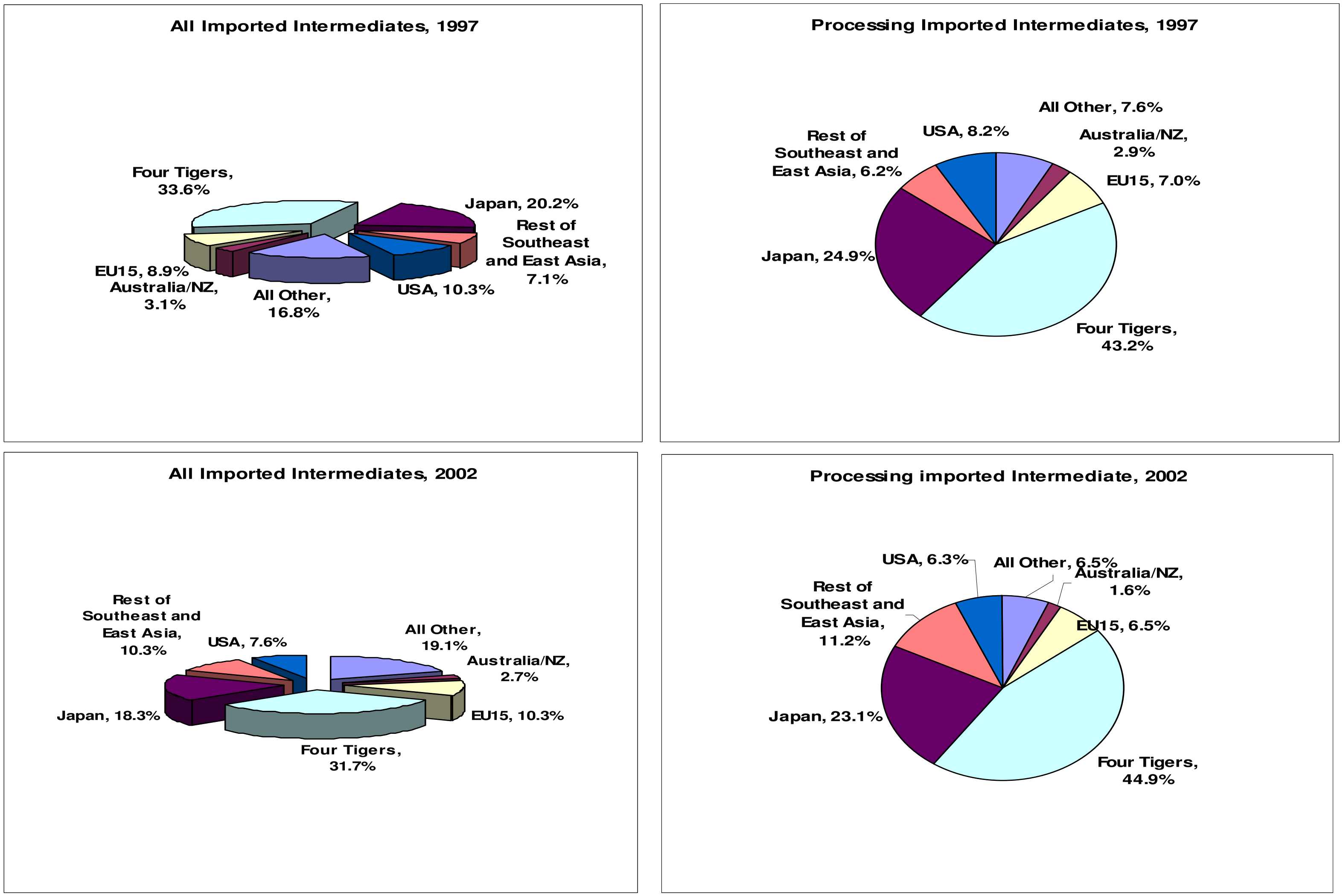
All Imported Intermediates, 1997
Four Tigers, 33.6%
Japan, 20.2%
Rest of Southeast and East Asia, 7.1%
USA, 10.3%
All Other, 16.8%
EU15, 8.9%
Australia/NZ, 3.1%
Processing Imported Intermediates, 1997
All Other, 7.6%
USA, 8.2%
Rest of Southeast and East Asia, 6.2%
Australia/NZ, 2.9%
EU15, 7.0%
Japan, 24.9%
Four Tigers, 43.2%
All Imported Intermediates, 2002
Rest of Southeast and East Asia, 10.3%
USA, 7.6%
All Other, 19.1%
Australia/NZ, 2.7%
Japan, 18.3%
EU15, 10.3%
Four Tigers, 31.7%
Processing imported Intermediate, 2002
USA, 6.3%
All Other, 6.5%
Australia/NZ, 1.6%
Rest of Southeast and East Asia, 11.2%
EU15, 6.5%
Japan, 23.1%
Four Tigers, 44.9%

Figure 3. Vertical Specialization of Chinese Merchandise Exports by Sector, 1997 and 2002: Non-Split Method

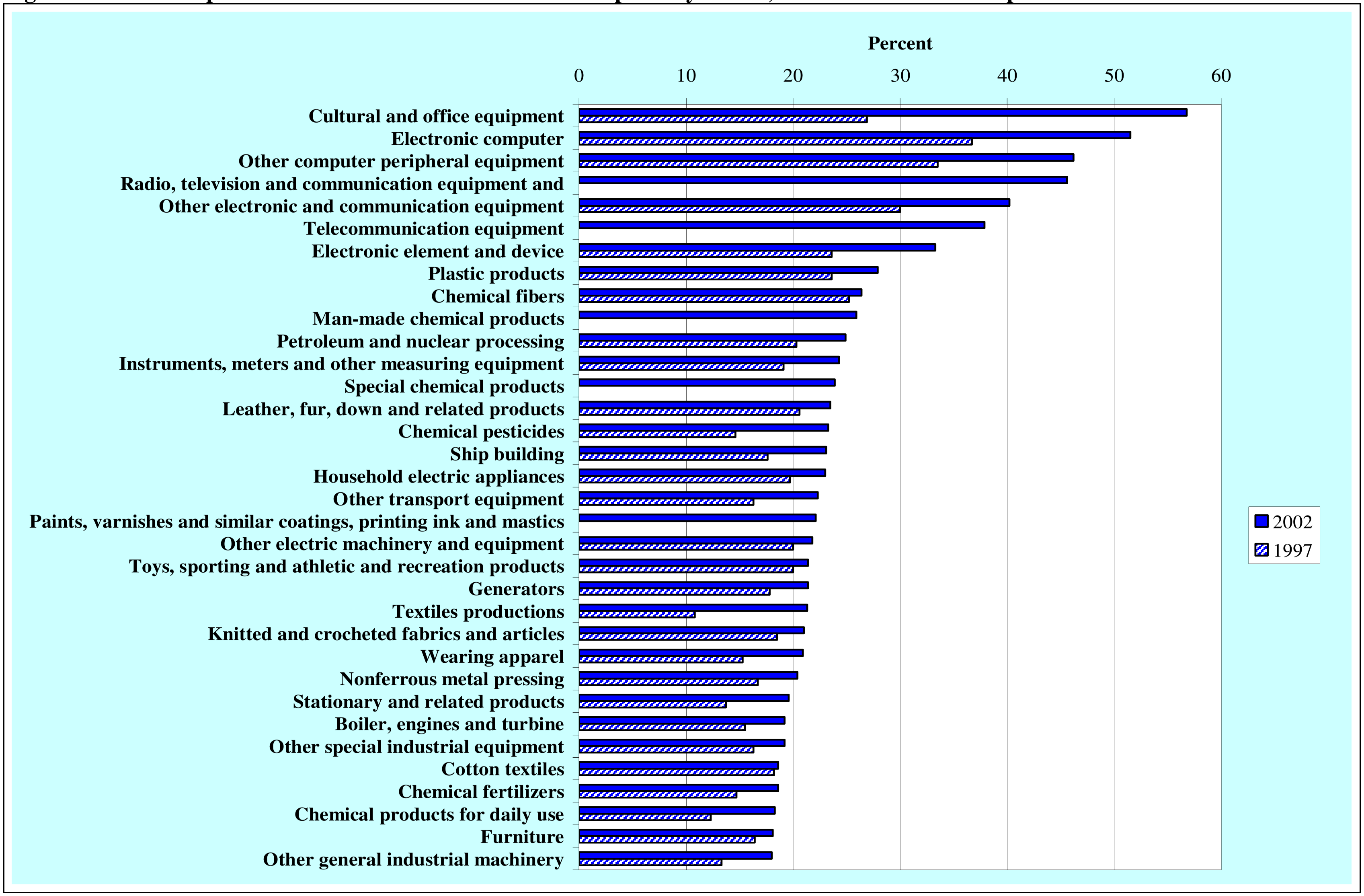

Figure 4. Vertical Specialization of Chinese Merchandise Exports by Destination, 1997 and 2002: Non-Split Method

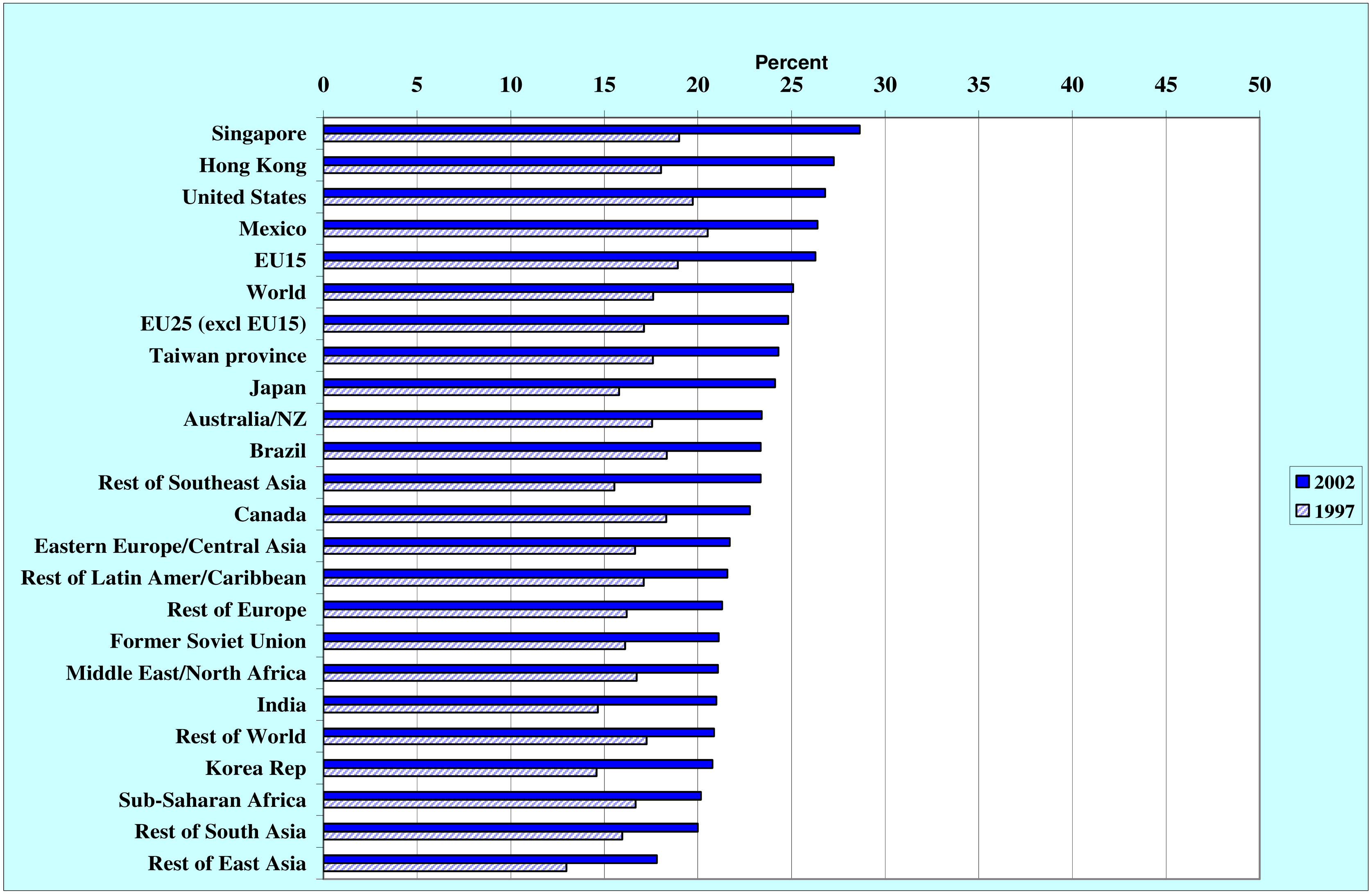

Figure 5.a. Vertical Specialization of Chinese Merchandise Exports by Sector, 2002: Non-Split and Split Methods

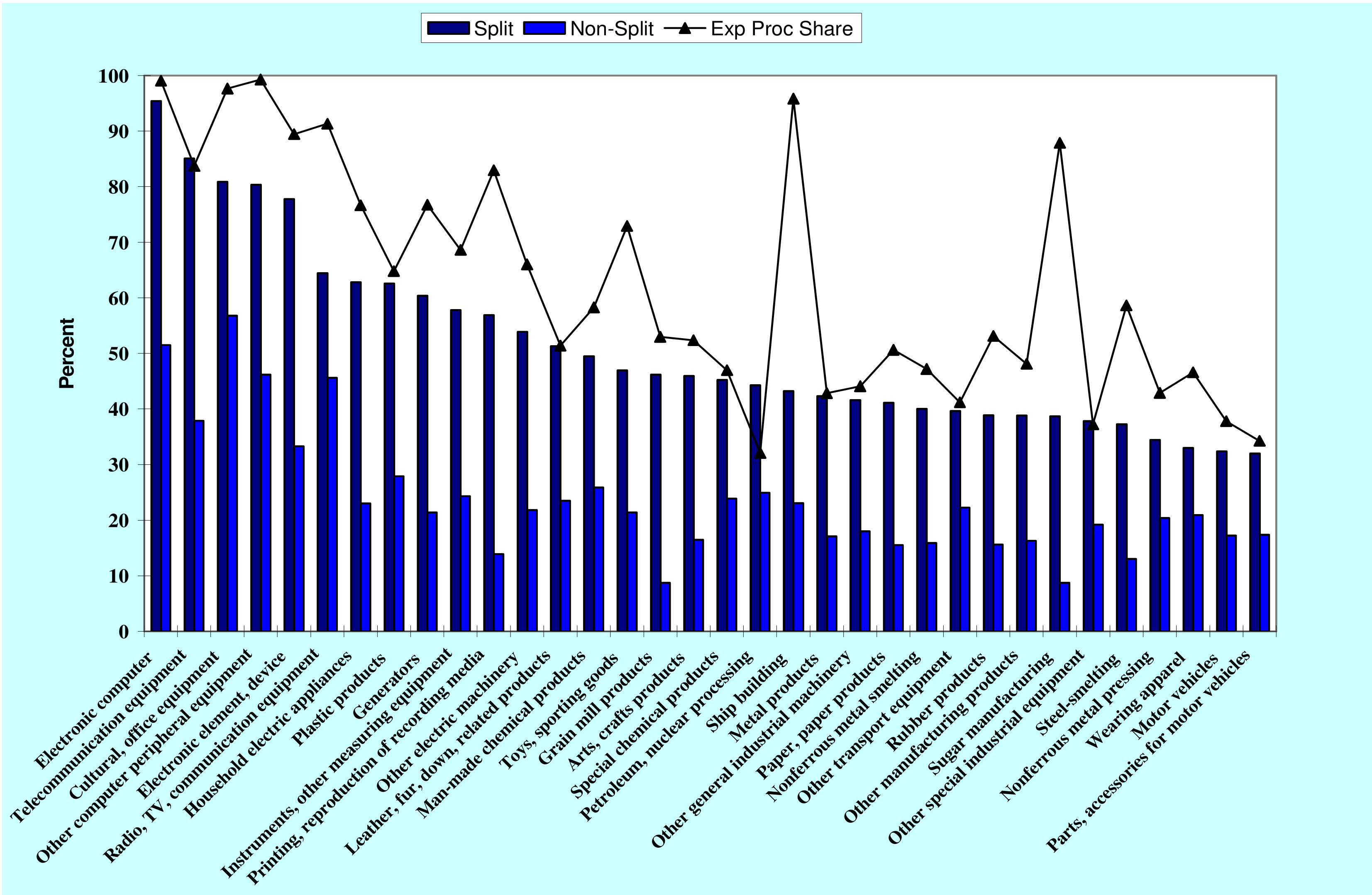

Figure 5.b. Vertical Specialization of Chinese Merchandise Exports by Sector and Trade Regime, 2002: Split Method

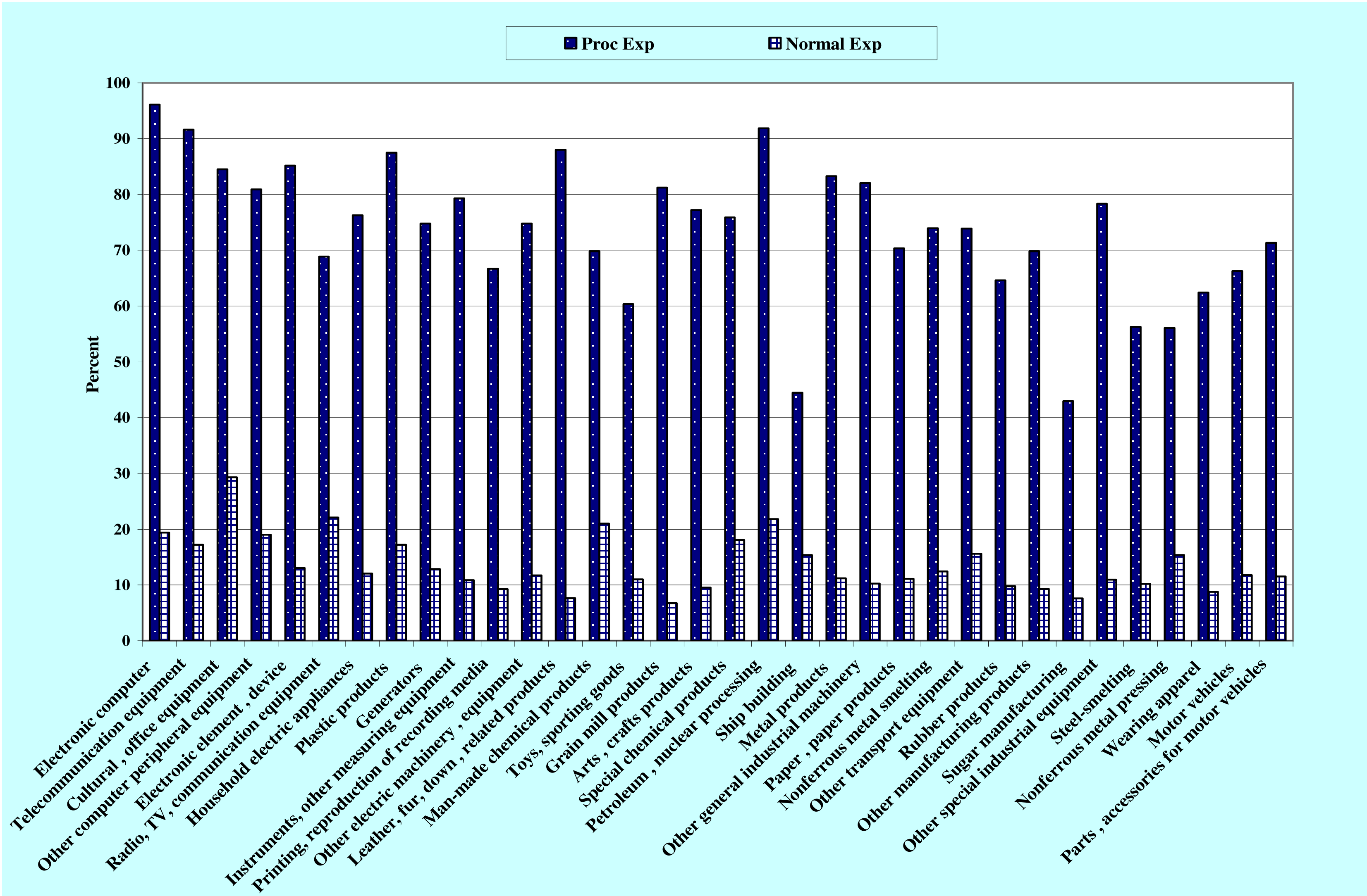

Figure 6. Vertical Specialization of Chinese Merchandise Exports by Destination, 2002: Non-Split and Split Methods