Fragmentation and East Asia's Information Technology Trade

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Abstract

This paper studies the growth and determinants of information technology (IT) trade in the Asia-Pacific region. We argue that the rise of IT trade must be understood within the context o increasing vertical fragmentation of production processes that has occurred over the past two decades. To evaluate this empirically, we estimate a set of pooled bilateral IT export equations for eight Asian countries, the U.S. and the E.U., where FDI inflows are introduced as a proxy for fragmentation. We apply a panel cointegration approach that allows for heterogeneity in short-run dynamics and in fixed effects. Consistent with production fragmentation, we find that the evolution of IT trade can be explained in part by traditional income and relative price effects but also by FDI inflow. (JEL C33, F14, F23)

Keywords: fragmentation, information technology, FDI and trade, trade elasticities, panel data.

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1 Introduction

Over the past two decades, international production fragmentation by U.S. and Japanese IT firms has gradually turned developing East Asia into a global manufacturing base for IT products (Dedrick and Kraemer 1998; Lowe and Kenney 1999; Borrus and Haggard 2000).[1] Induced by changes in IT technology as well as declines in transportation, communication and other coordination costs, IT firms fragmented their production processes and moved labor-intensive production stages to East Asia in order to take advantage of the region's lower labor costs.

It has been argued that the changing organization of production has altered the nature of IT trade in the Asia-Pacific region. Ernst and Guerrieri (1997) analyzed changes in the product composition of U.S. and Japanese electronics exports and imports to and from the East Asian region. They found the changes to be consistent with the spread of international production networks through fragmentation.

In this paper, we evaluate the impact of international production fragmentation on IT trade in the Asia-Pacific region. We estimate a set of pooled bilateral IT trade equations in which a proxy for fragmentation plays an important role. We use a pooled cointegration framework that allows for heterogeneity in short run dynamics and fixed effects. By pooling across bilateral export flows, this approach also helps to overcome the problems of small sample bias and low power that plague the estimation of individual bilateral trade equations. To our knowledge ours is the first paper to apply this methodology to the trade setting.

We find that trade in IT products can be explained by the standard trade model augmented by foreign direct investment. Changes in destination market income and relative prices drive exports, but exports are also positively related to inward FDI. This finding is consistent with the theory of fragmentation and also demonstrates the importance of incorporating such proxies in successful empirical modeling of trade flows in the IT sector.

The organization of the paper is as follows. In Section 2, we describe how production fragmentation has contributed to the emergence of East Asia's IT sector. We document the structure and evolution of Asia-Pacific IT trade patterns in Section 3. In Section 4, we model trade in IT prod-

[1] For our purposes, Information Technology includes data processing machines (computers, photocopy machines, calculators, etc.), radio and telecommunications equipment and electronic components (semiconductors, electronic tubes and valves, etc.). These correspond to standard international trade classification (rev. 2) categories 75, 76 and 776. This admittedly rough classification is necessitated by limitation in international trade data.

ucts using a variant of the standard trade model which permits a role for foreign direct investment inflows. We make concluding remarks in section 5.

2 Fragmentation and the Growth of East-Asian IT Manufacturing

The emergence of developing East Asia (Asian NIEs, ASEAN4 and China) as a dominant global IT manufacturing base is evident from an inspection of IT production and expenditure data (Table 1). While East Asia's share of world IT production was only 6 percent in 1985, it reached 26 percent in 2000 at a value of 348.6 billion U.S. dollars (slightly less than that of the United States). Unlike production, IT expenditure has remained concentrated in the developed world, with the share of IT expenditure to GDP remaining substantially higher in the U.S., Japan and the EU than in developing East Asia.

Industry studies such as Dedrick and Kraemer (1998), Lowe and Kenney (1999), and Borrus and Haggard (2000) indicate that international production fragmentation by American and Japanese IT firms has played a major role in building up East Asia's IT industry. At a moment when East Asia's electronics sector was virtually non-existent, U.S. and Japanese IT firms established their first affiliates for the sole purpose of export production. As the electronics sector became increasingly competitive during the 1980s, the presence of foreign affiliates mushroomed and stronger relations were built with non-affiliated host country firms. East Asia was gradually integrated into the worldwide networks of IT production.

The theory of fragmentation (Jones and Kierzkowski 1990; Jones and Kierzkowski 2001) and vertical foreign direct investment (FDI) (Helpman 1984; Helpman 1985) provide a framework in which to analyze U.S. and Japanese multinational firms' decision to move stages of their production process to developing East Asia. If different stages of the production process are separable and have varying factor intensities, then firms in labor-scarce developed countries have an incentive to relocate the production of their labor-intensive production blocks into low-wage countries. Firms will only do so, however, if the benefits of fragmenting their production process exceed the extra costs of coordinating activities across borders. Such coordination costs include trade and investment barriers, transportation costs, communication costs and governance costs.

A necessary condition for fragmentation is separability of production stages. If it is technically

Table 1: Developments in Information Technology Production

	IT Production ($ Mill)			Share of world IT production (%)		IT production /GDP (%)	IT expenditure /GDP (%)
Country	**1985**	**2000**	**CAGR (%) 1985–2000**	**1985**	**2000**	**2000**	**2000**
East Asia (EA)	30,262	348,591	14	6	26	13.7	5.7
NIEs	20,561	181,653	12	4	13	—	—
Hong Kong	3,680	8,083	4	1	1	5	8.8
Korea	6,501	76,059	14	1	6	16.5	6.6
Singapore	4,458	47,318	13	1	3	51	9.7
Taiwan	5,922	50,193	12	1	4	—	—
ASEAN4	4,120	85,903	17	1	6	—	—
Indonesia	580	10,791	17	0	1	7.1	2.2
Malaysia	1,851	44,539	18	0	3	49.7	6.8
Philippines	1,063	11,693	13	0	1	15.6	3.8
Thailand	626	18,880	20	0	1	15.4	3.6
China	5,581	81,035	15	1	6	9.4	5.4
United States	—	385,145	—	—	28	3.9	8.1
EU 15 (Excl. Japan)	—	230,272	—	—	17	3	7.8
Japan	89,390	263,451	6	19	19	5.5	8.3
Total Market	481,708	1,366,369	6	100	100	—	—

Source: IT Expenditure data: *World Development Indicators*; IT Production: *Yearbook of World Electronics Data*; GDP: IMF *International Financial Statistics*.

impossible to perform two or more stages in a production process separately, then the activities must remain within a single firm at a single location. Separability was significantly enhanced in the IT sector with the arrival of the modular IBM Personal Computer in the early 1980s (Ernst 2002). Before the PC, electronics companies generally built computers with a fully closed proprietary architecture. The closed system implied a high cost of coordinating interoperability between components and induced firms to produce almost all necessary components—semiconductors, hardware and operating systems—in-house and principally within one country (Dedrick and Kraemer 1998; Chandler 2001). The IBM PC with its modular product architecture permanently altered the structure of production by reducing the cost of coordinating activities across stages. The key feature of the modular system was that the standards of compatibility and interoperability among components were fixed and publicly known (Langlois and Robertson 1995). This allowed the makers of components to concentrate their capabilities at a reduced coordination cost and thus to improve their piece of the system independently from others. As a result, separability was enhanced and fragmentation was induced.

The modular structure of the PC also induced fragmentation through another channel. Once the *de facto* standards of interoperability and compatibility were set, barriers to entry into the industry were substantially lowered and thousands of IBM clones and component producers entered into the various niches of the computer business. The resulting competition drove down prices in almost all areas (Langlois and Robertson 1995). In order to survive in the highly competitive environment, electronics producers were seeking to reduce production costs by moving labor-intensive production blocks to East Asian (Dedrick and Kraemer 1998).

The change in industry structure also altered the factor intensities of production stages over time. As a consequence of the falling component prices, labor costs became a bigger share of PC production costs (Curry and Kenney 1999). Therefore, more pressure arose to take advantage of lower-cost labor or to improve labor productivity through international fragmentation.

East Asia was initially seen as a favorable place to move labor-intensive IT production blocks for a number of reasons. First, the East Asian countries were known to have not only an abundant supply of low-wage labor but also a large and growing pool of high-skilled engineers. In addition, East Asia had a relatively stable political and macroeconomic environment, conducive to long-term investment projects and business relations (Yusuf 2001). Finally, East Asia had already entered the more prosaic consumer electronics industry during the late 1960s (Lowe and Kenney 1999).

There were a number of favorable factors that further stimulated the fragmentation process into East Asia. First, in the early 1980s, East Asian countries generally changed their policy stance from import substitution to export promotion, thus providing an improved environment for international business linkages. Barriers to trade and investment were reduced, and domestic economic activities such as insurance, banking and transportation were deregulated. These reductions in barriers to trade are particularly conducive toward international production fragmentation because, in a fragmented world, a good needs to cross multiple occasions during the production process (Hummels, Rapoport, and Yi 1998).

Second, global transportation costs for distant travel and time-sensitive goods have declined in the last few decades (Hummels 2000). The precipitous drop in air shipping prices and the increase in the quality and speed of ocean freighters have significantly reduced the cost of time-sensitive goods. This has benefited the international trade of goods produced in internationally fragmented production processes where just-in-time linkages are important. At the same time, there has been an important decline in the cost of distant relative to proximate shipping transport, thus providing an extra motivation for trade between East Asia and the United States.

Third, the dramatic reduction in the cost of communication enhanced the coordination, management and monitoring of activities in different locations. In the last few decades, the cost of making phone calls has reduced precipitously; computers have allowed virtually costless means of communication via e-mail and Internet; the use of fax machines has decreased the need for courier services and sped up the communication of important documents. These reductions in communication costs have made it easier for firms to coordinate and monitor production in diverse countries.

3 The Evolution of Global IT Trade

Changes in the IT trade structure between the U.S., Japan and East Asian economies are consistent with the shift in the IT sector's organization of production. Similar to IT production, East Asia's IT trade in the last two decades has taken off at a rate substantially higher than the rest of the world. Between 1980 and 2000 East Asia's IT exports and imports grew by 21 and 20 percent a year, respectively, while global IT exports and imports both grew at an annualized rate of 15 percent. As a result, East Asia's share of world IT exports has risen from 14 percent in 1980 to 40 percent in 2000. East Asia as a whole is now the world's largest exporter for IT-related goods, by far surpassing the United States and Japan (Table 2).[2]

The growth in East Asia's IT trade has primarily been fueled by an increased in intraregional trade. As is illustrated in Table 3, intraregional trade in East Asia has risen substantially, reaching 40 percent of its IT exports and almost 60 percent of its IT imports in 2000. This rise has largely been at the expense of its export share to the United States and its import share from Japan. Between 1980 and 2000, the share of East Asian exports destined to the United States fell from 41 percent to 25 percent, while the share of East Asian imports sourced from Japan declined from 37 percent to 17 percent.

The increase in East Asia's intraregional trade share does not necessarily imply that East Asia's trade has become less reliant on final IT demand from the U.S., Japan and the E.U. Indeed, the fact that the share of intra-East Asian trade is more important as a source of imports (60 percent) than a destination of exports (40 percent) is consistent with a trading pattern in which East Asian economies trade intermediate goods within the region and sell final goods outside of the region.

An examination of the commodity composition of IT trade provides insight into the factor intensities of the production and trade relationships. By dividing IT-related goods into "IT Parts and Components" and "IT Final Goods", we obtain a rough indication of which regions specialize in the assembly of IT-related final goods and which regions specialize in the production of components of IT-related goods.[3] We use revealed comparative advantage (RCA) indices to examine the intensity of IT specialization across the various categories. Measures of export RCA are often used to help assess a country's export specialization. A value that exceeds unity implies that the country has a greater than average share of IT exports in that category.[4] Ng and Yeats (2001) argue that

[2]East Asia's share of exports remains higher than that of the United States even if we exclude intraregional East Asian trade, since nearly two-thirds of East Asia's IT-related exports are interregional (Table 3).

[3]We identify three of the eight three-digit SITC IT sectors as predominantly "Parts and Components" and the remaining five categories as primarily "Final Products". "Parts and Components" comprise SITC 759 (Parts of and accessories suitable for office machines and automatic data processing machines & units), 764 (telecommunication equipment and parts) and 776 (thermionic, cold & photo-cathode valves and tubes). "Final Products" include 751 (office machines), 752 (automatic data processing machines & units), 761 (television receivers), 762 (radio-broadcast receivers) and 763 (grammophones, dictating, sound recorders etc.). This rough measure is the best one can do with three-digit data.

[4]The export RCA index is calculated as the ratio of two ratios, the ratio of exports for each subsection of IT

Table 2: Developments in Information Technology Trade

	IT Exports ($ Mill)		Export Share (%)		IT Imports ($ Mill)		Import Share (%)		Growth Rate 1980-2000	
Country	**1980**	**2000**	**1980**	**2000**	**1980**	**2000**	**1980**	**2000**	**EX**	**IM**
EA (Incl.)*	11,513	413,818	14	40	8,953	288,600	11	28	21	20
EA (Excl.)*	9,110	249,966	11	24	6,549	124,749	8	12	19	17
NIEs	10,011	257,798	12	25	6,349	169,997	8	17	19	19
Hong Kong	2,493	50,302	3	5	2,047	49,479	2	5	17	18
Korea	1,797	61,743	2	6	1,131	32,845	1	3	20	19
Singapore	2,826	76,630	3	7	1,915	50,793	2	5	19	19
Taiwan	2,895	69,123	4	7	1,256	36,880	2	4	18	19
ASEAN4	1,438	109,694	2	11	2,031	66,594	2	6	26	20
Indonesia	102	7,631	0	1	308	1,015	0	0	25	6
Malaysia	1,252	55,759	2	5	1,006	38,077	1	4	22	21
Philippines	71	26,798	0	3	372	12,724	0	1	37	20
Thailand	13	19,506	0	2	345	14,778	0	1	47	22
China	64	46,326	0	5	573	52,009	1	5	41	27
United States	15,961	144,100	19	14	12,610	211,701	15	21	12	16
EU 15 (Excl.)*	11,367	98,661	14	10	15,965	143,213	19	14	12	12
Japan	18,057	110,857	22	11	2,043	59,533	2	6	10	19
Total Market	82,483	1,026,321	100	100	82,483	1,026,321	100	100	14	14

Source: Statistics Canada *World Trade Database*

*****"Incl." indicates that the aggregate includes intraregional trade; "Excl." indicates that intraregional trade is excluded.

Table 3: The Origins and Destinations of IT Trade

	Share of Exports Destined to							
	East Asia		**United States**		**EU-15**		**Japan**	
Exporting Region	1980	2000	1980	2000	1980	2000	1980	2000
East Asia (Incl.)*	20.9	39.6	41	25.4	21.2	17	4.6	9.9
East Asia (Excl.)*	—	—	51.9	42.1	26.7	28.2	5.8	16.5
United States	11.2	31.6	—	—	45.2	21.5	6.8	8.9
EU—15 (Excl.)*	11.1	25.4	12.6	16.7	—	—	2.4	4.8
Japan	18.3	43.4	27.2	29.5	28	19.9	—	—

	Share of Imports Originating from							
	East Asia		**United States**		**EU-15**		**Japan**	
Importing Region	1980	2000	1980	2000	1980	2000	1980	2000
East Asia (Incl.)*	26.8	56.8	19.9	15.8	14.2	8.7	37	16.7
East Asia (Excl.)*	—	—	27.2	36.5	19.3	20.1	50.5	38.6
United States	37.5	49.7	—	—	11.4	7.8	38.9	15.4
EU—15 (Excl.)*	15.3	49.2	45.2	21.6	—	—	31.7	15.4
Japan	25.8	69.1	53.1	21.4	13.4	7.9	—	—

Source: Statistics Canada *World Trade Database* *"Incl." indicates that the aggregate includes intraregional trade; "Excl." indicates that intraregional trade is excluded.

a similar import RCA index can be used as a reliable predictor of specialization in final product assembly. A country that specializes in the export of final assembly is likely to import more than proportionately parts and components in that sector. It follows that countries with above average import shares for components in a sector are relatively heavily specialized in assembly operation. Notice that for exports, the RCA indices presented in Table 4 are generally above one, indicating that for East Asian developing countries final goods make up a larger-than-average share of their IT trade. A larger-than-average piece of their IT imports are parts and components. This pattern is fairly stable across alternative markets for East Asian IT trade, and consistent with the notion that developing East Asia specializes in the labor-intensive assembly of final IT products while the developed world—Japan, the United States and Europe—specialize in the production of components, particularly semiconductors.

There are of some interesting exceptions to this rule within specific product subcategories. Semiconductors (SITC 776) is one example. While East Asia is a heavy importer of semiconductors,

in an economy to that economy's total IT exports, relative to the ratio of world exports for each corresponding section to world total IT exports. The index reveals the pattern of export specialization for an economy relative to worldwide patterns. The greater a sector's RCA, the more an economy specializes in that sector's exports relative to world specialization patterns. The import RCA index is defined analogously. While such indices by definition measure the degree of specialization of exports in product categories, the term "revealed comparative advantage" is an unfortunate misnomer. Because trade may be highly distorted by trade barriers and implicit or explicit domestic taxes and subsidies, such measures may "reveal" little about the actual comparative advantage of countries.

Table 4: East Asian Revealed Comparative Advantage Indices

Table 4a. East Asian RCA Indices: Exports (2000)

Product Group	Total	E.U. 15	U.S.	Japan	East Asia
IT Parts and Components	**0.96**	**0.92**	**0.91**	**0.96**	**0.95**
759 - Parts of and accessories suitable for 751-752	0.48	0.35	0.21	0.98	0.82
764 Telecommunications equipment and parts	0.7	0.64	0.69	0.83	0.97
776 Thermionic, cold & photo-cathode valves, tubes, parts	1.2	1.36	1.21	1.03	0.94
IT Final Goods	**1.05**	**1.08**	**1.1**	**1.04**	**1.14**
751 - Office machines	1.17	1.13	1.14	1.03	1.2
752 - Automatic data processing machines & units	0.96	1.04	1.19	0.98	1.02
761 - Television receivers	0.7	0.42	0.4	1.41	1.03
762 Radio-broadcast receivers	1.54	2.12	1.22	1.37	1.61

Table 4b. East Asian RCA Indices: Imports (2000)

Product Group	Total	E.U. 15	U.S.	Japan	East Asia
IT Parts and Components	**1.26**	**1.52**	**1.27**	**1.15**	**1.23**
759 Parts of and accessories suitable for 751-752	0.69	0.68	0.35	0.45	1.18
764 Telecommunications equipment and parts	0.65	1.05	0.46	0.57	0.9
776 Thermionic, cold & photo-cathode valves, tubes, parts	1.78	2.39	1.74	1.56	1.4
IT Final Goods	**0.65**	**0.3**	**0.64**	**0.68**	**0.7**
751 Office machines	1	0.56	0.68	1.02	1.03
752 - Automatic data processing machines & units	0.45	0.18	0.63	0.46	0.48
761 - Television receivers	0.27	0.2	0.24	0.43	0.4
762 Radio-broadcast receivers	0.33	0.08	0.1	0.18	0.34

Source: Statistics Canada World Trade Database

it is also a heavy exporter, presumably of lower value added memory chips and standardized components where the region's low labor costs provide a comparative advantage. Surprisingly, the region exports a lower-than-average number of televisions (SITC 761) to the E.U. and the U.S..

4 An Empirical Model of IT Trade

To evaluate the impact of international production fragmentation on IT trade in the Asia-Pacific region, we estimate pooled bilateral IT export equations. As in traditional empirical trade analysis, we expect that market size and relative price competitiveness serve as determinants of trade in IT products. But we also evaluate a potential role for fragmentation to explain export growth, proxied here by the stock of inward foreign direct investment (FDI) flows. We choose FDI as a proxy for fragmentation since IT is the primary vehicle through which multinational enterprises move production stages across borders.[5]

The literature on FDI indicates that the expected impact of FDI on trade depends on the nature of FDI. A distinction is typically made between horizontal and vertical FDI. FDI designed

[5]FDI is an imperfect proxy for fragmentation, since multinational enterprises can also move production stages across borders by outsourcing production to foreign firms. Nevertheless, considering the limited availability of data, FDI may be the best available proxy.

to serve local markets is often called horizontal FDI, since it typically involves duplicating parts of the production process as additional plants are established to supply different locations. This form of FDI usually substitutes for trade, since parent firms replace exports with local production. In contrast, FDI in search of low-cost inputs is often called vertical FDI since it involves the relocation of a part of the production process in a low-cost location. Vertical FDI is usually trade creating, since the reallocation of a production block to a host country is likely to induce an increase in imports of intermediate goods from an upstream production stage in the source country and an increase in exports to a downstream production stage in the source country.

Since international production fragmentation occurs in search of low-cost inputs, the associated FDI flows are vertical in nature. As a result, we would expect a positive relationship between FDI inflows into the IT sector and IT exports.[6] In other words, FDI inflows may be expected to lead to additional IT export growth beyond what is explained by income and relative price effects.

4.1 Model Specification

We take as our starting point the standard log-linear export demand equation,[7]

$$\ln \frac{X\$_{i,j}}{P_i^x} = \alpha_{i,j} + \beta_{i,j} \ln \frac{Y\$_j}{P_j^m} + \rho_{i,j} \ln \frac{P_i^x}{P_j^m} + \phi_{i,j} \ln \frac{PO_j^x}{P_j^m} \qquad (1)$$

where $X\$_{i,j}$ are nominal exports from country i to country j, Y\$ is nominal income in the importing country; $\frac{P_i^x}{P_j^m}$ is the "own" relative price expressed in common currency (hereafter, RPX_{ij}) and $\frac{PO_j}{P_j^m}$ is the import-weighted relative price of other exporters to the destination market expressed in common currency (hereafter, $RPO_{i,j}$). The latter two terms are essentially "real exchange rates" capturing the relative IT prices of home to foreign goods and third country to foreign goods.[8]

[6] Over the years a number of empirical studies have focused on the question of whether aggregate trade and FDI are complements or substitutes in East Asia. Urata (2001) uses country-level aggregate trade and investment data and finds that inward FDI stock promotes trade. Head and Ries (2001) use firm-level data for Japanese manufacturing firms and find a net complementary effect between trade and FDI, with substitution effects occurring for firms that do not export intermediate inputs. Ramstetter (1999) and Ramstetter (2002), finally, uses plant-level data and finds that foreign plants have higher trade propensities than local plants in Indonesian, Thai and Singapore manufacturing.

[7] This well-know model can be derived from a simple imperfect substitutes trade model, where the quantity demanded is a function of income in the destination market, own product price, and prices of competing products. See Armington (1969). The notation here loosely follows Goldstein and Khan (1985). Because a log-linear form imposes constant elasticities, the functional form is not without its critics, for example Marquez (1994). This form is nevertheless dominant in empirical practice.

[8] Representation in this form requires that demand be homogenous in prices and that foreign consumers choose between country i goods and a composite of all other countries' goods. Because we are modeling demand for a specific

Available bilateral trade data are reported in current dollar values for all countries, and there do not exist reliable time series of prices with which to deflate IT exports. We sidestep this data challenge by assuming that the relative IT price of home to foreign goods parallels relative aggregate prices of home and foreign contries. This assumption allows us to specify the model in nominal dollar terms.[9]

$$\text{(2)} \qquad \ln X\$_{ij} = \alpha_{ij} + \beta_{ij} \ln Y\$_j + (1+\rho_{ij}) \ln RPX_{ij} + \phi_{ij} \ln RPO_{ij} + (1-\beta_{ij}) \ln P_j^m$$

We are left with a term involving the unknown IT market price, P_j^m in (2). We will include a trend term in the estimating equation to allow for the effect of deterministic evolution of the level of IT prices.

Since fragmentation played such an important role in the build-up of East Asia's IT sector, there is good reason to think that East Asian exports of IT products will be influenced by the extent of inward foreign direct investment they have received. (In fact, a model that neglects this determinant of export flows may produce biased estimates of the underlying price and income elasticities.) We allow for such influences by appending a term measuring the dollar stock of inward FDI in the source market.

$$\text{(3)} \qquad \begin{aligned} \ln X\$_{ij} &= \alpha_{ij} + \beta_{ij} \ln Y\$_j + (1+\rho_{ij}) \ln RPX_{ij} + \phi_{ij} \ln RPO_{ij} \\ &\quad + (1-\beta_{ij}) \ln P^{m_j} + \omega_{ij} \ln FDIIN_i \end{aligned}$$

Note that because of data limitations, this measure is overall inward FDI without regard to industry or source country. The addition of this FDI term may help in identifying demand parameters by proxying for omitted supply influences.[10]

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sub-group of commodities, ideally we would like to include prices of all goods entering the foreign consumption basket. As a practical matter, we do not have reliable time series of prices for IT products, and so restrict our attention to aggregate price deflators, specifically consumer (or overall export) prices.

[9] Branson (1968) as cited in Goldstein and Khan (1985). But note that the interpretation of price elasticities for exports are different with this specification, since a rise in domestic export prices will raise the value of a given export volume one-for-one. So, at least for a price change originating in the exporting country, value elasticity = volume elasticity + 1.

[10] A number of studies have estimated import demand equations that augment the usual relative price and income elasticities with an exporter supply term. Sato (1977) includes manufacturing capacity in the exporting country as a supply term. Helkie and Hooper (1988) include the relative capital stock between the exporting and importing

The available time series for bilateral IT trade are very limited—the longest series in the Statistics Canada database run from 1980 to 1999, and price and foreign investment series are also limited. This makes it extremely difficult to estimate individual bilateral parameters with any precision, or to identify dynamics in individual equations. Following Bayoumi (1999), we estimate a panel regression of bilateral trade equations. We depart from Bayoumi, however, by applying an appropriate panel cointegration method. This has several important advantages. First, cointegration methods are needed to preserve potentially-important long-run relationships between exports and explanatory variables. Second, a cointegrated panel approach allows us to pool these while allowing for significant heterogeneity in the estimation of individual short run dynamics and fixed effects. Finally, by pooling our data in the cross sectional dimension, we are able to minimize the problem of small sample bias and the power issues that plague estimation of individual bilateral trade equations.

We model bilateral trade in information technology products among seven East Asian developing countries—Korea, Malaysia, Indonesia, Thailand, Singapore, the Philippines, and Taiwan—and the U.S., Japan, and the European Union. Data for Hong Kong and China were also collected but the absence of appropriate price deflators and, in the case of China a very short sample period, precludes their inclusion in this analysis.[11] Bilateral export values in current dollars are taken from the Statistics Canada World Trade Database. (See Appendix A for details.) We define information technology trade as the sum of eight three-digit SITC rev. 2 categories, as described in footnote 1.

For the destination-market activity variable, we use nominal dollar gross domestic product series from the International Monetary Fund *International Financial Statistics* online database. Arguably it would be better to specify IT export demands as a function of an IT-specific market demand measure, but such data are not readily available for most developing economies. Nominal exchange rates are from *International Financial Statistics*. Consumer prices are taken from The World Bank's *World Development Indicators* Database, 2001.[12] The construction of trade-weighted

country. Bayoumi (1999) and Gagnon (2003) include export-country real GDP as a proxy for supply. The justification of the inclusion of a supply term in these studies is different from ours. These studies based the inclusion of a supply term in the context of new trade theories, which focus on the implications for trade of increasing returns to scale in production and the desire of consumers for variety in consumption. The studies generally find that the inclusion of the exporter supply term significantly reduces the income elasticity.

[11]For our primary regressions, we have omitted four bilateral flows because of very short samples: Indonesian exports to Korea, the Philippines, and Taiwan, and Philippines exports to Indonesia. We have also interpolated the missing 1989 values for trade between the Philippines and Taiwan.

[12]The CPI is a potentially poor proxy for relative prices of tradable goods; we will also consider an specification

Table 5: Descriptive Statistics (All Series in Differenced Logarithms)

	Dollar Exports	Dollar GDP	Bilateral Relative Price, RPX	Relative Competitor Price, RPO	Dollar FDI Inflows
Mean	0.23	0.07	0.00	0.01	0.13
Median	0.18	0.09	0.00	0.01	0.12
Std. Dev.	0.66	0.13	0.12	0.10	0.12
Observations	1609	1609	1609	1609	1609
Cross-section range for mean	(-0.085, 0.646)	(0.041, 0.108)	(-0.068, 0.068)	(-0.027, 0.068)	(0.097, 0.176)
Cross sections	86	86	86	86	86

average relative competitor prices from exchange rates and CPIs is explained in Appendix A. For the European Union, we use an aggregate dollar GDP series from OECD. We construct EU-15 consumer price and exchange rate indices by weighting country series by total trade (aggregate imports plus exports). FDI inflow stock data are from the UNCTAD *Handbook of Statistics On-Line*.

Descriptive statistics for the pooled series are given in Table 5, presented in differenced logarithms for interpretability. Note that the cross-sectional average rate of growth of IT exports is very high—23 percent for the complete pool—and considerably higher than the rate of growth of nominal dollar output, 7 percent. The average rate of growth of the FDI stock is 13 percent over this two-decade period. There is considerable cross-sectional variation in bilateral export growth rates, ranging from a decline of 8.5 percent (Taiwan exports to Indonesia, which collapsed in dollar terms after 1997) to an average growth rate of nearly 65 percent (Thailand's IT exports to the U.S.).

4.2 Panel Cointegration Tests

Many or all of the model time series are likely to be non-stationary. In Appendix B we present results of panel unit root tests and conclude that each of the series we study here are in fact integrated of order one, I(1), in levels and of order zero, I(0), in first differences. Given this, one approach would be to estimate each bilateral export equation individually and test for cointegration

using relative export prices in future research.

one by one. However, as is the case for unit root tests, conventional single equation tests for the null hypothesis of no cointegration tend to have extremely low power and relatively large size distortions. These problems are particularly severe in the presence of moving average errors and in small samples such as ours (Haug 1993; Haug 1996).

Fortunately, it is possible to address the small sample properties of such tests by combining data on repeated observations over a cross-section of time series. Pedroni (1999) constructs panel cointegration test statistics that have very high power and minimal size distortions while allowing for heterogeneous cointegrating vectors as well as idiosyncratic error dynamics. Under the null hypothesis of no cointegration, the *spurious* regression is:

$$(4) \qquad lnX\$_{ij,t} = \alpha_{ij} + \delta_{ij}t + \gamma_t + lnZ_{ij,t}\beta_{ij} + e_{ij,t}, \quad \text{for } i \neq j, i, j = 1, \ldots, N, \; t = 1, \ldots, T,$$

and $e_{ij,t} \sim I(1)$. $Z_{ij,t} = [Y\$_j, RPX_{ij}, RPO_{ij}, FDIIN_j]'$ is the vector of right hand side variables. We allow for the possibility of fixed effects, a_{ij}, country specific deterministic trends, δ_{ij}, and heterogeneous cointegrating vectors, β_{ij}. The dataset underlying (4) is an unbalanced panel, with the number of usable observations ranges from 13 to 19.

Derivation of the asymptotic distribution for the panel cointegration test statistic requires that the errors in (4) are independent. In practice, this condition is likely to be violated and we allow for this possibility by modeling the cross sectional dependency using a common time dummy, γ_t. This approach assumes that each cross-sectional error can be decomposed into a shared disturbances and an idiosyncratic disturbance that is independent over the cross-section.

Pedroni (1997) and Pedroni (1999) consider panel (and group mean) statistics which use non-parametric adjustments to address both idiosyncratic serial correlation and endogenous feedback among variables. Table 6 shows the results of panel CI tests using the panel and group t- and ADF-statistics.

The first row of results allows for both a common time dummy and individual deterministic trends; the second includes individual deterministic trends; the third row includes only a common time dummy; and the fourth row includes only individual fixed effects. For all tests we reject the

Table 6: Panel Cointegration Tests

$lnX\$_{ij} = \alpha_{ij} + \delta_{ij}t + \gamma_t + \beta_{ij}lnZ_{ij,t} + e_{ij,t}$. (4) $H_o : e_{ij,t} \sim I(1)$				
	Panel ADF	Group ADF	Panel t	Group t
(1) *Unrestricted*	-9.61	-11.32	-12.15	-14.92
(2) $\gamma_t = 0$	-7.70	-9.94	-9.36	-9.94
(3) $\delta_{ij,t} = 0$	-7.33	-9.02	-7.03	-7.68
(4) $\delta_{ij,t} = \gamma_t = 0$	-4.65	-7.39	-5.67	-7.39
N	85			
T	21			
Max Lag	3			

Note: All statistics are significance at or below the 5% level. The test statistics are scaled so that they are distributed as standard normal, N(0,1).

null hypothesis of no cointegration at the 5% level.[13]

4.3 Group Mean Panel FMOLS Estimates

Having established the likelihood that a cointegrating relationship exists among the variables, we now turn to estimation of the panel under the maintained assumption of cointegration. It is well known that ordinary least squares (OLS) estimation of cointegrating regressions result in *superconsistent* estimates with the added benefit of negating the traditional problem of endogeneity of regressors.[14,15] In addition, panel estimation may help to overcome the limits of extremely short available time series for bilateral IT trade, price and foreign investment (the longest time series for the trade data is 1980–1999).

We estimate the pooled specification,

$$lnX\$_{ij,t} = \alpha_{ij} + \beta lnY\$_{j,t} + \gamma lnRPX_{ij,t} + \delta lnRPO_{ij,y} + \omega lnFDIIN_{i,t} + \mu_{ij,t}. \tag{5}$$

Pedroni (1996) shows that, as for the single equation case, the distribution of the panel OLS

[13]Based on Monte Carlo simulations reported in (Pedroni 1997), we should expect that the group ADF statistic has the best power in samples such as ours with small T and moderate N, followed by the panel ADF. Pedroni also considers rho and variance-ratio tests. Pedroni (1997) reports Monte Carlo simulations indicating that the panel rho and group rho have power ranging from 0 to 20% for samples with $T = 20, N = 20$. He finds that the variance-ratio tests consistently produced low power and large size distortions.

[14]That is, estimates converge to their true values at rate T as opposed to the conventional $\sqrt{T}$ (Stock 1987).

[15]In addition to the standard problem of omitted supply side, there are good theoretical reasons to expect trade levels to influence FDI. Investments may be made in response to anticipated trade opportunities, or trade may initially open a market for a firm, which may later have an incentive to move production into the market once scale economies are realized. In addition, common actors, such as per capita income levels, appear to explain both trade and FDI in cross-sectional analyses (Eaton and Tamura 1995).

estimator of the slope terms in (5) is asymptotically biased and dependent on nuisance parameters arising from the serial correlation properties of the data. The asymptotic bias arises due to the endogeneity of the regressors despite the superconsistency result.[16] Only under the overly restrictive assumption that the regressors are strictly exogenous and the serial correlation properties are homogeneous over the cross-section do the OLS estimator or t-statistics have their conventional distributions. Pedroni adapts the Phillips and Hansen (1990) fully modified OLS (FMOLS) approach to adjust for both endogeneity and the serial correlation properties of the data. The resulting group mean Panel FMOLS estimators and t-statistics are asymptotically unbiased, free of nuisance parameters, and normally distributed.[17]

The Panel FMOLS approach imposes few restrictions on the form of (5). While we do assume that slope parameters are homogeneous, we allow for heterogeneity via both fixed effects, α_{ij}, and idiosyncratic error dynamics. Heterogeneity in the error dynamics allows for differences in the way that individual countries adjust to disequilibrium, i.e. deviations from the long-run cointegrating relationship. Such error dynamics are modeled non-parametrically using the Newey-West estimator with the lag lengths allowed to differ over the cross-section. In addition, the non-parametric correction for endogeneity bias is allowed to differ cross-sectionally. To derive the distribution of the FMOLS estimators, Pedroni relies on the standard assumption of independence of the cross-sectional errors. This assumption is unlikely to hold in practice due to common shocks. For example, the emergence of the global tech bubble led to a surge in exports of IT products throughout Asia. This increase in IT exports is not likely captured by income, relative prices, or FDI. We attempt to ameliorate this cross-sectional dependency using a common-time dummy.

It is important to note that because the group mean panel FMOLS estimators are based on the "between dimension" of the panel, they have advantages over other so called "within dimension" panel esimators proposed in the literature. The group mean panel FMOLS t-statistics allow for tests of the null hypothesis of a common value for the cointegrating parameters against the alternative hypothesis that the cointegrating parameter takes on some different and possibly heterogeneous value, i.e. $H_o : \beta_{ij} = \beta_o, vs\, H_a : \beta_{ij} \neq \beta_o$. Furthermore, even in the event that the true cointegrating

[16]The panel OLS estimator converges to the true value at rate $T\sqrt{N}$ (Pedroni 1996).

[17]Unlike the Phillips and Hansen (1990) single equation FMOLS, Panel FMOLS estimators are normally distributed due to the averaging of the unit root distributions over the cross-section under the maintained assumption of independent idiosyncratic error processes.

vectors differ over the cross-section, the group mean estimator provides a consistent estimate of the sample mean of the heterogeneous cointegrating vectors. See Pedroni (2000).

Based on Monte Carlo studies using samples with time-series dimensions similar to ours ($N = 50$, $T = 20$), Pedroni concludes that the Panel FMOLS estimators "perform relatively well for the purpose of making inference in cointegrating panels with heterogeneous dynamics as the cross-section dimension grows large even for panels with relatively short time series dimensions" (Pedroni 1996, p. 7; but see his 2000 paper for richer Monte Carlo results).

Table 7 presents our panel FMOLS results. In the four columns of the table, we report results both with and without a common time dummy, and with and without the FDI measure.

Table 7: Panel FMOLS Regression Results

$$lnX\$_{ij,t} = \alpha_{ij} + \beta lnY\$_{j,t} + \gamma lnRPX_{ij,t} + \phi lnRPO_{ij,t} + \omega lnFDIIN_{i,t} + \mu_{ij,t}. \quad (5)$$

	Common Time Dummy		No Common Time Dummy	
	with FDI	w/o FDI	with FDI	w/o FDI
Importer's GDP	0.52	0.44	2.05	2.91
	(11.6)	(11.34)	(40.8)	(113.96)
Relative Competitor Price	1.61	1.30	1.84	2.74
	(9.19)	(5.24)	(15.26)	(19.12)
Relative Export Price	-1.58	-1.16	-0.5	-.13
	(-6.15)	(-2.69)	(0.63)	(5.79)
Exporters' FDI Inflows	0.63	—	0.58	—
	(9.76)	—	(18.4)	—
N	85		85	
T	21		21	
Max Lag	3		3	

Note: t-statistics are in parentheses. Fixed effects are not reported.

Looking first at the columns with a common time dummy, notice that the estimated elasticities conform with expectations. The income elasticity and competitor price elasticities are positive, and the own relative price elasticity is negative, consistent with trade theory, and all parameters are significantly different from zero at the 5% level. Note that the coefficient on "own" relative price is the "value elasticity" and the implied volume elasticity is one unit larger in absolute value, so that there is substantial price responsiveness of IT exports. (See footnote 9). Relative competitor prices also have substantial effects on bilateral export flows, with a one percent increase in competitors' prices raising exports by 1.3 percent in the long run.

The magnitude of the estimated income elasticity—0.44 to 0.52—is smaller than we might have expected for IT products, for which these countries presumably have relatively high income propensities. The income elasticity rises substantially when the time dummy is omitted in the rightmost two columns, and the relative export price elasticity becomes much smaller (insignificantly different from zero when FDI is included). Because a common time dummy is likely needed to account for systematic time effects, we consider the results of the model with a time dummy more reliable.[18]

We find support for our prediction that exports of IT production are positively related to FDI inflows into the exporting country. The magnitude of this effect is large, with a 1% increase in aggregate foreign investment inflows producing a 0.6% increase in IT exports. Point estimates for parameters other than FDI do not change dramatically when FDI is included.

5 Conclusion

International fragmentation of production processes has played an important role in shaping global trade patterns in Information Technology products. Changes in technology have facilitated vertical specialization in IT that has increasingly concentrated labor-intensive assembly operations in East Asia and have increased the trade in components both within the region and with the U.S. and Europe. The role of fragmentation in trade is reflected in empirical analysis that confirms that foreign investment flows play a role in explaining export patterns for IT products.

The emergence of East Asia as a global production base for IT products has important implications for the nature and extent of regional interdependence. By specializing in IT manufacturing, East Asian economies have become increasingly dependent on a highly cyclical sector, and also on macroeconomic conditions in the key North American market. For a number of the region's economies, IT exports to the U.S represent more than 5% of GDP; for Malaysia it is an astonishing 18%. Further work is needed to study these evolving trade linkages.

There are also dynamic questions that deserve further attention. It is likely that the development of international production networks initially leads to trade expansion between the source and the

[18]The common time dummy is intended to capture the impact of cross-sectional dependencies. If the IT surge of the past decade was caused in part by an exogenous shock to productivity growth, this would lead to increases in the export of IT products by all countries. If this common causes is not modeled, the strong export growth may instead be linked to growing income, which itself may be rising due to the productivity growth.

host country as the reallocation of production increases imports of intermediate goods from an upstream production stage in the source country and an increase in exports to a downstream production stage in the source country. Over time, this complementary relationship between trade and vertical FDI may diminish and even turn negative if domestic or third-country components start to be used instead of source country components.

We would also like to know more about the nature of production and trade relationships at a micro level. Using semi-aggregate data, one could look for differences in behavioral determinants of trade in components and final goods exports. Where detailed bilateral FDI data is available, it is possible to explore the links between IT investment and trade with more precision. We are looking at each of these issues in ongoing research.

Ultimately, fragmentation decisions occur at the firm level. Analysis using micro data on the sourcing of inputs and the commodity composition of outputs would shed additional light on how changing technical and competitive factors are driving the process of vertical specialization in the IT industry.

Appendix 1: Data Appendix

Trade data are taken from Statistics Canada World Trade Database, which provide bilateral trade flows for all countries and commodities, reported (where available) at the 4-digit SITC (Revision 2) level. Additional details on this data can be found in Robert C. Feenstra, Gordon H. Lipsey and Harry P. Bowen (1997). Trade data are reported on a dollar CIF basis. We define Information Technology (IT) trade as encompassing SITC 75 (Office Machines & Automatic Data Processing Equipment), 76 (Telecommunications & Sound Recording Apparatus) and 776 (Thermionic, Cold & Photo-Cathode Valves, Tubes, Parts). The countries included in East Asia are the four NIEs (Hong Kong, Korea, Singapore and Taiwan), ASEAN4 (Indonesia, Malaysia, Philippines and Thailand) and China. The developed economies included the U.S., Japan, and EU-15. In the estimation, we do not include Hong Kong and China.

Data on GDP were taken from IMF's *International Financial Statistics*. EU-15 GDP numbers are estimated by OECD.

CPI data were taken from World Bank, *World Development Indicators 2001*. For the EU-15, we constructed a European Union weighted average CPI, using national CPI indices weighted by total merchandise trade (exports plus imports) from the Statistics Canada dataset. Exchange rates for this purpose were taken from *International Financial Statistics*, as described below. We extended the national currency exchange rate series up to 1999 for this purpose.

Nominal exchange rates were taken from IMF, *International Financial Statistics* (see link above), using the period average rate.

FDI inflow stock data were taken from UNCTAD *Handbook of Statistics On-Line*.

As in Bayoumi (1999), the relative price of competitors products in each destination market (RPO) were calculated as the import-weighted average of common-currency relative prices:

$$RPO_{j,k} = \frac{\left(\frac{\sum_{i \neq j}^{N} \frac{P_i}{e_{i,US}} X_{i,k}}{\sum_{i \neq j}^{N} X_{i,k}}\right)}{\left(\frac{P_k}{e_{k,US}}\right)}$$

The exporters own relative price in the destination market is given by:

$$RPX_{j,k} = \frac{\frac{P_j}{e_{j,US}}}{\frac{P_k}{e_{k,US}}}$$

here P_i are prices in local currency, $e_{i,k}$ are local currency per dollar exchange rates, and $X_{i,k}$ are dollar bilateral exports from country i to country k.

Appendix 2: Unit Roots

We present results based on two standard tests for unitroots in panels, the Im, Pesaran and Shin (2003) test and the Levin and Lin (2002) Augmented Dicky Fuller (ADF) test.

For the Im Pesarn and Shin (IPS) test, we consider the following standard ADF type regression

$$\Delta y_{i,t} = \alpha_i + \beta_i y_{i,t-1} + \sum_{j=1}^{p_i} \rho_{ij} \Delta y_{i,t-j} + \epsilon_{i,t}, \tag{6}$$

where the null hypothesis of unit roots is

$$H_O : \beta_i = 0 \quad \text{for all } i,$$

against the alternatives,

$$\begin{aligned} H_1 : \quad & \beta_i < 0, \quad i = 1, 2, \ldots, N_1, \\ & \beta_i = 0, \quad i = N_1 + 1, \ldots, N. \end{aligned}$$

The IPS test, therefore, allows for individual fixed effects and allows β_i to differ over the cross section under the alternative hypothesis. In fact, the IPS test allows for some fraction (N_1/N) of the individual series to have unit roots.

In contrast, the Levin and Lin ADF (LLADF) test imposes homogeneity while still allowing for individual fixed effects.

$$\Delta y_{i,t} = \alpha_i + \beta y_{i,t-1} + \sum_{j=1}^{p_i} \rho_{ij} \Delta y_{i,t-j} + \epsilon_{i,t}, \tag{7}$$

where the null hypothesis of unit roots is

$$H_O : \beta = 0$$

against the alternatives,

$$H_1 : \beta < 0,$$

In practice, the IPS test is calculated as the average of individual ADF t-tests, while the LLADF test is an adjusted t-test for the null of a unit root from the panel regression in (7). The adjustments to the form of the standard ADF test result in a test statistic with a limiting normal distribution. In both cases, we include a common time dummy in an attempt to ameliorate any cross-sectional dependence that may exist in the errors of the ADF type regression (7), or (6).

The table below presents results for the tests of the null hypothesis that the logarithm of each series is characterized by a unit root process. In all cases, with the exception of the IPS test for FDI, the results are unable to reject the null hypothesis of a unit root.

Table 8: Panel Unit Root Tests

	IPS	**LLADF**	**T**	**N**
X	0.06	2.63	21	85
GDP	-1.73	-0.12	21	85
Po	-1.00	1.01	21	85
Px	-1.60	0.40	21	85
FDI	**-4.29**	-0.66	21	85

5% critical values: IPS = -2.47, LLADF= -1.64

Note: A bold value indicates significance at or below the 5% level.

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