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Vertical Intra-industry Trade and Fragmentation: An Empirical Examination of the US Auto-parts Industry

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1. INTRODUCTION

INTERNATIONAL product fragmentation, the splitting-up of the production process into separate components so they can be produced in different locations, represents one of the most important aspects of globalisation. The increasing degree of fragmentation across countries resulting from globalisation is reflected in the rapid growth of trade in intermediate goods. Despite this increase, the empirical literature has provided only descriptive statistics on the importance of trade in intermediate goods caused by fragmentation of production (Feenstra, 1998; Hummels et al., 2001; Yeats, 2001; Kimura and Ando, 2005; Ando, 2006). With the exception of Görg (2000), Jones et al. (2005), Egger and Egger (2005), Clark (2006), Athukorola and Yamashita (2006) and Kimura et al. (2007), empirical studies remain sparse. In this study, we investigate the determinants of fragmentation in the US auto-parts industry, to help fill this gap.

We chose this industry for several reasons. First, engineering industries have discrete production processes that can be separated economically, so production-sharing is possible across countries. In addition, empirical evidence has shown that auto-parts and components trade has drastically increased in both exports and imports in the US, as illustrated in Figure 1. The nominal value of imported parts tripled from $31.5 billion in 1989 to $93 billion in 2006, and of

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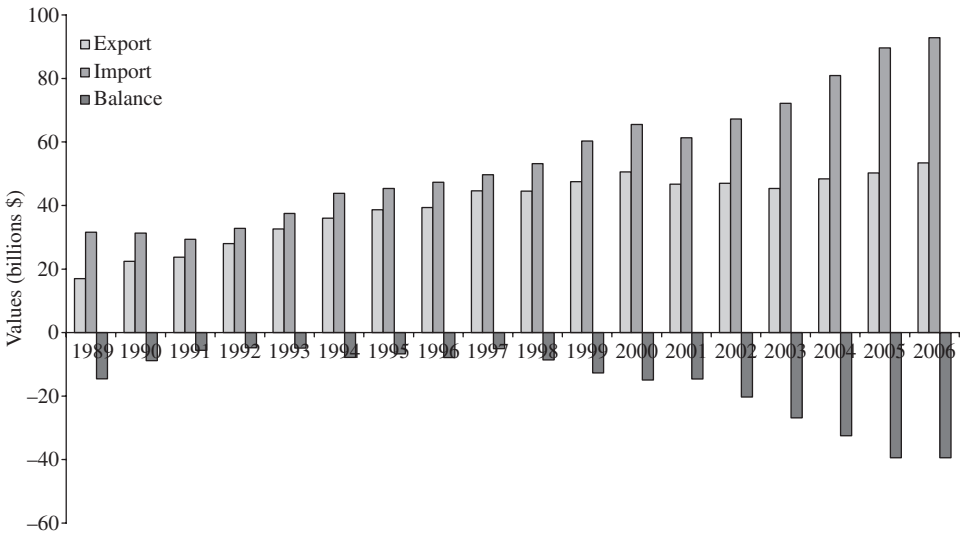
FIGURE 1
Development of the US Auto-parts Trade with the World, 1989–2006



Source: Authors' own calculation.

exported parts from $17 billion in 1989 to $53 billion in 2006. These increases suggest that intra-industry trade (IIT) and fragmentation became more prevalent in this sector. Second, the US is ranked as the world's second-largest exporter of auto-parts, following only Germany.[1] Finally, auto-parts is the one of the most important manufacturing and export sectors for the US.[2]

Using finely disaggregated trade data, this paper examines recent changes in trade patterns in the industry by breaking down the bilateral trade flows into inter-industry trade, vertical IIT and horizontal IIT. Following Ando (2006), vertical IIT is used as an indicator of fragmentation between the US and its 29 trading partners for the period from 1989 to 2006.[3] In particular, country-specific factors suggested by the fragmentation literature are tested using panel data techniques. This study fills a gap by providing information about the structure and determinants of vertical IIT as an indicator of fragmentation in the US auto-parts industry.

[1] US Automotive Parts Industry Annual Assessment, Department of Commerce, April 2009.
[2] In 2006, the US auto-parts industry shipments account for 4.2 per cent of total manufacturing shipments, while auto-parts employment represents 5.2 per cent of total manufacturing industries employment. Out of total manufacturing exports, the US auto-parts exports is 5.8 per cent in 2006 (US Automotive Parts Industry Annual Assessment).
[3] Several empirical studies have analysed the determinants of vertical IIT in the motor vehicle and auto-parts industry (Montout et al., 2002; Umemoto, 2005). However, the drawback of these empirical studies is that they do not incorporate hypotheses stemming from newly developed fragmentation literature.

The major findings can be summarised as follows. By 2006, vertical IIT dominated IIT flows, compared with 1989 for almost all countries. Hypotheses drawn from the fragmentation literature contribute to explaining this change, with the findings in particular suggesting the extent of vertical IIT is positively correlated with average market size, differences in market size, differences in factor endowments and outward foreign direct investment (FDI); while it is negatively correlated with distance and difference in per capita GDP. These findings support the claim that IIT in US trade in auto-parts is primarily a case of international fragmentation of vertical production chains.

The paper is organised as follows. Section 2 outlines the methodology for measurement of IIT and analyses its evolution and components in the US auto-parts industry. Section 3 presents the economic model and determinants of vertical IIT and addresses the key issue of estimation. Section 4 explains the empirical findings and Section 5 concludes.

2. THE MEASUREMENT OF FRAGMENTATION AND IIT

a. Fragmentation

Studies that have attempted to measure the degree of fragmentation can be divided into four groups based on their methods and data sources employed.[4] The first group use fragmentation indicators based on input–output tables (e.g. Campa and Goldberg, 1997; Feenstra and Hanson, 1997; Hummels et al., 2001). Other studies, represented by Görg (2000), Egger and Egger (2005) and Clark (2006), employ fragmentation indicators based on outward and inward processing trade statistics. Another group of studies measure the degree of fragmentation by using intra-firm trade statistics (e.g. Andersson and Fredriksson, 2000; Kimura and Ando, 2005). Finally, some analysts suggest using international trade statistics to estimate fragmentation by simply calculating the volume of trade in parts and components (e.g. Yeats, 2001; Kimura et al., 2007) or using the vertical IIT index (Ando, 2006) in intermediate goods.

The fragmentation indicator based on vertical IIT is employed in this paper.[5] As Jones et al. (2002) and Ando (2006) suggest, international fragmentation generates IIT in intermediate goods between countries that may exchange intermediate goods for intermediate goods, both of which are within the same industry classification. There are three possibilities that lead to two-way

[4] For a more detailed discussion of the empirical analysis of fragmentation, see Egger et al. (2001).
[5] It would be ideal to use intra-firm trade statistics to assess the degree of fragmentation. Unfortunately, these data are not available at the detail needed.

exchange of intermediate goods: horizontal trade in similar products with differentiated varieties (e.g. the exchange of small for large radiators); trade in vertically differentiated goods distinguished by quality (e.g. exchange of high-quality for lower quality fuel pumps); and vertical specialisation that involves the exchange of technologically linked products. Vertical IIT could be used as an indicator of international fragmentation within the same product category because it generates differences in unit values across technologically related exported and imported intermediates. This approach is supported by the findings of Jones et al. (2002), Ando (2006) and Kimura et al. (2007), which showed that the rapid increase in vertical IIT originates primarily from vertical linkages in production, rather than trade in quality differentiated goods. Thus, we use unit–price differentials between exported and imported intermediate goods as a criterion for distinguishing trade in horizontally differentiated intermediate goods from trade in technologically linked intermediate goods. However, it should be kept in mind that trade flows classified as vertical IIT could also include vertical IIT with differences in quality.

b. Methodology of Measuring IIT

We apply both the G–L-type trade decomposition developed by Grubel and Lloyd (1971, 1975) and Fontagne and Freudenberg's method to the US auto-parts industry trade in order to decompose bilateral trade flows into horizontal IIT and vertical IIT.[6] The adjusted G–L index is defined as:

$$IIT_{jkt} = \frac{\sum_{i=1}^{n} (X_{ijkt} + M_{ijkt}) - \sum_{i=1}^{n} |X_{ijkt} - M_{ijkt}|}{\sum_{i=1}^{n} (X_{ijkt} + M_{ijkt})}, \quad (1)$$

where X_{ijkt} and M_{ijkt} are the US exports and imports, respectively, of product i of industry j with country k at time t. Hence, IIT_{jkt} computes the export and import flows with country k in industry j, weighted according to the relative share of the trade flows of each product i included in industry j. The adjusted G–L index is equal to one if all trade is IIT and is equal to zero if all trade is inter-industry trade.

The first step in computing the G–L index is to select auto-parts (intermediate products) in the bilateral trade data. Once these are selected, the second step is to decompose total IIT into horizontal IIT and vertical IIT using the method suggested by Abd-el-Rahman (1991) and Greenaway et al. (1994, 1995). Assuming that price differentials between export prices and import prices outside a certain range reflect vertical specialisation, IIT is considered to be horizontal if the export and import values differ by less than 25 per

[6] The method developed by Fontagne and Freudenberg (1997) is also called 'the decomposition-type threshold method' by Ando (2006).

cent and to be vertical when the ratio of unit values falls outside following range:

$$\frac{1}{1.25} \leq \frac{P^X_{ijkt}}{P^M_{ijkt}} \leq 1.25, \tag{2}$$

where P^X_{ijkt} and P^M_{ijkt} are the unit values of the US's exports and imports, respectively; and indices i refer to the product, j the industry and k the partner country in year t. After we identify whether the IIT of product i is horizontal or vertical, the aggregated horizontal or vertical IIT is calculated using equation (1) at a six-digit product level of HTS items and then summed over all six-digit levels that comprise a particular industry.

For comparison purposes, an alternative method developed by Fontagne and Freudenberg (1997) is also employed to decompose total trade into three types: one-way trade (OWT), two-way trade in horizontally differentiated goods (TWTH) and two-way trade in vertically differentiated goods (TWTV). This method employs three steps to compute the share of each type of trade. To differentiate between OWT and two-way trade (TWT), the first step determines the degree of trade overlap. Trade in a product is TWT when the value of the minority flow of trade represents at least 10 per cent of the majority flow of trade; otherwise, it is OWT:

$$\frac{\min(X_{ijkt}, M_{ijkt})}{\max(X_{ijkt}, M_{ijkt})} \geq 0.1, \tag{3}$$

where X_{ijkt} and M_{ijkt} are the US exports and imports, respectively, of product i of industry j with country k at period t.

After determining that trade flows are TWT, the second step is to distinguish trade in horizontally differentiated goods from trade in vertically differentiated goods by following the method from Abd-el-Rahman (1991) and Greenaway et al. (1994, 1995). TWT is classified as TWTH if the export and import unit values differ by less than 25 per cent (i.e. if equation (2) holds) and as TWTV otherwise.

Finally, the share of each type of trade is calculated as:

$$S^Z_{jkt} = \frac{\sum_{i=1}^{N} \left(X^Z_{ikt} + M^Z_{ikt}\right)}{\sum_{i=1}^{N} \left(X_{ikt} + M_{ikt}\right)}, \tag{4}$$

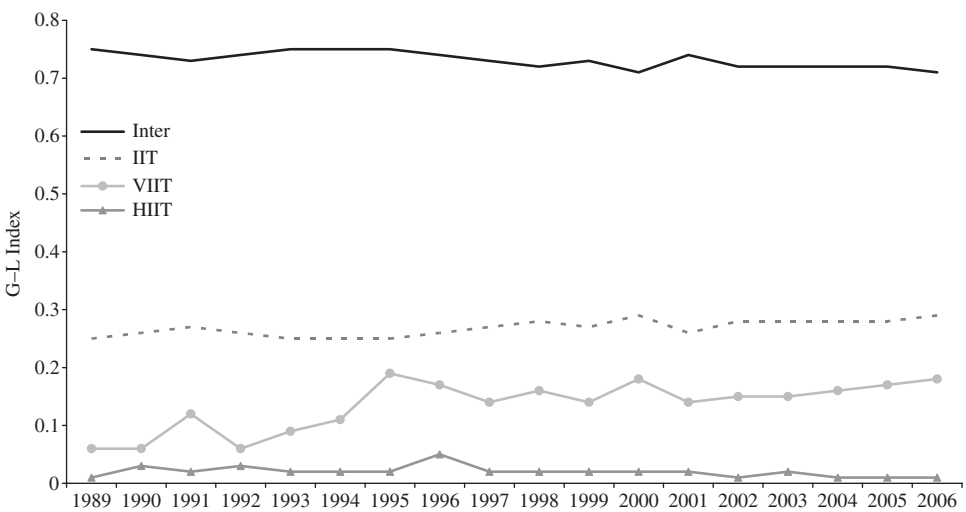
where S^Z_{jkt} stands for OWT_{jkt}, $TWTH_{jkt}$ or $TWTV_{jkt}$; indices Z refer to one of three trade categories depending on the corresponding trade type; and i refers to the product, j the industry, k the partner country in year t.

c. Evidence of IIT in the US Auto-parts Industry

The global auto industry has been undergoing significant structural transformation in recent years.[7] Among the most important and often cited trends is the increasing use of outsourcing, which has permanently altered the relationship between motor vehicle manufacturers and auto-parts suppliers. The ongoing process of product fragmentation that has shaped and continues to affect the industry has also had a major impact on the international pattern of the US auto-industry trade. Using the two approaches outlined in the previous section, the subsequent analysis investigates the recent changes in US auto-parts trade patterns that have resulted from the internationalisation of production.

Figure 2 presents measures of IIT and their components in the industry over the period from 1989 to 2006. The figure shows that the industry has undertaken a substantial amount of inter-industry trade, although the overall G–L index increased from around 24 per cent in 1989 to 29 per cent in 2006.[8]

FIGURE 2
Development of Intra-industry Trade in the US Auto-parts Industry



Source: Authors' own calculation.

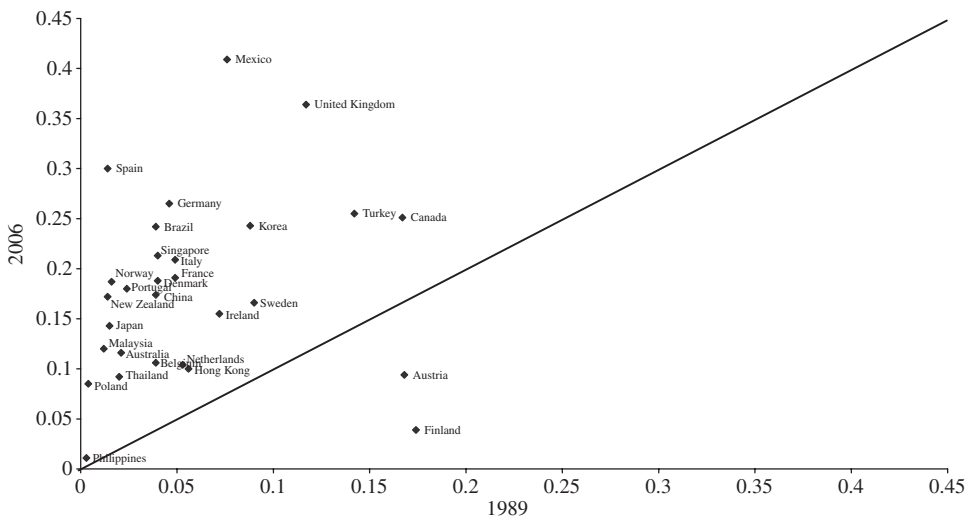
[7] A more complete analysis of trends in the auto industry can be found in Lall et al. (2004) and Cooney and Yacobucci (2005).

[8] Similarly, Ando (2006) provided empirical evidence that the auto industry trade in East Asia is mainly OWT as a result of the import-substituting policies in these developing countries, even though vertical IIT has become important for the auto-parts industry in recent years. Lall et al. (2004) argued that, in the auto industry, fragmentation is more constrained than in other sectors, such as the electronics sector.

Second, most of the IIT has been vertical, which has been rising since the early 2000s. This indicates that vertical international production-sharing has become an essential part of the industry. Horizontal IIT is very low compared with vertical IIT. [9]

In additional analysis, we investigate the vertical IIT indices for each trading partner for 1989 and 2006.[10] As Figure 3 shows, there are wide variations in vertical IIT across partner countries. In 2006, Mexico had the highest value, at 40 per cent, followed by the United Kingdom, Spain, Germany and Canada.[11] The high level of vertical IIT with NAFTA countries is primarily due to regional integration and geographic proximity. FDI by the global auto manufacturers may also have contributed to the increase in vertical IIT between the US and members of NAFTA. The second important finding is that the degree of vertical IIT in auto-parts was higher in 2006 than in 1989 for all countries with the exception of Finland and Austria.

FIGURE 3
Evolution of Vertical Intra-industry Trade by Country, 1989–2006



Source: Authors' own calculation.

[9] In order to save space, TWT shares are not reported here, but interested readers can obtain the results from the authors. TWT shares obtained from the decomposition method display a reasonably similar pattern. However, quantitatively, the results of the decomposition method are systematically higher than the G–L index results, consistent with the findings of Fontagne et al. (2006).

[10] TWTV shares are not reported here, but interested readers can obtain the results from the authors.

[11] Similarly, Jones et al. (2002) showed that the degree of IIT between the US and Mexico in auto-parts increased substantially from 67 per cent in 1992 to 85 per cent in 1999.

In sum, it is clear that OWT is the main pattern in the US auto-parts industry and that vertical IIT dominates horizontal IIT during the 2000s while horizontal IIT remained stable. These results support the claim that the US IIT in auto-parts is the result primarily of international fragmentation of vertical production chains, along with IIT of auto-parts of differing quality.

3. EMPIRICAL MODEL, THE DETERMINANTS OF FRAGMENTATION AND ESTIMATION

a. The Empirical Model

Using annual data from 1989 to 2006, the following logit transformation model is employed to explain the determinants of vertical IIT between the US and its 27 trading partners:[12]

$$\ln\left(\frac{y_{kt}}{1-y_{kt}}\right) = \alpha_k + \mu_t + \beta_m Z_{kt} + \beta_d DIST_k + \varepsilon_{kt}, \tag{5}$$

where y_{kt} stands for $VIIT_{kt}$ (or $TWTV_{kt}$) between the US and its trading partner country (k), Z_{kt} is a set of m country-specific variables, $DIST_k$ represents the geographic distance, α_k is the country effect, $k = 1, \ldots, K$, μ_t is the time effect, $t = 1, \ldots, T$, and ε_{kt} is the white noise disturbance term distributed randomly and independently.

b. The Determinants of Fragmentation

Several country-specific variables suggested by the fragmentation literature are used as explanatory variables.[13]

(i) Economic size (GDP)

Jones and Kierzkowski (2005) claimed that IIT in intermediate goods tends to increase with the bilateral market size of the two countries as a result of economies of scale in service link activities. In addition, larger markets support more varieties and qualities to be traded (Lancaster, 1980). Thus, the larger the international market, the larger the opportunities for production of differentiated intermediate goods and the larger the opportunities for trade in intermediate goods (Jones et al., 2005). As a result, vertical IIT is expected to be positively related to the average market size of the US and its trading partner, denoted as GDP_{kt}.

[12] Due to missing data, Poland and Singapore are excluded from the statistical analysis.
[13] The definitions and sources of explanatory variables are explained in the Appendix.

(ii) Differences in market size (DGDP)

Grossman and Helpman (2005) showed that a trading partner's market size encourages greater degrees of fragmentation between two countries. In large host markets, firms are likely to find a trading partner with the skills that match their needs, suggesting a negative relationship between the bilateral trade in intermediate goods and differences in market sizes. On the other hand, there are reasons to believe that large markets are more likely to be served by local production because the availability of local input producers in the host country should reduce the dependence on the imports of intermediate goods.[14] Consequently, the effect on vertical IIT of the difference in market size ($DGDP_{kt}$), which is measured by the absolute difference of total GDP between the US and its trading partners, may be ambiguous.

(iii) Differences in per capita GDP (DPCI)

Decisions related to international fragmentation may also be affected by the level of economic development. Athukorola and Yamashita (2006) and Kimura et al. (2007) emphasised the role of economic development in their studies of the determinants of fragmentation and argued that location advantages, such as inexpensive infrastructure, the existence of supporting industries and a favourable policy environment, make the host countries profitable locations for production. As a result, we predict that a greater divergence in the level of economic development of two countries yields a lower volume of IIT in vertically differentiated intermediate goods. This hypothesis is tested by including a measure of differences in per capita GDP between the US and its trading partner ($DPCI_{kt}$).

(iv) Differences in factor endowments (DKL)

Helpman (1984) showed that the vertical type of trade increases with differences in relative factor endowments. Assuming fragmentation typically occurs with vertical FDI, IIT in intermediate goods should be high when there are large differences in relative factor endowments from country to country. Similarly, Feenstra and Hanson's (1997) model of outsourcing predicts that fragmentation is more likely to take place between countries with dissimilar factor endowments. Following Clark (2006), the absolute value of the difference in the capital–labour ratio between the US and its trading partner (DKL_{kt}) is used to test this hypothesis.[15]

[14] See Andersson and Fredriksson (2000) for a more detailed discussion on the relationship between the host country's market size and intra-firm imports of intermediate goods.

[15] Many previous studies have relied on only one variable, particularly the differences in per capita GDP, in order to capture the effects of the differences in factor endowments on fragmentation (Egger and Egger, 2005; Kimura et al., 2007). With regard to vertical IIT, the use of the differences in per capita GDP as a measure of factor endowment differences may be problematic because this variable has two opposite effects on the vertical IIT: negative as a proxy for the level of economic development and positive as a proxy for differences in factor endowments.

(v) Foreign direct investment (FDI)

Vertical models by Helpman (1984), Helpman and Krugman (1985) and Egger et al. (2007) predict a complementary relationship between FDI and trade, given that affiliates in the host country perform final assembly or processing stages using imported intermediate goods from the parent firm. Similarly, Feenstra and Hanson's (1997) model predicts that the growth of the capital stock in the host country encourages the flow of intermediate goods for further processing between two countries. Thus, there is a positive relationship between vertical IIT and FDI. The US stocks of outward FDI into sample countries, FDI_{kt}, is used to test this hypothesis.

(vi) Geographical distance (DIST)

We also investigate the relevance of service-link costs for vertical IIT. According to Jones and Kierzkowski (1990, 2001), reductions in service-link costs – which consist of transport costs, telecommunication costs, coordination costs and other costs – should encourage the international fragmentation of production across countries. However, measures of service-link costs are not widely available. Among the various components, transportation costs between production sites are the most visible, and these are typically assumed to be a linear function of distance. For instance, Kimura et al. (2007) claimed that the distance between countries is indicative of service-link costs, particularly the transportation and telecommunication costs. Hence, geographical distance between the capital cities of the US and its trading partners, $DIST_k$, is used as proxy for service-link costs. The vertical IIT is expected to be negatively associated with distance ($DIST_k$) between the US and its trading partner.[16]

(vii) Bilateral exchange rate (EXCH)

The bilateral exchange rate ($EXCH_{kt}$) is included in our model to control for the effects of exchange rate changes on the degree of vertical IIT because changes in exchange rates may have an important impact on the international outsourcing decisions of firms.

(viii) Economic integration (NAFTA)

It is generally accepted that economic integration increases the degree of fragmentation as a result of specialisation, division of labour, product differentiation, economies of scale, declining costs for service links and reduction of trade barriers between member countries (Egger and Egger, 2005). The effect of the North American Free Trade Agreement is captured by a $NAFTA_{kt}$

[16] The magnitude of this effect on vertical IIT is important for intermediate goods because small changes in transportation costs have a major effect on fragmentation decisions as a result of multiple border-crossings involved in the value-added chain.

dummy, which takes the value of one for member countries and zero otherwise. Regional integration is expected to have a positive influence on the share of vertical IIT.

c. *Estimation*

We apply several estimation techniques to equation (5) in order to ensure the robustness of the results. The results for two definitions of vertical IIT index ($VIIT_{kt}$ and $TWTV_{kt}$) using the aforementioned explanatory variables are reported in Tables 1 and 2. First, equation (5) is estimated with pooled ordinary least squares (OLS) with a White heteroscedasticity correction. However, pooled OLS leads to biased results because it ignores unobserved cross-country heterogeneity. Using a panel data approach allows us to account for such effects. The most commonly employed panel models that control for the existence of such effects are the fixed effects (FE) model and the random effects (RE) model. In our study, diagnostic tests strongly indicate the RE model over the FE model.

Another step prior to estimation is to address heteroscedasticity and autocorrelation. The likelihood ratio (LR) test, reported in Tables 1 and 2, detected the presence of heteroscedasticity across panels and autocorrelation within panels. In addition, the Wooldridge test indicated the presence of autocorrelation only in the case of $VIIT_{kt}$, suggesting that the problem is not severe in the current panel data. To account for heteroscedasticity and autocorrelation, the literature proposes feasible generalised least squares (FGLS) as a means to obtain consistent and efficient estimators. However, Beck and Katz (1995) showed that test statistics based on the FGLS can be optimal only when there are substantially more time periods per unit than there are cross-sectional units. As our sample contains fewer annual observations per country than the number of countries, the method is not appropriate, and equation (5) is estimated using the panel-corrected standard errors (PCSE) method developed by Beck and Katz (1995).[17]

4. EMPIRICAL RESULTS

The regression results from the PCSE model reported in the last column of Tables 1 and 2 largely support the hypotheses drawn from the theoretical models of fragmentation. In addition, as can be seen from Tables 1 and 2, the estimated coefficients are qualitatively the same for $VIIT_{kt}$ and $TWTV_{kt}$, suggesting that the results are robust across both specifications. In particular, the market

[17] To account for serial correlation of residuals within panels, we assumed a simple AR(1) autoregressive process.

TABLE 1
Determinants of Vertical Intra-industry Trade in the US Auto-parts Industry, 1989–2006

Independent Variables	*Pooled OLS*	*Fixed Effects*	*FGLS*	*PCSE*
GDP_{kt}	2.051	3.019	2.058	2.255
	(2.29)**	(3.72)***	(2.44)**	(2.18)**
$DGDP_{kt}$	0.634	1.402	0.698	0.639
	(2.33)**	(0.70)	(2.36)**	(2.24)**
$DPCI_{kt}$	−0.127	−0.031	0.102	−0.117
	(−1.29)	(−0.12)	(0.90)	(−1.11)
DKL_{kt}	0.170	0.184	0.212	0.166
	(2.76)***	(3.68)***	(3.72)***	(3.27)***
FDI_{kt}	0.235	0.263	0.209	0.213
	(4.64)***	(1.89)*	(3.97)***	(3.77)***
$DIST_k$	−0.199		−0.219	−0.235
	(−1.68)*		(−2.21)**	(−1.91)*
$EXCH_{kt}$	0.041	−0.010	0.050	0.032
	(1.70)*	(−0.26)	(1.82)**	(1.47)
$NAFTA_{kt}$	0.267	0.233	0.123	0.215
	(1.20)	(3.07)***	(0.59)	(1.17)
Constant	−51.910	−51.499	−56.057	−54.655
	(−4.82)***	(4.87)***	(−5.73)***	(−3.03)***
R^2	0.26	0.16		
F-statistics	22.42***	109.29		
Wald statistic: $\chi^2(8)$			190.51***	182.55***
Wooldridge test for autocorrelation: $F(1,26)$			6.563**	
LR-test for heteroscedasticity: $\chi^2(26)$			160.56***	
Chow test (41,401)		9.21***		
Breusch–Pagan LM-test for random effects: $\chi^2(1)$			191.21***	
Hausman specification test: $\chi^2(7)$			2.24	
Number of groups		27	27	27
Number of observations	451	451	451	451

Notes:
The dependent variable is the logit transformation of $VIIT_{kt}$, G–L index in vertically differentiated products. Heteroscedasticity-consistent *t*-statistics (White–Newey) are reported in the first and second columns.
*Statistically significant at 10 per cent; **significant at 5 per cent; ***significant at 1 per cent.

size variable, GDP_{kt}, has a positive and significant association with vertical IIT. This result is in line with the results of Jones et al. (2005) and Kimura et al. (2007).

Contrary to expectations, the variable representing difference in size between trading partners, $DGDP_{kt}$, exerts a positive and statistically significant impact on both $VIIT_{kt}$ and $TWTV_{kt}$. However, the findings confirm the hypothesis that large markets are most likely to be served by local production because the availability of local input producers in the host country should reduce the dependence on the imports of intermediate goods from the home country.

TABLE 2
Determinants of Two-way Trade in Vertically Differentiated Goods in the US Auto-parts Industry, 1989–2006

Independent Variables	*Pooled OLS*	*Fixed Effects*	*FGLS*	*PCSE*
GDP_{kt}	2.328	3.830	1.609	2.328
	(2.07)**	(3.16)***	(1.90)*	(3.01)***
$DGDP_{kt}$	0.608	−0.646	0.585	0.608
	(1.90)*	(−0.25)	(2.08)**	(2.52)**
$DPCI_{kt}$	−0.211	−0.035	−0.021	−0.211
	(−1.77)*	(−0.16)	(−0.20)	(−2.00)**
DKL_{kt}	0.202	0.190	0.216	0.202
	(2.66)***	(2.19)**	(3.61)***	(4.30)***
FDI_{kt}	0.344	0.252	0.362	0.344
	(5.36)***	(1.17)	(6.86)***	(9.32)***
$DIST_k$	−0.265		−0.157	−0.265
	(−1.59)		(−1.16)	(−2.06)**
$EXCH_{kt}$	0.048	−0.061	0.034	0.048
	(1.42)	(−1.11)	(1.15)	(1.96)**
$NAFTA_{kt}$	0.165	0.107	0.136	0.165
	(0.51)	(0.96)	(0.46)	(0.75)
Constant	−54.426	−61.340	−45.922	−54.426
	(−3.82)***	(−3.70)***	(−4.52)***	(−4.25)***
R^2	0.26	0.23		
F-statistics	21.88***	244.79***		
Wald statistic: $\chi^2(8)$			223.47***	298.67***
Wooldridge test for autocorrelation: $F(1,26)$			0.591	
LR-test for heteroscedasticity: $\chi^2(26)$			158.03***	
Chow test (41,401)		9.04***		
Breusch–Pagan LM-test for random effects: $\chi^2(1)$			191.05***	
Hausman specification test: $\chi^2(7)$			0.39	
Number of groups		27	27	27
Number of observations	451	451	451	451

Notes:
The dependent variable is the logit transformation of $TWTV_{kt}$, the share of two-way trade in vertically differentiated products. Heteroscedasticity-consistent *t*-statistics (White–Newey) are reported in the first and second columns.
*Statistically significant at 10 per cent; **significant at 5 per cent; ***significant at 1 per cent.

The results illustrate that dissimilarities in GDP per capita, as an indicator of level of economic development, $DPCI_{kt}$, have a negative and significant effect on $TWTV_{kt}$ but an insignificant effect on $VIIT_{kt}$.[18] Thus, the negative estimate of the coefficient of $DPCI_{kt}$ suggests that the income gap between trading partners discourages multinational auto companies in developed countries from

[18] Cooney and Yacobucci (2005) suggested that a key determinant for location choices of auto-parts firms was the location of the assembly plant itself and the associated transportation infrastructure.

locating production in less developed countries. This is consistent with Athukorola and Yamashita (2006), which included per capita income differences as a proxy for inter-country differences in technological advancement and found negative coefficients for the bilateral trade flows in parts and components. This result may also partially reflect the fact that developed countries still account for much of the world's trade in auto-parts.

The coefficient on DKL_{kt} is statistically significant with the expected sign in both $VIIT_{kt}$ and $TWTV_{kt}$. Thus, there is strong empirical support for the hypothesis that differences in factor endowment are major determinants of vertical IIT in auto-parts. This result – that there is a positive relationship between the trade caused by fragmentation and differences in factor endowment – is similar to the results of studies by Egger and Egger (2005) and Athukorola and Yamashita (2006). The findings also support Klier and Rubenstein's (2006) claim that there has been a shift towards high-quality and capital-intensive production stages in the US auto-industry.

FDI_{kt} has a significant and positive effect on both $VIIT_{kt}$ and $TWTV_{kt}$, confirming our hypothesis that FDI stimulates fragmentation. This is consistent with the theoretical expectation that vertical-type FDI complements, rather than substitutes for, trade in intermediate goods. Similar findings also emerged in Görg (2000), Blonigen (2001), Türkcan (2007) and Yoshida et al. (2009). This is an important result as it supports the view that fragmentation plays a significant role in explaining the intra-firm trade in intermediate goods between different plants within the same MNE.

Moreover, our results indicate that the distance variable ($DIST_k$) as a proxy for service-link costs has, as expected, a negative and significant relationship with both specifications of the vertical IIT index. According to this result, transportation costs significantly hamper fragmentation across countries, verifying the hypothesis developed by Jones and Kierzkowski (1990, 2001) that cross-border outsourcing is more favourable if service-link costs are lowered.[19]

Our findings also suggest that many auto makers require auto-parts suppliers to be located near their plants because of the 'just-in-time' manufacturing model. A large portion of the US exports and imports of auto-parts are still heavy and bulky, necessitating production close to assembly plants (Klier and Rubenstein, 2006). Thus, the negative and significant coefficient of the distance variable points to the importance of the just-in-time production model in the US auto-parts industry as well.[20]

[19] Jones et al. (2005), Athukorola and Yamashita (2006) and Kimura et al. (2007) reported similar findings for the relationship between service-link costs and trade in intermediate goods.

[20] Cooney and Yacobucci (2005) claimed that distance may limit China's role in the US auto industry as a major supplier for auto-parts producers (particularly the original equipment industry) if a 'just-in-time' production model is used.

The coefficient of the bilateral exchange rate ($EXCH_{kt}$) is found to be insignificant for $VIIT_{kt}$ but positive and significant for $TWTV_{kt}$. The latter suggests that the magnitude of vertical IIT in auto-parts will decline with depreciation of the dollar. This is in line with Swenson (2000), who found that depreciation of the dollar has a negative influence on foreign processing by US firms.[21] Finally, the coefficients for $NAFTA_{kt}$ are positive but insignificant in both models, confirming that, before NAFTA was in place, the US and Canada had open bilateral trade in the auto industry as a result of the Canada–USA Auto Pact of 1965. Because of this, the implementation of NAFTA did not have a significant impact.

5. CONCLUDING REMARKS

The global auto industry has undergone significant structural transformations in the last two decades as a result of the international fragmentation of the production process. The increase in cross-border production-sharing activities gave rise to a massive surge of trade in auto-parts. This study's examination of the US auto-parts industry IIT makes several contributions. First, it presents a detailed examination of the pattern of the IIT and its components in the US auto-parts industry between the US and its 29 trading partners. Second, the development of the US's vertical IIT is analysed as an indicator for fragmentation, and several country-specific hypotheses are tested using panel econometrics techniques.

The results show that a substantial part of IIT in this industry between the US and its trading partners is vertical IIT and the degree of vertical IIT has increased significantly for most countries over the period. Its increasing importance confirms that US trade in auto-parts has primarily involved the exchange of technologically linked intermediates, rather than the exchange of varieties of the same intermediates.

The results obtained from PCSE estimation generally support the hypotheses drawn from the fragmentation literature. The estimated coefficients are similar and robust across the various estimation methods for both specifications of vertical IIT. In particular, the extent of vertical IIT is positively correlated with integrated market size; the difference in the market size variable is positively related to vertical IIT, as is outward FDI. While dissimilarity in factor endowments has a positive effect on fragmentation, differences in per capita GDP has a negative impact, as does distance.

[21] However, this result is inconsistent with Thorbecke (2008), who did not find a link between exchange rate changes and trade volumes induced by fragmentation.

The empirical analysis in this paper suggests that there are significant payoffs for improving the infrastructure in developing countries as reliable and inexpensive infrastructure is important in inducing fragmentation. In addition, the results indicate that policies that generate favourable economic conditions for FDI in developing countries can lead to important gains in terms of exports and FDI inflows in the region.

APPENDIX

a. Definition of Auto-parts Trade

The dependent variables in the models, measured at the six-digit Harmonised Tariff Schedule of the US, were derived from the United States International Trade Commission's (USITC) website: http://www.usitc.gov. For the measurement of IIT we employed the list provided by the Office of Aerospace and Automotive Industries' Automotive Team. This can be found at http://www.ita.doc.gov/td/auto.html. The database provides detailed annual bilateral trade data for product exports and imports in values (US$ at current prices) and quantities at the six-digit level of the HTS. Unit values at the six-digit product level of the HTS are then constructed as the value of imports and exports of the product divided by the corresponding quantities.

b. Definition of Explanatory Variables

Country-level variables for the US and its 29 OECD countries are retrieved primarily from the World Bank's *World Development Indicators* (WDI) CD-ROM. The following 29 top US trading partners are in the dataset: Australia, Austria, Belgium, Brazil, Canada, China, Denmark, Finland, France, Germany, Hong Kong, Ireland, Italy, Japan, Korea, Malaysia, Mexico, the Netherlands, New Zealand, Norway, the Philippines, Poland, Portugal, Singapore, Spain, Sweden, Thailand, Turkey, and the UK.

GDP_{kt} is proxied by the log of the average GDP of the US and a trading partner k, expressed in constant 2005 US dollars. In addition, $DGDP_{kt}$ is the log of the absolute difference in market size between the US and a trading partner, expressed in constant 2005 US dollars. $DPCI_{kt}$ is the log of the absolute difference in GDP per capita between the US and a trading partner.

DKL_{kt} is the log of the absolute difference in the capital-to-labour endowment ratios between the US and a trading partner, expressed in constant 2005 US dollars. Following Clark and Stanley (2003), physical capital endowments are calculated according to the perpetual inventory method, starting from the gross fixed capital formation, expressed in 2005 US dollars, from WDI

CD-ROM. To construct 1989 capital stocks for each trading partner and the US, we assume that the initial capital stock in 1989 was 2.5 times GDP in 1989 and depreciate them at 13.3 per cent from 1989 to 2006.

FDI_{kt} is the log of the US's outward FDI stock to its trading partner k, measured in constant 2005 US dollars. Outward FDI stock data in current dollars are compiled from the Bureau of Economic Analysis (BEA) database, which can be downloaded from http://www.bea.gov. The outward FDI stock series are converted into real terms using the US implicit GDP deflator with a base year of 2005, obtained from the BEA website.

$DIST_k$ is the log of the direct distance between the US's capital and a trading partner's capital and is taken from the United States Department of Agriculture's webpage: http://www.usda.gov.

$EXCH_{kt}$ is the log of the bilateral exchange rate between the US and a trading partner and is defined as the number of foreign currency units per unit of domestic currency so that $EXCH_{kt}$ falls when the domestic currency, the US dollar, depreciates. The series was taken from the International Financial Statistics (IFS) CD-ROM.

REFERENCES

Abd-el-Rahman, K. S. (1991), 'Firms' Competitive and National Comparative Advantages as Joint Determinant of Trade Composition', *Weltwirtschaftliches Archiv*, **127**, 83–97.

Andersson, T. and T. Fredriksson (2000), 'Distinction between Intermediate and Finished Products in Intra-firm Trade', *International Journal of Industrial Organization*, **18**, 773–92.

Ando, M. (2006), 'Fragmentation and Vertical Intra-industry Trade in East Asia', *North American Journal of Economics and Finance*, **17**, 257–81.

Athukorola, P. and N. Yamashita (2006), 'Product Fragmentation and Trade Integration: East Asia in Global Context', *North American Journal of Economics and Finance*, **17**, 233–56.

Beck, N. and J. N. Katz (1995), 'What to Do (and Not to Do) with Time-series Cross-section Data', *American Political Science Review*, **89**, 634–47.

Blonigen, B. A. (2001), 'In Search of Substitution between Foreign Production and Exports', *Journal of International Economics*, **53**, 81–104.

Campa, J. M. and L. S. Goldberg (1997), 'The Evolving External Orientation of Manufacturing Industries: Evidence from Four Countries', NBER Working Paper No. 5919 (Cambridge, MA: National Bureau of Economic Research).

Clark, D. P. (2006), 'Country and Industry-level Determinants of Vertical Specialization-based Trade', *International Economic Journal*, **20**, 211–15.

Clark, D. P. and D. L. Stanley (2003), 'Determinants of Intra-industry Trade between the United States and Industrial Nations', *International Economic Journal*, **17**, 1–17.

Cooney, S. and B. D. Yacobucci (2005), 'US Automotive Industry: Policy Overview and Recent History', CRS Report for Congress, 1-102. Available at http://www.ncseonline.org/NLE/CRSreports/05apr/RL32883.pdf.

Egger, H. and P. Egger (2005), 'The Determinants of EU Processing Trade', *The World Economy*, **28**, 147–68.

Egger, H., P. Egger and D. Greenaway (2007), 'Intra Industry Trade with Multinational Firms', *European Economic Review*, **51**, 1959–84.

Egger, P., M. Pfaffermayr and Y. W. Schnitzer (2001), 'The International Fragmentation of the Value Added Chain: The Effects of Outsourcing to Eastern Europe on Productivity and Wages in Austrian Manufacturing', Austrian Institute of Economic Research (WIFO) Monographs, 2/2001, pp. 1–132 (Vienna: WIFO).

Feenstra, R. C. (1998), 'Integration of Trade and Disintegration of Production in the Global Economy', *Journal of Economic Perspectives*, **12**, 31–50.

Feenstra, R. C. and G. H. Hanson (1997), 'Foreign Direct Investment and Relative Wages: Evidence from Mexico's Maquiladoras', *Journal of International Economics*, **42**, 371–93.

Fontagne, L. and M. Freudenberg (1997), 'Intra-industry Trade: Methodological Issues Reconsidered', CEPII Working Paper No. 1997-01 (Paris: CEPII).

Fontagne, L., M. Freudenberg and G. Gaulier (2006), 'A Systematic Decomposition of World Trade into Horizontal and Vertical IIT', *Review of World Economics/Weltwirtschaftliches Archiv*, **142**, 459–75.

Görg, H. (2000), 'Fragmentation and Trade: US Inward Processing Trade in the EU', *Weltwirtschaftliches Archiv*, **136**, 403–22.

Greenaway, D., R. Hine and C. Milner (1994), 'Country-specific Factors and the Pattern of Horizontal and Vertical Intra-industry Trade in the UK', *Welwirtschaftliches Archiv*, **131**, 77–100.

Greenaway, D., R. Hine and C. Milner (1995), 'Vertical and Horizontal Intra-industry Trade: A Cross Industry Analysis for the United Kingdom', *Economic Journal*, **105**, 1505–19.

Grossman, G. M. and E. Helpman (2005), 'Outsourcing in a Global Economy', *Review of Economic Studies*, **72**, 135–59.

Grubel, H. and P. J. Lloyd (1971), 'The Empirical Measurement of Intra-industry Trade', *Economic Record*, **470**, 494–517.

Grubel, H. and P. J. Lloyd (1975), *Intra-Industry Trade: Theory and Measurement of International Trade in Differentiated Products* (New York: John Wiley).

Helpman, E. (1984), 'A Simple Theory of International Trade with Multinational Corporations', *Journal of Political Economy*, **92**, 451–71.

Helpman, E. and P. Krugman (1985), *Market Structure and Foreign Trade: Increasing Returns, Imperfect Competition, and the International Economy* (Cambridge, MA: MIT Press)

Hummels, D., J. Ishii and K.-M. Yi (2001), 'The Nature and Growth of Vertical Specialization in World Trade', *Journal of International Economics*, **54**, 75–96.

Jones, R. W. and H. Kierzkowski (1990), 'The Role of Services in Production and International Trade: A Theoretical Framework', in R. W. Jones and A. Krueger (eds.), *The Political Economy of International Trade*, (Oxford: Blackwell), 31–48.

Jones, R. W. and H. Kierzkowski (2001), 'A Framework for Fragmentation', in S. W. Arndt and H. Kierzkowski (eds.), *Fragmentation: New Production Patterns in the World Economy* (Oxford: Oxford University Press), 17–35.

Jones, R. W. and H. Kierzkowski (2005), 'International Fragmentation and New Economic Geography', *North American Journal of Economics and Finance*, **16**, 1–10.

Jones, R. W., H. Kierzkowski and G. Leonard (2002), 'Fragmentation and Intra-industry Trade', in P. J. Lloyd and H. H. Lee (eds.), *Frontiers of Research in Intra-industry Trade* (Basingstoke: Palgrave Macmillan), 67–86.

Jones, R., H. Kierzkowski and C. Lurong (2005), 'What Does the Evidence Tell Us About Fragmentation and Outsourcing', *International Review of Economics and Finance*, **14**, 305–16.

Kimura, F. and M. Ando (2005), 'Two-dimensional Fragmentation in East Asia: Conceptual Framework and Empirics', *International Review of Economics and Finance*, **14**, 317–48.

Kimura, F., Y. Takahashi and K. Hayakawa (2007), 'Fragmentation and Parts and Components Trade: Comparison between East Asia and Europe', *North American Journal of Economics and Finance*, **18**, 23–40.

Klier, T. L. and J. M. Rubenstein (2006), 'Competition and Trade in the US Auto-parts Sector', *Chicago Fed Letter*, No. 222, 1–4.

Lall, S., M. Albaladejo and J. Zhang (2004), 'Mapping Fragmentation: Electronics and Automobiles in East Asia and Latin America', *Oxford Development Studies*, **32**, 407–32.

Lancaster, K. (1980), 'Intra-industry Trade under Perfect Monopolistic Competition', *Journal of International Economics*, **10**, 151–75.

Montout, S., J. L. Mucchielli and S. Zignago (2002), 'Regionalization and Intra-industry Trade. An Analysis of Automobile Industry Trade in NAFTA', *Revue Region et Developpement*, No. 16-2002, 137–60.

Swenson, D. L. (2000), 'Firm Outsourcing Decisions: Evidence from US Foreign Trade Zones', *Economic Inquiry*, **38**, 175–89.

Thorbecke, W. (2008), 'The Effect of Exchange Rate Volatility on Fragmentation in East Asia: Evidence from Electronics Industry', *Journal of Japanese and International Economies*, **22**, 535–44.

Türkcan, K. (2007), 'Outward Foreign Direct Investment and Intermediate Goods Trade: Evidence from the USA', *Economie Internationale*, **112**, 51–71.

Umemoto, M. (2005), 'Development of Intra-industry Trade between Korea and Japan: The Case of Automobile Parts Industry', CITS Working Paper Series, No. 2005-03 (Kitakyushu, Japan: Yokohoma National University).

US Department of Commerce, Office of Aerospace and Automotive Industries' Automotive Team (2009), 'US Automotive Parts Industry Annual Assessment'.

Yeats, A. J. (2001), 'How Big is Global Production Sharing?', in S. Arndt and H. Kierzkowski (eds.), *Fragmentation: New Production Patterns in the World Economy* (Oxford: Oxford University Press), 108–44.

Yoshida, Y., N. C. Leitao and H. Faustino (2009), 'Vertical Intra-industry Trade and Foreign Direct Investment between Japan and European Countries', *Atlantic Economic Journal*, **37**, 351–65.