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Vertical Gravity

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CONTENTS

ABSTRACT

We use a newly developed indicator of production sharing and processing trade to investigate the determinants of such trade in the context of a gravity model. The Network Trade Index measures countries' interdependence through the extent of trade in parts and components for further processing and assembly of final exports goods. The intensity of processing trade among 75 countries between 1998 and 2005 is then assessed against the typical gravity determinants of trade, such as distance and joint income, jointly with bilateral foreign direct investment stocks and trade policy measures, such as applied bilateral tariff levels and the existence of preferential trade agreements. We find that trade policy plays a significant role in facilitating the intensity of production sharing and vertical trade. Joint adherence to a preferential trade agreement increases processing trade substantially, and a fall of 10% in average applied tariffs is estimated to increase vertical trade integration by 6.2% on average.

I. INTRODUCTION

The progressive integration of world markets has led to the fragmentation of production across countries and the formation of global supply chains. As different stages of production are increasingly performed in different countries, the associated cross-border trade in parts and components, or vertical trade, has come to predominate world merchandise trade (Arndt and Kierzkowski, 2001; Cheng and Kierzkowski, 2001).[1] At the same time, there is little empirical evidence about how policies can influence vertical trade in particular, as opposed to policy influence on total trade. This paper aims to contribute to filling that gap.

Nowhere has the expansion of vertical trade networks and supply chains been more pronounced than in Asia, largely in response to infrastructure-induced declines in trade costs (Brooks and Hummels 2009) and foreign direct investment from outside the region (Brooks and Hill 2004). More recently, the People's Republic of China's (PRC) rapid growth as a regional hub of assembly and a global trade powerhouse has driven the process, particularly since 2001. By 2007, more than half of the PRC's total export value (Koopman, Wang, and, Wei 2008). At the same time, trade policy has been rapidly evolving in Asia, with both unilateral liberalization and proliferation of preferential trading arrangements being common.

Recent efforts to measure the intensity of 'vertical trade' among the countries involved in global production sharing and supply chains have led to the development of the Network Trade Index (NTI), defined as a supplier country's share in parts and components imports by a processing industry in the host country and weighted by that industry's share of total final goods exports from the host country (Ferrarini, 2011). In other words, the NTI measures the intensity of network or vertical trade in total trade between a pair of countries, with a higher index value corresponding to greater bilateral vertical trade.

A first in the literature to our knowledge, this paper assesses the determinants of vertical—as opposed to horizontal—trade in an augmented trade gravity framework. More specifically, we regress the NTI on the typical gravity variables, such as trading nations' physical distance and combined gross domestic product (GDP), as well as on indicators of countries' trade policy stance and the foreign direct investment (FDI) stock between vertically integrated trading partners.

We estimate the gravity model allowing for year- and dyad-specific fixed effects on the basis of a data set covering the period 1998–2005, a period during which international production networks and trade liberalization both spread rapidly in Asia. Controlling for total merchandise trade between countries, we find that the typical gravity factors are significant drivers of vertical trade, to an extent similar as is typically found in relation to horizontal trade gravity. Of greater interest, the regressions also confirm that trade policy plays an important role in determining countries' vertical trade integration. For example, a 10% decrease in average applied tariffs increases the vertical trade index by 6.2% on average, which is pushed significantly higher for country pairs that have a preferential trade agreement in place.

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[1] Vertical trade is not to be confused with 'vertical intra-industry trade', which refers to the exchange of similar goods differentiated by quality (and unit values). This, in turn, is different from 'horizontal intra-industry trade', referring to goods of similar quality being differentiated by their attributes or varieties. For a discussion of the different dimensions of intra-industry trade, see Krugman (1981) and Greenaway, Hine, and Milner (1995).

The paper is structured to first discuss calculation of the NTI in Section II. In Section III, we then present our empirical strategy and interpret the gravity estimation results. Concluding thoughts and issues for further research are elucidated in Section IV.

II. THE NETWORK TRADE INDEX

To gauge the intensity of vertical trade between any pair of countries, we compute the NTI developed in Ferrarini (2011). Equation (1) defines the NTI as partner *j's* share (c_s^{ij}) in reporter *i's* total imports of parts and components ($\Sigma^j c_s^{ij}$), weighted by the share of industry *s* in *i's* total final goods exports ($p^i_s/\Sigma i\ p^i_s$). To derive an economy-wide measure of vertical trade among any given country-pair, (NTI^{ij}), the index is cumulated across industries (Σ_s).

$$NTI^{ij} = \Sigma_s \frac{c_s^{ij}}{\Sigma_i c_s^{ij}} \frac{p_s^i}{\Sigma_i p_s^i} \quad (1)$$

$$\widehat{NTI}^{ij} = \frac{NTI^{ij} - NTI^{ij}_{min}}{NTI^{ij}_{max} - NTU^{ij}_{min}} \quad (2)$$

To facilitate comparability across country pairs and industries, equation (2) normalizes the NTI to range from zero (no network connection between country-pairs) to one (the strongest connection in the entire set of country-pair permutations). The NTI is computed on the basis of the *Base pour l'Analyse du Commerce International* (BACI) data set, compiled by the *Centre d'Études Prospectives et d'Informations Internationales* (CEPII).[2] The data is available in the 1996 revision of Harmonized System (HS) classification disaggregated at six digits, comprising more than 200 countries and 5,000 products. Compared to the underlying United Nations Commodity Trade Statistics Database (UN COMTRADE) data, BACI offers the advantage of mirrored and reconciled importer and exporter records, for a more consistent and complete world trade matrix of bilateral flows. The data series cover the period 1998–2007, for which the NTI is computed.

Most of the smaller or poorer developing countries are known to have weak network connections and their role in processing trade is marginal at best. For a leaner data set, we apply a first ad hoc filter that drops countries with population smaller than one million, and then drop all countries with GDP per capita in 2006–2007 smaller than $750. After excluding all countries with missing data in either year, the data set comprises 75 countries, listed in Table 1. Included are all of the world's major trading nations, both advanced and emerging, as well as a representative number of developing countries, mainly in Asia and Latin America.

To distinguish parts and components trade among the more than 5,000 product codes populating the HS data set at 6-digits, we adopt the exhaustive list of parts and components, based on UNCTAD Broad Economic Classification (BEC) and COMTRADE data.[3]

With vertical trade in parts and components thus isolated from horizontal trade in final goods, we compute and normalize the NTI following the equations (1) and (2). Table 2 lists the top 15 country pairs according to the NTI computed for 2006–2007 average trade flows. Country

[2] For a description of the data set, see Gaulier and Zignago (2010).
[3] See Ferrarini (2011) for a description of the parts and components data and a discussion of the caveats that come with any attempt of identifying such flows based on official trade data.

pairs are ranked by decreasing average values of the NTI by country pairs, i.e., $(NTI^{ij} + NTI^{ji})/2$. Rather unsurprisingly, the world's leading exporters of manufactured goods are also those linked most strongly to the global processing networks.

Table 1: List of Countries

Code	Country	Code	Country	Code	Country
DZA	Algeria	ITA	Italy	ZAF	South Africa
ARG	Argentina	JPN	Japan	SPA	Spain
AUS	Australia	HKG	Hong Kong, China	SRI	Sri Lanka
AUT	Austria	KAZ	Kazakhstan	SWE	Sweden
AZE	Azerbaijan	KOR	Korea, Rep. of	SWI	Switzerland
BLR	Belarus	KWT	Kuwait	THA	Thailand
BEL	Belgium	LVA	Latvia	TUN	Tunisia
BOL	Bolivia	LBY	Libya	TUR	Turkey
BRA	Brazil	LTU	Lithuania	TKM	Turkmenistan
BGR	Bulgaria	MKD	Macedonia	UKR	Ukraine
CAN	Canada	MAL	Malaysia	UKG	United Kingdom
CHL	Chile	MUS	Mauritius	USA	United States
PRC	China, People's Rep. of	MEX	Mexico	URY	Uruguay
COL	Colombia	MON	Mongolia	VEN	Venezuela
CRI	Costa Rica	MAR	Morocco	VIE	Viet Nam
HRV	Croatia	NET	Netherlands, The		
CZE	Czech Rep.	NZL	New Zealand		
DEN	Denmark	NGA	Nigeria		
ECU	Ecuador	NOR	Norway		
EGY	Egypt	PRY	Paraguay		
EST	Estonia	PER	Peru		
FIN	Finland	PHI	Philippines		
FRA	France	POL	Poland		
GER	Germany	POR	Portugal		
GRC	Greece	ROM	Romania		
HUN	Hungary	RUS	Russian Federation		
IND	India	SAU	Saudi Arabia		
INO	Indonesia	SIN	Singapore		
IRE	Ireland	SVK	Slovak Rep.		
ISR	Israel	SVN	Slovenia		

Note: List of 75 countries underlying the NTI computations. Three-digit International Organization for Standardization (ISO) codes are used, except for certain member economies of the Asian Development Bank (ADB), for which ADB's country codes or country names are used.

Source: Ferrarini (2011).

Table 2: Network Trade Index—All Industries

Code	Country	Code	Country	NTI	NTI (average)
JPN	Japan	PRC	China, People's Rep. of	0.707	0.646
PRC	China, People's Rep. of	JPN	Japan	0.585	0.646
MEX	Mexico	USA	United States	1.000	0.611
USA	United States	MEX	Mexico	0.221	0.611
CAN	Canada	USA	United States	0.881	0.579
USA	United States	CAN	Canada	0.277	0.579
AUT	Austria	GER	Germany	0.892	0.507
GER	Germany	AUT	Austria	0.122	0.507
CZE	Czech Rep.	GER	Germany	0.813	0.489
GER	Germany	CZE	Czech Rep.	0.164	0.489
HKG	Hong Kong, China	PRC	China, People's Rep. of	0.764	0.443
PRC	China, People's Rep. of	HKG	Hong Kong, China	0.122	0.443
HUN	Hungary	GER	Germany	0.750	0.422
GER	Germany	HUN	Hungary	0.094	0.422
THA	Thailand	JPN	Japan	0.626	0.395
JPN	Japan	THA	Thailand	0.164	0.395
PRC	China, People's Rep. of	KOR	Korea, Rep. of	0.393	0.375
KOR	Korea, Rep. of	PRC	China, People's Rep. of	0.356	0.375
KOR	Korea, Rep. of	JPN	Japan	0.543	0.363
JPN	Japan	KOR	Korea, Rep. of	0.182	0.363
TUN	Tunisia	FRA	France	0.700	0.359
FRA	France	TUN	Tunisia	0.019	0.359
SVK	Slovak Rep.	GER	Germany	0.651	0.349
GER	Germany	SVK	Slovak Rep.	0.047	0.349
POL	Poland	GER	Germany	0.597	0.348
GER	Germany	POL	Poland	0.099	0.348
JPN	Japan	USA	United States	0.407	0.342
USA	United States	JPN	Japan	0.278	0.342
ITA	Italy	GER	Germany	0.409	0.288
GER	Germany	ITA	Italy	0.167	0.288

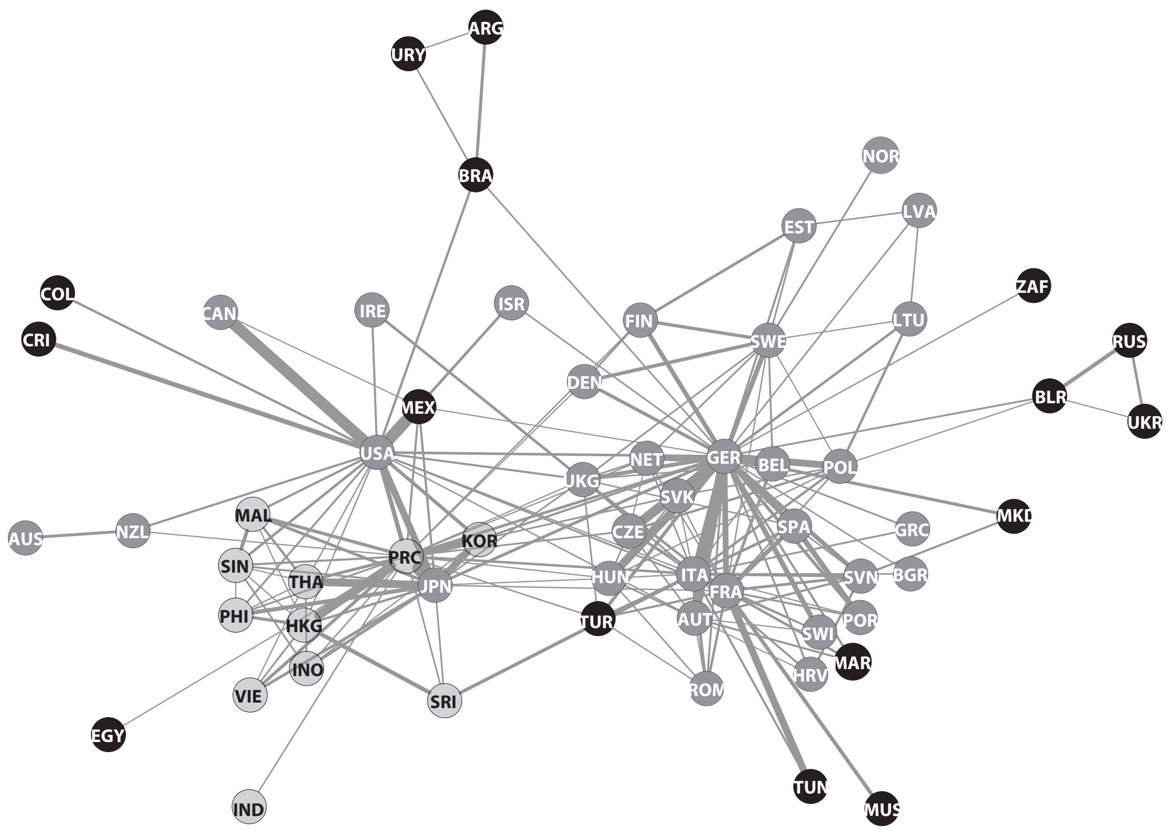
NTI = Network Trade Index

Note: Top 15 country pairs ranked by decreasing NTI.

Source: Ferrarini (2011).

Figure 1 visualizes the 2006–2007 NTI as a map showing the strongest network connections, with NTI greater than 0.05. Countries are represented by a circle, the coloring of which indicates whether a country pertains to developing Asia (white), the group of high-income countries (black) or that of developing countries outside Asia (gray). The map is based on a spring-embedded algorithm sorting through the data. Circles' position within the network and the proximity to each other are thus proportional to the force of attraction countries exert on each other through the various network relations of processing trade that run directly between any pair of countries, and indirectly via third countries or country-clusters. The strength of bilateral network relationships determines the width of the lines connecting the countries.

Figure 1: The Global Vertical Trade Network (across industries)



See Table 1 note.

Source: Ferrarini (2011).

The evidence arising out of Figure 1 is that global processing trade centers on three major regional hubs. The first is the United States (US), mainly through its strongly networked automotive and electric/electronics production with the other North America Free Trade Agreements (NAFTA) member states (Canada and Mexico) on the one hand, and its close connections to the Asian electronics production network on the other. The Asian network itself constitutes the second global hub, especially in relation to trade-in parts and components within the electric and electronics industries surrounding the PRC–Japan axis, also involving a number of economies in East and Southeast Asia. The third is the European network with Germany at its center, broadly linking the single market's value chains, most notably in relation to Europe's strong automotive industry. Apart from Mexico—mainly because of its maquiladoras[4] network ties to the US industries and markets—our analysis suggests that outside East and Southeast Asia, developing countries are not yet involved in the global production networks to any substantial degree.

[4] Mexico's maquiladoras are free trade zones of processing factories scattered about the country's border with the US.

III. VERTICAL GRAVITY

To put the NTI to work in a gravity setting, we combine the NTI by country-pairs and years as a regressand with a number of relevant regressors drawn from the comprehensive gravity data set compiled by the Peterson Institute for International Economics (DeRosa, 2007), which covers all the 75 countries listed in Table 1 up to 2005.[5]

In terms of the regressors included on the right-hand side, we follow the lines of the well-established gravity equation of Andrew Rose's influential work investigating the effects of trade policy and WTO membership on countries' trade (Rose, 2004). In addition, we add to our specification tariff and FDI stock data from DeRosa (2007), to account for most-favored nation trade policy and direct investment links, respectively. More specifically, our vertical gravity is specified as follows:

$$\begin{aligned}\ln\left(NTI_{ij}^{t}\right) = {} & \beta_0 + \beta_1 \mathrm{lnDist_{ij}} + \beta_2 \ln(\mathrm{Y_iY_j})^{\mathrm{t}} + \beta_3 \ln\left(\frac{\mathrm{Y_iY_j}}{\mathrm{Pop_iPop_j})^{t}}\right. + \beta_4 \ln\left(\mathrm{Area_iArea_j}\right) + \\ & \beta_5 \mathrm{ComBorder_{ij}} + \beta_6 \mathrm{Landlocked_{ij}} + \beta_7 \mathrm{ComLang_{ij}} + \beta_8 \mathrm{ComCol_{ij}} + \\ & \beta_9 \mathrm{Colony_{ij}^t} + \beta_{10} \mathrm{lnFDI_{ij}^t} + \beta_{11} \mathrm{Trade_{ij}^t} + \beta_{12} \mathrm{lnTariff_{ij}^t} + \beta_{13} \mathrm{PTA_{ij}^t} + \\ & \gamma_1 \mathrm{Year} + \gamma_2 \mathrm{Cty1Cty2} + \varepsilon_{ij}^{t}\end{aligned} \qquad (3)$$

(i) *i*, denotes the supplier (exporter) of parts and components and *j*, the processing and exporting country, and *t* indicates time in years.

(ii) *lnNTIt ij* is the logarithm of the NTI by country pairs, averaged across industries.

(iii) *lnDistij* is the logarithm of the the geodesic distance between trading countries' capital cities (logs).

(iv) *ln(YiYj)t* is the logarithm of country pairs' combined real GDP.

(v) *ln(YiYj/PopiPopj)t* is the logarithm of country pairs' combined real GDP per person.

(vi) *ln(AreaiAreaj)* is the logarithm of country pairs' combined territorial land area.

(vii) *ComBorderij* is an indicator variable set equal to 1 for countries sharing a common land border.

(viii) *Landlockedij* is an indicator variable that is unity for landlocked countries.

(ix) *ComLangij* is an indicator variable set equal to 1 if countries *i* and *j* share a common language.

(x) *ComColij* is an indicator variable that is unity if countries *i* and *j* have ever shared a common colonizer after 1945.

(xi) *Colonytij* is an indicator variable set equal to 1 if countries i and j ever where a colony of one another.

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5 The Peterson data set in turn combines, expands, and updates data originally compiled by Rose (2004) with data from a number of other sources, including the UNCTAD FDISTAT database on bilateral FDI stocks.

(xii) *lnFDItij* is the logarithm of the cumulative FDI stock of country *i* (the importer of parts and components) in *j* (the processing country).

(xiii) *lnTradetij* is the logarithm of total merchandize trade between countries *i* and *j*.

(xiv) *lnTarifftij* is the logarithm of average applied MFN tariffs between countries *i* and *j*.

(xv) *PTAtij* is an indicator variable that is unity when countries *i* and *j* have a Preferential Trade Agreement (PTA) in place at time *t*.

(xvi) *Year* is a vector of dummy variables to capture unobserved systemic effects on international trade flows.

(xvii) *Cty1Cty2* is a vector of dummy variables to capture unobserved effects specific to individual country-pairs.

(xviii) *Constant* is a constant term.

(xix) εtij represents the omitted influences on vertical trade, assumed to be fulfilling the basic tenets on which OLS regression is premised.

The first column of Table 3 lists the estimated coefficients of the vertical trade gravity specified in Equation 3. The second column fits the same regression, except that the FDI variable is now omitted to lift its constraint on the data set due to its scarce availability across countries and time (23,369 observations are available for the regression against 8,961 when FDI is included). This provides a robustness test of the other core coefficients estimated on the basis of the narrow data set including FDI stocks. The third column reports the estimated coefficients of a traditional gravity regression with total trade flows as the dependent variable. It provides a benchmark comparison of the vertical gravity coefficients with those accruing from canonical gravity regression. The fourth column contains the estimates of a FDI gravity equation, with bilateral FDI stocks as the regressand. It provides additional insights about the causal relationships running between FDI—assumed to be a core variable underlying production sharing and network trade—and the other variables featuring in the vertical gravity framework. The key findings are now discussed in turn.

Table 3: Gravity Regressions (Fixed Effects)

	(1) ln(NTI_{ij})	(2) ln(NTI_{ij})	(3) ln($Trade_{ij}$)	(4) ln(FDI_{ij})
ln($Dist_{ij}$)	–0.666***	–0.761***	–0.677***	–0.360***
	(0.0754)	(0.0597)	(0.0416)	(0.0887)
ln(Y_iY_j)	0.528***	0.827***	0.865***	0.519***
	(0.0491)	(0.0350)	(0.0217)	(0.0565)
ln(Y_iY_j/Pop_iPop_j)	–0.456***	–0.369***	–0.108***	0.165***
	(0.0390)	(0.0319)	(0.0248)	(0.0465)
ln($Area_iArea_j$)	–0.197***	–0.268***	–0.0514***	0.00689
	(0.0201)	(0.0188)	(0.0151)	(0.0271)
$ComBorder_{ij}$	0.343**	0.912***	0.556***	0.545***
	(0.162)	(0.195)	(0.103)	(0.205)
$Landlocked_{ij}$	0.205**	0.161*	–0.273***	–0.130
	(0.0913)	(0.0879)	(0.0609)	(0.117)
$ComLang_{ij}$	–0.211	0.215*	0.503***	1.154***
	(0.139)	(0.116)	(0.0838)	(0.146)
$ComCol_{ij}$	0.682**	0.208	1.411***	1.101**
	(0.341)	(0.335)	(0.226)	(0.498)
$Colony_{ij}$	0.0812	0.384	0.189	1.267***
	(0.194)	(0.241)	(0.141)	(0.262)
ln FDI_{ij}	0.193***		0.111***	
	(0.0183)		(0.0113)	
ln $Trade_{ij}$	0.194***	0.289***		0.465***
	(0.0387)	(0.0226)		(0.0484)
ln $Tariff_{ij}$	–0.620***	–1.293***	0.0709	–1.598***
	(0.0992)	(0.0635)	(0.0559)	(0.113)
ln PTA_{ij}	0.296***	0.856***	0.326***	0.232
	(0.113)	(0.100)	(0.0679)	(0.142)
Constant	–16.72***	–31.17***	–24.46***	–26.27***
	(1.607)	(1.218)	(0.847)	(1.869)
Observations	8,961	23,369	9,028	9,028
Country Pairs	1,897	4,646	1,917	1,917
R-squared	0.559	0.542	0.808	0.629

Pooled OLS regression with year- and country-pair-specific fixed effects.
Robust standard errors in parentheses., *** p<0.01, ** p<0.05, * p<0.1.
Source: Authors' estimates.

Column 1 of Table 3 provides the core results of our analysis. With the exception of the ComLang and Colony indicators, all the coefficients are highly significant, both economically and statistically. The estimates roughly compare with those of the horizontal gravity in Column 3. For example, a 1% increase in the distance between countries is estimated to reduce the average intensity of processing trade between country pairs by more than 0.67%. Even after controlling for the overall trade volume between country pairs, physical distance between countries is thereby shown to matter a great deal for vertical trade integration.[6]

The combined size of trade partners' economies, measured by the product of their GDPs, is estimated to positively influence the extent of network trade (0.528). By contrast, the coefficient of combined per capita GDP takes a negative sign. When it is interpreted as a measure inversely proportional to population size, a negative sign on this coefficient falls in line with the typical gravity finding of lower trade intensity when the combined domestic market

[6] Column (4) shows that bilateral trade as an explanatory variable is affected to a similar degree by distance (0.68).

potential of country pairs is greater. This is corroborated by the coefficient on the combined land area also taking a negative sign, which corresponds with the usual gravity finding of relatively less international trade involving trade partners that extend over larger geographic areas. Whereas the focus on population size most likely suits the interpretative context of a traditional gravity equation—such as in column 4, where the related coefficient is even higher, at 0.86—in a vertical trade gravity regression a more pertinent interpretation of the per capita GDP regressor would consider it a proxy for countries' degree of development and capital endowment.

The more similar per capita incomes are (for a given level of total income), the less likely are countries to find advantage in vertical trade. This can be expected from differences in relative factor endowments. In that case, the negative sign of the estimated coefficient in Column 1 points to vertical trade taking place prevalently between countries of relatively lower combined capital endowment, as is typically the case when vertical trade involves at least one developing partner country. Put differently, processing trade involves mostly developing countries on at least one end of the relationship. Prior evidence in relation to trade networks, including Figure 1, indicate that this indeed tends to be the case.[7]

Turning to the key gravity indicators, countries sharing a common border (0.34) or history of colonization by a third country (0.68) are shown to integrate more heavily.[8] Interestingly, however, being landlocked is estimated to increase vertical trade (0.21) rather than limiting it, as is typically found by traditional gravity regression, including column 4 where the coefficient is estimated at –0.27. Considered that North American and Asian processing trade mostly involves countries with access to (their own) seaports, the only plausible explanation is that this result is driven by European vertical trade, which notably involves a number of landlocked countries heavily involved in automotive supply chains, such as Austria, Switzerland, Czech Republic, or Hungary. A similar explanation could be put forward in relation to the common language indicator, which takes a negative sign, albeit it is not statistically significant. However, this contrasts with the findings of traditional gravity regressions, such as column 4, where linguistic and cultural affinity typically is found to be driving bilateral trade (0.50). Moreover, the regression involving the larger sample (Column 2) yields a ComLang coefficient equal to 0.215, with significance level of 10%. All in all, vertical gravity finds common language to influence vertical trade positively.

Countries with stronger economic ties are also more vertically integrated. This arises from the estimated coefficient on FDI, which shows a 1% increase in the FDI stock a processing country *i* holds in a country *j* that it imports parts and components from, increases the intensity of vertical trade between the two countries by 0.19% above average, all else the same. In this context, it appears to be resource-seeking FDI (as opposed to market-seeking or efficiency-enhancing FDI) that is most relevant, where the resources being sought may include intermediate inputs. Total trade between two countries has a similar effect.

Among more direct policy measures, trade protection, as measured by average bilateral applied tariffs, is estimated to heavily dampen vertical trade integration. On average, a 1% decrease in applied tariffs is estimated to raise the intensity of processing trade by 0.62%. This finding conforms with established wisdom that production fragmentation is typically premised on a more liberal trade regime between the countries involved, in order to facilitate the multiple

[7] With a few notable exceptions, such as the strong processing trade between the US and Canada.

[8] As mentioned, the indicator of a direct colonial relationship (Colony) is not statistically significant at the 10% threshold level.

border-crossings of parts and components and intermediate products vertical integration typically entails.[9]

The coefficient of the preferential trade agreement (PTA) dummy in the regression shows that preferential trade is estimated to increase network trade significantly. Again, this finding is consonant with extant evidence, including Figure 1, which shows that each of the three major processing trade networks is associated with the existence of a strong PTA. This is true for NAFTA (US, Canada, Mexico), the European Union and EFTA, and to a lesser extent the ASEAN Free Trade Agreement in Asia.[10]

Large-sample coefficients in column 2 are qualitatively similar to the smaller sample, which is constrained by the availability of FDI stocks data. Distance now appears to play a stronger role, as do combined GDP, land area, and a common border. Most notable is the difference in the trade policy coefficients, which now are significantly higher.[11] A 10% fall in applied tariffs is estimated to raise the intensity of vertical trade by nearly 13%, which is lifted even further for countries with preferential trade agreements in place. Jointly these findings strongly confirm the role of trade policy in spurring vertical integration and appear robust to variations in sample size.

A comparison of Columns 1 and 2 with Column 3 shows vertical and horizontal trade to generally be influenced by similar factors. Coefficients' signs and size are roughly in line with each other. Exceptions are the Landlocked indicator, which restricts horizontal trade but not processing trade, and also the Tariff variable, which has almost zero economic and statistical significance for the case of total bilateral trade.

Finally, column 4 reports the FDI-gravity regression, with FDI stocks on the left-hand side of the equation. The estimated coefficients for distance, GDP and common borders are qualitatively similar to the trade regressions, confirming that FDI and trade respond to similar characteristics of external economic relations. However, in stark contrast to trade, FDI appears to be more heavily driven by deep cultural factors, as can be evinced from the signs and comparative size of the ComLang, ComCol and Colony coefficients. This may reflect a higher level of confidence necessary for relatively irreversible FDI. The influence of trade policy is more ambiguous, particularly in view of the PTA coefficient lacking significance within the commonly accepted thresholds. This comes somewhat unexpected, considering that matters of investment access and protection typically represent a key factor underlying countries' adherence to PTAs. This is however not entirely inconsistent with the general literature which exhibit ambiguous impact of PTAs of FDI flows. Berger et al (2010) refined the analysis by taking into account the actual investment provisions in PTAs and found that FDIs only respond positively to FTAs if market access guarantees as represented by liberal national treatment conditions are in place.

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9 However, it should be noted that production sharing is often facilitated by special trade regimes applied to processing trade (e.g., Engman, Ondera, and Pinali 2007), whereas the tariff level used in the regression is merely an indicator of the average trade barriers between the two countries. A substantial portion of undertakings for exports of parts and components occur within special economic zones (SEZs) ranging from free trade zones, export processing zones, and free ports, which enjoy more lenient regulations on taxes, labor, and trade. The report of the Multi-Donor Investment Climate Advisory Service of the World Bank Group (2008) provides a profile of SEZ programs of different countries. A close examination of the profile reveals that activities of vertical-trade-intensive industries such as automotives and electronics are commonplace in SEZs.

10 The (implicit) importance of the Association of Southeast Asian Nations (ASEAN) Free Trade Agreement for network trade is likely to increase significantly when it becomes supplanted by the PRC–ASEAN Free Trade Agreement and eventually ASEAN+3.

11 The interaction of FDI and PTAs is empirically difficult to assess, since a surge in FDI may commonly precede implementation of an expected PTA.

As outlined in Equation 3, the regression underlying column 1 includes time- and dyad-specific dummy variables, in lieu of fixed effects to account for unobservable or unmeasurable global systemic and country-specific influences on trade.[12] As a robustness check, Table 4 reports a model similar to Equation 3, which is now estimated as panel random effects including only year dummies but does not account for dyad-specific effects. By and large, the random-effects regressions confirm the previous findings. The notable differences compared to the regressions in Table 3 are with regard to Landlocked, the coefficient of which in the vertical gravity is now close to zero and is statistically insignificant in the small sample, and significantly negative in the large sample (excluding FDI). Different also is the finding in relation to Colony, the coefficient of which is now strongly positive and highly significant in both the small and the large sample. A final distinction worthy of mention concerns the coefficient on Tariff in the horizontal gravity regression reported in Column 3, now taking the expected sign. In all likelihood, these differences are to be explained by an elevated degree of multicollinearity involving the explanatory variables and gravity indicators in conjunction with the dyad indicators included in the regressions underlying Table 3. Whether or not this is the case, the benefits from including dyad-specific effects in a vertical gravity regression are assumed to outweigh the costs of increasing multicollinearity problems, if only to better account for the potentially large amount of factors that are left unexplained in the regressions (R-squared is not much higher than 0.50).

In sum, the analysis of vertical gravity shows the framework to be as useful an empirical tool to investigate the determinants of processing trade with an appropriate dependent variable as it has proven to be in its more traditional application to horizontal trade. Our analysis shows that gravity explains a substantial share of variation in the vertical trade index. Controlling also for total trade and FDI stocks, the key findings are of a substantial causality running from trade policy to vertical trade integration.

[12] The coefficient estimates for these dummies are not reported in Table 3.

Table 4: Gravity Regressions (Random Effects)

	(1) ln(NTI_{ij})	(2) ln(NTI_{ij})	(3) ln($Trade_{ij}$)	(4) ln(FDI_{ij})
ln($Dist_{ij}$)	–0.832***	–1.167***	–0.890***	–0.613***
	(0.0640)	(0.0523)	(0.0374)	(0.0840)
ln(Y_iY_j)	0.563***	0.850***	0.861***	0.778***
	(0.0414)	(0.0300)	(0.0222)	(0.0457)
ln(Y_iY_j/Pop_iPop_j)	–0.272***	–0.210***	–0.125***	0.0544
	(0.0339)	(0.0264)	(0.0220)	(0.0355)
ln($Area_iArea_j$)	–0.171***	–0.237***	–0.0159	–0.0352
	(0.0228)	(0.0202)	(0.0169)	(0.0276)
$ComBorder_{ij}$	0.511***	1.335***	0.636***	0.804***
	(0.167)	(0.189)	(0.0929)	(0.221)
$Landlocked_{ij}$	0.0962	–0.197**	–0.250***	–0.327**
	(0.0975)	(0.0875)	(0.0637)	(0.128)
$ComLang_{ij}$	–0.0454	0.207	0.702***	1.637***
	(0.153)	(0.135)	(0.0934)	(0.153)
$ComCol_{ij}$	0.721**	0.665**	1.124***	1.163***
	(0.330)	0.283)	(0.183)	(0.368)
$Colony_{ij}$	0.614***	0.811***	0.367**	1.596***
	(0.215)	(0.263)	(0.145)	(0.293)
ln FDI_{ij}	0.0674***		0.0315***	
	(0.0111)		(0.00796)	
ln $Trade_{ij}$	0.174***	0.151***		0.181***
	(0.0297)	(0.0164)		(0.0397)
ln $Tariff_{ij}$	–0.411***	–0.569***	–0.163***	–0.916***
	(0.0747)	(0.0544)	(0.0478)	(0.103)
ln PTA_{ij}	0.0922	0.247***	0.0568	0.0955
	(0.0758)	(0.0555)	(0.0404)	(0.0983)
Constant	–21.08***	–33.25***	–23.12***	–33.62***
	(1.352)	(1.084)	(0.799)	(1.663)
Observations	8,961	23,369	9,028	9,028
Country Pairs	1,897	4,646	1,917	1,917
R-squared	0.529	0.530	0.787	0.586

Panel random-effects regression with year dummies (not reported).
Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.
Source: Authors' estimates.

IV. CONCLUSION

This paper employed the newly developed NTI to estimate the determinants of processing trade in a typical gravity framework augmented by FDI and trade policy variables. The first such approach in the literature to our knowledge, the vertical gravity framework proves to be a useful tool to explaining a substantial share of variation in the vertical trade index. Controlling also for total trade and FDI stocks, we find robust evidence of a substantial causality running from trade policy to vertical trade integration. This constitutes relevant empirical evidence for trade and industrial policy to be conducive to trade and FDI in general, and vertical trade in particular, especially in the regions most heavily reliant on international production sharing, such as Asia.

The examination in this paper shows the value of exploring vertical trade through a gravity model with a more directly relevant measure of vertical trade intensity. A further extension could include using a measure of demand that is less consumption-based than GDP (reflecting the intermediate character of the goods being traded) as suggested by Baldwin and Taglioni (2011). Preliminary efforts in this direction suggest the gains in explanatory power are likely to be small, but may be worth exploring further. Of perhaps greater promise in the context of production networks may be incorporating heterogeneity of firms, which Helpman, Melitz, and Rubinstein (2008) have shown can be accomplished in a gravity model without firm-level data. This could potentially account for location-specific differences in trade costs among firms engaging in international value chains. Incorporating firm heterogeneity in the model may also help to ascertain whether the impact of trade barriers on trade flows is magnified by a higher elasticity of substitution between goods, as suggested by Krugman (1980), or weakened as suggested by Chaney (2008).

Given the growing importance of international production networks in global production, trade, and consumption, improved understanding of the trade flows involving their parts and components, and the impacts of alternative policies on this important aspect of international trade flows, will become increasingly important for our understanding of international trade.

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Vertical Gravity

The paper examines the drivers of international production networks and vertical trade integration in an augmented gravity model that employs the newly developed Network Trade Index as a regressant. Based on bilateral trade data among 75 countries from 1998 to 2005, the findings emphasize trade policy's role in facilitating network trade. For example, a 10% tariff reduction raises vertical trade by 6.2%, on average. Preferential trade agreements are found to significantly boost vertical integration.

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