Proximity and Production Fragmentation*

Robert C. Johnson† Guillermo Noguera‡

December 30, 2011

Paper Prepared for the 2012 AEA Meetings

*We thank Nina Pavcnik for helpful conversations, as well as Joseph Celli, Michael Lenkeit, and Sean Zhang for research assistance.

†Department of Economics, Dartmouth College, Hanover, NH 03755, USA. E-mail: robert.c.johnson@dartmouth.edu.

‡Columbia Business School, Uris Hall, 3022 Broadway, New York, NY 10027, USA. E-mail: gn2195@columbia.edu.

Recent decades have seen an acceleration in cross-border production fragmentation, defined by specialization across vertically linked stages of the production process. In practice, this means that countries import intermediate inputs, combine those inputs with domestic value added, and re-export the combined product either as a final good or as an input into later production stages abroad.

These fragmented production processes are commonly referred to as 'global' production chains. However, anecdotes suggest that many of these chains might be more accurately described as 'local' production chains, since they include geographically proximate countries. For example, auto parts trade is concentrated *within* North America, while production and assembly of electronic components occurs *within* Asia. And for good reason too: proximity conserves on trade costs that are incurred based on the distance gross shipments travel between production stages. Further, regional trade integration initiatives have lowered trade barriers preferentially among nearby countries.

Building on this logic, one might expect to see increases in production fragmentation over time concentrated among proximate trading partners. This in turn implies fragmentation may be driving localization in trade over time. In this paper, we present evidence supporting both of these conjectures.

To measure changes in fragmentation, we draw on new data developed in Johnson and Noguera (2012) that measures trade in gross and value added terms over the past four decades. Comparing gross and value added trade sheds light on fragmented production chains because these chains give rise to 'double counting' in trade statistics. This double counting implies that gross trade is a multiple of the actual amount of value added exchanged between countries. Changes in the magnitude of this double counting then serve as a measure of changes in fragmentation.

We present three results documenting how changes in fragmentation are related to proximity. First, we show that value added to export ratios are lower and are falling more rapidly over time among partners within geographic regions than among partners split across regions.

Second, we show that the weighted average distance from source to destination is lower for gross trade than trade in value added, and this discrepancy is growing over time. Put differently, gross trade increasingly travels shorter distances than value added trade, consistent with fragmentation serving to localize trade. Third, we show that bilateral value added to export ratios have fallen more among nearby trading partners, due to the fact that gross trade has increased most among proximate trade partners.

1 Measuring Value Added Trade Through Time

To measure the value added content of trade, we build on an active literature on the construction of global input-output tables, including Johnson and Noguera (forthcoming).[1] The basic approach is to link national input-output tables together using bilateral trade data to form a synthetic global input-output table that tracks shipments of both final and intermediate goods between countries.[2] The resulting framework can be used to construct the value added content of bilateral trade, tracking value added from the location at which it is produced to the destination at which it is absorbed in final demand.

At an intuitive level, if one knows the entire global input-output structure, then one can compute how much output from each source country is needed (either directly or indirectly) to produce final goods absorbed in each destination. If one also knows the value added to output ratios used in producing that output in the source, then one can compute the value added embodied in that implicit gross output transfer. We call the value added produced in country i and absorbed in country j 'value added exports' and denote the bilateral flow by VA_{ij}.[3] In our work below, we focus on comparing these value added exports to gross

[1] See also Bems, Johnson, and Yi (2010), Trefler and Zhu (2010), Daudin, Rifflart, and Schweisguth (2011), Erumban, Los, Stehrer, Timmer, and de Vries (2011), and Koopman, Powers, Wang, and Wei (2011).

[2] We make two proportionality assumptions within each sector to do this. First, we split imports from each source country between final and intermediate use by applying the average split across all sources for that destination. Second, we split those imported intermediates across purchasing sectors by applying shares of total imported intermediate use in the destination.

[3] Value added exports can be defined both at the sector level and in the aggregate, summing across sectors. We focus on aggregate exports in this paper, but present sector-level results in our related work.

exports, which we notate X_{ij}. We devote special attention to the ratio of value added to gross trade, which we term the 'VAX ratio.'

Previous researchers have constructed these global input-output tables for short time horizons, often a single year or at most a decade. In Johnson and Noguera (2012), we extend this work by bringing together data on trade, production, and input-use at the sector level for 1970-2009.[4] This data allows us to construct a sequence of global input-output tables, one for each year, and therefore track changes in intermediate sourcing, final goods flows, and hence the value added content of trade over time.

Importantly, the time series dimension includes information that helps identify the causes and consequences of fragmentation. Changes in fragmentation differ across countries both in absolute magnitudes and in the timing of those changes, which opens the door to linking these changes to observables. Further, in a regression context, this type of data allows one to link changes in fragmentation to changes in bilateral trade costs, controlling for time-varying source and destination characteristics as well as pair-specific characteristics that are fixed over time.

We combine data from several sources, including the OECD Input-Output Database, the UN National Statistics Database, the NBER-UN Trade Database, and the CEPII BACI Database.[5] In calculations below, we aggregate this data where necessary to form four composite sectors: agriculture and natural resources, non-manufacturing industrial production, manufacturing, and services. Based on data availability, we include 42 countries in the framework, covering the OECD plus major emerging markets (including Brazil, China, India, Mexico, and Russia). We aggregate the remaining countries into a composite rest-of-the-world.[6]

[4]Hummels, Ishii, and Yi (2001) constructed measures of fragmentation for 10 countries over 1970-1990. Our work both extends country and time coverage, and most importantly adds a bilateral dimension to the measurement of fragmentation over time.

[5]See Johnson and Noguera (2012) for a more detailed description of data sources and methods.

[6]Because we do not have input-output data for these countries, we assume that all exports from the 42 countries to the rest-of-the-world are absorbed there. Because data for the Czech Republic, Estonia, Russia, Slovakia, and Slovenia only becomes available from the early 1990's, we implicitly include these countries in the rest-of-the-world during the first two decades and incorporate them separately thereafter.

2 Fragmentation Inside versus Outside Regions

We begin by defining proximity in terms of regions, grouping countries into regions R. To quantify fragmentation inside versus outside each region, we compute the VAX ratio for trade between countries inside the region ($i, j \in R$) and compare it to the VAX ratio for trade between countries in the region and partners outside the region ($k \notin R$). We define the VAX ratio for trade inside the region as $VAX_{IN} \equiv \frac{VA_{IN}}{X_{IN}}$, where $VA_{IN} \equiv \sum_{i \in R} \sum_{j \in R} VA_{ij}$ and $X_{IN} \equiv \sum_{i \in R} \sum_{j \in R} X_{ij}$.[7] Similarly, define the VAX ratio for trade outside the region as $VAX_{OUT} \equiv \frac{VA_{OUT}}{X_{OUT}}$, where $VA_{OUT} \equiv \sum_{i \in R} \sum_{k \notin R} (VA_{ik} + VA_{ki})$ and $X_{OUT} \equiv \sum_{i \in R} \sum_{k \notin R} (X_{ik} + X_{ki})$.

We compute these VAX ratios for three regions (North America, East Asia, and Europe) and report results for four years (1975, 1985, 1995, and 2005) in Table 1. There are three points to take away from the table.

Table 1: Value Added to Export Ratios Inside versus Outside Geographic Regions

	Europe			East Asia			North America		
	VAX_{IN}	VAX_{OUT}	Difference	VAX_{IN}	VAX_{OUT}	Difference	VAX_{IN}	VAX_{OUT}	Difference
1975	0.70	0.87	-0.17	0.77	0.88	-0.11	0.81	0.94	-0.13
1985	0.65	0.85	-0.20	0.73	0.87	-0.14	0.78	0.92	-0.14
1995	0.65	0.84	-0.19	0.75	0.88	-0.13	0.66	0.89	-0.23
2005	0.59	0.79	-0.20	0.61	0.79	-0.19	0.64	0.85	-0.21
total change	-0.11	-0.08		-0.16	-0.08		-0.16	-0.08	

Europe includes EU members who joined prior to 2004. East Asia includes China, Indonesia, Japan, South Korea, Thailand, and Vietnam. North America includes the Canada, Mexico, and the United States. The VAX_{IN} column is total value added trade divided by total gross trade inside the region. The VAX_{OUT} column is total trade in value added divided by total gross trade between countries in the region and countries outside the region. The final row is the change in VAX ratios from 1975 to 2005.

First, VAX ratios are falling over time both inside and outside regions. Thus, fragmentation is increasing on both the local and global scale. The size of the decline varies across regions and trading partners, but is in the range of 0.10 to 0.15.[8]

Second, VAX ratios are lower for trade inside regions than trade outside them in each

[7] Note that $X_{ii} = 0$ by definition of exports and we set $VA_{ii} = 0$ here for notational convenience.

[8] This is similar to the overall decline in the global VAX ratio reported in Johnson and Noguera (2012).

year. For example, the VAX ratio is around 0.2 smaller inside Europe than outside Europe, depending on the year. This holds true for the other regions as well, and suggests that intra-regional trade is more fragmentation intensive than trade outside regions.

Third, the gap between VAX_{IN} and VAX_{OUT} is growing over time. This can be seen in total changes from 1975 to 2005, which are larger for trade inside regions relative to outside regions. Further, looking decade by decade, changes are not uniform through time. For example, the large gap between inside and outside VAX ratios for North America emerges during the 1985-1995 decade, the period in which CUSFTA and NAFTA were introduced. The fact that VAX ratios are falling most rapidly within regions implies that fragmentation is concentrated among geographically proximate countries.

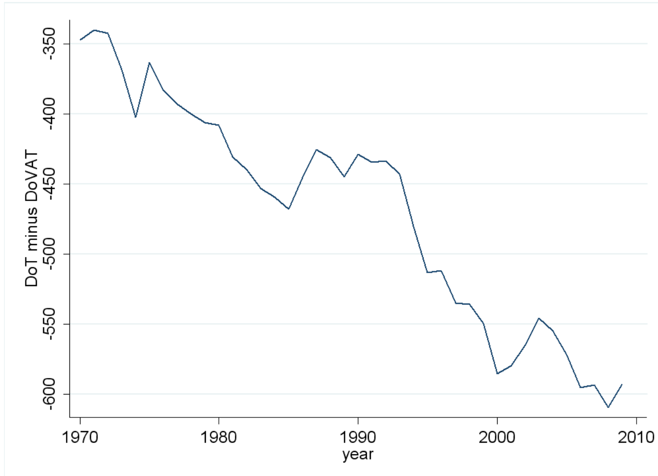
3 Distance and Fragmentation

To explore the link between proximity and fragmentation further, we turn to distance as a measure of proximity. To measure distance, we use the population weighted distance (in kilometers) between two countries from the CEPII Distances database.[9] We perform two exercises. First, we compute the average distance between source and destination for gross and value added trade, and compare these distances through time. Second, we assess how changes in bilateral VAX ratios from 1970 to 2009 are related to distance.

We draw on Carrère and Schiff (2005) to measure the average distance between source and destination for the two types of trade. For each country, we define distance traveled as a weighted average of bilateral distances d_{ij}, where the weights are either gross or value added

[9] See `http://www.cepii.fr/anglaisgraph/bdd/distances.htm`. We use the 'distw' measure, but results are not sensitive to the measure of distance used.

Figure 1: Difference in Distance Traveled for Gross and Value Added Trade (All Countries)



trade shares. To be explicit, export distances for country i are:

$$\text{DoT}_i^x \equiv \sum_{j \neq i} \left(\frac{X_{ij}}{X_i} \right) d_{ij}$$

$$\text{DoVAT}_i^x \equiv \sum_{j \neq i} \left(\frac{VA_{ij}}{VA_i} \right) d_{ij},$$

where the x superscript denotes exports, $X_i \equiv \sum_{j \neq i} X_{ij}$ is total gross exports, and $VA_i \equiv \sum_{j \neq i} VA_{ij}$ is total value added exports. Distances for imports (DoT_i^m and DoVAT_i^m) can be measured analogously. Further, distances for the world can be computed by weighting each country by their share of global exports or imports.

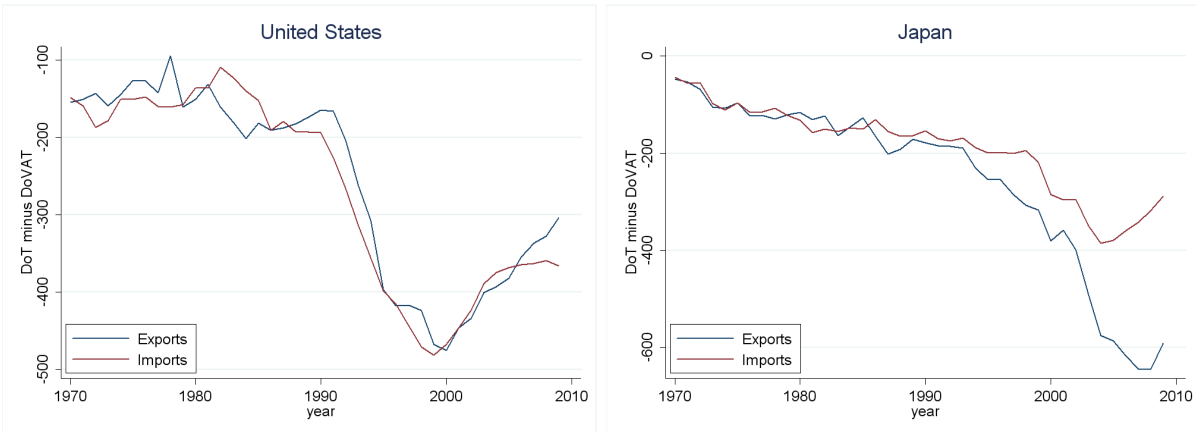
In the figures, we focus on the difference between distance for gross trade and value added trade $\text{DoT}_i^z - \text{DoVAT}_i^z$, with z denoting the direction of trade.[10] We plot distances for all countries in Figure 1 and distances for the United States and Japan in Figure 2.[11]

In both the aggregate and for individual countries, the average distance for gross trade is smaller than for value added trade, which is consistent again with production chains serving

[10] As Carrère and Schiff (2005) point out, distances for gross trade are falling in many countries, and we find the same to be true of value added trade. By looking at the difference, we focus on the relative size of these downward trends.

[11] The figures are computed using bilateral trade among the 37 countries for which we have a complete 1970-2009 time series (see footnote 7).

Figure 2: Difference in Distance Traveled for Gross and Value Added Trade (United States and Japan)



to make gross trade more local. To benchmark this value, the distance traveled by gross trade is roughly 10% smaller than the distance traveled by value added trade.[12] Further, the distance traveled by gross trade is falling relative the distance traveled by value added trade, pointing to fragmentation increasing among nearby partners. Gross trade travels 7% shorter distance than value added in 1970, versus 12% in 2009.

The timing of these changes in individual countries is suggestive regarding mechanisms. Echoing the regional results above, we see U.S. distances falling sharply in the 1990-2000 period during which CUSFTA and NAFTA take force. For Japan, we see sharp declines only after 1995. Moreover, Japan has a much sharper change for exports than imports, which hints at the reorientation of Asian supply chains in which Japan increasingly ships intermediates to processing and assembly destinations within Asia (e.g., China).

These average distance measures are suggestive evidence of the localization of gross trade relative to trade in value added over time. To look directly at gross and value added flows, we turn to regressions. Specifically, we compute the change in log bilateral gross exports, log bilateral value added exports, and the log of the bilateral VAX ratio between 1970 and 2009. We then regress these changes on exporter and importer fixed effects and the log of

[12]Across all years, the median distance traveled by gross trade is about 4400km, while the median distance traveled by value added trade is 4900km.

bilateral distance ($\log(d_{ij})$).[13] The exporter and importer fixed effects allow individual source and destination countries to experience different changes on average, while the coefficient on distance measures whether changes are larger or smaller for countries that are farther apart.

Table 2: Distance and Changes in Bilateral Trade

	$\Delta(\log(VAX_{ij}))$	$\Delta(\log(X_{ij}))$	$\Delta(\log(VA_{ij}))$
$\log(d_{ij})$	0.10***	-0.22***	-0.12***
	(0.01)	(0.04)	(0.03)
R^2	0.53	0.65	0.70
Within R^2	0.09	0.04	0.02
Obs.	1090	1090	1090

The dependent variable in each column is the log change in value added to export ratios, gross exports, or value added exports between 2009 and 1970. For example, $\Delta(\log(VAX_{ij})) \equiv \log(VAX_{ij}^{2009}) - \log(VAX_{ij}^{1970})$. Exporter and importer fixed effects included in all regressions. Robust standard errors are in parentheses, and three stars denotes significance at the 1% level.

Table 2 reports the regression results.[14] In the first column, we see that the decline in the VAX ratio for a given bilateral pair is smaller as distance between the pair increases. Plainly, VAX ratios fall more for nearby country pairs than for faraway country pairs. The second and third column report results for log exports and log value added exports as well. Because $\log(VAX_{ij}) = \log(VA_{ij}) - \log(X_{ij})$ by construction, the difference in coefficients on distance in these regressions equals the coefficient on the VAX ratio in the first column. Yet in these columns we can look at how changes in gross and value added trade together generate the overall change the VAX ratio. Changes in both value added and gross trade are negatively related to distance, which implies that both value added and gross trade have become more localized over time in absolute terms. Interestingly, this phenomenon is stronger for gross trade than for value added trade, and this is what makes changes in the VAX ratio correlated

[13] In these regressions, we drop observations for which bilateral trade is less than $1 million in 1970 (measured in 1970's dollars). Small values of trade tend to be associated with very large VAX ratios. While these do not strongly influence the point estimates, they skew the goodness of fit statistics.

[14] Regarding model fit, the fixed effects account for a substantial portion of the overall variation, since many changes in trade and VAX ratios are exporter or importer specific. The Within R^2 for the value added to export ratio is sizable, however, implying that variation in distance accounts 17% of the overall R^2.

with distance.

Both ways of looking at the role of distance in shaping gross and value added trade yield the same end result. Changes in fragmentation are associated with differential growth in gross relative to value added trade at short distances. As such, the rise of fragmentation appears to be intimately related to growing localization of international trade.

4 Conclusions

Collectively, these results point to a strong role for proximity in explaining fragmentation patterns, and hence changes in trade patterns over time. There are of course many mechanisms through which distance may matter. Most directly, distance may be important due to costs of transporting goods across space, whether directly measured costs per kilometer or less directly measured costs of time in transit. Distance may also capture costs of communication along the production chain that rise in distance. These both imply a direct causal relationship between distance-dependent trade costs and fragmentation. At the same time, distance may simply be a proxy for other observables, such as language similarity, that facilitate trade. Another concern is that distance or geographic regional membership may be picking up the effect of regional integration initiatives, such as deepening of the EU or NAFTA over time. More work is needed to sort out these possible channels.

Further, we believe that work aimed at quantifying how important trade frictions are relative to country-specific determinants of fragmentation would be valuable, likely using models of fragmentation in which trade costs take center stage as in Yi (2003, 2010). We expect that the identifying information contained in the time-varying bilateral value added trade flows introduced in this note will be helpful in these endeavors.

References

Bems, Rudolfs, Robert C. Johnson, and Kei-Mu Yi. 2010. "Demand Spillovers and the Collapse of Trade in the Global Recession." *IMF Economic Review*, 58(2): 295–326.

Carrère, Celine, and Maurice Schiff. 2005. "On the Geography of Trade: Distance is Alive and Well." *Revue economique*, 56(6): 1249–1274.

Daudin, Guillaume, Christine Rifflart, and Daniele Schweisguth. 2011. "Who Produces for Whom in the World Economy?" *Canadian Journal of Econoimcs*, 44(4): 1403–1437.

Erumban, Abdul Azeez, Bart Los, Robert Stehrer, Marcel Timmer, and Gaaitzen de Vries. 2011. "Slicing Up Global Value Chains: The Role of China." Unpublished Manuscript, University of Groningen.

Hummels, David, Jun Ishii, and Kei-Mu Yi. 2001. "The Nature and Growth of Vertical Specialization in World Trade." *Journal of International Economics*, 54: 75–96.

Johnson, Robert C., and Guillermo Noguera. 2012. "Fragmentation and Trade in Value Added over Four Decades." Unpublished Manuscript, Dartmouth College.

Johnson, Robert C., and Guillermo Noguera. forthcoming. "Accounting for Intermediates: Production Sharing and Trade in Value Added." *Journal of International Economics*.

Koopman, Robert, William Powers, Zhi Wang, and Shang-Jin Wei. 2010. "Give Credit Where Credit Is Due: Tracing Value Added in Global Production Chains." NBER Working Paper No. 16426.

Trefler, Daniel, and Susan Chun Zhu. 2010. "The Structure of Factor Content Predictions." *Journal of International Economics*, 82: 195–207.

Yi, Kei-Mu. 2003. "Can Vertical Specialization Explain the Growth of World Trade?" *Journal of Political Economy*, 111: 52–102.

Yi, Kei-Mu. 2010. "Can Multi-Stage Production Explain the Home Bias in Trade?" *American Economic Review*, 100(1): 364–393.