

Measuring Trade Profile with Granular Product-level Data*

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Abstract

The product composition of bilateral trade encapsulates complex relationships about comparative advantage, global production networks, and domestic politics. Despite the availability of product-level trade data, most researchers rely on either the total volume of trade or certain sets of aggregated products. In this paper, we develop a new dynamic clustering method to effectively summarize this massive amount of product-level information. The proposed method classifies a set of dyads into several clusters based on their similarities in *trade profile* — the product composition of imports and exports — and captures the evolution of the resulting clusters over time. We apply this method to two billion observations of product-level annual trade flows. We show how typical dyadic trade relationships evolve from sparse trade to inter-industry trade and then to intra-industry trade. Finally, we illustrate the critical roles of our trade profile measure in International Relations research on trade competition.

Key Words: clustering algorithm, trade competition, comparative advantage, intra-industry trade, zero trade, dyadic data

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1 Introduction

Since Ricardo, scholars have relied upon the concept of comparative advantage to explain why countries trade and to identify the winners and losers of trade (e.g., Rogowski, 1987; Scheve and Slaughter, 2001; Hiscox, 2002). While comparative advantage still plays a central role in explaining trade, consumer preferences for product variety and the use of global production chains by firms have dramatically altered patterns of international trade. The fast-growing political economy literature on product- and firm-level theories demonstrate the importance of examining bilateral trade at the granular level in understanding the distributional consequences of international trade (e.g., Antràs and Staiger, 2012; Grossman and Rossi-Hansberg, 2012; Jensen, Quinn, and Weymouth, 2015; Osgood, 2016; Kim, 2017).

Despite the substantive importance of products and the massive amount of product-level bilateral trade flow data that are becoming available, most studies still rely on the total volume of trade aggregated across products (e.g., Mansfield, Milner, and Rosendorff, 2000; Gartzke, 2007; Tomz, Goldstein, and Rivers, 2007; Carnegie, 2014) or certain sets of aggregated products (e.g., Dorussen, 2006; Elkins, Guzman, and Simmons, 2006; Goenner, 2010; Chatagnier and Kavaklı, 2017). For many, computational and methodological challenges prohibit effective summaries of the massive amount of product-level data and preclude insights based on product composition. For example, our data set, which is based on the United Nations Comtrade Database, covers more than 600 products and 59,000 directed dyads over 53 years (1962 – 2014). As illustrated in Figure 1, this yields approximately two billion observations of product-level bilateral trade flows. Identifying systematic patterns in such data is difficult for several reasons. The high-dimensionality of the data and a large number of meaningful comparisons can easily overwhelm researchers conducting simple descriptive analyses. Bigger data sets also may contain more noise, which can mask important systematic patterns. Regression models are also of limited use because they require researchers either to consider each product separately or to aggregate trade flows across multiple products, overlooking the composition of trade as a whole.

In this paper, we address this product-level trade data challenge by developing a new dynamic clustering method. Specifically, we group country-pairs into a fixed number of clusters based on the similarity of their *trade profile*, defined as the product composition of imports and exports.

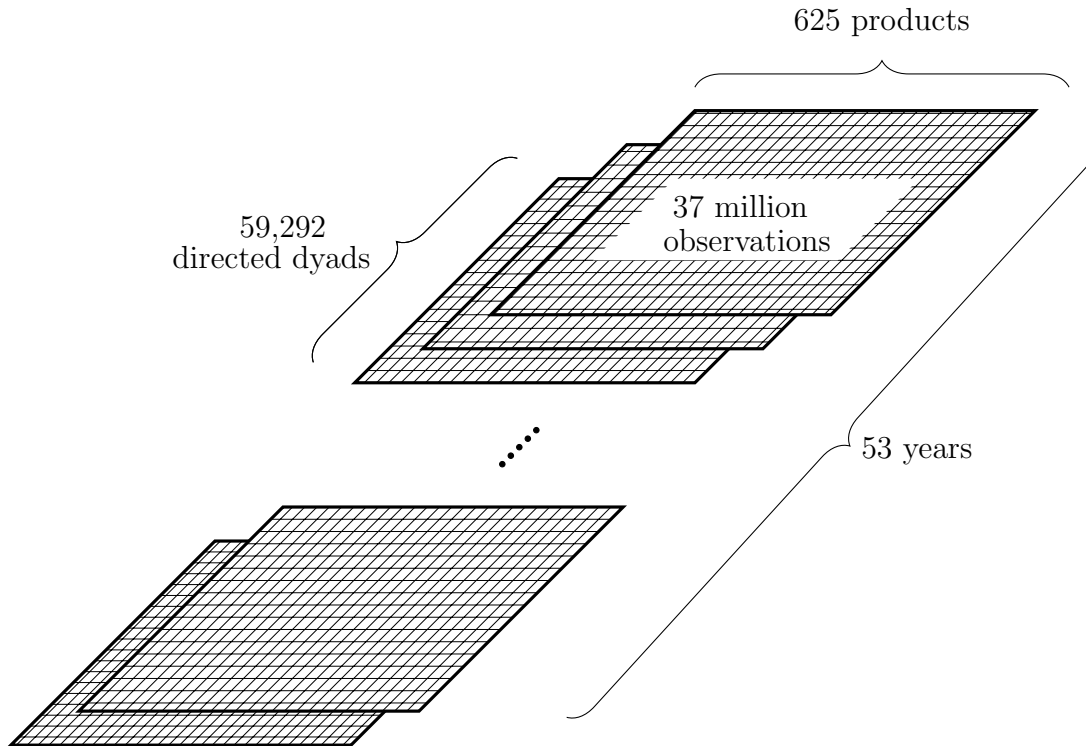


Figure 1: **Two Billion Observations of Product-level Trade Data:** We analyze bilateral trade of 625 products among 59,292 directed dyads over 53 years (1962 – 2014).

For example, U.S.–South Korea may be in the same cluster with U.S.–Japan because their current bilateral trades involve similar exchanges of chemical products and cars. However, the two dyads might have belonged to different clusters in the 1960s when they traded disparate products. This approach is different from Hidalgo and Hausmann (2009) who use product-level trade data to infer the relationships between products. In contrast, we model the dynamic patterns of trade between countries over time based on their trade portfolio.

We focus on dyadic trade relationships based on their product-level trade for two reasons. First, countries still play an important role in controlling the movements of goods as they set trade policies and negotiate international agreements. In addition, the growing number of bilateral trade agreements, in contrast to stagnant multilateral negotiations, attests to the significant and heterogeneous interests countries have vis-à-vis their partners. Second, the proposed dyadic clustering method allows researchers to distinguish bilateral trade relationships based on the *types* of products that countries exchange. This is in sharp contrast to the long-held approach where researchers consider the total *volume* of trade across certain sets of aggregated products or of each separate product. The use of highly disaggregated products in clustering is also consistent with the recognition of firms as key political actors. That is, countries face different types of

domestic and international political constraints as firms vary in their choice of entering foreign markets (Eaton, Kortum, and Kramarz, 2011) and their distinct global ties with partners across multiple production stages (Johns and Wellhausen, 2016). In sum, we consider the distribution of product-level bilateral trade in its entirety to characterize the nature and evolution of dyadic trade over time.

We overcome several methodological challenges that are unique in dealing with trade data. In particular, we model zero trade explicitly. In fact, many countries do not trade with each other, and the prevalence of zero trade becomes even more pronounced once we consider product-level trade. While there exist increasing concerns in the literature about systemic differences between dyads who trade versus those who do not (e.g., Silva and Tenreyro, 2006), most applied research still excludes non-trading dyads entirely from their analysis (e.g., Mansfield, Milner, and Rosendorff, 2000; Tomz, Goldstein, and Rivers, 2007). Furthermore, our dynamic clustering method, which is based on a hidden Markov model (Frühwirth-Schnatter, 2007; Park, 2012), allows researchers to effectively compare the composition of product-level trade not only across dyads (including non-trading pairs) but also across time given a dyad. Finally, we derive a fast Expectation-Maximization (EM) algorithm to address the computational challenges in modeling the evolution of bilateral trade relations over time (Dempster, Laird, and Rubin, 1977).

We find that there exists a path along which typical dyadic trade relationship evolves. Specifically, we show that most dyads engage in little trade with each other, but when they do they start by relying on comparative advantages especially in exporting crude materials and manufacturing goods. This relationship then evolves into intra-industry trade, in which two countries simultaneously export and import products within the same manufacturing industry. Although many previous studies have identified comparative advantage, increasing returns to scale, and consumers' love of variety as distinct sources of gains from trade (e.g., Krugman, 1979), to the best of our knowledge, no study exists to identify dynamic changes and the sequence in their relative importance in characterizing dyadic trade relations at this level of disaggregation and scope. We also contribute to the literature that emphasizes the links between trade and development (Grossman and Helpman, 1990; Redding, 1999) by identifying the *timing* of structural transition for each dyad as well as the set of products that play distinct roles in the evolution of global trade.

Finally, while our cluster membership serves as a simple summary of complex bilateral trade

patterns, we also demonstrate that this measure can be used to capture key variables of interest in International Relations research. In particular, we construct an improved measure of trade competition that encapsulates the degree to which two countries trade similar products with the same partners. Using our measure, applied researchers can effectively examine whether bilateral trade competition affects other state behaviors in international politics.¹

The open-source software, `dynCluster`: `Dynamic Clustering Algorithm`, is available as an R package for implementing the proposed methods. All dyad-year cluster memberships, the measure of trade competition, and visualization tools used in this paper will also be made publicly available.

2 Data and Methodology

2.1 Annual Product-Level Dyadic Trade Data

We analyze annual SITC (Standard International Trade Classification) four-digit product-level dyadic trade data from 1962 to 2014.² SITC is a widely used classification of internationally traded goods that is maintained by the United Nations. The classification reflects the materials used in production, the processing stage, uses of the products, and technological changes — facilitating economic analyses of long-term trends of international trade across various products.³ Moreover, its hierarchical structure is useful for aggregating and disaggregating different sets of products and industries for analytic purposes where a four-digit classification gives the most detailed classification of products available for a large number of countries and periods. For example, the SITC commodity 6513 is “Cotton yarn & thread, grey, not mercerized,” which belongs to Section 6 (Manufactured goods), Division 65 (Textile), and Group 651 (Textile yarn).⁴

To ensure that product classifications are comparable across the five decades, we use the list of all 625 SITC Revision-1 four-digit products consistently across the entire period. When countries

¹In Appendix G, we provide an example of such application and show that trade competition has little effect on increasing the likelihood of signing Bilateral Investment Treaties (BITs) unlike previous studies (Elkins, Guzman, and Simmons, 2006).

²See Appendix D for a comparison with another widely used database.

³<http://unstats.un.org/unsd/iiss/Print.aspx?Page=Standard-International-Trade-Classification>

⁴We find that there exists significant variation at the 4-digit level. Specifically, almost 70% of the variation in trade volume can be explained by the variation across 4-digit products *within* 3-digit industry categories.

report their trade statistics based on a different revision number, the United Nations Statistics Division maps them to the corresponding Revision-1 product using concordance tables.⁵ We use the resulting data in our analysis. We then consider a total of 244 states based on the list of 289 country and region codes available from the United Nations Comtrade Database.⁶ Out of the list, we include all countries and political entities that have existed for at least one year during the period while only excluding regional entities such as the European Union. For example, we include United Nations' non-member observer states such as Palestine. In addition, we consider newly independent countries (e.g., Belarus) as unique states after independence but record them as part of another distinct state (e.g., the Soviet Union) prior to independence. Likewise, we include three unique German states: the German Democratic Republic (East Germany) and the Federal Republic of Germany (West Germany) from 1962 to 1990, and unified Germany since 1991.

For each product and country pair, we record the volume of trade (measured as its value in US dollar). While the Comtrade database is one of the best sources available for trade data widely used in academic research, it is still possible that certain countries may fail to report their trade activities, especially for highly disaggregated commodity categories. Thus, we carefully check the availability of data for each product and partner: When reports on product-level trade are available from both importer and exporter, we use importer's valuation which generally includes the cost of transportation and insurance to the frontier of the importing country or territory, i.e., CIF (Cost insurance and freight) valuation. We use exporter's reports when no additional information from the importing country is available. When neither importer nor exporter reports a positive volume of trade, we consider the product as not being traded.⁷ Although this choice might introduce some discrepancies due to the difference between CIF and FOB (Free on board) valuation, the reliance on reports from both direction ensures that products with some trade are identified. Note that 72.4% of all dyads have a positive trade in at least one product for any given year. Since we also consider the absence of bilateral trade at the product level, we have a data set

⁵The concordance table is available at <https://unstats.un.org/unsd/trade/classifications/correspondence-tables.asp>

⁶The complete list of the country and region names along with their years of existence are available from <http://unstats.un.org/unsd/tradekb/Knowledgebase/50377/Comtrade-Country-Code-and-Name>

⁷One might view the zero trade cutoff arbitrary. For instance, the import statistics of the U.S. consist of goods valued at more than \$2,000. We deal with this issue by modeling the selection probability explicitly in Section 2.2.

of approximately two billion observations ($\approx 244 \times 243 \times 625 \times 53$).⁸ Table D.1 in Appendix D reports descriptive statistics for our dyadic trade data and shows the prevalence of sparse trade.

2.2 A New Dynamic Clustering Algorithm for Dyadic Data

We develop a new dynamic clustering algorithm to summarize the evolution of global trade patterns at the product level. Given the enormous size of our data, it is extremely difficult, if not entirely impossible, to discover systematic patterns by simply “looking at” the data. In this setting, a probabilistic model can provide useful summaries of this large data set. We develop a dynamic finite mixture model (Frühwirth-Schnatter, 2007; Imai and Tingley, 2012) and identify a pre-specified number of latent clusters, each of which represents a distinct pattern of bilateral trade.

The primary goal of the proposed method is to assign a cluster membership to each dyad so that a set of dyads with similar trade profiles, i.e., product compositions of exports and imports, are grouped together. We consider bilateral trade across all products in its entirety instead of focusing on either the total volume of trade or arbitrary sets of aggregated products separately from one another. In this regard, the proposed algorithm helps conduct systematic comparisons of trade composition across a large number of country-pairs given substantial noise in disaggregated product-level trade data (Mahutga, 2006). Furthermore, we allow the cluster membership of each dyad to evolve over time. In this way, the algorithm captures the dynamic patterns of global trade profile. Researchers specify the number of clusters based on the desired degree of summarization where a greater number of clusters implies a finer level of summary (we also offer a data-driven method to choose the number of clusters below).

Methodology. Suppose we have a total of N countries over T years. The proposed algorithm requires researchers to choose the number of clusters, which is represented by M (though see below for a data-driven method to select the number of clusters). Let $Z_{ijt} \in \{1, 2, \dots, M\}$ be a latent cluster membership for a dyad consisting of country i and country j in year t where $i, j \in \{1, \dots, N\}$, $i < j$, and $1 \leq \underline{T}_{ij} \leq t \leq \bar{T}_{ij} \leq T$ with \underline{T}_{ij} and \bar{T}_{ij} representing the start and end years of the dyad, respectively. We allow different start and end years for each dyad because some countries do not exist for the entire period.

For the same dyad, $X_{ijtk} \in [0, \infty)$ represents the export of product k from country i to

⁸The raw data are downloaded from the UN Comtrade Database using its data extraction API.

country j in year t . Similarly, X_{jitk} is the trade flow of opposite direction, representing the export of the same product k from country j to country i . We are interested in the trade profile or product composition of trade for each annual dyadic trade flow. To do this, we first compute the trade proportion for each product relative to the total volume of a given trade flow, $V_{ijtk} = X_{ijtk} / \sum_{k'=1}^K X_{ijtk'}$ such that $\sum_{k=1}^K V_{ijtk} = 1$ where K is the total number of products.⁹ Then, a dyadic trade profile for country i and j in year t can be characterized by a $2K \times 1$ stacked vector $\mathbf{V}_{ijt} = (V_{ijt1}, \dots, V_{ijtK}, V_{jit1}, \dots, V_{jitK})^\top$ where $i < j$.

When clustering dyadic trade profile, the results should not depend on how the stacked vector of dyadic trade profile \mathbf{V}_{ijt} is created. Specifically, although we defined \mathbf{V}_{ijt} such that $i < j$ (so as to avoid double-counting the same dyad), this is an arbitrary constraint. Indeed, we can define \mathbf{V}_{ijt} by flipping the order in which trade profiles of exports and imports are stacked. That is, we can stack the trade profile for the exports from country j to country i on the top of that for the exports from country i to country j , i.e., $\mathbf{V}_{ijt}^* = (V_{jit1}, \dots, V_{jitK}, V_{ijt1}, \dots, V_{ijtK})^\top$. As a consequence, two dyad-year observations with similar dyadic trade profile, i.e., $\mathbf{V}_{ijt} \approx \mathbf{V}_{i'j't}$, may appear completely different if the order in which trade profiles are stacked is reversed, i.e., $\mathbf{V}_{ijt} \not\approx \mathbf{V}_{i'j't}^*$.

To address this “flipping problem,” we create a total of $2M$ pseudo clusters so that each cluster corresponds to two pseudo clusters. This enables us to account for two possible ways in which one dyadic trade profile is similar to another (by flipping the order of stacking trade profiles for one of the dyad-year observations). We use $Z_{ijt}^* \in \{1, 2, \dots, 2M\}$ to represent this pseudo cluster membership where for a dyad-year observation with $Z_{ijt} = z$ we have either $Z_{ijt}^* = z$ (the dyad-year belongs to cluster z without flipping) or $Z_{ijt}^* = z + M$ (the dyad-year belongs to cluster z once flipped). Since the model parameters stay identical for clusters z and $z + M$, these two pseudo clusters form one final cluster.

Figure 2 illustrates the proposed dyadic clustering methods when there are six distinct dyads consisting of four countries. Each country-pair exchanges four products. To capture the difference in trade profiles, we use three colors (blue, white, and red) to denote different levels of trade (low,

⁹Alternatively, if we wish to account for the relative trade volume of imports and exports, we can instead use the trade proportion relative to the total volume of both exports and imports rather than calculating it separately, i.e., $V_{ijtk} = X_{ijtk} / \sum_{k'=1}^K (X_{ijtk'} + X_{jitk'})$.

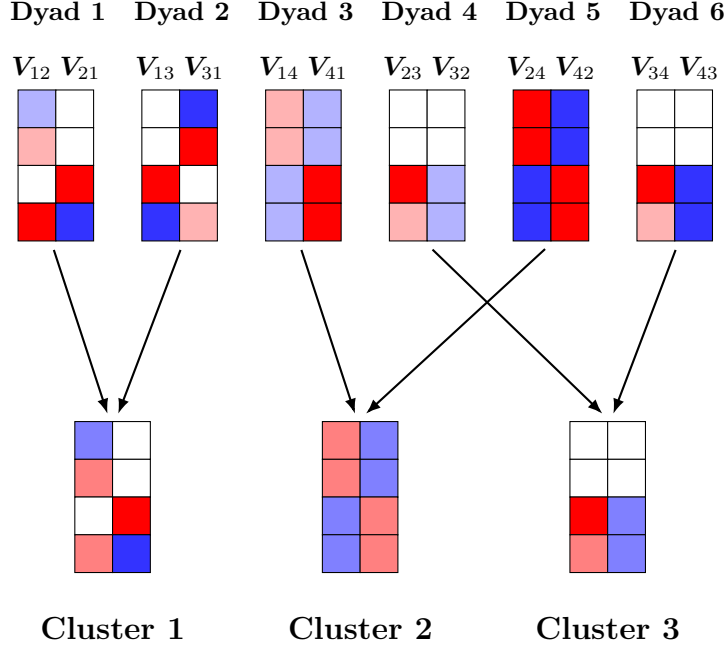


Figure 2: **An Illustration of the Clustering Methods:** This figure illustrates the proposed clustering method with four countries and four products. The first row represents the trade profiles of six dyads, while the second row describes the estimated mean trade proportions characterizing each cluster. Blue, white, and red colors represent general levels of trade (low, medium, and high) while the gradients of each color capture the differences across each dyad that researchers observe in the data. It shows that dyads with similar patterns of trade across products are grouped into a common cluster. Furthermore, the formation of Cluster 1 demonstrates the “flipping problem” in which the ordering of the stacked trade profile vector can be arbitrarily chosen by the researcher.

medium, and high). It is clear from the figure that Dyad 3 and Dyad 5 exhibit similar patterns of trade whereby one country exports more of the first two products while the other exports more of the latter two. Likewise, Dyad 4 and Dyad 6 form Cluster 3 because countries 2 and 3 trade similarly compared to countries 3 and 4. The formation of Cluster 1 demonstrates the “flipping problem.” Although Dyad 1 and Dyad 2 exhibit seemingly distinct patterns of trade, the trade profile at the dyad-level resembles to each other. Specifically, the stacked vector of $(\mathbf{V}_{12}^\top, \mathbf{V}_{21}^\top)^\top$ is similar to $(\mathbf{V}_{31}^\top, \mathbf{V}_{13}^\top)^\top$ once the order of data involving countries 1 and 3 is reversed. Thus, our algorithm groups the two dyads into one cluster given that countries 1 and 2, and 1 and 3 exhibit similar patterns of trade at the *dyadic* level.

As shown in Table D.1, a significant proportion of products have zero trade for many dyad

years. Thus, we first model zero trade given a latent pseudo cluster membership,

$$D_{ijtk} \mid Z_{ijt}^* = z \sim \text{Bernoulli}(q_{kz}) \quad \text{for } k = 1, \dots, K \quad (1)$$

where $D_{ijtk} = \mathbf{1}\{V_{ijtk} = 0\}$. An important constraint here is $q_{kz} = q_{k,z+M}$ because two pseudo clusters, i.e., $Z_{ijt}^* = z$ and $Z_{ijt}^* = z + M$, imply the same cluster.

We then model the proportion of trade among non-zero trade products using the log normal distribution (Aitchison, 1982). This part of the model is defined as follows,

$$W_{ijtk} \mid D_{ijtk} = 0, Z_{ijt}^* = z \sim \mathcal{N}(\mu_{kz}, \sigma_{kz}^2) \quad \text{for } k = 1, \dots, K - 1 \quad (2)$$

where $W_{ijtk} = \log \frac{V_{ijtk}}{V_{ijtK} + c}$ with the baseline product K and c is a small constant used to avoid division by zero. We use a value of $c = 0.0001$ in our application. Again, we have important parameter constraints, i.e., $\mu_z = \mu_{z+M}$ and $\sigma_{kz}^2 = \sigma_{k,z+M}^2$, based on the relationship between pseudo clusters and clusters. While in theory one can allow for correlations across products, we assume independence given the computational challenge due to a large number of products in our data.¹⁰ Next, we use the Hidden Markov Model so that cluster membership for a given dyad changes over time (Frühwirth-Schnatter, 2007; Park, 2012).

$$Z_{ijt}^* \mid Z_{ij,t-1}^* = z \sim \text{Multinomial}(P_{z1}, \dots, P_{z,2M}) \quad \text{for } i < j \quad (3)$$

where $P_{zz'}$ is the transition probability from cluster z to cluster z' . Appendix A describes the details of this algorithm.

Quantities of Interest. To characterize the resulting clusters, we use the mean trade proportion for each product given a cluster. Note that the model parameter μ_{kz} is difficult to interpret because it is based on the log proportion scale relative to the arbitrary baseline product. Therefore, we estimate the average product proportion relative to the total *trade volume*, $\mathbb{E}(V_{ijtk})$, for product k given cluster z by Monte Carlo simulation. Specifically, we first sample W_{ijkz} from $\mathcal{N}(\hat{\mu}_{kz}, \hat{\sigma}_{kz}^2)$ for $k = 1, \dots, K - 1$ where $\hat{\mu}_{kz}$ and $\hat{\sigma}_{kz}^2$ are the maximum likelihood estimates of μ_{kz} and σ_{kz}^2 . We then estimate the expected trade proportion $\mathbb{E}(V_{ijtk})$ by $\frac{1}{L} \sum_{l=1}^L \{\exp(w_{kl}) / \sum_{k'=1}^K \exp(w_{k'l})\}$

¹⁰One possible approach is to incorporate the regularized estimation of a large covariance matrix into our dynamic clustering analysis (e.g., Bickel and Levina, 2008; Friedman, Hastie, and Tibshirani, 2008). We leave such an extension for future research.

where w_{kl} is the l th Monte Carlo draw of W_{ijk} , $w_{Kl} = 0$ for all l , and L is the total number of Monte Carlo draws. These estimates facilitate substantive interpretation of each cluster as we demonstrate below.

Choosing the Number of Clusters. We propose a data-driven approach to selecting the number of clusters based on the hold-out likelihood criteria. An advantage of this approach is that it avoids overfitting. We caution, however, that this type of data-driven approach, which measures the goodness-of-fit of the model, may not necessarily optimize the interpretability of the results. Thus, we suggest that researchers try different numbers of clusters and examine how sensitive their substantive conclusions are to the choice of clusters.

Since our model is dynamic, we set aside a certain number of last time periods as a validation data set while fitting our model with different numbers of clusters to the remaining data. We then evaluate the log (observed-data) likelihood using the validation data. For example, if the last time period alone is set aside as the validation data set, then, the formal expression of the hold-out log-likelihood function to be evaluated is given by,

$$\sum_{i=1}^N \sum_{j>i} \log \left\{ \sum_{(z_{\bar{T}_{ij-1}}, z_{\bar{T}_{ij}})} \pi_{z_{\bar{T}_{ij-1}}} P_{z_{\bar{T}_{ij-1}}, z_{\bar{T}_{ij}}} \prod_{k=1}^{2K} q_{kz_{\bar{T}_{ij}}}^{D_{ij\bar{T}_{ij}k}} (1 - q_{kz_{\bar{T}_{ij}}})^{(1-D_{ij\bar{T}_{ij}k})} \phi(W_{ij\bar{T}_{ij}k} \mid \mu_{kz_{\bar{T}_{ij}}}, \sigma_{kz_{\bar{T}_{ij}}}^2)^{\mathbf{1}_{\{k \neq K, k \neq 2K\}}(1-D_{ij\bar{T}_{ij}k})} \right\}$$

where we have integrated out the latent group indicator variables. We then choose the number of clusters that maximize this hold-out log-likelihood.

3 Empirical Patterns of International Product-Level Trade

In this section, we first describe the characteristics of each cluster identified by the proposed dynamic clustering algorithm. We then show the evolution of dyadic trade relations with the changing cluster memberships over time. Our key finding is that typical dyadic trade relationships evolve from sparse trade to inter-industry trade and then to intra-industry trade while the specific timing for such transition varies significantly by dyads. The proposed algorithm enables us to examine these changes over time at any levels of aggregation including industries, countries, dyads, regions, and the whole world.

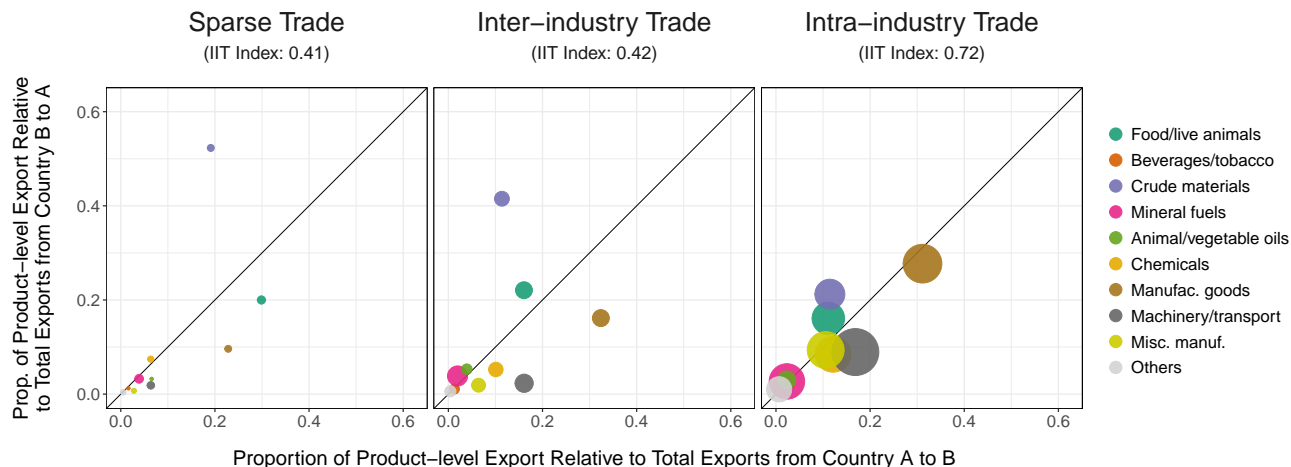


Figure 3: **Three Types of International Trade.** The location of each circle represents the mean industry level exports in each direction of bilateral trade. Circle sizes represent the magnitude of trade flows by dyads within the cluster. Circles on the 45-degree line indicate that dyads export and import products in the same industry in the same proportion. Dyads classified as **Intra-industry trade** tend to have most industries placed closer to the 45-degree line.

3.1 Characteristics of Dyadic Trade Profiles

We begin our analysis by setting the number of latent clusters to three in order to get a parsimonious summary of the massive product-level trade data. As we see later, the basic patterns consistently emerge in the analyses with greater numbers of clusters. Our hold-out log-likelihood calculation described above shows that the 7-cluster model is the most preferred and the 15-cluster model has the second highest value (see Figure B.3 in Appendix B.3). As shown below, these models provide finer pictures of the patterns uncovered by the 3-cluster model. Therefore, throughout this paper, we supplement the results based on the 3-cluster model with those from the 7 and 15-cluster models.

As explained above, the proposed clustering algorithm assigns a cluster membership, $Z_{ijt} \in \{1, 2, 3\}$, to dyad-year observations with similar trade profiles. More precisely, the algorithm produces the estimated probability that a given dyad-year observation belongs to each cluster. Since the product-level trade data are high-dimensional, three clusters are well separated. Consequently, a vast majority of dyad-year observations belong to one cluster with a high probability, making it easy for us to classify observations.

To facilitate the characterization of each cluster as well as the comparisons across different

levels of aggregation, we first consider the trade profiles of the resulting three clusters at the SITC one-digit industry level (see Table D.1). Figure 3 depicts the trade proportion for a given industry in each direction of trade flow, which is defined as the proportion of the relevant products relative to the total volume of exports from one country to another (see the discussion at the end of Section 2.2). We plot the trade proportion of each SITC one-digit industry in the exports from country A to country B (x-axis) against that in the exports from country B to country A (y-axis). If circles are located close to the 45-degree line, therefore, countries export similar products to each other. The size of a circle is proportional to the total volume of trade for the corresponding industry within each cluster.

We find three distinct clusters of international trade that we respectively denote as **Sparse Trade**, **Inter-industry Trade**, and **Intra-industry Trade**. First, as seen by the size of circles, dyads in the **Sparse Trade** cluster tend to trade very little (i.e., sparse) across various products relative to dyads in other clusters. That is, the membership in this cluster implies a sufficiently shallower bilateral trade relationship compared to other country-pairs, although it is still possible that there exist positive volumes of trade for some products between the trading partners. In fact, when these dyads do trade we find that in most cases one country exports crude materials to the other country in exchange for food/live animals.¹¹ Second, the trade profile of the **Inter-industry Trade** cluster shows that dyads in the cluster exchange dissimilar goods: one country exports crude materials while the other country tends to export manufactured goods. The force of comparative advantage is particularly pronounced in the machinery and transportation equipment industry (dark grey circle) as countries in this cluster tend to export such products only in one direction.

Finally, dyads in the **Intra-industry Trade** cluster tend to export and import products in the same industries and in similar proportions, as shown by the convergence of products toward the 45-degree line. For example, about 30% of exports and imports are from the manufacturing industry for both countries in a typical dyad-year of the cluster. To explore this pattern further at the product level, we calculate the extent to which dyads exchange similar products. The Intra-Industry Trade or IIT index at the top of each panel reports the mean product-level Grubel-Lloyd index for each cluster, measuring the degree to which two countries export products in similar

¹¹ We thank an anonymous reviewer for pointing out the possibility that countries may report zero trade for other strategic reasons, which might change the interpretation of the cluster.

proportions (averaging across all products).¹² The IIT Index equals 1 if for every product country A exports the same amount as it imports from country B, while the index equals zero if for every product the trade occurs only in one direction. As expected, the **Intra-industry Trade** cluster has the highest score of 0.72, suggesting that dyads in this cluster tend to trade the same SITC four-digit products in similar amounts with each another. Similar patterns arise when we increase the number of clusters to seven and fifteen as shown in Appendix B.1.

We emphasize that the three types of cluster labels are general characterizations of dyadic trade patterns rather than referring to specific industries. For example, membership in the **Intra-industry Trade** cluster does not necessarily imply that in every industry there is intra-industry trade. To gain a better understanding of each cluster, we examine its trade profile at the product level. Figure 4 displays the product-level trade proportions for exports from country A to country B (left column of each cluster) and for exports from country B to country A (right column of each cluster) where each line segment corresponds to one of the 625 SITC four-digit products. We group the products by industry to facilitate the comparison. The color of a line segment indicates the extent to which the trade proportion of a product deviates from the mean proportion of trade across all clusters.¹³ A darker red line segment represents a higher proportion while a darker blue line segment represents a lower proportion of the product’s trade. In addition to the analysis based on three clusters (left plot), we also examine the results based on the seven cluster model (right plot).

Several clear patterns emerge from the figure. First, dyads in **Inter-industry Trade** cluster tend to import and export different sets of products, as shown by the stark red-blue contrast between the two columns and across products. Specifically, bilateral trade in this cluster is characterized by one country exporting crude materials and food while its partner focuses on exporting industrial goods in chemical, manufacturing, and machinery industries. Second, the differences across the clusters are noticeable especially in these industrial goods as shown in the upper half part of each figure (see the differences especially in “Chemicals and related products” and above). Dyads in

¹²Formally, this index for cluster z is defined as, $1/K \sum_{k=1}^K \{1 - |m_{kz}^{AB} - m_{kz}^{BA}| / (m_{kz}^{AB} + m_{kz}^{BA})\}$ where m_{kz}^{AB} denotes exports of product k from country A to country B in cluster z .

¹³We calculate this quantity for each product k in cluster z for both directions. For example, given the product-level trade proportions m_{kz}^{AB} for exports of product k from country A to country B in cluster z , the deviation from the mean is given by, $m_{kz}^{AB} - \frac{1}{2K} \sum_{z'=1}^K (m_{kz'}^{AB} + m_{kz'}^{BA})$.

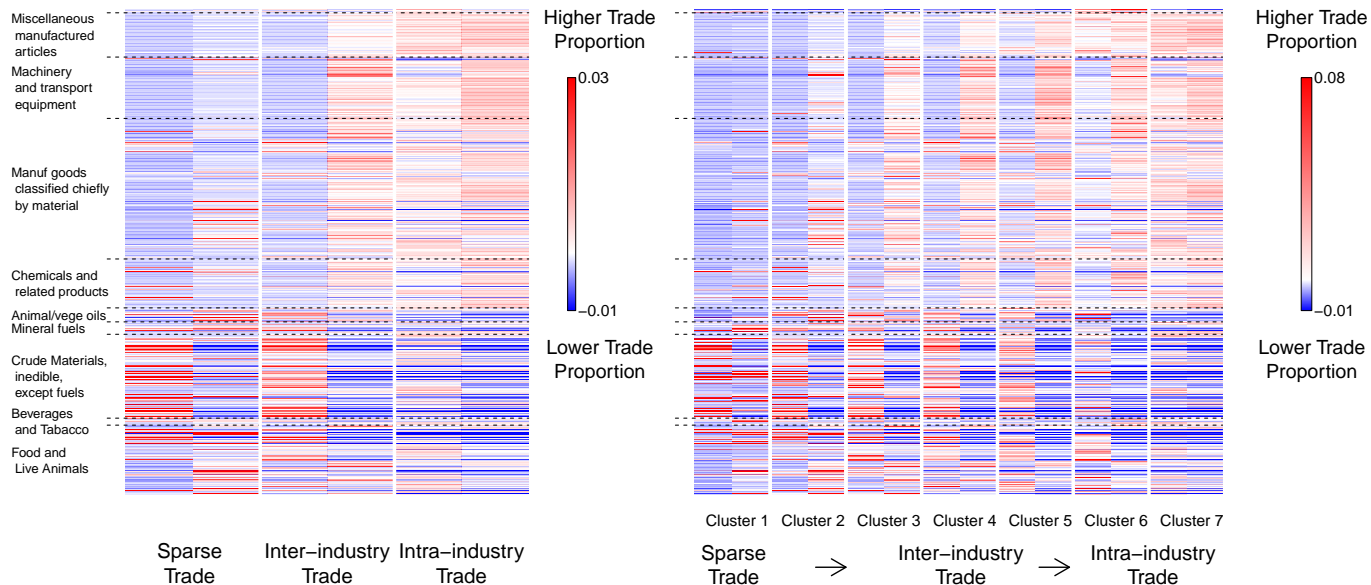


Figure 4: **Trade Profile at the Product Level.** The left panel shows results from our main 3-cluster model. Each row represents one product at the SITC four-digit level. Within each cluster, the left column plots exports from country A to country B while the right column plots exports from country B to country A. The color of each segment indicates the extent product-level trade deviates from the mean proportion of trade across clusters. Red (blue) represents higher (lower) proportions of trade. The right panel shows results from a more fine-grained 7-cluster model.

the Intra-industry Trade cluster tend to trade in higher proportions of industrial goods with each other (two red columns) and lower proportions of food, beverages, and crude materials (two blue columns). This suggests that exchanges of similar products occur mainly through industrial goods. Third, dyads in Sparse Trade tend to exchange little in industrial goods (two blue columns) while utilizing comparative advantages in food, beverages, and crude materials (red-blue contrast) if they do trade.

The right panel of Figure 4 shows that these patterns become even more conspicuous in the results based on the 7-cluster model. As we move from Sparse Trade to Inter-industry Trade and then to Intra-industry Trade, we observe an increase in exchanges of similar products indicated by the progressive change from two blue, blue-red, and two red columns for industrial goods. For food and crude materials, we also see the stark red-blue contrast as we move towards the Inter-industry Trade cluster in the middle. We emphasize that a finer degree of summary can be achieved by increasing the number of clusters. This can be seen from the maximum deviation of the mean proportion reported in the color-bar legend in each panel. For any given product, the mean

proportion differs by up to 0.03 in the 3-cluster model whereas the 7-cluster model can distinguish the mean difference up to 0.08. Nevertheless, the basic patterns remain essentially identical. We further illustrate this point with results from different numbers of clusters in Appendix B.2.

The three general trade profiles identified by our clustering algorithm shed light on some of the main theoretical underpinnings in the international political economy literature. First, the theory of comparative advantage has been a fundamental explanation for why countries have political cleavages across industries (Rogowski, 1987). However, most applications of the classical Stolper-Samuelson theorem conceptualize comparative advantages based on only a few factor endowments such as labor, land, and capital while distinctions across dyads and products are often ignored (Milner and Kubota, 2005). We leverage information on product-level trade to empirically identify the dyad-years with comparative advantage relationships and the products in which such forces are dominant.

Second, intra-industry trade has become an important factor in trade politics as most developed countries now exchange similar goods. We show that industries with differentiated products such as manufacturing are the primary venues for high intra-industry trade. It is important to emphasize that the co-occurrence of imports and exports within the same industry implies that import-competing domestic firms, importers, exporters, and even multinational firms may coexist within the same industry. Our analysis identifies a set of particular dyads and industries in which political cleavages within an industry might be particularly pronounced due to higher heterogeneity in firm preferences.¹⁴ Finally, although zero trade-flows across pairs of countries are already well-known by researchers (e.g., Silva and Tenreyro, 2006; Helpman, Melitz, and Rubinstein, 2008), we show that there are significant variations in the levels of sparse trade at the product-level even among dyads with active trade relations. This raises concerns for most empirical studies that have neglected the product-level heterogeneity in the margins of trade. Our finding suggests that researchers should pay as much attention to the selection of trading partners (extensive margins) as to volumes of bilateral trade (intensive margins) at the product-level.

¹⁴See also Kim (2017), which shows the importance of within-industry heterogeneity.

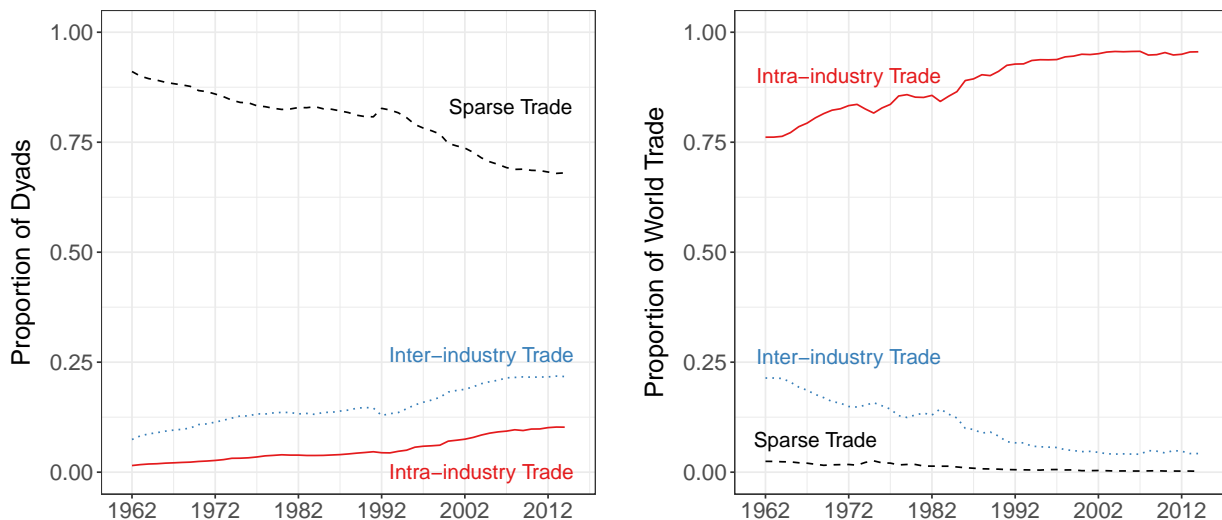


Figure 5: **Dynamic Changes in Cluster Membership from 1962 to 2014**: The left panel plots the proportion of dyad membership out of total dyads in each cluster. The right panel plots the proportion of world trade occupied by each cluster.

3.2 Evolution of Dyadic Trade Relations

A vast literature on international political economy suggests that trade between two countries depend on many factors that change over time. These factors include barriers to market access (Bagwell, Mavroidis, and Staiger, 2002), improvements in information and communication technology (Baldwin, 2016), domestic politics (Grossman and Helpman, 1994), political institutions (Mansfield, Milner, and Rosendorff, 2000), alliances (Gowa and Mansfield, 1993), and state power (Krasner, 1976). An implication is that bilateral trade relations change as the trading environment and the global trading system evolve. However, few existing studies relate such factors to the changing composition of trade profiles. In contrast, as explained in Section 2.2, a key feature of our clustering algorithm is its ability to identify the dynamics of dyadic trade relations.

Figure 5 depicts the dynamic changes of cluster membership from 1962 to 2014. The left panel shows that the membership size of **Sparse Trade** has decreased continuously during this period while the number of dyads belonging to **Inter-industry Trade** and **Intra-industry Trade** increased, especially since the revolution in information and communication technology (ICT) in the 1990s accelerated the fragmentation of production processes (Baldwin, 2016, 79-105). Over the last several years, however, the growth in **Inter-industry Trade** appears to have slowed down while the growth in **Intra-industry Trade** has persisted. The growth in cluster membership, however, does

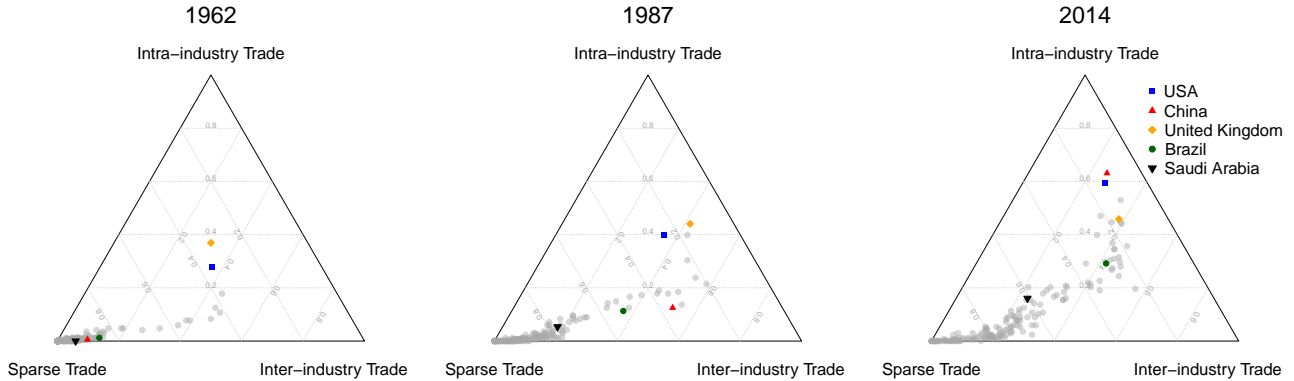


Figure 6: **A Path to Intra-industry Trade:** This plot describes a path along which dyadic trade relationships evolve from sparse trade to inter-industry trade and then to intra-industry trade. Each point represents a country. The location of each point corresponds to the proportion of dyads involving the country that belongs to each cluster. We highlight the location of five countries: USA, China, United Kingdom, Brazil, and Saudi Arabia.

not necessarily imply that more trade volumes are accounted for by the cluster. As it is seen from the right panel of the figure, the overall trade volumes explained by the dyads in the **Inter-industry Trade** cluster have actually decreased over time. In fact, as of 2014, over 90% of global trade is due to the bilateral trade among the dyads that are in the **Intra-industry Trade** cluster even though only about 10% of dyads belong to the cluster.

Next, we shift our focus to monadic trade relations in order to investigate how individual countries underwent different dynamic changes in their trade relations over time. Figure 6 illustrates how each country’s trade relationships with its partners have changed over the last 50 years. Each point in the triangles represents a country. The distance from each vertex corresponds to the proportion of dyads involving the country that belongs to each of the three clusters. For example, a point at the center of the triangle means the country is in each of three clusters with exactly one-third of its partners. The differences in the distribution of points across the three panels illustrate distinct landscapes of international trade in each period. We observe that most countries first increase their trade relationships based on comparative advantages (moving right), and then engage in intra-industry trade with more partners (moving up). To be sure, not all dyads follow the same path. This suggests that international specialization is a dynamic process that is determined endogenously by changes in comparative advantage (Proudman and Redding, 2000). As Redding (1999) argues, countries face a trade-off between specializing further based on existing comparative advantages, and investing in other sectors with no technological edges. The different

trajectories followed by different countries are also illustrated by the movements of five countries from each continent highlighted in the figure. China has dramatically changed its trade relations with its partners whereas the United Kingdom has maintained similar trade profiles with most countries.

Finally, this paper makes an important empirical contribution by characterizing the *evolution* of dyadic trade relations. Specifically, we identify the highly heterogeneous timing of any structural transition of bilateral trade patterns for *each* dyad across time. In Figure 7, we focus on five countries and their relationships with each partner country from 1962 to 2014. It shows that the U.S. engages in two-way intra-industry trade (red) with many of its partners. The list of such partners has grown steadily over time. This pattern is in contrast to those of China and the United Kingdom. In particular, China exhibits a strikingly steep trajectory of growing memberships in the Intra-industry Trade cluster while the United Kingdom maintains similar trade profiles with its partners as shown by the relatively flat color composition.¹⁵

In sum, the proposed dynamic clustering algorithm yields new insights about changes in global trade profile. Our analysis shows how typical dyadic trade relationships evolve and provides a simple summary of massive trade data. Our approach contrasts with existing empirical studies of international trade as we consider bilateral trade across numerous products in its entirety.

4 An Application: A New Measure of Trade Competition

Having detailed the value of our clustering algorithm in summarizing the dynamic evolution of bilateral trade, we now illustrate the use of our cluster membership in the analysis of trade competition. Specifically, we show that our framework can incorporate the extent of competition that each country faces with all of its trading partners at the product level.

Trade competition has been one of the key theoretical concepts in international relations. For example, scholars argue that trade competition can affect how policies and institutions diffuse across borders (e.g., Jensen, 2003; Simmons and Elkins, 2004; Simmons, Dobbin, and Garrett, 2006). Despite its theoretical importance, surprisingly few measures are available to capture how countries compete for trade partners at the product level. In this section, we use our dyadic cluster

¹⁵Figure C.1 in Appendix C illustrates the evolutionary path of bilateral trade relations for all dyads that have existed between 1962 and 2014.

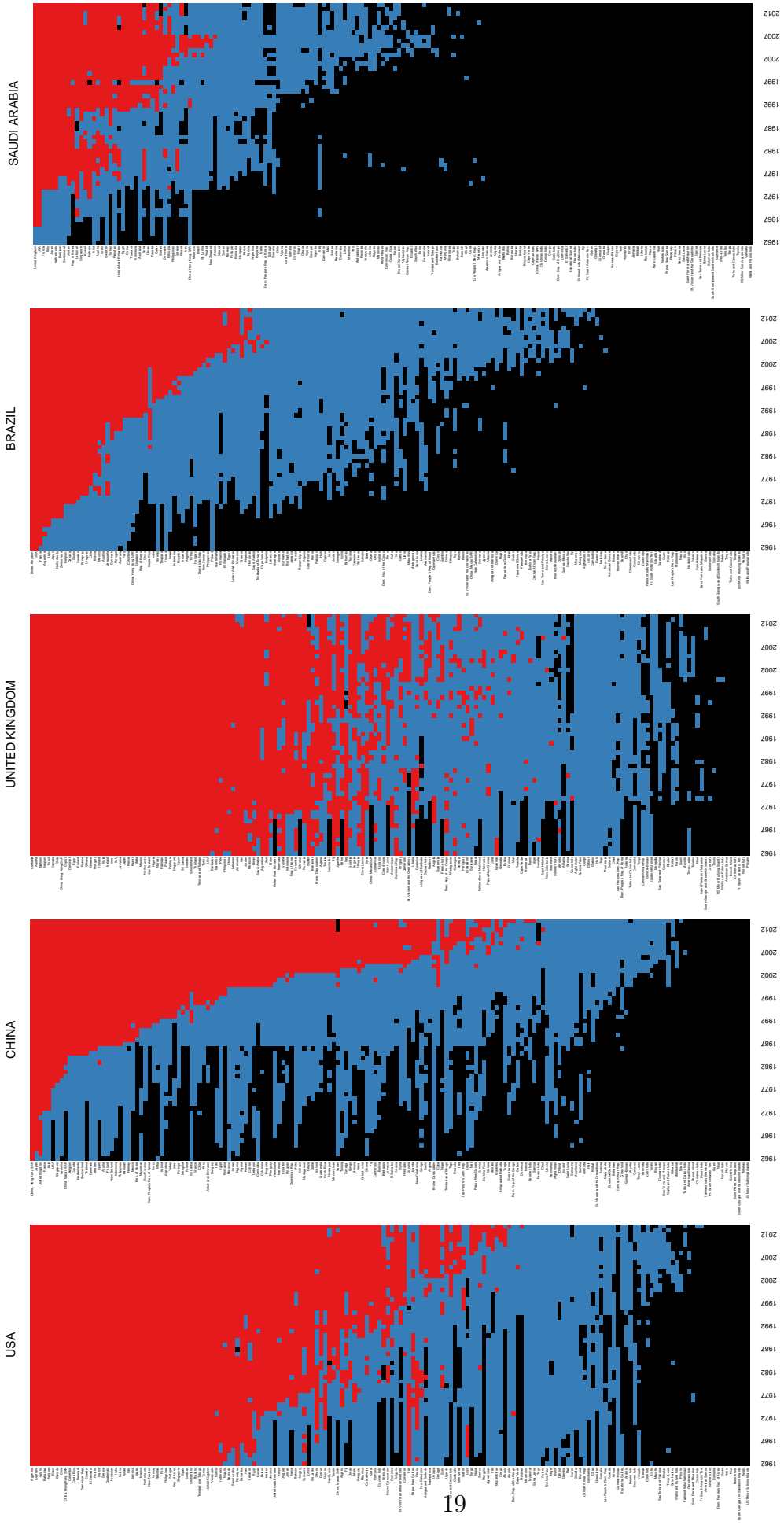


Figure 7: **Changing Trade Profiles with Partners.** This figure illustrates the dynamic changes of cluster membership for dyads involving five countries: USA, China, United Kingdom, Brazil, and Saudi Arabia. Each row represents one partner. We color each polygon according to its dyad-year trade profile: red (Intra-industry Trade), blue (Inter-industry Trade), and black (Sparse Trade). The panels exclude partners that do not persist throughout the time period 1962-2014.

membership to construct an improved measure of trade competition.

Simmons and Elkins (2004) define trade competition as “the degree to which nations compete in the same foreign markets” without reference to products that are traded (p. 178). In contrast, we exploit the availability of product-level trade data and define trade competition as the extent to which two countries trade *similar* products with the *same* partners. We argue that the degree of trade competition must be examined at the product level. This is because competition over price and quality tends to be specific to products that are sufficiently similar to each other. When two countries export different products to the same partners, they do not necessarily compete with each other even when the overall trade volumes are similar in the same time period.¹⁶ Although it is possible that countries trading the same products with different partners have an “intention” to compete, we focus on directly measuring the existence of *observed* trade competition in each market.¹⁷

The Proposed Measure. We use our dyadic trade cluster membership to measure trade competition between countries i and j in a given year t . We consider whether the dyadic trades of the two countries with the same trading partner h belong to the same cluster z . If dyads (i, h) and (j, h) belong to the same cluster, they trade similar products with the same trading partner, implying that the two countries are in competition with each other. Our measure captures trade competition in both exports and imports since our cluster membership is based on dyadic trades. This is a desirable feature because, for example, countries compete in importing raw materials as much as they compete in exporting manufacturing goods. In addition, we do not consider joint membership in the **Sparse Trade** cluster as evidence for trade competition because trade competition does not arise in the absence of trade.

Formally, we begin by defining an indicator variable for trade competition between countries i and j involving partner h in year t is defined as,

$$C_{ijt}^h = \mathbf{1}\{Z_{iht} = z, Z_{jht} = z \mid z \neq \text{Sparse Trade}\}. \quad (4)$$

Notice that we take into account the role of each country in defining this measure. That is,

¹⁶See Cao and Prakash (2010) who criticize diffusion studies that do not distinguish between products or partners (p. 483).

¹⁷ In other words, our measure does not capture latent strategic intentions for competition. We thank an anonymous reviewer for pointing this out.

countries i and j are not in competition, even when they are in the same cluster with a common partner h , if the roles within the cluster involving h are reversed, i.e., $Z_{iht} = z$ and $Z_{hjt} = z$.

Next, we aggregate this competition indicator variable across all trading partners using Gower (1971)'s similarity metric with bilateral trade volumes as weights since the level of competition is likely to be higher in a larger market. That is, our measure of trade competition for countries i and j in year t is defined as,

$$\bar{C}_{ijt} \equiv \sum_{h \in \{1, \dots, N\} \setminus \{i, j\}} \left(\frac{S_{iht} + S_{jht}}{\sum_{h' \in \{1, \dots, N\} \setminus \{i, j\}} S_{ih't} + S_{jh't}} \right) C_{ijt}^h, \quad (5)$$

where S_{iht} denotes the share of country i 's trade with partner h out of its total trade volume in year t . Thus, our measure assigns the highest level of trade competition to two countries that belong to the same cluster for their trading relationships with all existing partners. Furthermore, the measure weights the importance of trade competition with specific partners by their dyadic trade volumes.

Comparison with the Existing Measures. The proposed measure of trade competition makes several improvements over existing measures. First, our measure is based on the similarity in trade profiles of all SITC four-digit products. This allows us to capture competition at a disaggregated level in a systematic fashion, yielding a more precise measure. In contrast, other measures are based on aggregate exports and imports (Lee and Strang, 2006), certain select industries (Simmons and Elkins, 2004; Elkins, Guzman, and Simmons, 2006), or only SITC first-digit products (Cao and Prakash, 2010, 2011).¹⁸ Clustering based on the data at a finer product level improves the validity of our measure because substitution among different products can be easily justified at disaggregate levels. In other words, the elasticity of substitution decreases as the level of aggregation increases. For example, the degree of trade competition should be higher when two countries export oranges vs. mandarins (SITC 0571) than oranges vs. apples (SITC 0571 vs. SITC 0574), fruits vs. vegetables (SITC 057 vs. SITC 054), or food vs. manufactured products (SITC 0 vs. SITC 6). This is because it is easier to substitute between goods at more disaggregated levels.

Second, our measure discounts the level of trade competition when there exists little trade. Existing measures either ignore the importance of sparse trade entirely or deal with the problem

¹⁸We summarize and compare existing measures in Table E.1 in the appendix.

by imposing strong constraints. For example, Chatagnier and Kavaklı (2017) calculate the simple correlation between two vectors of trade profiles to summarize the degree of trade competition between two countries. Although their measure is also based on SITC four-digit product trade, the prevalence of sparse trade implies that two countries can be misleadingly considered to be in high competition when they do not trade most of the products with the same partners. This is because a high correlation between two trade profile vectors can result when most elements are close to zero. In contrast, our measure is based on the clustering algorithm that explicitly models zero trade. We consider trade competition to exist only when both countries engage in trade with its partners with sufficient amounts of product-level trade.

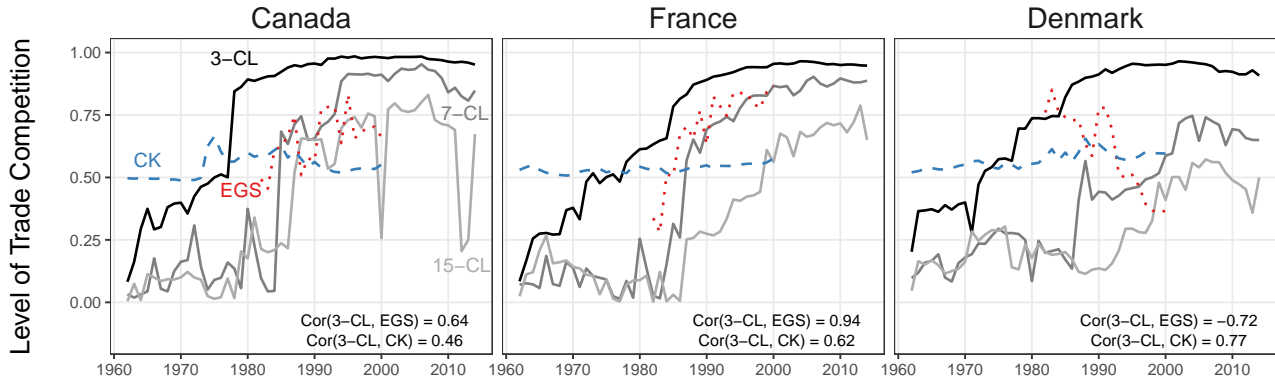
Third, our measure incorporates the levels of competition in each trading partner’s market. While many existing measures of trade competition distinguish between different products at some level (Simmons and Elkins, 2004; Elkins, Guzman, and Simmons, 2006; Chatagnier and Kavaklı, 2017), few consider the levels of competition separately for each trade partner. Most measures are based on a simple correlation for two countries’ product-level exports to the world. As a result, existing measures of trade competition may mask the fact that two countries could be exporting similar products to *different* partners, which also inflates the level of competition. In contrast, we build our measure explicitly on dyadic trade profiles and further weight the importance of competition in each partner countries by trade volume to capture such nuances (see Figure F.1 in Appendix F for this important distinction).

Finally, our measure considers both export and import competition. The rise of global supply chains implies that countries not only compete in their export markets but also compete in import markets for inputs to the products they produce (e.g. rare earth materials for the production of computer chips). However, to the best of our knowledge, all existing measures have focused exclusively on export competition. This leads to understated levels of trade competition for dyads that compete mainly in imports and not exports.¹⁹

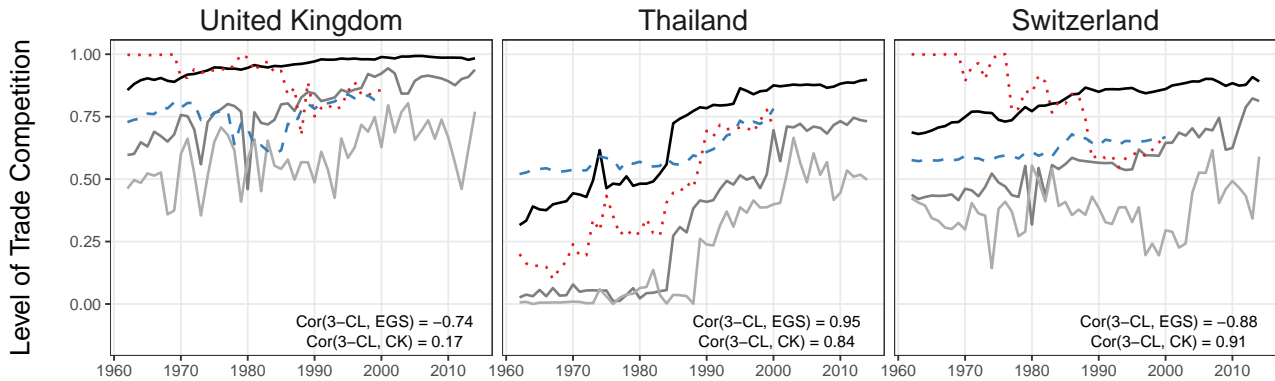
Figure 8 compares our measures of trade competition (labeled as 3-CL, 7-CL, and 15-CL for 3-cluster, 7-cluster, and 15-cluster models, respectively) against those based on the existing measures proposed by Elkins, Guzman, and Simmons (2006) (EGS) and Chatagnier and Kavaklı (2017) (CK).

¹⁹Figure E.1 in Appendix E shows that the correlations between the proposed measure and the existing measures are centered around zero.

Top Trade Competitors of China in 2014



Top Trade Competitors of USA in 2014



Top Trade Competitors of Japan in 2014

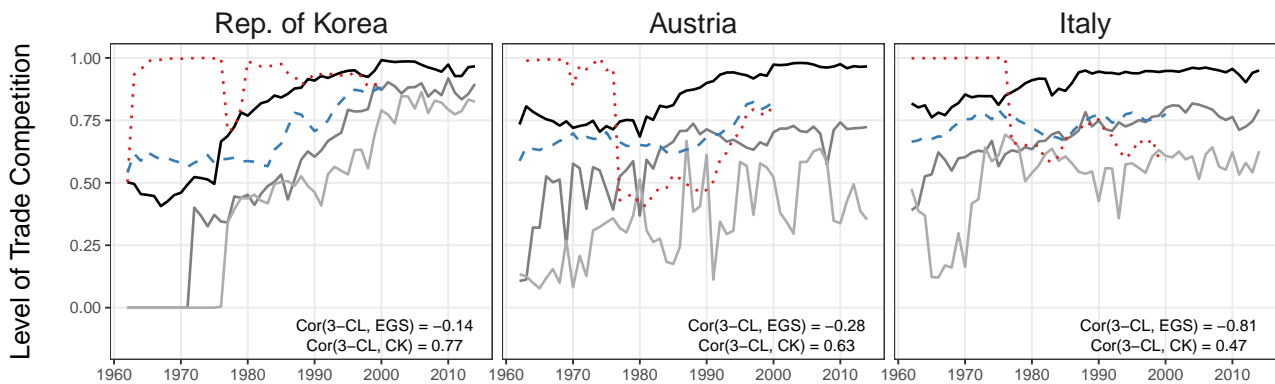


Figure 8: **A New Measure of Trade Competition:** This figure reveals the changing levels of trade competition between China, USA, and Japan and their respective top three competitors in 2014. The thick black and grey solid lines represent our proposed measures based on 3-cluster (3-CL), 7-cluster (7-CL), and 15-cluster models (15-CL), respectively. EGS (red dotted line) is based on Elkins, Guzman, and Simmons (2006) while CK (blue dashed line) uses the measure developed by Chatagnier and Kavaklı (2017). We present the correlations between our measure from the 3-cluster model and the other two measures at the bottom-right corner.

In particular, it shows the changing levels of trade competition between China, USA, and Japan and their top three competitors as of 2014.²⁰ In general, our measure based on our 3-cluster model (black solid line) changes smoothly over time as expected for bilateral trade competition. Yet, as shown in the top panel, it also captures the dramatic increase in China's trade competitiveness with others after its economic reforms in 1978, especially against Canada.

In contrast, EGS shows wide temporal fluctuations while CK exhibits little variation over time. In the middle row, our measure identifies the United Kingdom as the top and persistent trade competitor of the United States. In contrast, EGS would suggest that the United Kingdom or Switzerland's competition with the United States has actually decreased over time.²¹ In the bottom panel, our measure identifies South Korea as Japan's top competitor, with increased competition corresponding to South Korea's rapid economic growth based on export-oriented industrialization since the 1970s. This contrasts with EGS which shows that Japan experienced the highest level of trade competition with South Korea in the 1960s.

The measures based on our 7-cluster (grey solid line) or 15-cluster models (light-grey solid line) exhibits similar patterns over time. As expected, there exists more variation with a larger number of clusters as the underlying cluster membership captures finer differences in trade profiles. This can be useful to identify smaller changes in trade competition. For example, we find a big jump in the level of trade competition between Japan and South Korea in the mid-1970s. This period corresponds to the third Five-Year Plan (1972–1976) during which President Park Chung-hee transformed South Korea's economy by providing aggressive subsidies to heavy chemical industries. Note that measures based on different numbers of clusters should be interpreted in relative terms within each model, and hence smaller values from our 7-cluster or 15-cluster model do not suggest that trade competition is lower than what one finds from our 3-cluster model.²²

²⁰The top three competitors are chosen according to our measure based on our 3-cluster model as of 2014. We focus on competitors that persist throughout the time period 1962–2014.

²¹ Researchers' priors about top competitors may oftentimes be driven by patterns of aggregate industries, especially those that are conspicuous in public discourse. For example, one may think Canada is a top competitor of the U.S. because it also exports many food products or machinery. However, the level of competition might not be high if wheat is the primary agriculture products that Canada exports whereas soybeans and corns take up the most significant portion of the U.S. agricultural exports.

²²Technically, finer gradations make it harder for two dyads to belong to the same cluster (see equation 4) and can thus shift trends downward. In Appendix E, we report a metric of discrepancy between the different measures.

In Appendix G, we apply our proposed measure of trade competition to the study of the diffusion of Bilateral Investment Treaties (BITs). In contrast to the original findings of Elkins, Guzman, and Simmons (2006), our reanalyses show that trade competition has no clear effect on increasing the likelihood of signing BITs. Instead, the results suggest that bilateral trade relationships built on vertical or horizontal production linkages play a more important role.

5 Concluding Remarks

In this paper, we characterized dyadic trade relations based on approximately two billion product-level trade data. We found that countries focus on different sources of gains from trade as their trade relationships evolve. In particular, a typical pair of countries starts trading based on their respective comparative advantage while variety gains from exchanging similar products within the same industry become more important later. This important sequential transition has been overlooked in most studies of international trade and development. Our findings suggest that the nature of bilateral trade relationships changes over time, and hence countries might have to deal with different domestic political conflicts depending on their trading partners at different points in time.

One important advantage of the proposed dynamic clustering methods is its ability to summarize a massive amount of highly disaggregated data with a simple cluster membership variable. Researchers can use our measure to account for the types of bilateral trade relationships over time without incurring enormous computational and methodological costs. We also demonstrate the use of this cluster membership to construct a measure of trade competition. Using this measure, we find that dyadic trade relationships can be more important than competitive economic pressures in explaining the likelihood of signing BITs (see Appendix G).

Dyadic clustering methods have broader applications in political science research. Indeed, measurements of social and economic interactions involving pairs of political actors are taken at increasingly disaggregated levels. For example, scholars in international relations observe highly specific dyadic exchanges of services (e.g., transportation, travel, communications, construction, insurance, financial, royalties, etc.), capital (in various forms of direct investment, portfolio investment, debt flows, aid, etc.), and people (with different skill sets and occupations). Outside of Appendix F provides further comparisons between our measure and other existing measures.

International Relations, dynamic clustering methods such as the one proposed here can be used to analyze various relationships between political actors that evolve over time (e.g., campaign contributions, lobbying activities, co-sponsorships among politicians, citations of court opinions). These methodologies provide an effective means to uncover systematic patterns underlying high-dimensional data.

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Appendix A The Details of the EM Algorithm

In this appendix, we describe the details of our EM algorithm. First, we specify a prior distribution for computational stability. For each dyad-year, we introduce M artificial observations with the following known non-zero cluster membership probability $w_{ijtz} = \delta/(N(N-1))$ for $z = 1, \dots, 2M$. This has the overall effect of adding δM worth of prior observations to the empirical dataset. All together, the log-likelihood function is given by,

$$\sum_{i=1}^N \sum_{j>i} \log \left\{ \sum_{\mathbf{z} \in \mathcal{Z}} \pi_{z_1} \left[\prod_{k=1}^{2K} q_{kz}^{D_{ij1k}} (1 - q_{kz}^{(1-D_{ij1k})}) \phi(W_{ij1k} \mid \mu_{kz}, \sigma_{kz}^2)^{\mathbf{1}\{k \neq K, k \neq 2K\}(1-D_{ij1k})} \right. \right. \\ \left. \left. \prod_{t=\underline{T}_{ij}+1}^{\bar{T}_{ij}} P_{z_{t-1}, z_t} \prod_{k=1}^{2K} q_{kz_t}^{D_{ijtk}} (1 - q_{kz_t})^{(1-D_{ijtk})} \phi(W_{ijtk} \mid \mu_{kz_t}, \sigma_{kz_t}^2)^{\mathbf{1}\{k \neq K, k \neq 2K\}(1-D_{ijtk})} \right] \right\}$$

where $\pi = (\pi_1, \dots, \pi_{2M})$ to be initial probabilities for time $t = \underline{T}_{ij}$, $\mathbf{z} = (z_1, \dots, z_T)$ is a vector of mixture labels over time, \mathcal{Z} is a set of all possible mixture labels over time, and ϕ is the Normal density function.

We fit this model using a Expectation-Maximization (EM) algorithm and obtain the maximum likelihood estimates of the model parameters. The derivation is largely based on the presentation of the EM algorithm for hidden Markov models in Bishop (2006). We begin with the following complete-data log-posterior density function,

$$\sum_{i=1}^N \sum_{j>i} \sum_{z=1}^{2M} \mathbf{1}\{Z_{ij1} = z\} \log \pi_z + \sum_{i=1}^N \sum_{j>i} \sum_{t=2}^T \sum_{z=1}^{2M} \sum_{z'=1}^{2M} \mathbf{1}\{Z_{ijt}^* = z, Z_{ij,t-1}^* = z'\} \log P_{z'z} \\ + \sum_{i=1}^N \sum_{j>i} \sum_{k=1}^{2K} \sum_{t=\underline{T}_{ij}}^{\bar{T}_{ij}} \sum_{z=1}^{2M} \mathbf{1}\{Z_{ijt}^* = z\} \log \left\{ q_{kz}^{D_{ijtk}} (1 - q_{kz})^{(1-D_{ijtk})} \phi(W_{ijtk} \mid \mu_{kz}, \sigma_{kz}^2)^{\mathbf{1}\{k \neq K, k \neq 2K\}(1-D_{ijtk})} \right\}$$

The E-step is based on the forward-backward algorithm,

$$\zeta_{ijtz} = \Pr(Z_{ijt}^* = z \mid \mathbf{V}_{ij\underline{T}_{ij}}, \dots, \mathbf{V}_{ij\bar{T}_{ij}}) = \frac{p(\mathbf{V}_{ij\underline{T}_{ij}}, \dots, \mathbf{V}_{ijt}, Z_{ijt}^* = z) p(\mathbf{V}_{ij,t+1}, \dots, \mathbf{V}_{ij\bar{T}_{ij}} \mid Z_{ijt}^* = z)}{p(\mathbf{V}_{ij\underline{T}_{ij}}, \dots, \mathbf{V}_{ij\bar{T}_{ij}})}$$

where throughout we condition on (P, q, μ, σ^2) . Below, we obtain the expression for this term. First, following Bishop (2006, p. 620), we have a recursive relationship,

$$\alpha_{ijtz} = p(\mathbf{V}_{ij\underline{T}_{ij}}, \dots, \mathbf{V}_{ijt}, Z_{ijt}^* = z) = p(\mathbf{V}_{ijt} \mid Z_{ijt}^* = z) \sum_{z'=1}^{2M} \alpha_{ij,t-1,z'} \Pr(Z_{ijt}^* = z \mid Z_{ij,t-1}^* = z') \\ = \prod_{k=1}^{2K} q_{kz}^{D_{ijtk}} (1 - q_{kz}^{(1-D_{ijtk})}) \phi(W_{ijtk} \mid \mu_{kz}, \sigma_{kz}^2)^{\mathbf{1}\{k \neq K, k \neq 2K\}(1-D_{ijtk})} \sum_{z'=1}^{2M} \alpha_{ij,t-1,z'} P_{z'z}$$

where

$$\begin{aligned}\alpha_{ij\mathcal{T}_{ij}z} &= p(\mathbf{V}_{ij\mathcal{T}_{ij}}, Z_{ij\mathcal{T}_{ij}}^* = z) = \Pr(Z_{ij\mathcal{T}_{ij}}^* = z)p(\mathbf{V}_{ij\mathcal{T}_{ij}} | Z_{ij\mathcal{T}_{ij}}^* = z) \\ &= \pi_z \prod_{k=1}^{2K} q_{kz}^{D_{ij\mathcal{T}_{ij}k}} (1 - q_{kz}^{(1-D_{ij\mathcal{T}_{ij}k})}) \phi(W_{ij\mathcal{T}_{ij}k} | \mu_{kz}, \sigma_{kz}^2)^{\mathbf{1}_{\{k \neq K, k \neq 2K\}}(1-D_{ij\mathcal{T}_{ij}k})}\end{aligned}$$

Therefore, we obtain,

$$\zeta_{ijtz} = \frac{\alpha_{ijtz}\beta_{ijtz}}{\sum_{z'=1}^{2M} \alpha_{ijtz'}\beta_{ijtz'}} = \frac{\alpha_{ijtz}\beta_{ijtz}}{\sum_{z'=1}^{2M} \alpha_{ijTz'}}$$

In addition, again following Bishop (2006, p. 622), we have another recursive relationship,

$$\begin{aligned}\beta_{ijtz} &= p(\mathbf{V}_{ij,t+1}, \dots, \mathbf{V}_{ijT} | Z_{ijt}^* = z) = \sum_{z'=1}^{2M} \beta_{ij,t+1,z'} \Pr(Z_{ij,t+1}^* = z' | Z_{ijt}^* = z) p(\mathbf{V}_{ij,t+1} | Z_{ij,t+1}^* = z') \\ &= \sum_{z'=1}^{2M} \beta_{ij,t+1,z'} P_{zz'} \prod_{k=1}^{2K} q_{kz'}^{D_{ij,t+1,k}} (1 - q_{kz'}^{(1-D_{ij,t+1,k})}) \phi(W_{ij,t+1,k} | \mu_{kz'}, \sigma_{kz'}^2)^{\mathbf{1}_{\{k \neq K, k \neq 2K\}}(1-D_{ij,t+1,k})}\end{aligned}$$

where $\beta_{ijTz} = 1$. We also note

$$p(V_{ij\mathcal{T}_{ij}}, \dots, V_{ij\bar{\mathcal{T}}_{ij}}) = \sum_{z=1}^{2M} \alpha_{ij\bar{\mathcal{T}}_{ij}z} = \sum_{z=1}^{2M} \alpha_{ijtz}\beta_{ijtz}$$

Finally, we have

$$\begin{aligned}\xi_{ijt}(z', z) &= \frac{\alpha_{ij,t-1,z'} P_{z'z} \beta_{ijtz} p(\mathbf{V}_{ijt} | Z_{ijt}^* = z)}{p(\mathbf{V}_{ij\mathcal{T}_{ij}}, \dots, \mathbf{V}_{ij\bar{\mathcal{T}}_{ij}})} \\ &= \frac{\alpha_{ij,t-1,z'} P_{z'z} \beta_{ijtz} \prod_{k=1}^{2K} q_{kz}^{D_{ijtk}} (1 - q_{kz}^{(1-D_{ijtk})}) \phi(W_{ijtk} | \mu_{kz}, \sigma_{kz}^2)^{\mathbf{1}_{\{k \neq K, k \neq 2K\}}(1-D_{ijtk})}}{\sum_{\tilde{z}=1}^{2M} \alpha_{ij\tilde{z}} \beta_{ij\tilde{z}}}\end{aligned}$$

for $t = \mathcal{T}_{ij} + 1, \dots, \bar{\mathcal{T}}_{ij}$ where we set $\alpha_{ij,\mathcal{T}_{ij}-1,z} = 1$.

To derive the M-step, first define,

$$\mathbf{A} = \begin{pmatrix} \mathbf{0} & \mathbf{I}_{K-1} \\ \mathbf{I}_{K-1} & \mathbf{0} \end{pmatrix} \quad \mathbf{B} = \begin{pmatrix} \mathbf{0} & \mathbf{I}_K \\ \mathbf{I}_K & \mathbf{0} \end{pmatrix}$$

The M-step for π and P is,

$$\begin{aligned}\pi_z &= \frac{\sum_{i=1}^N \sum_{j>i} \zeta_{ij\mathcal{T}_{ij}z}}{\sum_{i=1}^N \sum_{j>i} \sum_{z'=1}^{2M} \zeta_{ij\mathcal{T}_{ij}z'}} \\ P_{z'z} &= \frac{\sum_{i=1}^N \sum_{j>i} \sum_{t=\mathcal{T}_{ij}+1}^{\bar{\mathcal{T}}_{ij}} \xi_{ijt}(z', z)}{\sum_{i=1}^N \sum_{j>i} \sum_{\tilde{z}=1}^{2M} \sum_{t=\mathcal{T}_{ij}+1}^{\bar{\mathcal{T}}_{ij}} \xi_{ijt}(z', \tilde{z})}\end{aligned}$$

for $z = 1, 2, \dots, 2M$. In addition,

$$q_{kz} = \frac{\sum_{i=1}^N \sum_{j>i} \sum_{t=\underline{T}_{ij}}^{\bar{T}_{ij}} \{\zeta_{ijtz} D_{ijtk} + \zeta_{ijt,z+M} (\mathbf{B}\mathbf{D}_{ijt})_{ijtk}\}}{\sum_{i=1}^N \sum_{j>i} \sum_{t=\underline{T}_{ij}}^{\bar{T}_{ij}} (\zeta_{ijtz} + \zeta_{ijt,z+M})}$$

for $k = 1, 2, \dots, 2K$ and $z = 1, \dots, M$ where $\mathbf{D}_{ijt} = (D_{ijt1}, \dots, D_{ijtK}, D_{jit1}, \dots, D_{jitK})$. We then set $q_{k,z+M} = q_{kz}$ for $z = 1, \dots, M$.

$$\begin{aligned} \mu_{kz} &= \bar{Y}_{kz} \\ \sigma_{kz}^2 &= \frac{1}{N_{kz}} \left[\sum_{i=1}^N \sum_{j>i} \sum_{t=\underline{T}_{ij}}^{\bar{T}_{ij}} \zeta_{ijtz} (1 - D_{ijtk}^*) (Y_{ijtk} - \bar{Y}_{kz})^2 \right. \\ &\quad \left. + \zeta_{ijt,z+M} \{1 - (\mathbf{A}\mathbf{D}_{ijt}^*)_{ijtk}\} \{(\mathbf{A}\mathbf{Y}_{ijt})_{ijtk} - \bar{Y}_{kz}\}^2 \right] \end{aligned}$$

where

$$\begin{aligned} N_{kz} &= \sum_{i=1}^N \sum_{j>i} \sum_{t=\underline{T}_{ij}}^{\bar{T}_{ij}} \zeta_{ijtz} (1 - D_{ijtk}^*) + \zeta_{ijt,z+M} \{1 - (\mathbf{A}\mathbf{D}_{ijt}^*)_{ijtk}\} \\ \bar{Y}_{kz} &= \frac{1}{N_{kz}} \sum_{i=1}^N \sum_{j>i} \sum_{t=\underline{T}_{ij}}^{\bar{T}_{ij}} \zeta_{ijtz} (1 - D_{ijtk}^*) Y_{ijtk} + \zeta_{ijt,z+M} \{1 - (\mathbf{A}\mathbf{D}_{ijt}^*)_{ijtk}\} (\mathbf{A}\mathbf{Y}_{ijt})_{ijtk} \end{aligned}$$

for $z = 1, 2, \dots, M$ and $k = 1, \dots, 2(K-1)$ for μ_{kz} and σ_{kz}^2 where $\mathbf{Y}_{ijt} = (W_{ijt1}, \dots, W_{ijt,K-1}, W_{jit1}, \dots, W_{jit,K-1})$ and $\mathbf{D}_{ijt}^* = (D_{ijt\underline{T}_{ij}}, \dots, D_{ijt,K-1}, D_{jit1}, \dots, D_{jit\bar{T}_{ij},K-1})$.

Now, Bishop (2006) recommends rescaling of α_{ijtz} and β_{ijtz} in the above algorithm because they become very small. The normalized version is given by,

$$\tilde{\alpha}_{ijtz} = \frac{\alpha_{ijtz}}{\sum_{z'=1}^{2M} \alpha_{ijtz'}} = \frac{\alpha_{ijtz}}{p(\mathbf{V}_{ij\underline{T}_{ij}}, \dots, \mathbf{V}_{ijt})} = \frac{\alpha_{ijtz}}{\prod_{t'=\underline{T}_{ij}}^t p(\mathbf{V}_{ijt'} \mid \mathbf{V}_{ij\underline{T}_{ij}}, \dots, \mathbf{V}_{ij,t'-1})}$$

The denominator can be written as $\prod_{t'=\underline{T}_{ij}}^t c_{ijt'}$ where $c_{ijt'}$ can be obtained from the following recursion relationship

$$\begin{aligned} c_{ijt} \tilde{\alpha}_{ijtz} &= p(\mathbf{V}_{ijt} \mid Z_{ijt}^* = z) \sum_{z'=1}^{2M} \tilde{\alpha}_{ij,t-1,z'} P_{z'z} \\ &= \prod_{k=1}^{2K} q_{kz}^{D_{ijtk}} (1 - q_{kz}^{(1-D_{ijtk})}) \phi(W_{ijtk} \mid \mu_{kz}, \sigma_{kz}^2) \mathbf{1}\{k \neq K, k \neq 2K\}^{(1-D_{ijtk})} \sum_{z'=1}^{2M} \tilde{\alpha}_{ij,t-1,z'} P_{z'z} \end{aligned}$$

where

$$\begin{aligned}
c_{ij1} &= \sum_{z=1}^{2M} \alpha_{ijT_{ij}z} \\
c_{ijt} &= \frac{\sum_{z=1}^{2M} \alpha_{ijtz}}{\prod_{t'=\underline{T}_{ij}}^{t-1} c_{ijt'}} \quad \text{for } t = \underline{T}_{ij} + 1, \dots, \bar{T}_{ij}
\end{aligned}$$

Similarly,

$$\beta_{ijtz} = \tilde{\beta}_{ijtz} \prod_{t'=t+1}^{\bar{T}_{ij}} c_{ijt'}$$

and the recursion relationship is

$$\begin{aligned}
c_{ij,t+1} \tilde{\beta}_{ijtz} &= \sum_{z'=1}^{2M} \tilde{\beta}_{ij,t+1,z'} P_{zz'} p(V_{ij,t+1} \mid Z_{ij,t+1}^* = z') \\
&= \sum_{z'=1}^{2M} \tilde{\beta}_{ij,t+1,z'} P_{zz'} \prod_{k=1}^{2K} q_{kz'}^{D_{ij,t+1,k}} (1 - q_{kz'}^{(1-D_{ij,t+1,k})}) \phi(W_{ij,t+1,k} \mid \mu_{kz'}, \sigma_{kz'}^2) \mathbf{1}_{\{k \neq K, k \neq 2K\}} (1 - D_{ij,t+1,k})
\end{aligned}$$

Then we have

$$\begin{aligned}
\zeta_{ijtz} &= \tilde{\alpha}_{ijtz} \tilde{\beta}_{ijtz} \\
\xi_{ijt}(z', z) &= c_{ijt} \tilde{\alpha}_{ij,t-1,z'} P_{z'z} \tilde{\beta}_{ijtz} p(V_{ijt} \mid Z_{ijt}^* = z) \\
&= c_{ijt} \tilde{\alpha}_{ij,t-1,z'} P_{z'z} \tilde{\beta}_{ijtz} \prod_{k=1}^{2K} q_{kz}^{D_{ijtk}} (1 - q_{kz}^{(1-D_{ijtk})}) \phi(W_{ijtk} \mid \mu_{kz}, \sigma_{kz}^2) \mathbf{1}_{\{k \neq K, k \neq 2K\}} (1 - D_{ijtk})
\end{aligned}$$

To examine the sensitivity of this algorithm to its starting values, we use several random starting values and then report the results that are based on the run with the greatest value of log posterior density function.

Appendix B Results from Models Using Different Numbers of Clusters

B.1 Characterization of Clusters

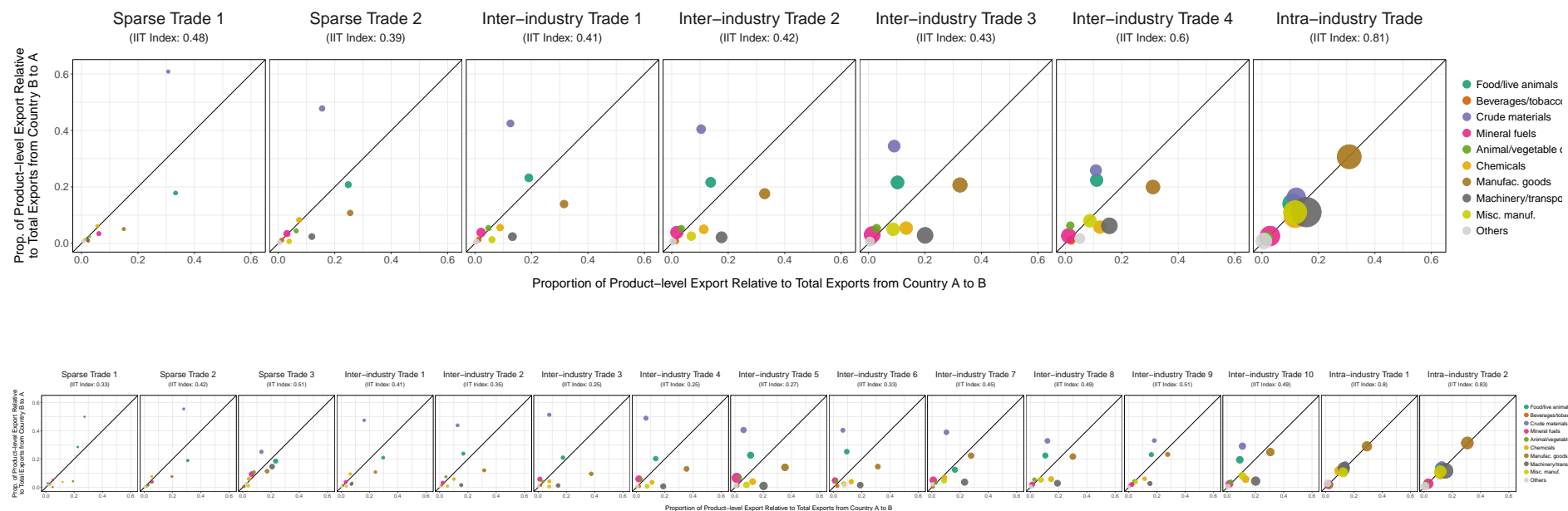


Figure B.1: **7 vs. 15 Types of International Trade.** This figure complements Figure 3 with results from 7 and 15-cluster models. Again, each circle represents exports of a product at the first-digit level of SITC. Circle sizes represent the average magnitude of products exported by dyads within each profile. The axes indicate the size of product exports as a proportion of total exports in a given direction. Circles on the 45-degree line indicate dyads exporting and importing products in the same proportion.

B.2 Comparing Trade Profiles Across Models

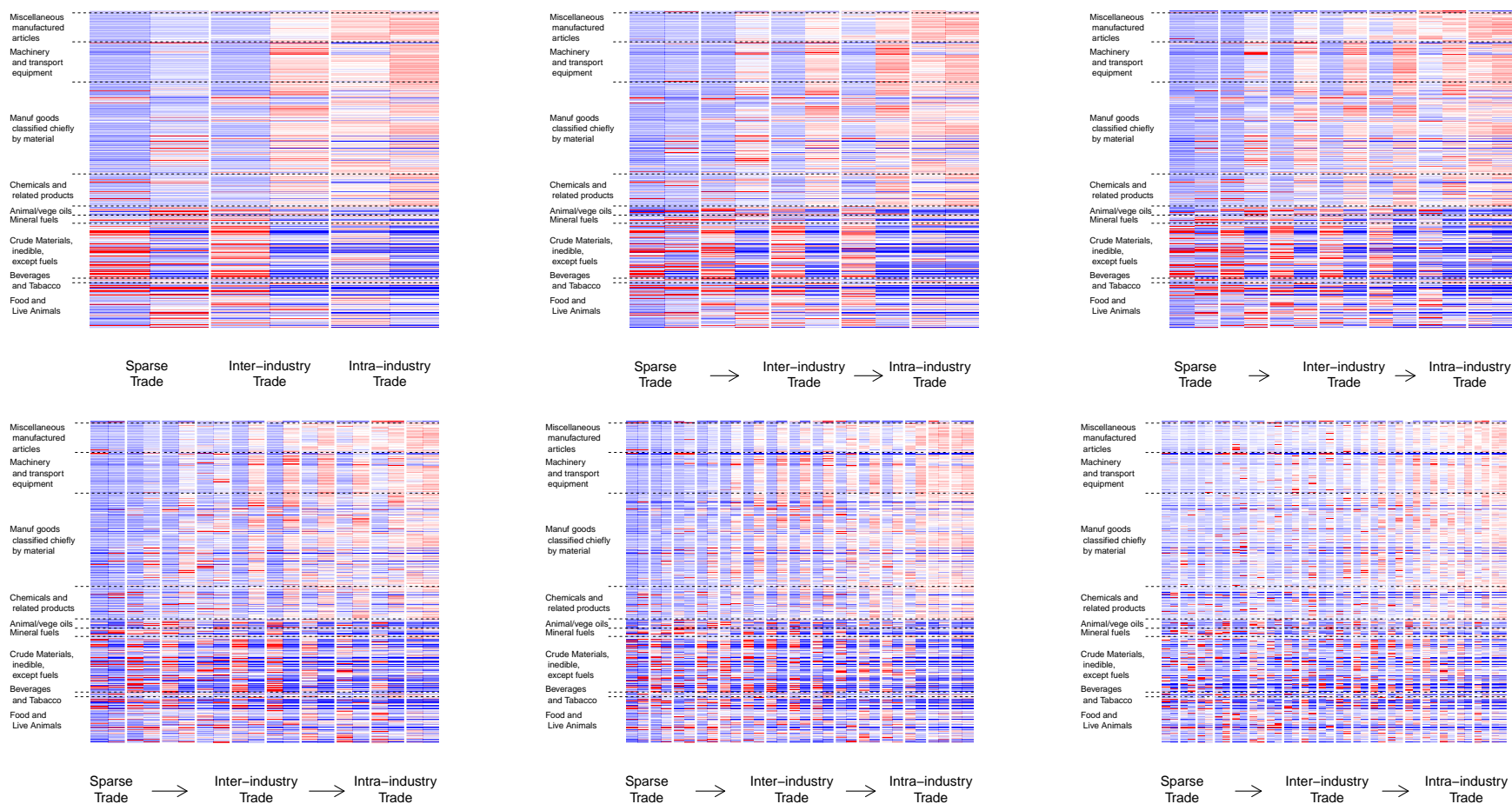


Figure B.2: **Robust Patterns of Sparse, Inter-industry Trade, and Intra-industry Trade.** This figure complements Figure 4 and compares differences in trade at the product level across models using different numbers of clusters. Top row (left to right): 3, 5, and 7. Bottom row (left to right): 10, 15, and 20. The 3, 7, 15-cluster models draw on yearly data while the 5, 10, 20-cluster models use decades data. While we see finer gradations of trade profiles as the number of clusters increases, the basic patterns remain essentially identical. Again, the color of each segment indicates the extent product-level trade deviates from the mean proportion of trade across profiles. Red (blue) represents higher (lower) proportions of trade.

B.3 Comparing Hold-Out Log-Likelihood across Models

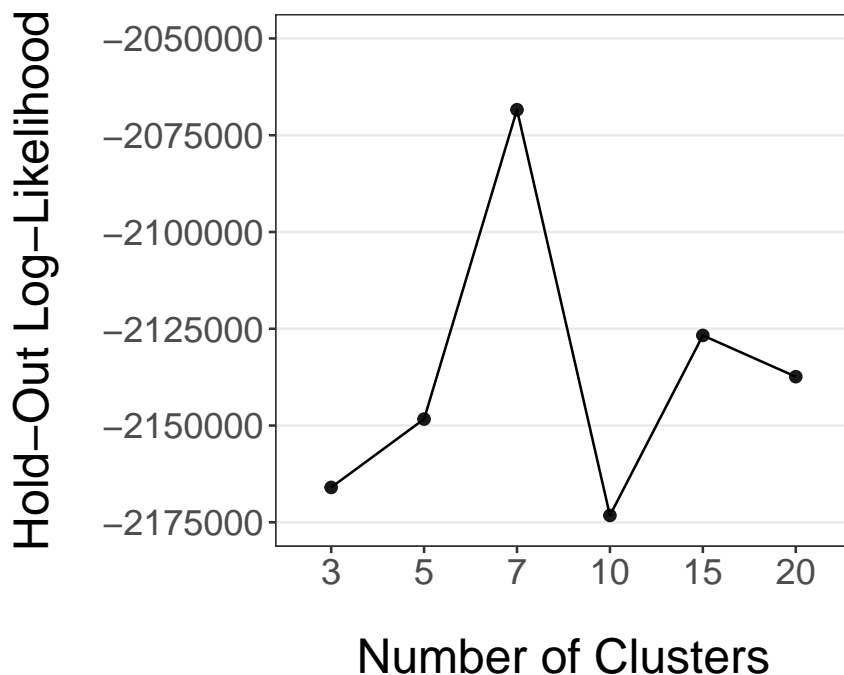


Figure B.3: **Choosing the Number of Clusters.** This figure compares the hold-out log-likelihood across models using different numbers of clusters and decades data (1962, 1972, 1982, 1992, 2002, and 2012). Specifically, we set aside data from 2012 as a test set and fit models with different numbers of clusters to data from the first five decades. We then take the parameters from the resulting fitted model and compute the hold-out log-likelihood using data from 2012 (see Section 2.2 for details). Overall, the results suggest that a 7-cluster model yields the highest hold-out log-likelihood while a 15-cluster model comes in second. These results lend support for our choice of 7- and 15-cluster models as the main robustness models throughout our analyses. It is important to note that while a 3-cluster model yields a relatively lower log-likelihood, it provides the cleanest conceptualization and mapping with the existing theoretical literature in international political economy. Furthermore, Figure B.2 above show that 7- or 15-cluster models are simply more fine-grained versions of the 3-cluster model. Finally, the substantive conclusion in our International Relations application (see Appendix G) also holds across the three models.

B.4 Comparison between Cluster Membership across Models

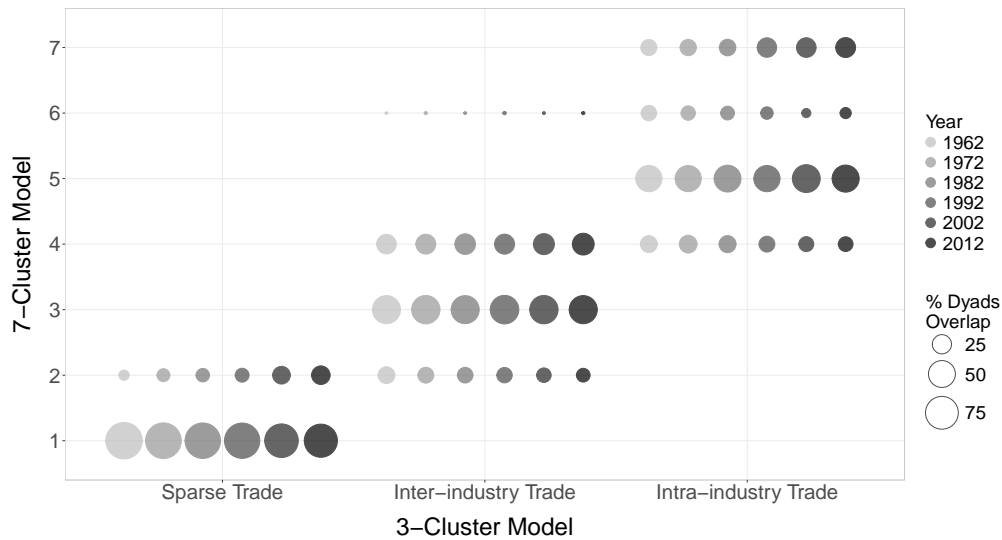


Figure B.4: **Splitting Trade Profiles**. This figure illustrates concordance between our three main trade profiles and profiles extracted from a more fine-grained seven-cluster model. Each circle represents the percentage of dyads that overlap across models during a given year. Larger circles indicate higher percentages of overlap. Darker circles indicate more recent years. Concordance is fairly stable across time.

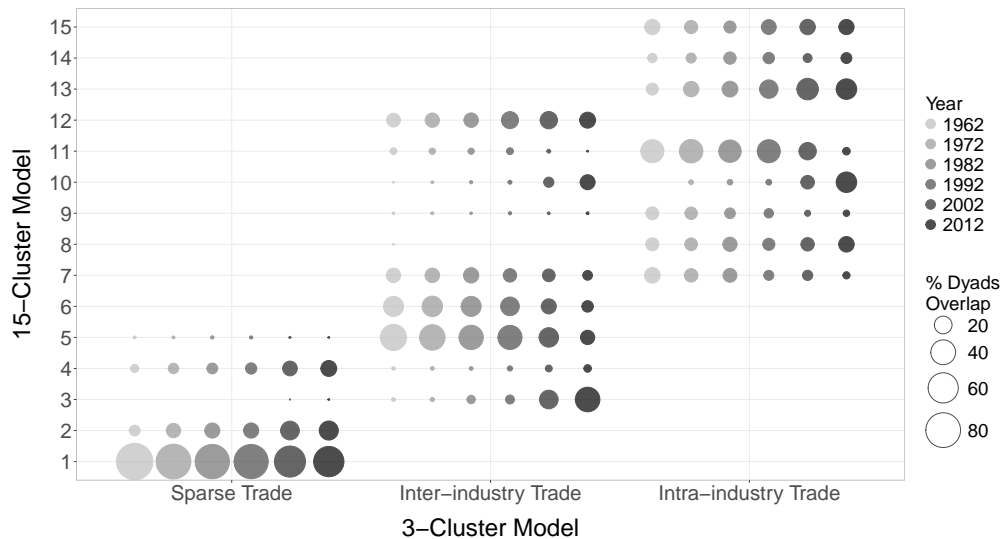


Figure B.5: **Splitting Trade Profiles: 3 to 15**. This figure complements Figure B.4 and illustrates concordance between our three main trade profiles and profiles extracted from a more fine-grained fifteen-cluster model. Again, each circle represents the percentage of dyads that overlap across models during a given year. Larger circles indicate higher percentages of overlap. Darker circles indicate more recent years.

Appendix C The Evolution of Bilateral Trade Relations

Figure C.1 reveals a common path along which many bilateral trade relationships evolve dynamically over time. Each thin line represents the changing cluster membership of a dyad that has existed from 1962 to 2014. A black line traces the evolution of cluster membership for a dyad that belonged to **Sparse Trade** cluster in 1962, whereas blue and red lines trace those for the dyads that were part of **Inter-industry Trade** and **Intra-industry Trade** clusters in 1962, respectively. As it is clear from the figure, most dyads in the **Sparse Trade** cluster move (if they do) to the **Inter-industry Trade** cluster and then to the **Intra-industry Trade** cluster. It is uncommon for them to enter directly into **Intra-industry Trade**. Likewise, transitioning from **Inter-industry Trade** to **Intra-industry Trade** is more typical than going to **Sparse Trade**. The composition of colored lines, which encode the original cluster memberships, demonstrates this point.

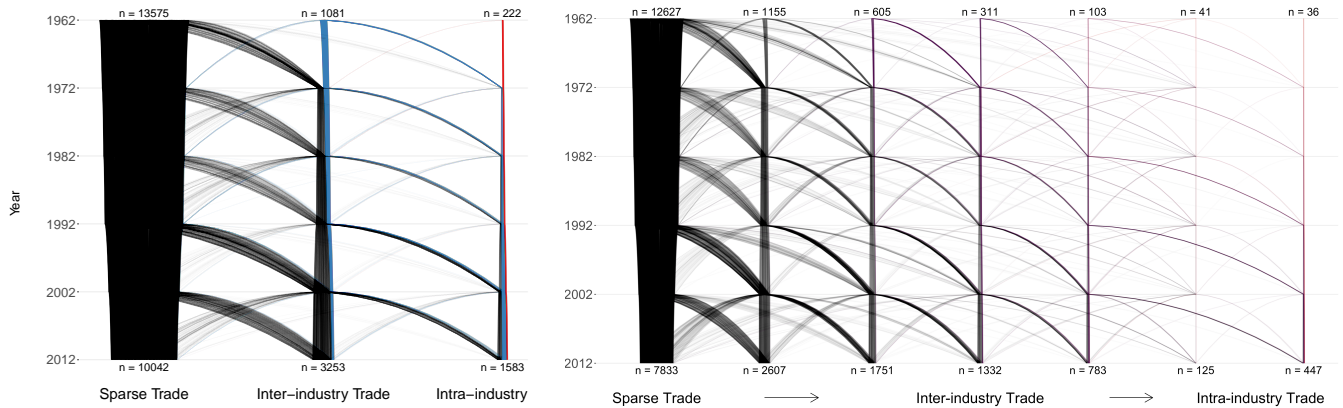


Figure C.1: **Path of Dyads to Intra-Industry Trade.** This figure illustrates the movements of dyad membership across trade profiles and time in 3-cluster (left) and 7-cluster (right) models. Each line represents one dyad in our data set. Dyads that begin in **Sparse Trade**, **Inter-industry Trade**, **Intra-industry Trade** in 1962 are colored black, blue, and red, respectively. We also report the number of dyads in each cluster in 1962 (top) and 2012 (bottom). We find a general movement of dyads from **Sparse Trade** to **Intra-industry Trade** via **Inter-industry Trade**.

We also find that it is rare for dyads to revert back through the path. The cluster membership becomes sticky once the dyad enters the **Intra-industry Trade** cluster. When dyads do backslide, they are oftentimes driven by external shocks such as economic sanctions or conflict. For example, Iran's cluster membership with multiple countries such as the United Kingdom, Sweden, Azerbaijan, Oman, Pakistan, South Africa, and Malaysia reverted from **Intra-industry Trade** to **Inter-industry**

Trade in 2012. This timing corresponds with when the U.S. and the EU stepped up their sanctions on Iran and restricted the trade of many products in the arms, oil, and energy sector.²³ Such sanctions reduced the variety of products traded and explain why Iran and its partners reverted back to inter-industry trade. In contrast, dyads that revert from **Inter-industry Trade** to **Sparse Trade** tend to involve conflict zones. For example, Sudan’s cluster membership with Japan, Switzerland, Sweden, Australia, Austria, Belgium, and many more countries reverted back to **Sparse Trade** in 2012, which was when a war broke out between Sudan and South Sudan over oil-rich regions. Both patterns of evolution and reversion can also be seen from a more fine-grained analysis based on a 7-cluster model in the right panel, where we observe that the lines “trickle down” to the right.²⁴

²³For U.S. sanctions see <https://www.whitehouse.gov/the-press-office/2012/07/31/fact-sheet-sanctions-related-iran>. For EU sanctions, see <http://www.consilium.europa.eu/en/policies/sanctions/iran/>.

²⁴We compare the distribution of dyadic cluster membership across models with different number of clusters in Appendix B.4.

Appendix D Comparison with Feenstra et al. (2005)

Feenstra et al. (2005) is another dataset used by researchers. We use UN Comtrade data in order to cover recent periods after year 2000 and to use a consistent product categories over time as described above. The two datasets are also highly similar to each other: The average correlation between them is about 0.9 even when we account for the differences in the missing observations in respective dataset. For example, we observe more than 224,000 positive trade values for which Feenstra et al. (2005) has missing observations in 1962 alone. When we focus on products with positive trade values in both data, the correlation ranges from 0.98 to 0.99 across all years.

SITC First Digit: Description	# Four Digit Products	Mean (\$M)		S.D (\$M)		% Zero	
		1962	2014	1962	2014	1962	2014
0: Food and Live Animals	89	0.57	23.21	8.14	275.46	85.6	61.8
1: Beverages and Tobacco	9	0.06	3.06	1.83	45.27	92.8	74.5
2: Crude Materials, inedible, exc. fuels	108	0.49	15.57	8.87	422.06	86.8	67.3
3: Mineral fuels	16	0.33	42.29	7.19	879.06	94.3	83.4
4: Animal/vege oils	18	0.03	2.03	0.68	41.19	94.6	84.0
5: Chemicals and related products	63	0.22	40.82	3.35	540.60	89.7	63.4
6: Manufactured goods	181	0.71	44.01	11.69	571.02	86.6	57.1
7: Machinery and transport equipment	79	0.78	114.85	14.75	2101.69	89.1	54.2
8: Miscellaneous manufactured articles	57	0.20	38.99	3.82	887.80	88.5	53.6
9: Others	5	0.04	8.17	1.35	237.29	92.4	72.6

Table D.1: **Descriptive Statistics from Dyadic Trade Data** : The table groups a total of 625 SITC four digit products (second column) into ten industry categories based on the first digit of the SITC code. The next four columns show the means and standard deviations of the dyadic trade volume (in million dollar) for each industry in 1962 and 2014, respectively. The last two columns report the percentage of dyads that do not trade any products of the given industry in each year.

Table D.1 reports descriptive statistics for our dyadic trade data based on the first digit industry code (“Section”) of the 625 products. We note that industries with differentiated products such as manufactured goods tend to have more SITC four-digit products than other industries with substitutable goods. As it is clear from the differences in the mean volumes (in million US dollars) of dyadic trade between 1962 and 2014, commodity trade has dramatically increased over the last 53 years. Moreover, the magnitude of the standard deviations implies that dyadic trade is highly heterogeneous even at the aggregated industry level. One important source of such variation is the prevalence of dyads with sparse trade. Indeed, the last two columns (“% Zero”) show that a large proportion of dyads do not trade any products of the given industry.

Appendix E Comparing Measures of Trade Competition

		Partners	
		No	Yes
Products	No	Lee and Strang, 2006	
	Yes	Simmons and Elkins, 2004 (9 industries)	Cao and Prakash, 2010, 2011 (10 industries)
		Elkins, Guzman, and Simmons, 2006 (13 industries)	
		Chatagnier and Kavaklı, 2017 (1253 products)	

Table E.1: **Existing Measures of Trade Competition.** This table categorizes studies on whether they distinguish between products and partners. To the best of our knowledge, no existing measures further distinguish between export and import competition. Note that Chatagnier and Kavaklı (2017) rely on Feenstra et al. (2005)’s trade data, which is also based on UN Comtrade data. This dataset includes more products (1253) compared to ours (625) because Feenstra et al. (2005) created artificial product categories to adjust for inconsistencies in UN’s data at different levels of aggregation due to missing four-digit data reports at the time of the study. Also note that Cao and Prakash (2010, 2011) distinguish between different partners but assign equal weights to all partners regardless of dyadic trade volume. Since zero trade with a partner implies no trade competition, they ignore all observations with no trade in at least one industry when calculating correlations (Cao and Prakash, 2010, p. 487).

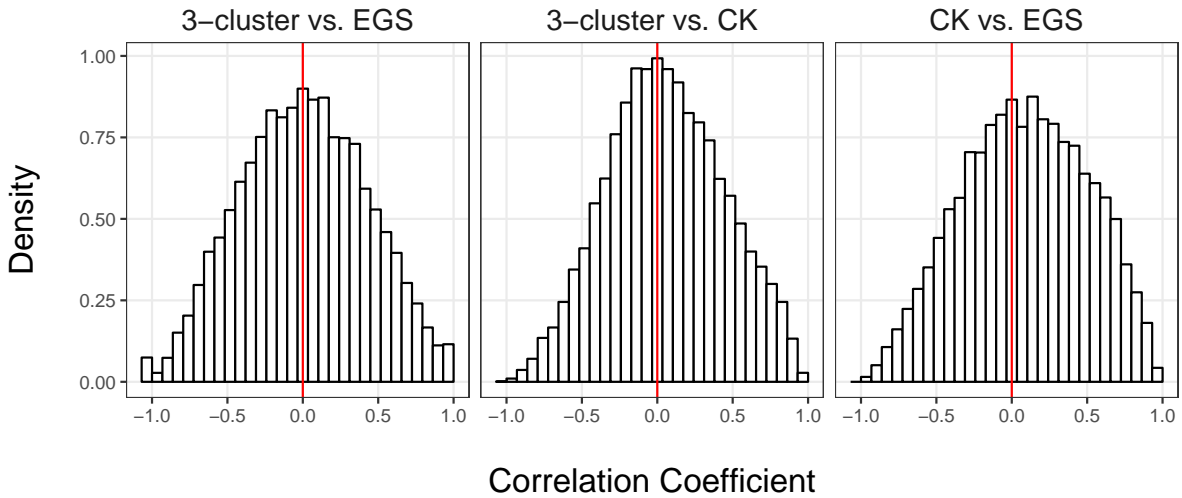


Figure E.1: **Distribution of Within-Dyad Correlations Between Measures.** We calculate dyad-level correlations of trade competition across different measures and plot the distribution. The results show, on average, zero correlation between our 3-cluster measure and Elkins, Guzman, and Simmons (2006), our 3-cluster measure and Chatagnier and Kavaklı (2017), or between Elkins, Guzman, and Simmons (2006) and Chatagnier and Kavaklı (2017).

More formally, we compute the level of discrepancy between competition measures using the metric below:

$$\frac{\sqrt{\text{mean}\{(x_{it} - y_{it})^2\}}}{\sqrt{\frac{1}{2}\{\text{var}(x_{it}) + \text{var}(y_{it})\}}}$$

where x_{it} and y_{it} represent two different measures of trade competition for country i and year t , and the metric captures the number of standard deviation differences with respect to the mean variation of the two measures.

Table E.2 summarizes the levels of discrepancy between five different competition measures. Overall, the discrepancy between our 3 and 7-cluster measures (1.00) or 7 and 15-cluster measures (0.78) are relatively small. Compared to the former, the discrepancy between our 3-cluster measure and EGS' measure is 1.7 times larger while the discrepancy between our 3-cluster measure and CK's measure is more than 2 times larger.

	3-Cluster	7-Cluster	15-Cluster	EGS	CK
3-Cluster	0				
7-Cluster	1.00	0			
15-Cluster	1.30	0.78	0		
EGS	1.70	2.25	2.55	0	
CK	2.07	3.32	4.14	1.25	0

Table E.2: **Level of Discrepancy Between Competition Measures.**

Appendix F Zero Trade Undermines Existing Measures of Trade Competition

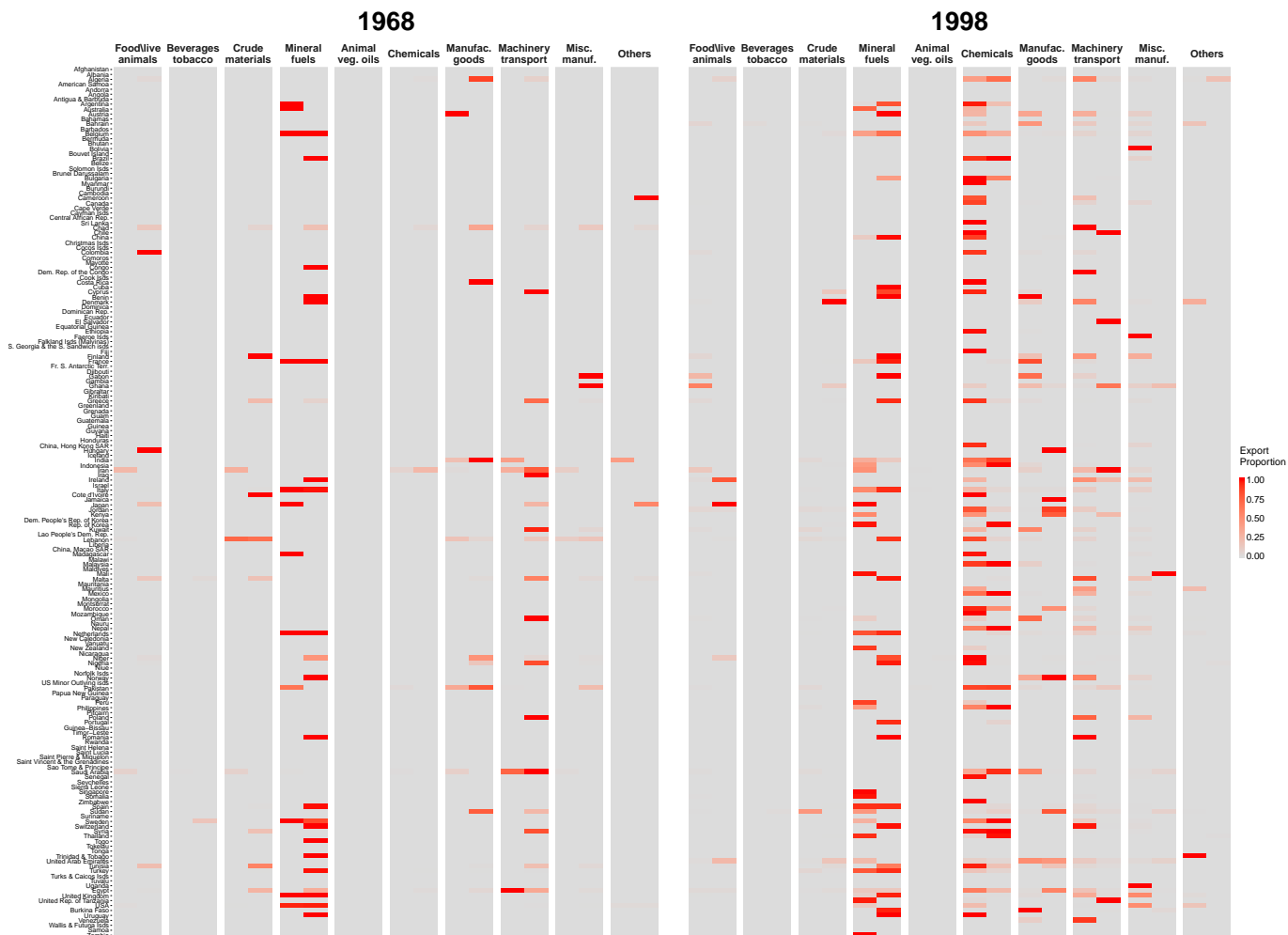


Figure F.1: Differences in Proportion of Industry-level Exports to Trading Partners: Qatar vs. Libya. Red bars represent industries with higher proportions of exports while grey bars correspond to industries with zero trade. For each industry, export proportions of Qatar and Libya are plotted in the left and right column, respectively. The figure shows that Chatagnier and Kavaklı (2017)’s near perfect correlation in 1968 is an artifact of zero trade. Once we separate out industries with zero trade, it is clear that Qatar and Libya compete more in 1998, which is captured by the increased number of red bars particularly in mineral fuels and chemical industries.

Figure F.1 illustrates the problem of zero trade. Chatagnier and Kavaklı (2017) identify Qatar and Libya as an example of extremely high trade competition (p. 11). According to their measure, the two countries’ trade profiles yield near perfect correlations from 1962 to 1995 and a minimum

value of 0.92 since then. In other words, a slight decrease in trade competition over time. We take this particular dyad and plot the proportion of industry-level exports by Qatar and Libya to their trading partners out of total exports in 1968 and 1998. We chose these two years because, according to our measure, the level of competition between the two countries is the lowest (≈ 0.25) in 1968 and the highest (≈ 0.75) in 1998. That is, a significant increase in trade competition over time. Overall, the figure shows that Chatagnier and Kavaklı (2017)'s near perfect correlation in 1968 is an artifact of zero trade.²⁵ Once we separate out industries with zero trade, it is clear that Qatar and Libya compete more in 1998, which is largely due to increased competition in mineral fuels and chemical industries.

²⁵Chatagnier and Kavaklı (2017) impute zero for missing values, which further inflates their correlations.

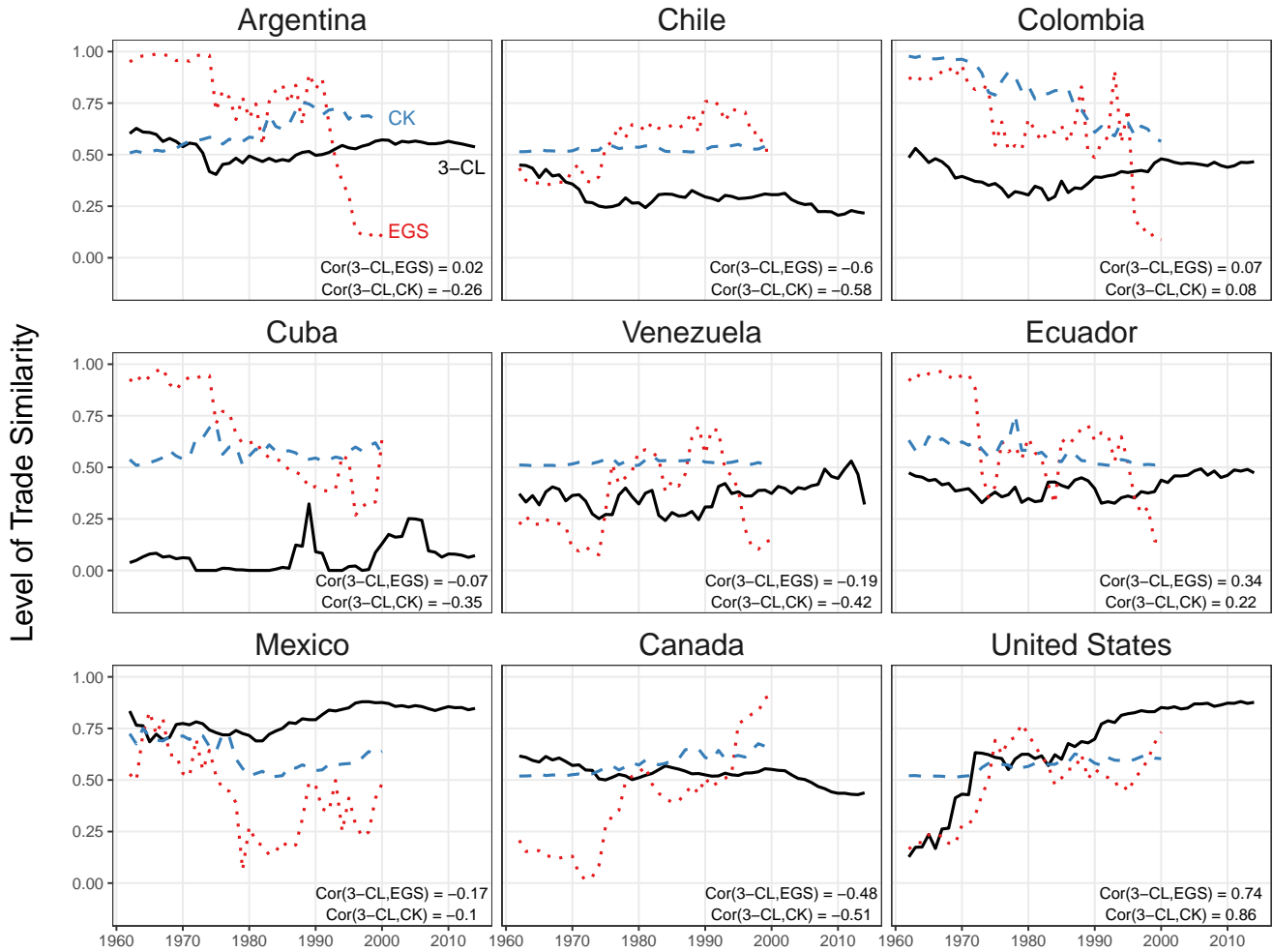


Figure F.2: **Brazil's Trade Competitors: Replication of Figure 6 in Elkins, Guzman, and Simmons (2006)**. Elkins, Guzman, and Simmons (2006) suggest that Brazil's competition with Latin American countries has decreased over time while competition with North America has increased. Our 3-cluster measure shows a more complicated story. While Brazil's competition with Latin American countries has decreased in the 60s, it has rebounded since the 80s. Furthermore, while Brazil has increased competition with the United States, competition with Canada actually decreased. The Brazil-Cuba example demonstrates the importance of accounting for zero or little trade. Without accounting for zero trade, Elkins, Guzman, and Simmons (2006)'s measure inflates the levels of competition. Results from Chatagnier and Kavaklı (2017)'s measure illustrate why correlating vectors of product-level trade in the presence of zero trade and data sparsity is problematic. Chatagnier and Kavaklı (2017) show very little variation across time with most results clustered around 0.5, which is zero on the scale for correlations.

Appendix G Trade Competition and Bilateral Investment Treaties

Protection of foreign direct investment (FDI) against governments' expropriating motives is key to the stability of global production network. In their seminal work, Elkins, Guzman, and Simmons (2006) argue that international competition among potential host countries drive the spread of BITs. According to this argument, countries are more likely to sign BITs with others when their competitors have done so. This influential study led to numerous subsequent research on policy diffusion in the field of International Political Economy.

Method and Measurement. The authors consider three different measures of international competition: (1) the degree to which countries have similar proportion of exports to trading partners, (2) the degree to which countries export the same basket of goods, and (3) the degree to which countries have similar educational and infrastructural resources (p. 830). To facilitate a direct comparison with our measure, we consider the second measure of trade competition, which is based on the similarity in trade profiles and featured throughout their analyses. In particular, it corresponds to the illustration of Brazil and its partners' export market similarity (see Figure 6, p. 832) and the analyses based on "BITs Among Export Product Competitors" (see Model 2 of Table 2, p. 837; Figure 7a, p. 839). They find the strongest diffusion effect of competition using this measure.

As mentioned earlier, one limitation of the measure developed by Elkins, Guzman, and Simmons is that it is based on exports of only thirteen industries to the world and does not distinguish partner specific trade. Another issue is that much of their trade competition measure is imputed. Out of 1,232,622 dyad-years for which there exists their competition measure, 94.5% (1,164,296) has at least one country's export data missing for at least one industry. The authors first impute exports to the world for each industry, whenever they are recorded as missing. To do this, the authors fit a linear regression model, in which the observed exports are regressed on their observed 10-year lag values, and then predict missing exports from the fitted model. Using these imputed data, they calculate *dyadic* correlations in export profiles (i.e., the measure of trade competition). Unfortunately, missing data for at least one industry over 10 years makes it impossible to do imputation for many dyads, resulting in missing correlation values for around 81.7% of dyads. To remedy this problem, they impute missing correlations using another linear regression model with the 10-year lag correlation values as predictors. Almost 70% (855,086) of their competition

measures are imputed in this step. Finally, these doubly imputed correlations are then truncated at -1 and 1 . As a result, this trade competition measure is largely based on the imputed values.

Elkins, Guzman, and Simmons test their argument using a Cox proportional hazard spatial regression model where the outcome variable Y_{ijt} is the number of years without a BIT between a host country i and a home country j up to year t since 1958 (or since the year of the dyad’s existence). The hazard function is defined as follows:

$$\lambda_0(t) \exp(\rho W_{i,t-1}^\top Y_{t-1}^* + \alpha^\top X_{it} + \beta^\top Z_{jt} + \delta^\top V_{ijt}) \quad (6)$$

where $\lambda_0(t)$ is the baseline hazard function at year t , W_{it} is an N dimensional spatial weight vector whose j th element represents the degree of trade competition between countries i and j in year t (the i th element of this vector is zero), and Y_{t-1}^* is an N dimensional vector that represents the count of BITs that each country had up to the previous year.²⁶ Finally, X_{it} , Z_{jt} , and V_{ijt} represent host country, home country, and dyad-specific covariates, respectively. The spatial lag $W_{i,t-1}^\top Y_{t-1}^*$ is equal to the weighted average of numbers of BITs in force among other host countries, with greater weights assigned to countries that are in competition with country i . Using this survival analysis framework, they find evidence that host countries are more likely to enter into BITs when more of the host’s closest trade competitors have signed BITs.

Within the Cox proportional hazard model given in equation (6), we replace the aforementioned trade competition measure W_{it} used by Elkins, Guzman, and Simmons with our improved measures. We use the measures based on 3, 7, and 15-cluster models, but as shown below, the substantive results appear not to depend critically on the number of clusters. To ensure a fair comparison, we follow all the other choices made in the original study including the model specification and the estimation procedure. We also subset the original data excluding dyad-years for which dyadic cluster memberships do not exist. This yields a dyadic data set with 233,374 observations.²⁷ As shown below, this restriction does not significantly change the original finding

²⁶Elkins, Guzman, and Simmons (2006) miscalculate cumulative BITs in force in their construction of spatial lags in revision 5 (2008) of their replication dataset. In addition, the authors lag spatial lags by two periods instead of one period stated in their article (pp. 829–830). We correct for these coding errors.

²⁷There are three main reasons why the restriction is necessary. First, the original study begins in 1958 while data for our dyadic cluster membership begin in 1962. Second, some dyads exist but do not report bilateral trade data at the product level until 2000. Third, we drop observations with missing country concordance. For example, dyads associated with Russia technically did not exist pre-1991. While Elkins, Guzman, and Simmons combine data for Soviet Union and Russia, we treat them as separate entities given the different reporting on product-level trade. We present our replication of the original study (rev. 5, 2008) using 256,914 observations in Table G.1 in

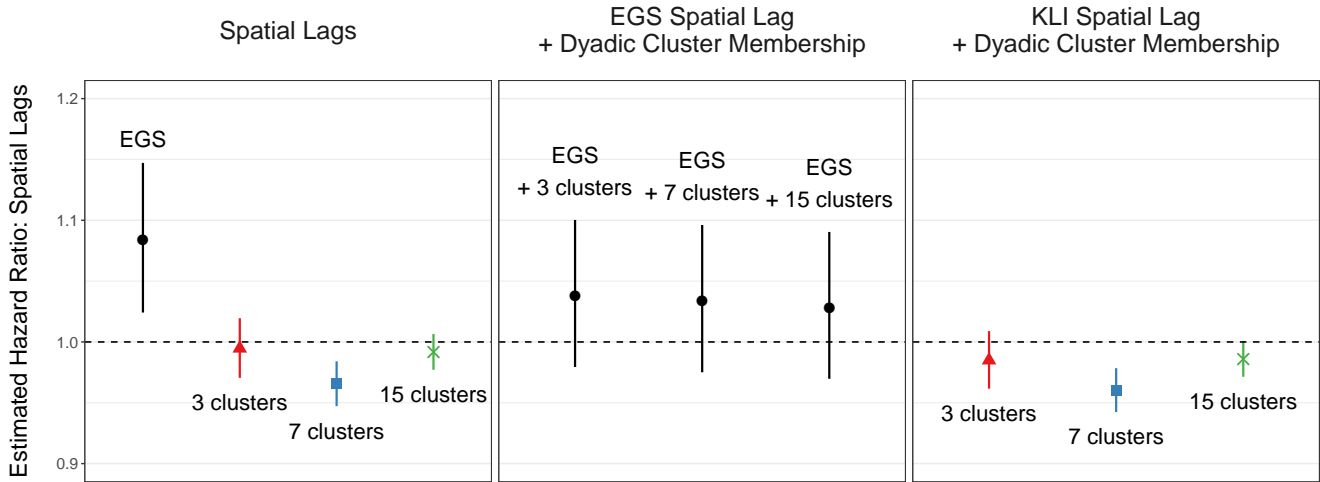


Figure G.1: **Estimated Effects of Trade Competition on Signing BITs:** This figure replicates the main finding from Elkins, Guzman, and Simmons (2006) or EGS and compares it against the results based on the proposed measures of trade competition. The left panel shows that using different measures of trade competition (labeled as 3 clusters, 7 clusters, and 15 clusters) results in estimated effects that are substantively different. In addition, the middle panel shows that the positive diffusion effect becomes statistically insignificant even when we use the spatial lags from EGS if we control for dyadic trade profiles. Finally, we find negative estimated effects of trade competition when we use our spatial lags along with dyadic cluster membership dummies. The vertical lines represent the 95% confidence intervals.

of Elkins, Guzman, and Simmons (2006), but it facilitates a direct comparison of the results. We present all model details in Appendix G.

Findings. Figure G.1 summarizes our findings. First, the left panel of Figure G.1 compares our replication of the original analysis against the results based on our spatial lags. Consistent with the original finding (labeled as EGS), we find a positive diffusion effect of trade competition on signing BITs. However, the estimated effect of trade competition is no longer positive once we use the new spatial lags. In fact, we find that trade competition has a *negative* (the estimated hazard ratio < 1) and statistically significant effect using the more fine-grained measure of competition based on the 7-cluster model. Although the difference (3.5%) is small substantively, this suggests that host countries are more likely to sign BITs when trade competitors have fewer BITs in force.

In the next analysis, we maintain the original spatial lags from Elkins, Guzman, and Simmons while including our cluster membership dummy variables as additional controls. This analysis aims to separate the diffusion effect from the effect of dyadic trade profiles, which may capture

both vertical and horizontal production linkages motivating FDI decisions.²⁸ It is important to emphasize that our cluster membership measure allows applied researchers to account for trade profiles at the product level, which has not been possible because of the high-dimensionality of product-level data.

The middle panel of Figure G.1 reveals that even the original trade competition measure loses its statistical significance once dyadic trade patterns are accounted for. Meanwhile, we find that dyadic cluster membership variables are statistically significant across all models: Table G.2 in Appendix G shows that dyads in **Intra-industry Trade** or **Inter-industry Trade** relationships are more likely to sign BITs compared to the baseline **Sparse Trade**, with larger effects for the former. This is consistent with the view that the economic gains of BITs can outweigh sovereignty losses as developing countries become more integrated into their investors' global value chain (Baldwin, 2016, 102-103). It also suggests that *dyadic* trade relationships that capture production linkages can be more important than *network* competition effects when explaining the spread of BITs. Finally, we estimate the effect of trade competition using our spatial lags while controlling for dyadic cluster memberships. The right panel of Figure G.1 shows that trade competition tends to deter countries from signing BITs.

More broadly, our findings suggest that governments might have fewer incentives to tie their hands when competitive pressures are high. That is, commitments to foregoing certain policy tools might be perceived as superfluous costs that are particularly onerous when their competitors have already taken the advantageous position of signing BITs with their partners. Alternatively, trading partners that sign BITs earlier than others might be fundamentally different from others to begin with. Indeed, the null findings, when including dyadic cluster membership in our model, suggest that the *types* of goods traded—often ignored in empirical research—can be important determinants of signing BITs. Finally, there might exist other mechanisms through which foreign investments can be protected. For example, recent research shows that the level of integration of domestic firms into global production networks deters governments from expropriating foreign investments (Johns and Wellhausen, 2016). We leave for future research the task of investigating these alternative possibilities.

²⁸See discussion in Elkins, Guzman, and Simmons (2006, p. 836).

Table G.1: Replication Results for Model 2 of Elkins, Guzman, and Simmons (2006)

	<i>Dependent variable:</i>					
	BITs in Force					
	EGS Original	EGS Corrected	EGS Subset	3-CL	KLI Sp. Lag 7-CL	15-CL
Bits among export product competitors	1.128*** (0.033)					
Bits among export product competitors (correct)		1.087** (0.030)	1.084** (0.031)			
Bits among trade competitors (3-CL)				0.995 (0.013)		
Bits among trade competitors (7-CL)					0.965*** (0.009)	
Bits among trade competitors (15-CL)						0.992 (0.008)
Average annual global fdi flows	1.405*** (0.110)	1.346*** (0.106)	1.512*** (0.129)	1.552*** (0.130)	1.550*** (0.131)	1.550*** (0.130)
Host extractive industries/exports	0.719** (0.081)	0.726** (0.082)	0.705** (0.082)	0.680** (0.080)	0.632*** (0.075)	0.663*** (0.080)
Perceptions of host corruption	0.973 (0.031)	0.975 (0.031)	0.991 (0.033)	0.990 (0.033)	0.998 (0.033)	0.991 (0.033)
Host legal tradition (common law)	0.688*** (0.054)	0.689*** (0.054)	0.673*** (0.057)	0.679*** (0.058)	0.660*** (0.057)	0.677*** (0.058)
Bits among those with same religion	0.995 (0.011)	0.997 (0.011)	0.993 (0.011)	0.999 (0.011)	1.001 (0.011)	1.000 (0.011)
Learning from success	1.349 (0.520)	1.542 (0.592)	1.386 (0.564)	1.461 (0.593)	1.415 (0.575)	1.442 (0.586)
Coercion: host use of imf credits	1.280*** (0.093)	1.286*** (0.093)	1.331*** (0.101)	1.360*** (0.103)	1.320*** (0.100)	1.356*** (0.103)
Host gdp (ln)	1.163*** (0.040)	1.168*** (0.040)	1.165*** (0.041)	1.177*** (0.042)	1.212*** (0.044)	1.184*** (0.043)
Host gdp/capita	0.948 (0.026)	0.948 (0.026)	0.924** (0.027)	0.923** (0.027)	0.945 (0.028)	0.928* (0.028)
Host gdp growth	0.987** (0.004)	0.987*** (0.004)	0.987** (0.004)	0.986*** (0.004)	0.986*** (0.004)	0.986*** (0.004)
Host net fdi inflows (% of gdp), t-1	0.997 (0.007)	0.998 (0.007)	0.995 (0.007)	0.996 (0.007)	0.997 (0.007)	0.996 (0.007)
Host illiteracy rate	0.267*** (0.044)	0.262*** (0.043)	0.191*** (0.034)	0.175*** (0.031)	0.172*** (0.030)	0.175*** (0.031)
Host capital account/gdp	1.002 (0.004)	1.002 (0.004)	1.000 (0.005)	1.001 (0.005)	1.001 (0.005)	1.001 (0.005)
Host law and order	1.320*** (0.037)	1.315*** (0.037)	1.329*** (0.039)	1.329*** (0.039)	1.336*** (0.039)	1.334*** (0.039)
Host democracy	0.995 (0.005)	0.995 (0.005)	0.994 (0.005)	0.995 (0.005)	0.995 (0.005)	0.995 (0.005)
Host diplomatic representation	1.006*** (0.002)	1.006*** (0.002)	1.007*** (0.002)	1.008*** (0.002)	1.008*** (0.002)	1.008*** (0.002)
Host privatization record	1.061*** (0.018)	1.061*** (0.018)	1.061*** (0.018)	1.061*** (0.018)	1.065*** (0.018)	1.062*** (0.018)
Home net fdi outflows (% of gdp)	1.134*** (0.014)	1.135*** (0.014)	1.134*** (0.015)	1.135*** (0.015)	1.135*** (0.015)	1.135*** (0.015)
Dyadic trade (% of host's gdp)	1.556 (0.439)	1.559 (0.438)	1.325 (0.424)	1.374 (0.434)	1.471 (0.460)	1.392 (0.439)
Common colonial heritage	0.429*** (0.092)	0.432*** (0.092)	0.447*** (0.097)	0.449*** (0.097)	0.442*** (0.096)	0.448*** (0.097)
Common language	1.333* (0.156)	1.330* (0.156)	1.366* (0.167)	1.348* (0.165)	1.362* (0.167)	1.349* (0.165)
Alliance	1.467*** (0.162)	1.460*** (0.161)	1.480*** (0.167)	1.467*** (0.166)	1.464*** (0.166)	1.461*** (0.165)
Cold war	0.334*** (0.059)	0.347*** (0.061)	0.333*** (0.061)	0.328*** (0.060)	0.331*** (0.061)	0.329*** (0.060)
Number of bits globally, by year	0.821*** (0.029)	0.851*** (0.028)	0.832*** (0.029)	0.895*** (0.024)	0.918*** (0.023)	0.897*** (0.022)
Observations	256,914	256,914	233,374	233,374	233,374	233,374
R ²	0.007	0.007	0.008	0.008	0.008	0.008
Max. Possible R ²	0.090	0.090	0.092	0.092	0.092	0.092
Log Likelihood	-11,313.270	-11,317.140	-10,388.130	-10,391.930	-10,385.760	-10,391.420
Wald Test	1,592.500***	1,587.550***	1,534.100***	1,512.600***	1,480.710***	1,501.670***
LR Test	1,741.637***	1,733.902***	1,785.891***	1,778.278***	1,790.628***	1,779.300***
Score (Logrank) Test	2,149.539***	2,149.912***	2,148.399***	2,087.621***	2,076.066***	2,108.138***

Note: This table presents hazard ratios with standard errors in parentheses. *p<0.05; **p<0.01; ***p<0.001. Column 1 is the exact replication of Elkins, Guzman, and Simmons (2006)'s finding using their revised replication data (rev. 5, 2008). Given the data revision, this replication will not exactly match those in the published article but do not change substantive findings. Unfortunately, the authors still miscalculate cumulative BITs in force in their construction of spatial lags in the latest revised dataset. In addition, the authors lag spatial lags by two periods instead of one period stated in their article (p. 829-830). Column 2 corrects these problems. Column 3 further excludes dyad-years that are missing data on dyadic cluster memberships to ensure fair comparison of results across models. We drop all observations before data for our measures were available in 1962. We also drop observations involving dyads that do not report bilateral trade data at the product level until 2000 (e.g., South Africa, Lesotho, Botswana, Namibia, and Swaziland). Finally, we drop observations with missing country concordance (e.g., Russia pre-1991 and Vietnam pre-unification). The new baseline (Column 3) yields a slightly smaller hazard ratio for the spatial lag, but does not change substantive findings. We provide replication code for both studies.

Table G.2: Model 2 of Elkins, Guzman, and Simmons (2006): Controlling for Dyadic Trade Profiles

	<i>Dependent variable:</i>					
	BITS in Force					
	KLI Dummies			KLI Sp. Lag + Dummies		
	3-CL	7-CL	15-CL	3-CL	7-CL	15-CL
Bits among export product competitors (correct)	1.038 (0.031)	1.034 (0.031)	1.028 (0.031)			
Bits among trade competitors (3-CL)				0.985 (0.012)		
Bits among trade competitors (7-CL)					0.960*** (0.009)	
Bits among trade competitors (15-CL)						0.986 (0.007)
Average annual global fdi flows	1.459*** (0.131)	1.454*** (0.132)	1.436*** (0.131)	1.485*** (0.132)	1.479*** (0.133)	1.453*** (0.131)
Host extractive industries/exports	0.797 (0.094)	0.805 (0.095)	0.814 (0.097)	0.773* (0.092)	0.731** (0.087)	0.766* (0.093)
Perceptions of host corruption	0.984 (0.033)	0.977 (0.033)	0.975 (0.033)	0.988 (0.033)	0.989 (0.033)	0.981 (0.033)
Host legal tradition (common law)	0.578*** (0.050)	0.571*** (0.049)	0.562*** (0.049)	0.574*** (0.050)	0.552*** (0.049)	0.556*** (0.049)
Bits among those with same religion	0.996 (0.011)	0.997 (0.011)	0.998 (0.011)	0.999 (0.011)	1.001 (0.010)	1.002 (0.011)
Learning from success	1.939 (0.862)	2.340 (1.068)	2.404 (1.103)	1.985 (0.882)	2.351 (1.078)	2.409 (1.107)
Coercion: host use of imf credits	1.326*** (0.102)	1.349*** (0.104)	1.327*** (0.102)	1.332*** (0.102)	1.313*** (0.101)	1.325*** (0.102)
Host gdp (ln)	0.973 (0.035)	0.950 (0.034)	0.944 (0.034)	0.982 (0.035)	0.985 (0.036)	0.959 (0.035)
Host gdp/capita	0.810*** (0.024)	0.802*** (0.024)	0.800*** (0.024)	0.814*** (0.024)	0.824*** (0.025)	0.808*** (0.024)
Host gdp growth	0.991* (0.004)	0.990* (0.004)	0.991* (0.004)	0.991* (0.004)	0.991* (0.004)	0.991* (0.004)
Host net fdi inflows (% of gdp), t-1	0.999 (0.007)	1.001 (0.007)	1.002 (0.007)	0.999 (0.007)	1.003 (0.006)	1.002 (0.007)
Host illiteracy rate	0.242*** (0.044)	0.270*** (0.049)	0.281*** (0.051)	0.228*** (0.041)	0.252*** (0.046)	0.270*** (0.049)
Host capital account/gdp	1.005 (0.005)	1.005 (0.005)	1.004 (0.005)	1.005 (0.005)	1.005 (0.005)	1.005 (0.005)
Host law and order	1.244*** (0.037)	1.227*** (0.037)	1.222*** (0.037)	1.247*** (0.037)	1.235*** (0.037)	1.230*** (0.037)
Host democracy	0.995 (0.005)	0.995 (0.005)	0.995 (0.005)	0.995 (0.005)	0.995 (0.005)	0.996 (0.005)
Host diplomatic representation	1.006*** (0.002)	1.006*** (0.002)	1.006*** (0.002)	1.007*** (0.002)	1.007*** (0.002)	1.006*** (0.002)
Host privatization record	1.060*** (0.019)	1.056** (0.019)	1.057** (0.019)	1.062*** (0.019)	1.061*** (0.018)	1.060*** (0.019)
Home net fdi outflows (% of gdp)	1.030* (0.013)	1.018 (0.013)	1.014 (0.013)	1.031* (0.013)	1.018 (0.013)	1.014 (0.013)
Dyadic trade (% of host's gdp)	0.207* (0.134)	0.263 (0.198)	0.186 (0.161)	0.216* (0.139)	0.265 (0.201)	0.185 (0.160)
Common colonial heritage	0.551** (0.118)	0.569** (0.121)	0.579* (0.123)	0.550** (0.118)	0.554** (0.118)	0.571** (0.122)
Common language	0.881 (0.103)	0.823 (0.096)	0.800 (0.093)	0.875 (0.103)	0.829 (0.096)	0.798 (0.092)
Alliance	0.919 (0.101)	0.897 (0.098)	0.872 (0.095)	0.912 (0.100)	0.882 (0.096)	0.857 (0.094)
Cold war	0.290*** (0.058)	0.269*** (0.055)	0.267*** (0.055)	0.288*** (0.057)	0.268*** (0.055)	0.266*** (0.055)
Number of bits globally, by year	0.890** (0.032)	0.898** (0.033)	0.908** (0.033)	0.930** (0.026)	0.955 (0.026)	0.940* (0.026)
Inter-industry Trade (3-CL dummy)	7.750*** (0.643)			7.763*** (0.644)		
Intra-Industry Trade (3-CL dummy)	21.163*** (2.151)			21.344*** (2.166)		
Sparse Trade 2 (7-Cluster, dummy)		6.122*** (0.950)			6.026*** (0.935)	
Inter-industry Trade 1 (7-CL, dummy)		17.198*** (2.592)			17.012*** (2.563)	
Inter-industry Trade 2 (7-CL, dummy)		41.641*** (6.327)			41.287*** (6.269)	
Inter-industry Trade 3 (7-CL, dummy)		62.899*** (10.266)			63.095*** (10.279)	
Inter-industry Trade 4 (7-CL, dummy)		65.192*** (15.091)			63.122*** (14.624)	
Intra-Industry Trade (7-CL, dummy)		52.576*** (12.930)			55.021*** (13.486)	
Sparse Trade 2 (15-Cluster, dummy)			2.139*** (0.484)			2.118*** (0.480)
Inter-industry Trade 1 (15-CL, dummy)			14.285*** (3.812)			14.329*** (3.822)
Inter-industry Trade 2 (15-CL, dummy)			7.591*** (1.519)			7.525*** (1.506)
Inter-industry Trade 3 (15-CL, dummy)			14.257*** (2.766)			14.106*** (2.737)
Inter-industry Trade 4 (15-CL, dummy)			21.529*** (4.344)			21.265*** (4.293)
Inter-industry Trade 5 (15-CL, dummy)			51.878*** (10.310)			51.204*** (10.182)

Inter-industry Trade 6 (15-CL, dummy)			75.560*** (20.448)			74.907*** (20.276)
Inter-industry Trade 7 (15-CL, dummy)			65.484*** (20.302)			64.690*** (20.059)
Inter-industry Trade 8 (15-CL, dummy)			38.329*** (11.289)			38.839*** (11.435)
Inter-industry Trade 9 (15-CL, dummy)			67.219*** (13.407)			67.544*** (13.459)
Inter-industry Trade 10 (15-CL, dummy)			33.913*** (6.636)			33.961*** (6.642)
Inter-industry Trade 11 (15-CL, dummy)			84.825*** (18.772)			85.991*** (19.006)
Intra-Industry Trade 1 (15-CL, dummy)			123.958*** (37.990)			123.510*** (37.827)
Intra-Industry Trade 2 (15-CL, dummy)			62.040*** (21.214)			64.007*** (21.885)
Observations	233,374	233,374	233,374	233,374	233,374	233,374
R ²	0.012	0.013	0.014	0.012	0.014	0.014
Max. Possible R ²	0.092	0.092	0.092	0.092	0.092	0.092
Log Likelihood	-9,837.334	-9,700.605	-9,685.963	-9,837.384	-9,692.699	-9,684.673
Wald Test	2,217.930***	2,155.060***	2,189.270***	2,208.950***	2,141.350***	2,178.840***
LR Test	2,887.479***	3,160.937***	3,190.220***	2,887.378***	3,176.748***	3,192.800***
Score (Logrank) Test	3,915.965***	4,278.225***	4,440.638***	3,871.017***	4,234.568***	4,400.623***

Note: This table presents hazard ratios with standard errors in parentheses. *p<0.05; **p<0.01; ***p<0.001. Column 1-3 maintain our corrected version of Elkins, Guzman, and Simmons (2006)'s spatial lag but include cluster membership dummy variables as additional controls. Column 4-6 substitute in our proposed spatial lags while also including the corresponding cluster membership dummy variables as additional controls. For the latter, we omit Sparse Trade as the baseline category.