

# **A Disaggregated Analysis of Unexplained Trade for the United States**

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## Abstract

Building upon Ahmad and Phillips (2026a), this paper uses a gravity framework to capture unexplained trade flows for the United States at the industry and product level rather than at the level of broad sectors. By conducting our analysis at a more disaggregate level, we are able to better identify factors such as illegal transshipments that may be responsible for generating unexplained trade between countries. Our disaggregated analysis largely replicates the primary trends found in our previous paper, such as generally negative U.S. gaps in overall imports and exports as well as a decline in unexplained U.S. imports from China over the last five years. However, our results also reveal considerable heterogeneity across ITPD industries and HS6 products, with median unexplained trade or unexplained trade-to-bilateral trade ratios not representative for a significant share of industries and products during the sample period. We also provide detailed analysis for 2022 trade under six highly imported product and industry codes, finding that China is in the highest ten percent of unexplained exporters for grain mill products and soap/cosmetics but in the bottom ten percent of unexplained exporters for nonferrous metals.

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# 1 Introduction

Illegal transshipments, defined here as any re-routing of trade across third-party countries that is undertaken to explicitly avoid tariffs or sanctions, are of concern for policymakers because they undermine the original purpose for imposing tariffs and sanctions.<sup>1</sup> Because illegal transshipments are both unobserved in the data and difficult to impute, papers such as Ahmad and Phillips (2026a) and Tyazhelnikov and Romalis (2024) have leveraged the features of gravity modeling to provide insight into where illegal transshipments may be occurring. These papers use the gap between actual trade and trade predicted by the gravity model as an indicator of potential transshipments. While these gravity residuals may sometimes represent nothing more than statistical noise, they might also include a systematic component that observed trade factors such as distance, language, and free trade agreements may not account for, and thus constitute a form of “unexplained trade” that warrants further empirical investigation.<sup>2</sup>

Transshipment analysis at the economy-wide or sector level provides several advantages; sector-level data is often more complete than product-level data, and aggregated analysis is both more concise and less computationally intensive than product-level analysis. Product-level analysis nonetheless offers two major benefits. First, all trade, including illegally transshipped trade, is conducted at the product level, giving product-level analysis additional relevance compared to discussion at a more aggregated level. Policies such as sanctions that are relevant to illegal transshipments are also frequently applied to individual products rather than entire sectors. Furthermore, product-level analysis allows us to examine the considerable heterogeneity that may exist among products within a broad sector grouping. Large-scale insights such as those presented in Ahmad and Phillips (2026a) may obscure considerable differences among product codes.

In this paper, we estimate gravity regression residuals for two sets of disaggregate categories: 125 manufacturing industries from the International Trade and Production Data for Estimation (ITPD-E) and around 5000 products at the Harmonized System (HS) 6-digit level from CEPII’s BACI dataset. ITPD-E analysis both includes data on domestic trade flows and provides continuity with Ahmad and Phillips (2026a), while the HS 6-digit analysis allows us to examine unexplained trade at a much more granular level. Our discussion focuses on heterogeneity among product codes—for example, whether industries or products with very positive or very negative levels of unexplained trade have different trends over time than the median unexplained trade level—as well as the ability to analyze specific products in more detail. We also use pseudo-adjusted R-squared results to discuss the explanatory power of our gravity regressions, demonstrating that our gravity

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<sup>1</sup>For reasons of logistical efficiency, some shipments may pass through a third country en route to their eventual destination. These transshipments are legal if documented accurately, and are also easier to measure since sources such as the USITC’s DataWeb and UN Comtrade provide direct measurements of them. This paper is focused on illegal transshipments.

<sup>2</sup>For a more detailed discussion of the mechanics behind gravity regressions and illegal transshipments, see Ahmad and Phillips (2026a).

variables generally predict bilateral trade very well and so the discrepancy between trade and its gravity predictions for certain country pairs is all the more worthy of attention.

Our results show that the primary findings in Ahmad and Phillips (2026a) continue to be present when running gravity regressions using disaggregated data. In particular, median unexplained imports from China have been falling in recent years, a fall that coincides with an increase in median unexplained imports from Vietnam and Cambodia but not an increase in unexplained imports from Mexico and Canada. These median results, however, accompany a significant degree of heterogeneity among product or industry codes. Product-level unexplained trade varies widely both in absolute levels and as a fraction of bilateral trade, and time trends among the highest and lowest percentiles of all unexplained trade observations often behave differently than time trends in median unexplained trade. Analysis of individual product and industry codes reveals that a decrease in unexplained imports of integrated circuits from China coincides with an increase in unexplained imports of integrated circuits from Brazil, the Philippines and Vietnam; meanwhile, a decrease in unexplained imports of non-ferrous metals from Europe coincides with an increase in unexplained imports from India, Malaysia, and Thailand.

Section 2 reviews related works examining transshipments. Section 3 presents analysis for the ITPD-E products, while Section 4 presents analysis for the HS 6-digit products. Section 5 concludes.

## 2 Related Literature

This paper is an extension of Ahmad and Phillips (2026a), which used gravity analysis to better understand the determinants of unexplained trade, including possible illegal transshipments. In order to make its results more concise, Ahmad and Phillips (2026a) aggregated the 125 ITPD-E products into 14 sectors. We complement that paper’s analysis by using its framework to present findings at the product level for U.S. trade.

Our methodology also complements that of other studies on illegal transshipments that have used granular data as their primary unit of analysis. Freund (2025) uses HS 6-digit level data from UN Comtrade to measure potential Chinese evasion of Section 301 tariff duties. Che et al. (2025), meanwhile, captures trade evasion using the discrepancy between import values recorded at U.S. ports and export values recorded at ports in China, finding U.S. importers are more likely to under-report quantities and unit values as well as reclassify products following tariff hikes. Iyoha et al. (2025) computes a similar measure of re-routing to Freund (2025) and uses it in a difference-in-differences regression to determine the effect of U.S. tariffs on China on transshipments through Vietnam. Chupilkin et al. (2023) performs a similar difference-in-difference estimation, but with Russia rather than China as the country of interest. The disaggregated analysis in

these papers comprises descriptive statistics or country-specific event studies, while our paper applies a gravity regression framework to determine discrepancies in U.S. trade flows.

A limited number of other studies apply a gravity approach to measure transshipments. Tyazhelnikov and Romalis (2024) relies on a structural gravity approach to estimate the value of shipments that illegally circumvented import controls on agricultural products that Russia implemented following its annexation of Crimea in 2014. A slightly more extensive body of literature uses the gravity model to investigate the causes and consequences of legal transshipments. For example, Lankhuizen and Thissen (2019) discusses how re-exports can bias gravity regression results, and displays the results of gravity regressions that explicitly take re-exports into account. Andriamananjara et al. (2004), a USITC working paper, uses a gravity framework to show that re-exports from the United States respond more sensitively than domestic exports to variables such as distance and port policies.

### 3 ITPD Industry Regressions

We first estimate unexplained trade using all ITPD mining and manufacturing industries, consisting of ITPD codes 29 through 153. This set of regressions uses the same data as Ahmad and Phillips (2026a), but is run at a more disaggregated level.

Data for explanatory variables comes from the USITC’s Dynamic Gravity Dataset, which has information on bilateral variables related to geographic characteristics, cultural relationships, and trade facilitation measures for a total of 286 countries between 1948 and 2019. Because the Dynamic Gravity Dataset does not have data after 2019, we supplement it with information from the Design of International Trade Agreements (DESTA) dataset that catalogs all trade agreements signed prior to 2023.

The following PPML specification describes our ITPD gravity analysis:

$$\text{Trade}_{ijt} = \exp(\vec{\beta} \cdot \overrightarrow{\text{Geographic}}_{ijt} + \vec{\alpha} \cdot \overrightarrow{\text{Cultural}}_{ijt} + \gamma \text{Agreement}_{ijt} + \delta \text{DOM}_{ijt} + \phi_{it} + \eta_{jt} + \varepsilon_{ijt}) \quad (1)$$

where  $\text{Trade}_{ijt}$  are trade flows from exporter  $i$  to importer  $j$  in year  $t$ .  $\overrightarrow{\text{Geographic}}_{ijt}$  is a vector of bilateral geographic characteristics, namely the logged distance between  $i$  and  $j$ , a binary variable equal to one if  $i$  and  $j$  share a border, a binary variable equal to one if either  $i$  or  $j$  is landlocked, and a binary variable equal to one if either  $i$  or  $j$  is an island nation.  $\overrightarrow{\text{Cultural}}_{ijt}$  is a vector of shared cultural characteristics; we include binary variables representing common language, common legal system, and colonial ties.  $\text{Agreement}_{ijt}$  is a single binary variable equal to 1 if countries  $i$  and  $j$  both participate in a free trade agreement in year  $t$ . Finally, we include a binary variable  $\text{DOM}_{ijt}$  that is equal to one if the given bilateral flow represents

trade within the same country, or domestic trade, and zero otherwise.  $\phi_{it}$  and  $\eta_{jt}$  represent origin-time and destination-time fixed effects. This regression specification is identical to the specification in Ahmad and Phillips (2026a), but we run it for 125 industries rather than 14 aggregated sectors.<sup>3</sup>

### 3.1 Measures of Fit

We assess the explanatory power of gravity regressions for analysis of the disaggregated industries and products featured in this paper. Because this paper features PPML regressions, the primary measure of fit is the pseudo-adjusted R-squared.

Measures of fit for a regression are themselves, of course, based on residual size. However, higher R-squared values in general boost our confidence in the worth of ‘unexplained’ trade as a measurement. If traditional gravity variables perform well in predicting trade movements, the unexplained portion of those movements becomes all the more important and may indicate the presence of factors such as illegal transshipping. If traditional gravity variables explain close to none of the observed movements in trade, then it is difficult to draw conclusions from the discrepancy between trade and gravity predictions of trade.

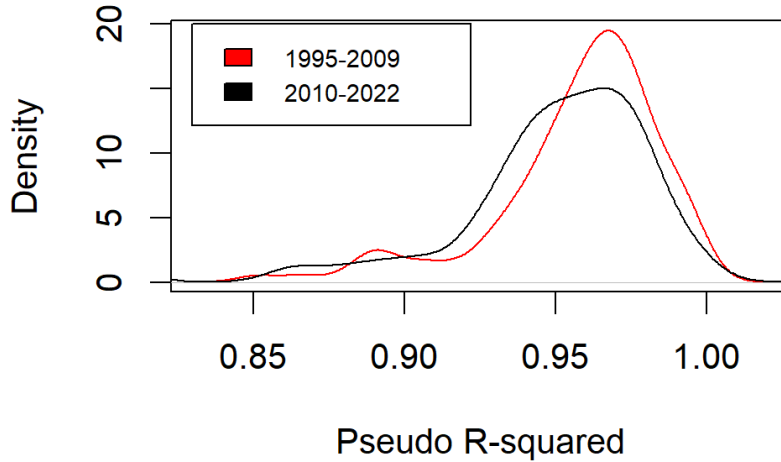


Figure 1: Density plot of pseudo R-squared estimates

Although the density plot of estimated pseudo R-squared values shows a left tail (Figure 1), the bulk of pseudo R-squared estimates are between 0.9 and 1, indicating that gravity variables generally have a high degree of explanatory power over bilateral trade. The concentration of values close to 1.0 is slightly higher for the 1995-2009 period than the 2010-2022 period, implying that gravity variables have slightly less explanatory power in the later time period.

We next present pseudo-adjusted R-squared information for different aggregated sectors (Table 1). Be-

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<sup>3</sup>For more detailed information on our gravity regression setup, see Ahmad and Phillips (2026a). For a more detailed discussion of gravity regression results in Section 3, see Section 6.1 in the Appendix.

cause the distribution across industries is left-skewed, we report both the median and the 10th percentile of all pseudo-adjusted R-squared values. Median measures of fit at the sector level are all close to 1 in both time periods, with sector medians strongly consistent across time periods. Sectors with a notable leftward skew include apparel in the 1995-2009 period and wood/paper and vehicles/vehicle parts in the 2010-2022 period.

| Sector                        | 1995-2009       |        | 2010-2022       |        |
|-------------------------------|-----------------|--------|-----------------|--------|
|                               | 10th Percentile | Median | 10th Percentile | Median |
| Food manufacturing            | 0.941           | 0.975  | 0.935           | 0.971  |
| Apparel                       | 0.889           | 0.942  | 0.922           | 0.935  |
| Wood, paper                   | 0.913           | 0.974  | 0.862           | 0.965  |
| Chemicals                     | 0.944           | 0.959  | 0.942           | 0.950  |
| Metals, fabricated metals     | 0.956           | 0.975  | 0.926           | 0.950  |
| Machinery                     | 0.932           | 0.957  | 0.928           | 0.953  |
| Electrical, optical equipment | 0.938           | 0.960  | 0.936           | 0.945  |
| Vehicles, vehicle parts       | 0.904           | 0.948  | 0.856           | 0.951  |

Table 1: Explanatory power by aggregated sector

The minimum pseudo-adjusted R-squared in Table 1 is around 0.8, while the highest is close to 1. Individual industries whose regressions' pseudo-adjusted R-squared values appear in the lowest ten percent often include basic chemicals except fertilizers; ships/boats; and jewelry. Trade in these industries may reflect niche idiosyncratic factors rather than the more universal gravity framework. Industries whose regressions' pseudo-adjusted R-squared values appear in the lowest ten percent include mining of iron ores; four food manufacturing industries; cutting, shaping and finishing of stone; and structural metal products. The wood/paper sector includes industries with very high fit (publishing of books, reproduction of recorded media) as well as industries with very low fit (publishing of recorded media, printing).

For any industry that has lower measures of fit, these results signify that either 1) specific features of that industry (including, possibly, transshipments) cause bilateral trade to diverge from gravity predictions or 2) gravity modeling is simply not a very informative method to make inferences about that industry. Further industry-specific exploration of these results would require in-depth qualitative knowledge of each individual industry, which is beyond the scope of this paper. Nonetheless, the generally high pseudo-adjusted R-squared levels observed in this chapter suggest that gravity broadly does a good job capturing international bilateral trade movements, and that any movements *not* explained by gravity are worth noting.

### 3.2 Heterogeneity Analysis

Figure 2 displays median values and other percentiles by year for unexplained trade in all industries from all sources. Because higher values of unexplained trade may simply reflect higher trade, we express unexplained

trade relative to bilateral trade flows. Due to the strong dispersion and negative skew among these ratios, we transform the ratios using the inverse hyperbolic sine function.<sup>4</sup>

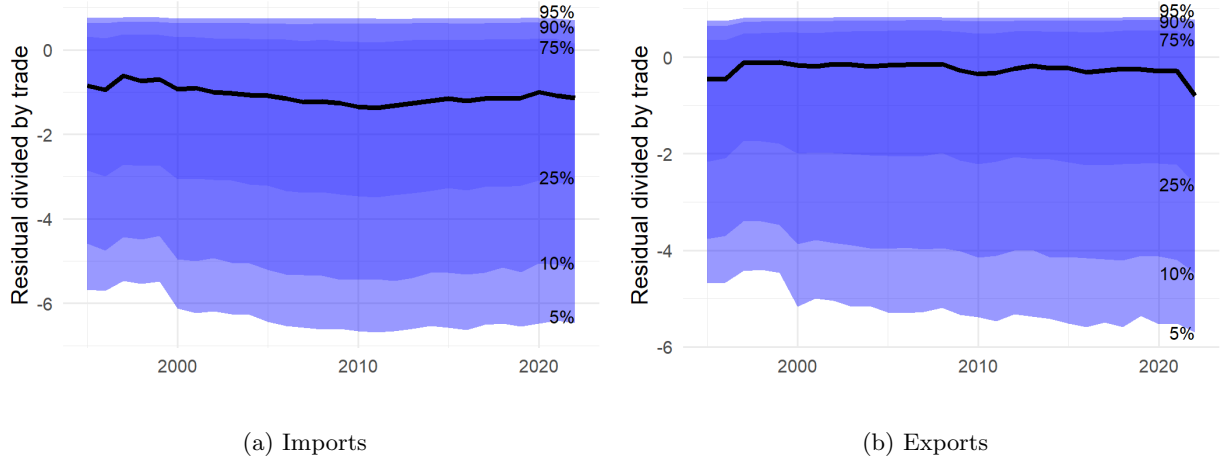


Figure 2: Median and percentile analysis for residuals of all U.S. trade, ITPD industries. Residual-to-trade ratios transformed using hyperbolic sine function

Median unexplained imports, represented by the bolded line in Figure 2a), are consistently negative and have become more negative since the 1990s, with the magnitude peaking during the global financial crisis in the early 2010s. This observation dovetails with Ahmad and Phillips (2026a), which finds that median unexplained imports for aggregated sectors are more negative in the 2010-2022 period than in the 1995-2009 period. However, our industry-level analysis reveals that a substantial level of heterogeneity exists. Upper percentiles change very little over the 28-year period in our sample, while the 5th percentile becomes more negative during the 2000s and partially recovers during the 2010s.

Figure 2b) shows the same type of analysis as Figure 2a), but for U.S. exports instead of imports. Median exports are less negative than median imports, a result also observed for more aggregated sectors in our previous research. While the 5th and 10th percentiles in Figure 2a) reach a low point in 2010 before slowly recovering, the 5th and 10th percentiles in Figure 2a) show a steady downward trend over time. This observation may suggest that exports in certain U.S. industries were unable to recover fully from the financial crisis, and continued to be well below gravity-consistent predictions for a decade afterward.

<sup>4</sup>For any value  $x$ , the inverse hyperbolic sine is  $\sinh^{-1}(x) = \log(x + \sqrt{x^2 + 1})$ . While logarithms are the most common way that the economics literature transforms variables in order to concisely represent them on a graph, logarithms are undefined for negative values. The inverse hyperbolic sine function both compresses dispersion and works with variables, including trade residuals in this paper, of which a substantial fraction of values are negative.

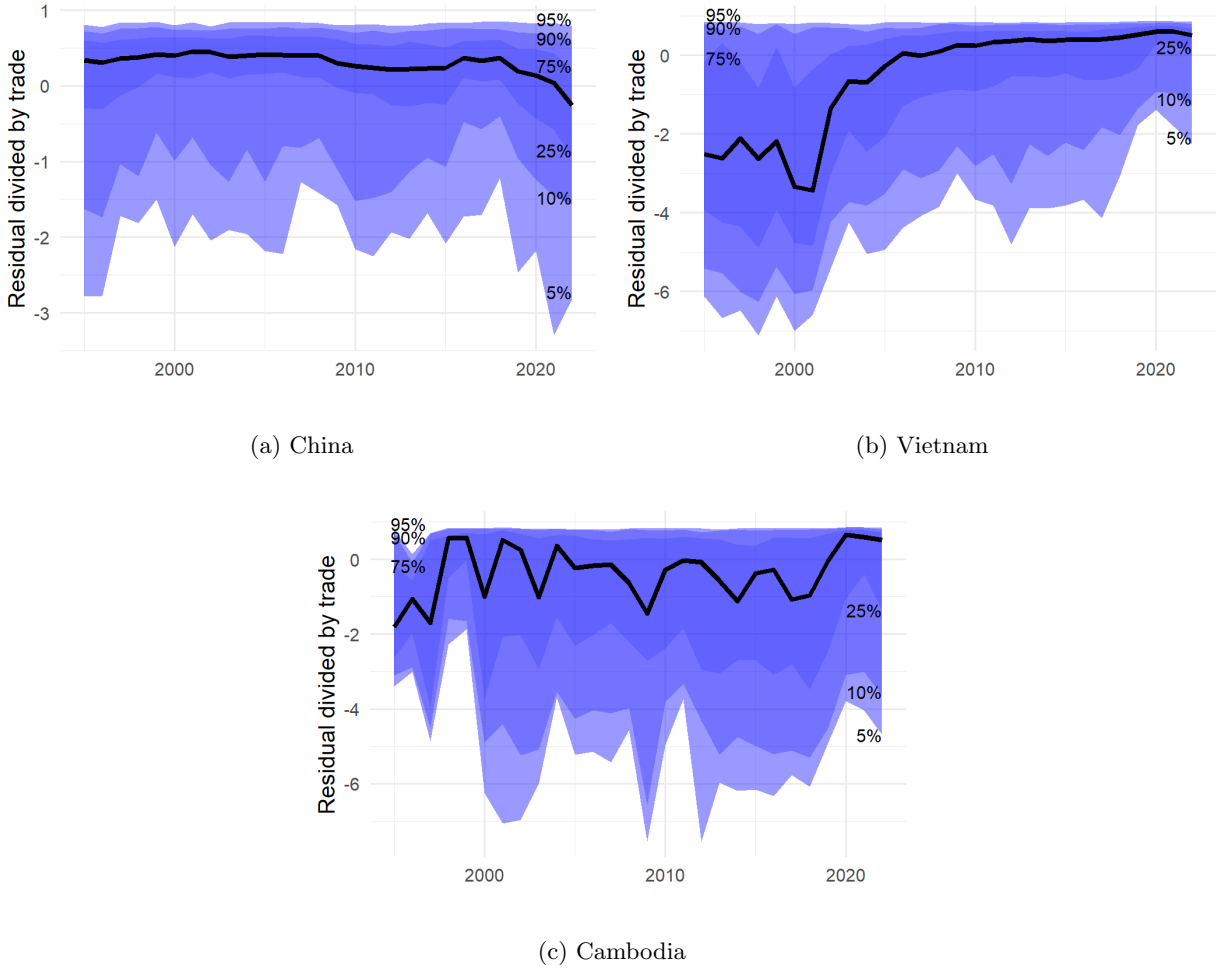


Figure 3: Median and percentile analysis for U.S. imports from East Asia, ITPD industries

Like Figure 2, Figure 3 largely echoes the findings of our earlier paper. Median unexplained imports from China are positive, implying that the United States has mostly imported more from China than its gravity relationships with China would predict, but drop over the last five years and become negative. Meanwhile, median unexplained imports from Vietnam and Cambodia are extremely negative during the 1990s but become more positive over time. Disaggregated analysis, however, reveals that the variance among unexplained imports by product from China also increases in recent years, potentially reflecting increased geopolitical turbulence. Vietnam, on the other hand, has a very high variance among products during the 1990s; we hypothesize that a period of uncertainty would have followed the United States' normalizing of relations with Vietnam in 1994, with trade in some products still much lower than gravity predictions and trade in other products rapidly rising.

Like their sector-level analogues in our previous paper, Figure 4 (page 10) shows that median import residuals with respect to Canada and Mexico are positive and have not changed much since 1995. Hetero-

geneity analysis, however, enables us to see that the 5th percentile of import residuals from both countries is more volatile than the median, with steep drops during the 2000s. Figure 4a) indicates that the 5th, 10th, and 25th residuals in Mexico have been converging over time, while no such convergence exists for Canada.

Taken together, the results in this subsection largely support the hypothesis that China may be illegally re-routing its exports to the United States through Vietnam and Cambodia, but is not re-routing exports through Mexico and Canada. However, trade in the real world occurs at very disaggregated levels, and median-level observations would not hold for every individual industry.

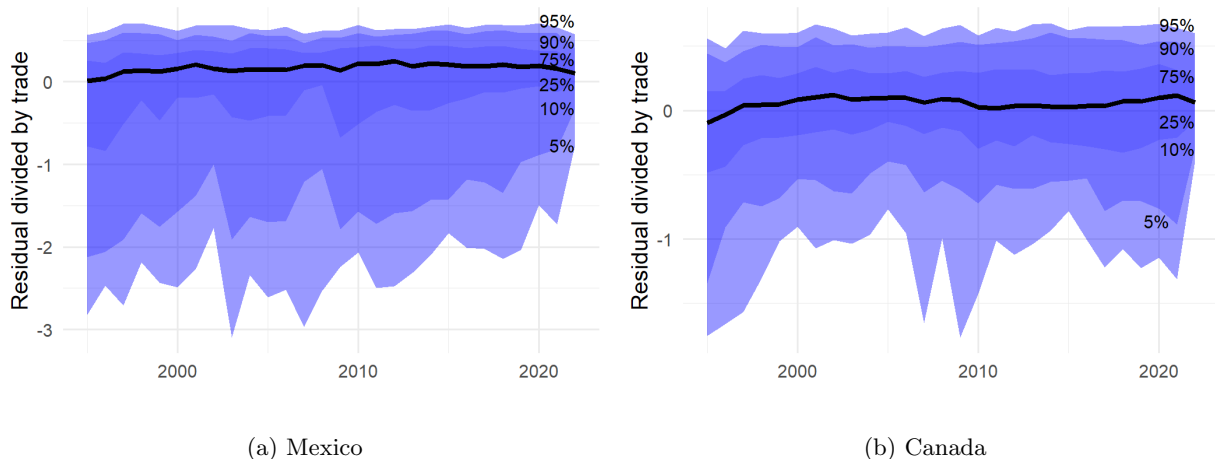


Figure 4: Median and percentile analysis for U.S. imports from North America, ITPD industries

### 3.3 Industry-Specific Analysis

One advantage of disaggregated analysis relative to sector-level analysis is the ability to examine detailed unexplained trade patterns for specific products or industries.<sup>5</sup> In both Section 3 and Section 4, we leverage this ability by discussing the geographic distribution of unexplained trade for three individual codes: one code belonging to an agricultural industry, one code belonging to an extractive industry, and one code belonging to a manufacturing industry. Codes are chosen based on relevance, namely how highly traded they are as well as the likelihood of illegal transshipments in that code. For codes whose unexplained import profile has changed significantly over the last decade, we map out unexplained imports for both 2016 and 2022.

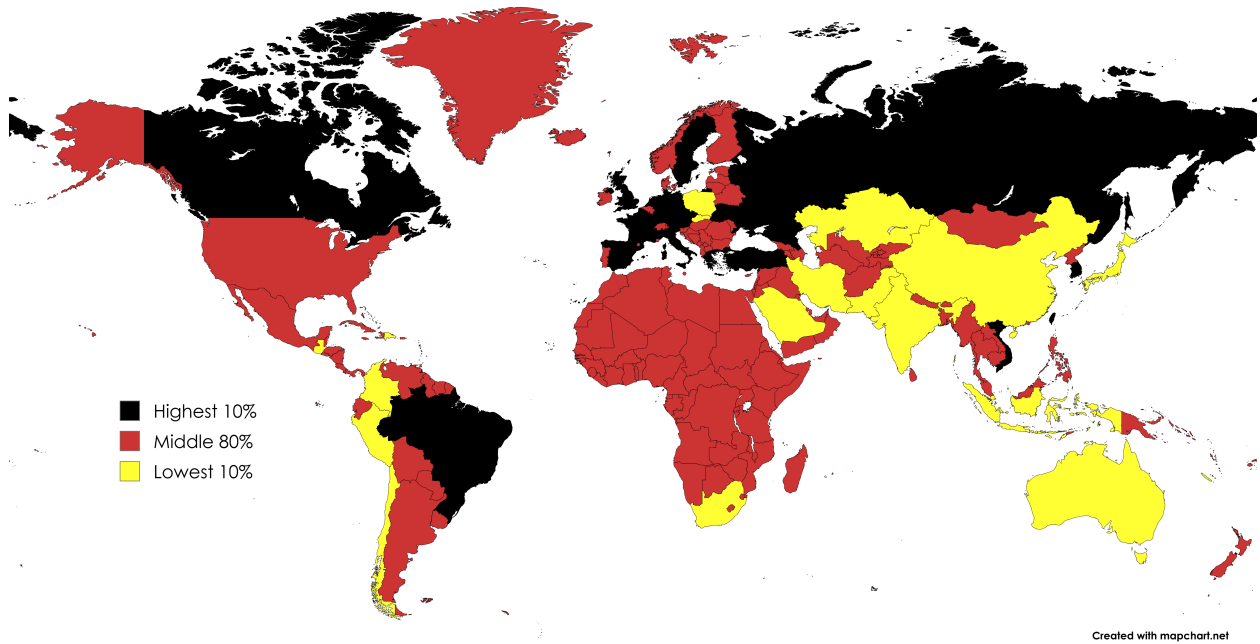
In Figures 5-7, we present unexplained imports by country in 2022 for ITPD 39 (grain mill products), ITPD 102 (basic precious and non-ferrous metals) and ITPD 87, which includes soap and cosmetics. Due to

<sup>5</sup>While ITPD industries are not as disaggregated as the HS6 products discussed in Section 4, they nonetheless represent a fairly granular level of analysis that is frequently unavailable for productivity and input-output data.

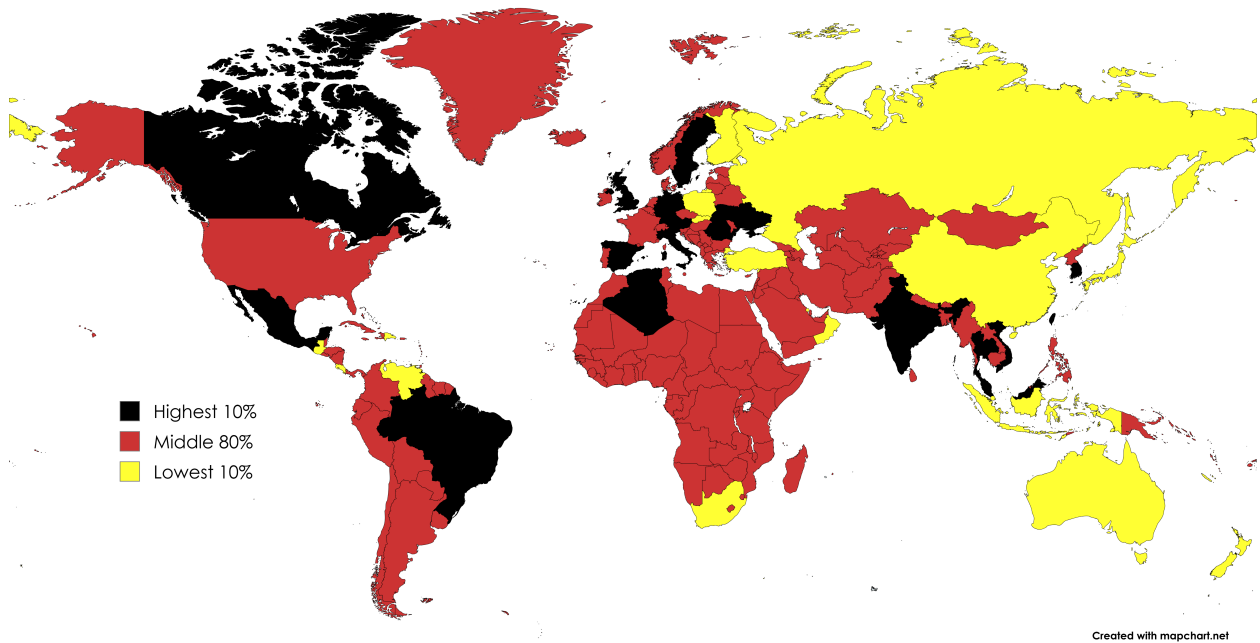
the high frequency of bilateral trade observations that are low or zero, Figures 5-7 categorize countries by absolute level of unexplained trade, rather than unexplained trade as a fraction of observed bilateral trade.

Figure 5: Countries with highest and lowest unexplained grain mill product exports to the United States

Unlike grain imports, the geographic distribution of unexplained imports under ITPD code 102 have changed in their geographic distribution between 2016 and 2022 (Figure 6, see next page), and we therefore map out these imports for both years. Unexplained imports in 2016 under these codes are strongly oriented towards Europe, and imports from nearly all Southeast Asian countries are bilateral trade relationships would lead us to expect. In 2022, the geographic profile shifted toward Latin America and South Asia, with several South Asian countries (India, Malaysia, Thailand) entering the top decile and several European countries (France, Greece) leaving it. Ripple effects from the Russo-Ukraine War may explain Europe's decline as a supplier of non-ferrous metals to the United States, but interestingly Ukraine itself continues to have high unexplained exports under this code.



(a) 2016 unexplained trade



(b) 2022 unexplained trade

Figure 6: Countries with highest and lowest unexplained ITPD 102 exports to the United States

In Figure 7, we turn our attention to ITPD code 87, which includes soap cleaning and cosmetic preparations. In this industry, the United States imports drastically less than gravity predictions from the majority of its Latin American neighbors, including both Canada and Mexico. Unexplained imports from Europe are largely very negative as well, with the exception of small countries such as Ireland, Belgium, and Switzerland.

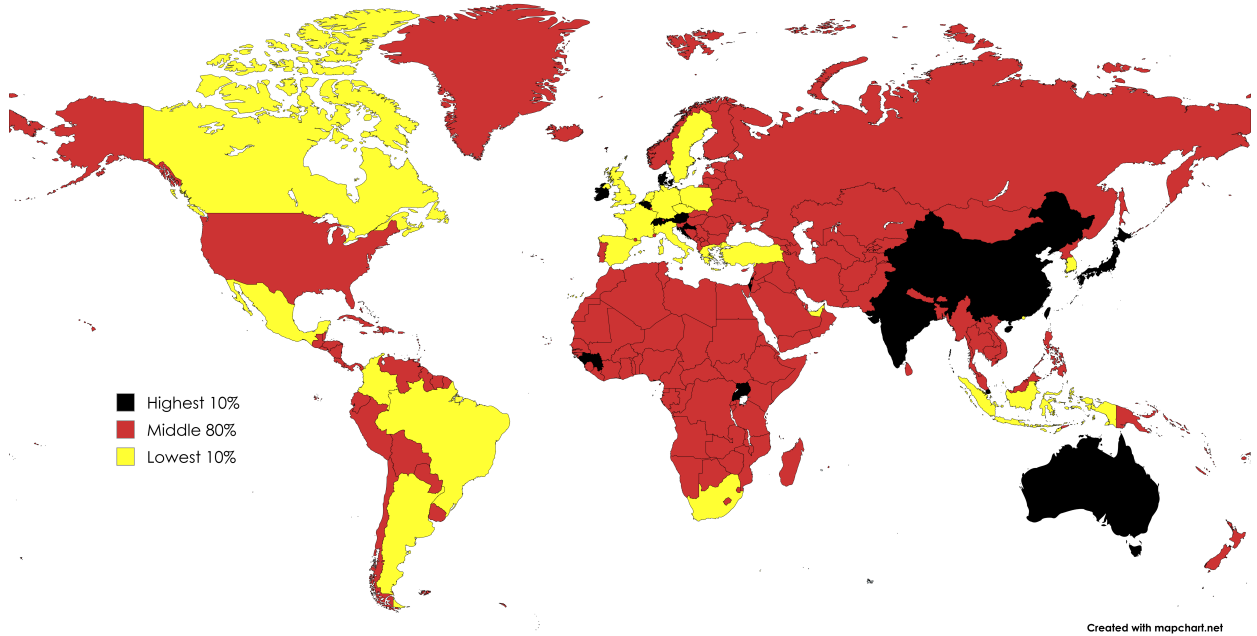


Figure 7: Countries with highest and lowest unexplained soap and cosmetics exports to the the United States

China and India, on the other hand, export significantly more to the United States than gravity theory would indicate, as do two countries in Africa.

## 4 HS6 Product Regressions

Section 3 allows for a close comparison with the results of Ahmad and Phillips (2026a) by disaggregating the 14 ITPD sectors featured in that paper into over a hundred industries. Nonetheless, observed trade and transshipments occur at a still more disaggregated level, and we bring our analysis to this level of disaggregation by performing gravity regressions on a dataset of HS6 products.

We run these disaggregated regressions using the CEPII-BACI dataset. BACI records trade flows at the HS6 level, and we measure product codes using the 1992 HS revision to ensure consistency across the 28 years in our sample.<sup>6</sup> This data provides an advantage over raw trade numbers from sources such as UN Comtrade by reconciling differences between bilateral trade flows reported at the country of origin and the same bilateral trade flows reported at the country of destination; while these trade flows should in theory match, their raw data values almost never do. Our sample consists of 5018 products for the 1995-2009 period and 4949 products for the 2010-2022 period.

<sup>6</sup>While later revisions are available, trade flows cannot be recorded under an HS classification system that did not exist at the time of recording. Data on bilateral trade in 1995 under the 2022 HS revision therefore does not exist, but data on bilateral trade in 2022 is recorded under every previous HS revision.

The PPML gravity regression is as follows:

$$\text{Trade}_{ijt} = \exp(\vec{\beta} \cdot \overrightarrow{\text{Geographic}_{ijt}} + \vec{\alpha} \cdot \overrightarrow{\text{Cultural}_{ijt}} + \gamma \text{Agreement}_{ijt} + \phi_{it} + \eta_{jt} + \varepsilon_{ijt}) \quad (2)$$

where all variables are the same as in Section 3, including origin-time fixed effects  $\phi_{it}$  and destination-time fixed effects  $\eta_{jt}$ . This regression specification differs from the specification of Section 3 only by the lack of domestic data flows—in other words,  $i \neq j \forall i \forall j$ —and the consequent lack of an explanatory binary variable  $\text{DOM}_{ijt}$ . While the ITPD dataset includes such variables, HS6-level data does not. For more information on gravity results in Section 4, see subsection 6.2 of the Appendix.

Yotov (2022) itemizes the benefits of including an indicator for domestic trade flows when estimating gravity equations. The paper argues that the inclusion of such a variable both allows for further dimensions of analysis, such as an estimation of international borders and home biases, and ensures proper measurement of the effects of policy variables such as FTAs. However, this paper is not focused on measuring domestic-specific concepts such as home bias, and we are concerned with properly measuring gravity *residuals* rather than the precise coefficients on different gravity variables. We therefore conclude that the absence of domestic-level data in our HS6 dataset is unfortunate, but not catastrophic.<sup>7</sup>

#### 4.1 Measures of Fit

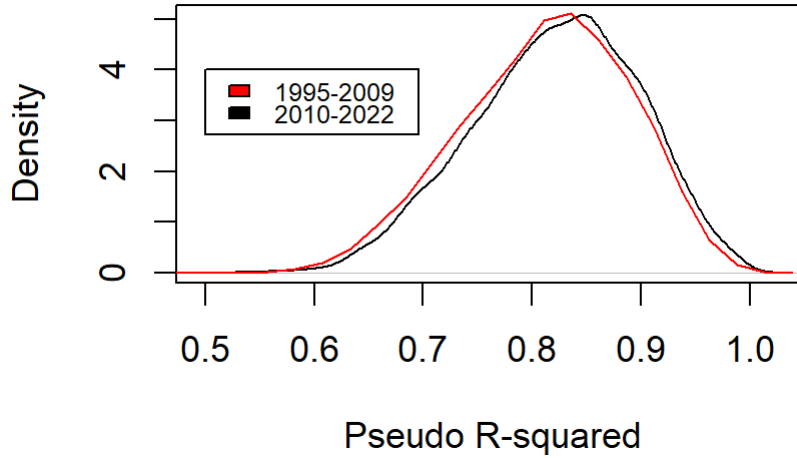


Figure 8: Density plot of pseudo R-squared estimates

Figure 8 plots the distribution of pseudo R-squared values for the regressions involving HS6 products. Estimates range from .5 to slightly above 1, with the highest concentration between 0.8 and 0.9. These

<sup>7</sup>We could impute HS6-level domestic trade flows using ITPD domestic trade flows and a concordance between ITPD industries and HS6 products. However, since we are already estimating gravity regressions using ITPD industries, we conclude that the inclusion of such imputations in a regression would be redundant and possibly introduce further imprecision.

pseudo R-squared estimates are lower than the ITPD industry-level pseudo R-squareds shown in Figure 1 or the sector-level pseudo R-squareds in Ahmad and Phillips (2026a), indicating the presence of product-specific variability that would not show up in regressions involving more aggregated observations. Universal trade factors such as distance, contiguity, etc. have less explanatory power over individual products.

| Sector                        | 1995-2009       |        | 2010-2022       |        |
|-------------------------------|-----------------|--------|-----------------|--------|
|                               | 10th Percentile | Median | 10th Percentile | Median |
| Food manufacturing            | 0.841           | 0.745  | 0.826           | 0.727  |
| Apparel                       | 0.782           | 0.688  | 0.848           | 0.718  |
| Wood, paper                   | 0.826           | 0.728  | 0.822           | 0.709  |
| Chemicals                     | 0.808           | 0.719  | 0.814           | 0.710  |
| Metals, fabricated metals     | 0.796           | 0.706  | 0.814           | 0.715  |
| Machinery                     | 0.831           | 0.699  | 0.816           | 0.691  |
| Electrical, optical equipment | 0.849           | 0.729  | 0.846           | 0.720  |
| Vehicles, vehicle parts       | 0.845           | 0.728  | 0.837           | 0.708  |

Table 2: Explanatory power by aggregated sector, HS6 regressions

Table 2 shows that the pseudo-adjusted R-squared is remarkably consistent across sectors and periods, with virtually all median estimates falling between 0.8 and 0.85 and virtually all 10th percentile estimates falling between 0.7 and 0.75. Unlike the estimates shown in Table 1, measures of fit for every sector have a pronounced left tail, due to the presence of multiple disaggregated products whose trade behavior cannot be explained by worldwide trade relationships. Like ITPD industries, HS6 products belonging to the apparel sector have lower measures of fit in the 1995-2009 period.

The minimum pseudo-adjusted R-squared level is around 0.55 in both time periods, with a maximum of around 0.995. Products with levels below 0.6 are most likely to be products in the machinery sector, including HS6 840510 (gas generators) and HS6 842611 (overhead traveling cranes on fixed support), and also include a few products in HS 56 (wadding, felt, and nonwovens). Products with levels close to 1 include HS6 890120 (tankers) and a couple of codes belonging to the food manufacturing sector.

Taken together, the results presented in this subsection imply that more caution is warranted when using our unexplained trade methodology for HS6 products compared to ITPD industries, especially the HS6 products with pseudo-adjusted R-squared values below 0.7. Gravity regressors generally explain less of the variation in product-level trade, which means that the portion of trade *not* explained by gravity could reflect a wider variety of factors. Nonetheless, gravity continues to broadly explain product-level international trade, and as noted in the introduction the use of unexplained trade analysis is particularly relevant when applied to individual products.

## 4.2 Heterogeneity Analysis

As in Section 3.2, we discuss product-level heterogeneity by plotting median unexplained trade values against the 5th, 10th, 25th, 75th, 90th, and 95th percentiles. Unexplained trade values are first expressed as a fraction of bilateral trade and then transformed by the inverse hyperbolic sine function. We begin by discussing U.S. imports and exports from all sources before presenting results specific to certain countries of origin.

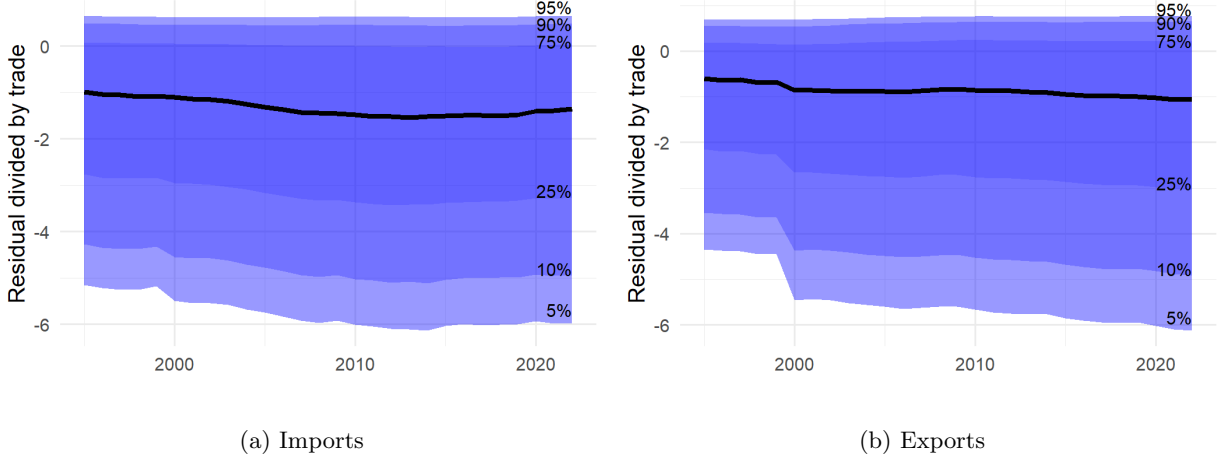


Figure 9: Median and percentile analysis for all U.S. trade, HS6 products

Percentile analysis at the HS6 product level reveals similar trends to percentile analysis at the ITPD industry level. The median import residual is around -1 in 1995, reaches its most negative point in 2010 and then gently recovers throughout the following decade. Likewise, the interquartile range is left-skewed and the 5th percentile displays significantly more volatility than the 95th percentile.

As with residuals measured using ITPD industries, U.S. export residuals measured using HS6 products are generally less negative than their import residual counterparts. The 5th and 10th residuals are monotonically declining across time, indicating that some products are increasingly exported less relative to gravity relationships. Export residuals in Figure 9b) steadily decrease after 2010, rather than recover as import residuals do. At the same time, the 90th and 95th percentile of unexplained exports are largely unchanged over time.

The general trends in Figure 3 also appear in Figure 10, with unexplained trade from China decreasing in the last five years and unexplained trade from Vietnam and Cambodia increasing simultaneously. Figure 10 also captures the high volatility of import residuals from Vietnam and Cambodia during the 1990s, a volatility that diminishes over time.

Nonetheless, the percentile trends in Figure 10 do differ from Figure 3 in interesting ways, indicating the greater heterogeneity that comes with a more disaggregated level of analysis. While the trends in median

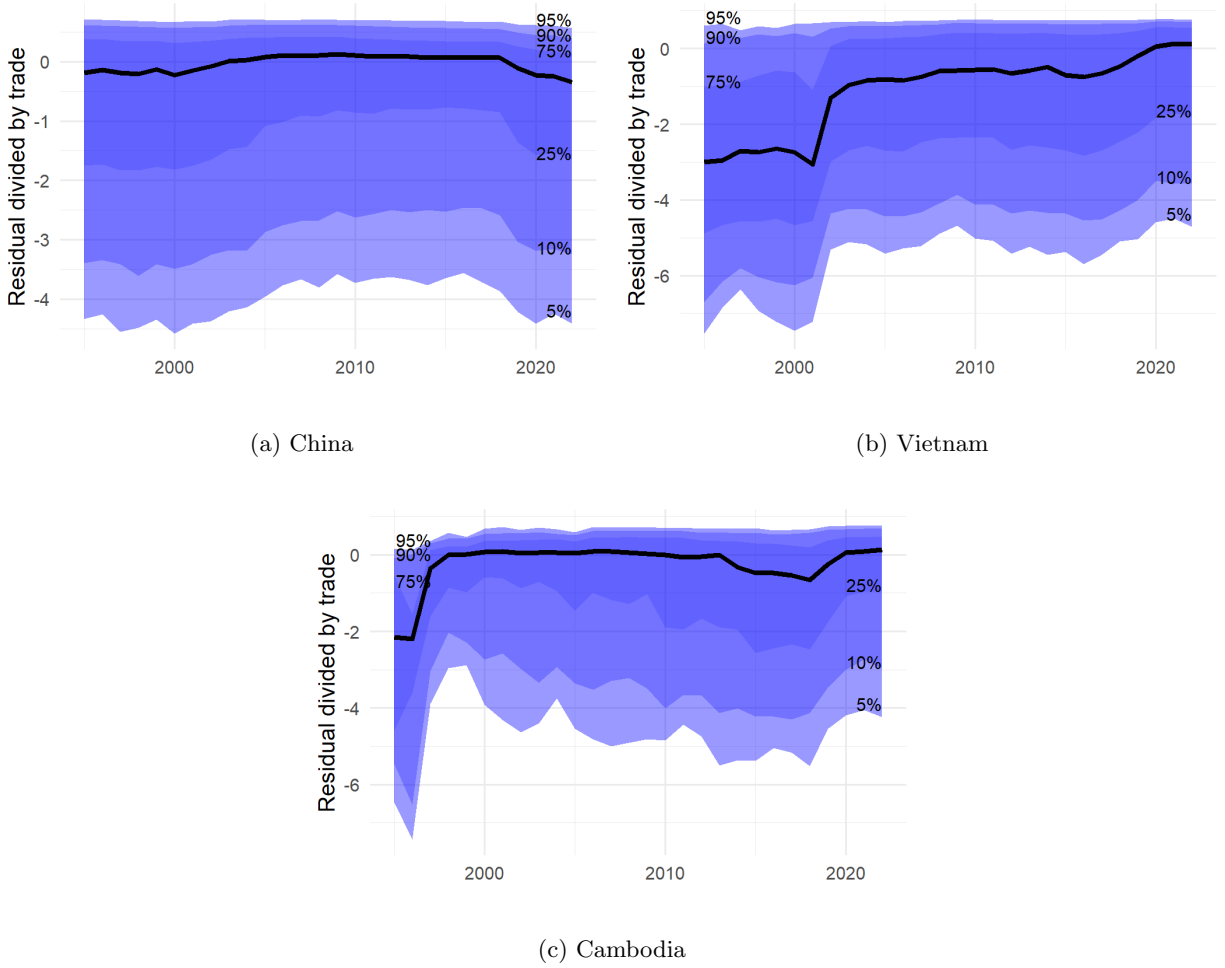


Figure 10: Median and percentile analysis for U.S. imports from East Asia, HS6 products

Chinese import residuals are similar, the median residual in Figure 3a) is consistently positive before 2022, while the median residual in Figure 10a) starts out negative and only becomes positive during the 2000s. The 5th and 10th percentiles attain significantly more negative values when measured for HS6 products. On the other hand, median unexplained trade from Cambodia displays *less* volatility when measured at the HS6 product level, perhaps due to the greater number of observations.

Median unexplained import values for Canada and Mexico (Figure 11) continue to have little fluctuation across time. However, median unexplained trade values in Figure 11a) and 11b) are noticeably lower than their counterparts in Figure 4a) and 4b), being slightly negative instead of slightly positive. This contrast implies that some HS6 products have imports from Canada and Mexico that are much lower than the close distance, free trade agreements, and (in Canada's case) common language would predict.

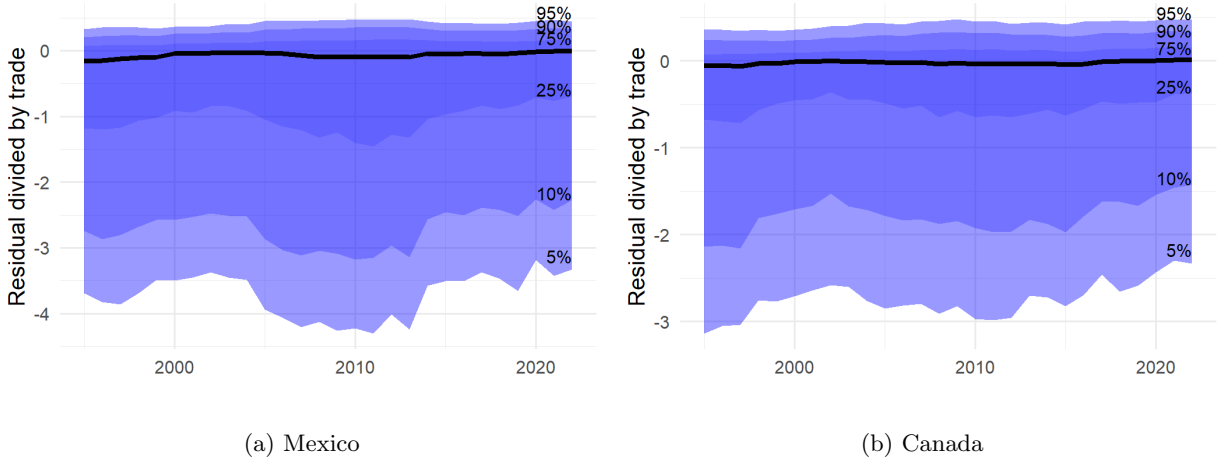


Figure 11: Median and percentile analysis for U.S. imports from North America, HS6 products

### 4.3 Product-Specific Analysis

As in Section 3.3, we provide product-specific analysis for one agricultural/food product, one extractive product, and one manufacturing product. These products are HS6 220300 (beer made from malt), HS6 270900 (crude petroleum) and HS6 854211 (electronic integrated circuits and parts thereof).

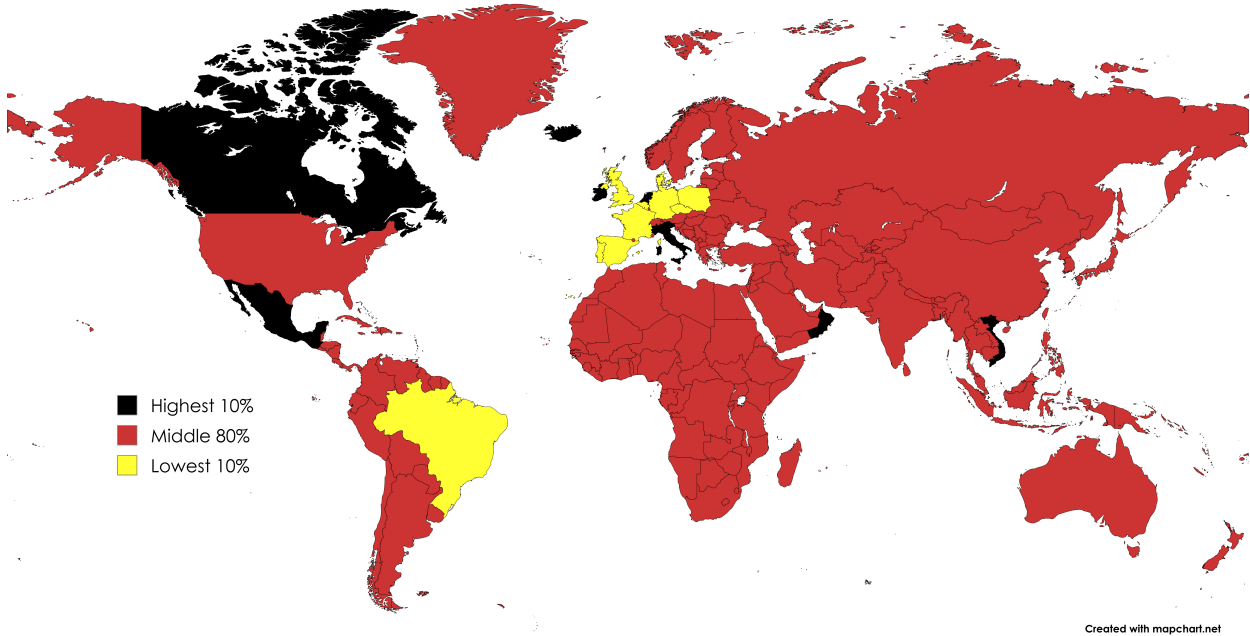


Figure 12: Countries with highest and lowest unexplained malted beer exports to the United States

Countries with the highest and lowest unexplained exports of malted beer are clustered in Europe and North America (Figure 12), befitting these countries' status as significant beer producers. The United States im-

ports significantly more beer from Canada and Mexico than variables such as FTAs and distance predict, as well as significantly less beer from European producers such as Belgium, Denmark, and Germany. European countries with high levels of unexplained exports to the United States include Ireland, which produces Guinness, and Italy, which produces Peroni.

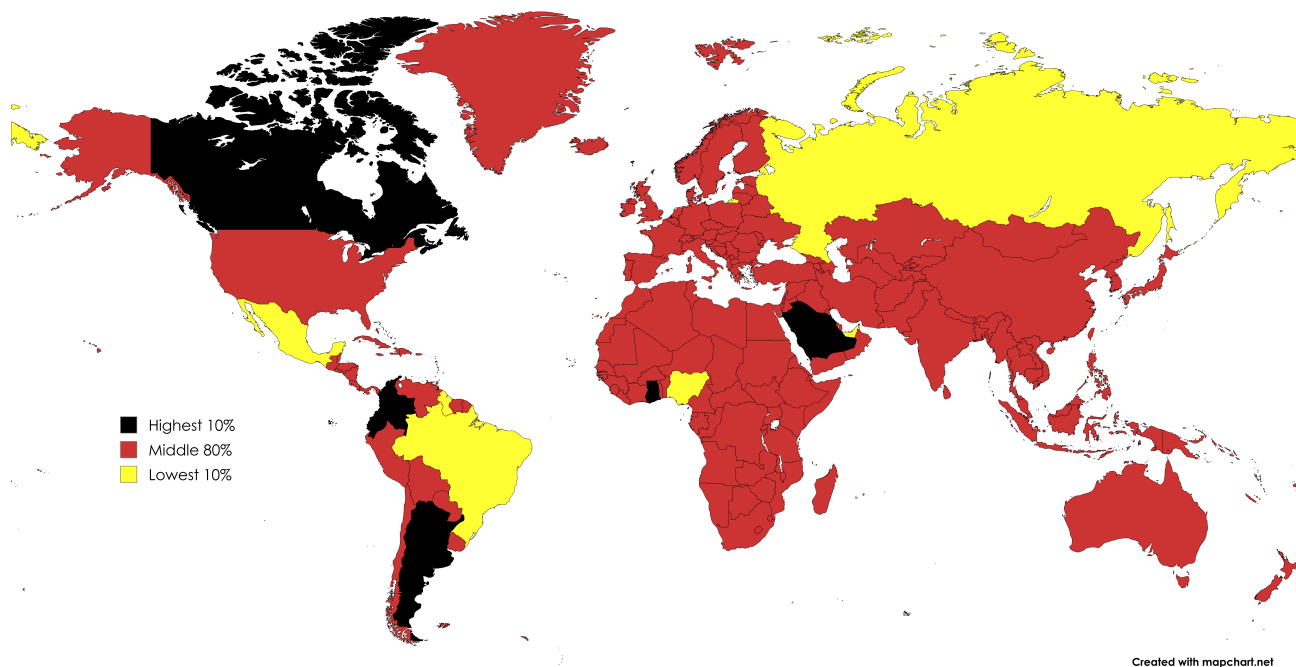
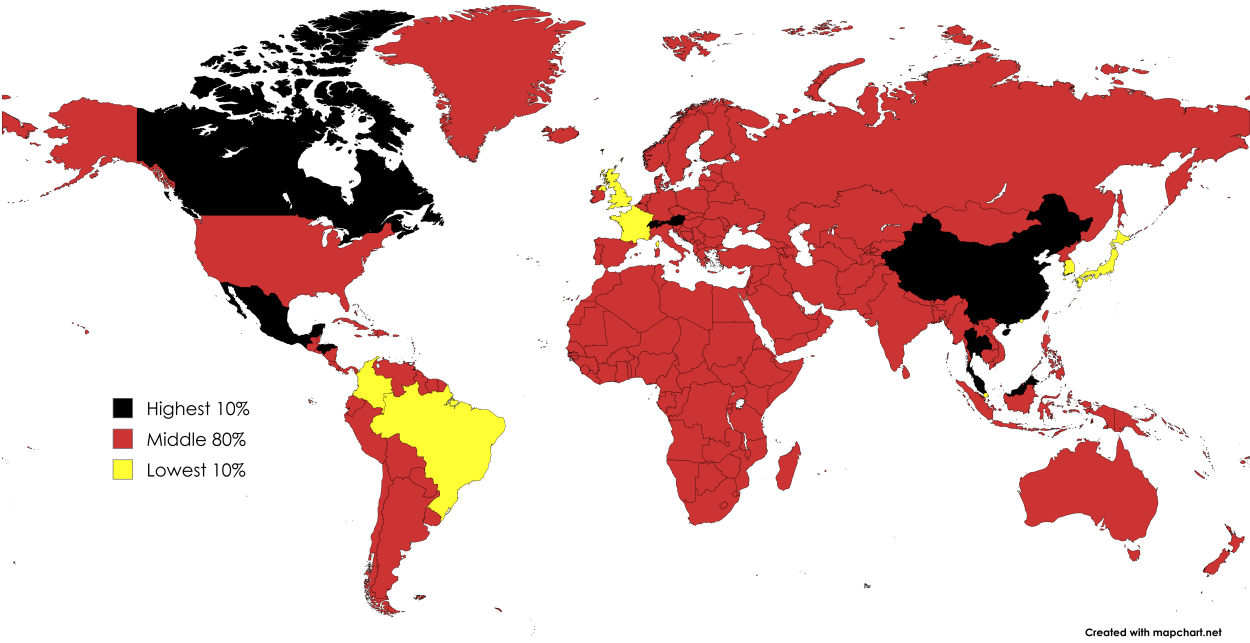


Figure 13: Countries with highest and lowest unexplained crude petroleum exports to the United States

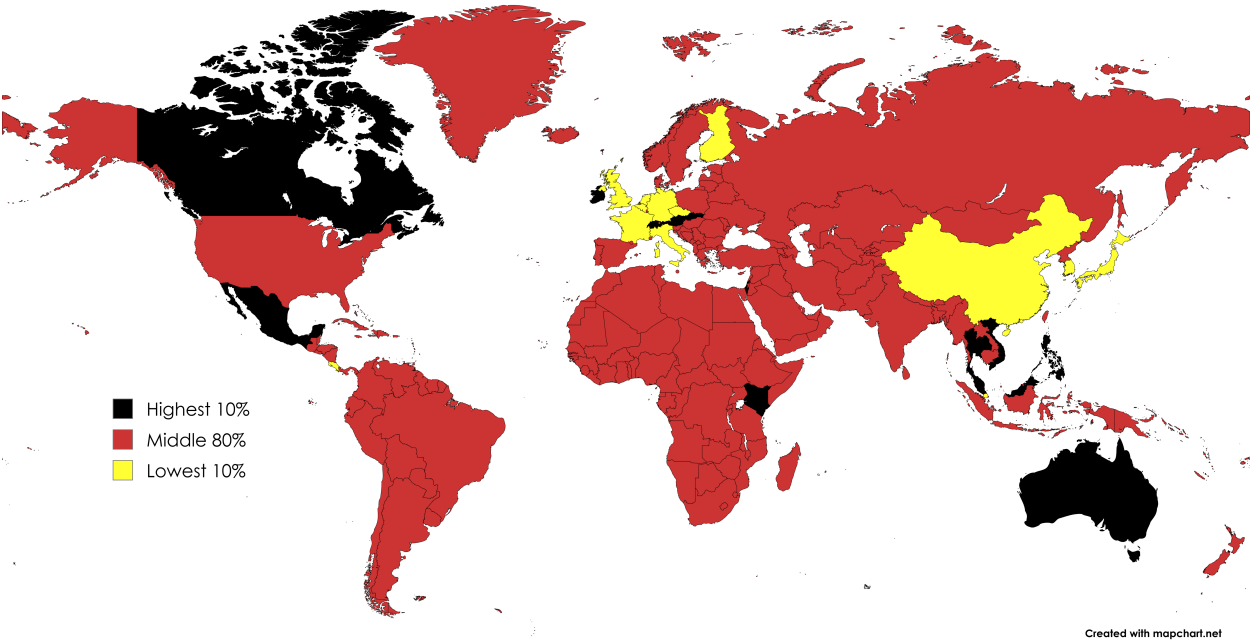
In Figure 13, the countries with abnormally high or abnormally low unexplained crude petroleum exports to the United States are all countries with significant oil production. Substantial heterogeneity exists within regions; Colombia, Argentina, Ghana, and Saudi Arabia all have high unexplained oil exports to the United States, while neighboring countries Brazil, Nigeria, and the United Arab Emirates do not. While Canada exports more crude petroleum to the United States in 2022 than its multilateral relationships would predict, Mexico exports much less.

While trade in oil and beer does not change substantially between 2016 and 2022, trade in electronic circuits does. We therefore present maps of abnormally high or abnormally low unexplained trade in HS 854211 both in 2016 (Figure 14a), before recent geopolitical uncertainty and fragmentation, and in 2022 (Figure 14b). While China is in the top decile of exporters in 2016, by 2022 it had fallen to the bottom decile of exporters, a change coinciding with Vietnam and the Philippines becoming top residual exporters and Brazil and Colombia ceasing to be in the bottom decile of exporting countries. These results provide further evidence of transshipments from China to Southeast Asian countries, and potentially South American countries as well. Canada and Mexico, moreover, are both in the highest tenth percentile of unexplained

trade both in 2016 and in 2022.



(a) 2016 unexplained trade



(b) 2022 unexplained trade

Figure 14: Countries with highest and lowest unexplained integrated circuits exports to the United States

## 5 Conclusion

In this paper, we expand on the analysis done in Ahmad and Phillips (2026a) by estimating unexplained trade at a more disaggregated level. While more unwieldy, this analysis provides additional relevance—both trade and transshipments occur at a disaggregated level—and allows us to discuss heterogeneity among individual products or industries within broader sector groupings. We estimate a standard PPML gravity framework using two sets of products: the full list of ITPD mining and manufacturing products and the full list of HS 6-digit codes.

Analysis done in this paper replicates many of the headline results from our previous paper. U.S. imports and exports for most products are still lower than gravity results would suggest, and this discrepancy is higher for imports than for exports. Trade residuals with China have declined in recent years, accompanied by an increase in unexplained imports from Vietnam and Cambodia but not a corresponding increase in unexplained imports from Canada and Mexico. However, the use of more disaggregated datasets reveals a large level of heterogeneity among products, and trend lines among the 90th and 95th percentile (products with large levels of unexplained trade) or the 5th percentile (products with large levels of missing trade) can behave quite differently from trends in the median. Code-specific analysis across countries reveals other interesting patterns and contrasts. For example, China’s exports to the United States are much higher than expected for grain mill products and soap/cosmetics but much lower than expected for non-ferrous metals, and unexplained imports of circuits in HS6 854211 shift from China to Southeast Asia between 2016 and 2022.

The analysis and observations found in this paper raise new questions, providing ample opportunities for future work. An estimation of bilateral unexplained trade for specific products can reveal 1) which products are most likely to have transshipments occurring and 2) where any such transshipments are taking place. Given the heterogenous patterns and trend lines displayed in Sections 3 and 4, another promising avenue of research involves delving into *why* patterns in unexplained trade behave how they do. For example, the 90th and 95th percentiles of all our unexplained trade observations often appear more stable than the medians. Future researchers may be interested to know why unexplained trade has been roughly consistent among products whose bilateral trade vastly exceeds gravity-predicted trade levels, even as strongly negative unexplained trade levels have fluctuated to a much greater degree.

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## 6 Appendix: Gravity Regression Results

This appendix goes through results of the gravity regressions described in Sections 3 and 4. Due to the sheer number of regressions performed, we are unable to display results for each individual regression. We instead display our regression results in summary tables that show, for each variable, the number of regressions in which that variable’s coefficient was negative and statistically significant at the 10% level, positive and statistically significant at the 10% level, or not significant at the 10% level.

Overall, gravity results strongly resemble those in Tables 5 and 6 of Ahmad and Phillips (2026a). Distance coefficients are overwhelmingly negative, while contiguity coefficients are overwhelmingly positive. Although the slightly higher frequency of negative coefficients for the colonial ties indicator in some periods may seem counterintuitive, colonial ties could logically decrease bilateral trade between a pair of countries if the countries’ colonial history leads to a more strained geopolitical relationship. The primary advantage of disaggregated gravity regressions is their ability to reveal heterogeneity among products; product-specific factors can lead to unexpected relationships between gravity regressors and trade in a few select instances.

### 6.1 ITPD industry regressions

| Variable            | 1995-2009                |                          |                    | 2010-2022                |                          |                    |
|---------------------|--------------------------|--------------------------|--------------------|--------------------------|--------------------------|--------------------|
|                     | Negative,<br>significant | Positive,<br>significant | Not<br>significant | Negative,<br>significant | Positive,<br>significant | Not<br>significant |
| log(Distance)       | 124                      | 1                        | 0                  | 124                      | 0                        | 1                  |
| Contiguity          | 5                        | 119                      | 3                  | 10                       | 114                      | 1                  |
| Colonial ties       | 42                       | 77                       | 6                  | 70                       | 51                       | 4                  |
| Common legal system | 26                       | 95                       | 4                  | 17                       | 106                      | 2                  |
| Common language     | 12                       | 111                      | 2                  | 17                       | 104                      | 4                  |
| FTA                 | 12                       | 110                      | 3                  | 10                       | 114                      | 1                  |
| Both landlocked     | 82                       | 36                       | 7                  | 67                       | 52                       | 6                  |
| Both islands        | 87                       | 32                       | 6                  | 64                       | 57                       | 4                  |

Table 3: Count of gravity regression result type by explanatory variable

Gravity predictors generally have highly significant effects on logged trade between countries, with over 95% of regressions for each variable yielding a coefficient that is statistically significant at the 10% level. The direction of coefficients matches prior expectations.

Regression results are mostly, but not entirely, consistent across time periods. One exception is colonial ties, which are more likely to have a positive effect on trade in the 1995-2009 period but more likely to have a negative effect on trade in the 2010-2022 period. One possible explanation is that when independence was more recent, commerce in formerly colonized countries depended more on those countries’ former colonizers, and as time went by this dependence lessened. Mutual island status and mutual landlocked status have a

more frequent negative relationship with trade in 1995-2009 than in 2010-2022.

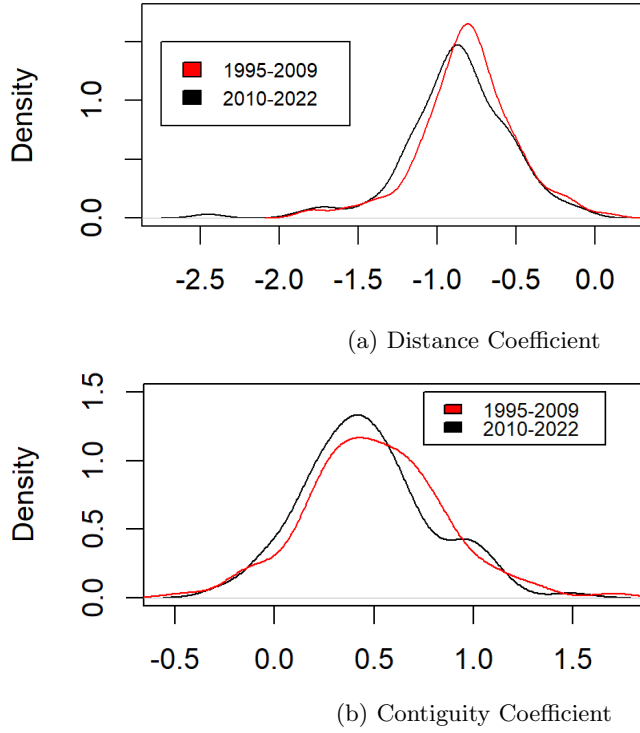


Figure 15: Density plots of estimates for selected coefficients, ITPD industry regressions

Figures 15a) and 15b) are density plots for, respectively, the coefficients on logged distance and the coefficients on contiguity. As shown in Figure 15a), the bulk of distance estimates are slightly lower in magnitude than -1, consistent with established gravity regression findings. Distance elasticities show a left tail, with the most negative estimate being around -2.5. Contiguity estimates, meanwhile, are most likely to be slightly below 0.5 and display a right tail, with the maximum coefficient estimates being around 2. TV and radio receivers are the only product with a distance elasticity below -2 in the earlier period, while musical instruments; building and repair of sport boats; and other articles of paper and paperboard had distance elasticities below -2 in the later period. Other transport equipment n.e.c. and other manufacturing n.e.c are the only two products to have a contiguity coefficient above 1.5 in the earlier period, while no products have a contiguity coefficient above 1.5 in the later period.

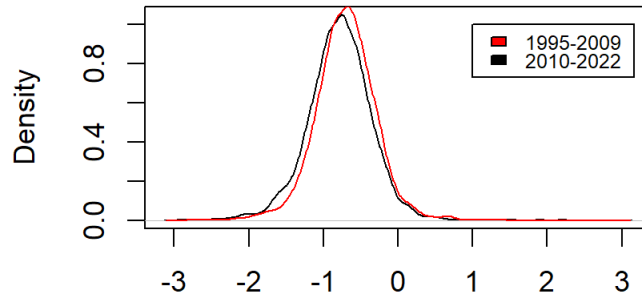
## 6.2 HS6 product regressions

As with the ITPD regressions in Section 6.1, distance measures continue to show the expected overwhelmingly negative relationship with trade, while contiguity, common legal systems, common language, and free trade agreements continue to have strongly positive relationships with trade. Colonial ties in both periods are

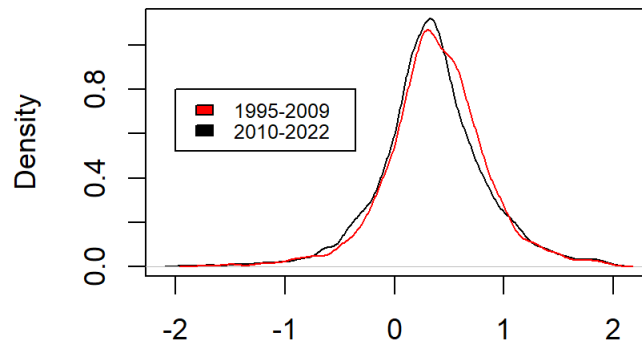
| Variable            | 1995-2009                |                          |                    | 2010-2022                |                          |                    |
|---------------------|--------------------------|--------------------------|--------------------|--------------------------|--------------------------|--------------------|
|                     | Negative,<br>significant | Positive,<br>significant | Not<br>significant | Negative,<br>significant | Positive,<br>significant | Not<br>significant |
| log(Distance)       | 4809                     | 190                      | 16                 | 4594                     | 136                      | 19                 |
| Contiguity          | 794                      | 4177                     | 44                 | 893                      | 3818                     | 79                 |
| Colonial ties       | 2966                     | 1991                     | 58                 | 3204                     | 1496                     | 49                 |
| Common legal system | 1421                     | 3538                     | 55                 | 1141                     | 3563                     | 45                 |
| Common language     | 1544                     | 3417                     | 53                 | 1550                     | 3149                     | 50                 |
| FTA                 | 1077                     | 3882                     | 54                 | 1051                     | 3648                     | 49                 |
| Both islands        | 2670                     | 2159                     | 181                | 2541                     | 2033                     | 165                |
| Both landlocked     | 2587                     | 2293                     | 110                | 2568                     | 2003                     | 125                |

Table 4: Count of result type by explanatory variable

more likely to have a positive relationship with bilateral trade than a negative one.



(a) Distance Coefficient



(b) Contiguity Coefficient

Figure 16: Density plots of estimates for selected coefficients

As shown in Figure 16a), the bulk of distance estimates are slightly lower (in magnitude) than -1. As with the ITPD regressions, distance has a *slightly* less negative impact on trade during the 1995-2009 period, but density profiles for both eras are quite similar. Meanwhile, the bulk of continuity coefficients in both periods are between 0 and 1, with the greatest mass of estimates falling slightly below .5. Compared with 2010-2022, a slightly higher mass of estimates in the 1995-2009 period are in the interval [.5,1]; this observation also matches the density pattern in the ITPD regressions.