An Anatomy of U.S. Establishments' Trade Linkages in Global Value Chains*

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Abstract

Global value chains (GVC) are a pervasive feature of modern production but they are hard to measure. Using confidential microdata from the U.S. Census Bureau, we develop comprehensive linkages between U.S. manufacturing establishments' imports, production, and exports to construct the imported content of exports. We find that for every dollar of exports, imported inputs represent approximately 13 cents in 2002 and 20 cents by 2017. Using a gravity framework, we find that these GVC flows are higher within "round-trip" (input and output market are the same) linkages, regional trade agreements, and multinational firm boundaries. The strong complementarities between input and output markets are muted by proportionality assumptions in global input-output tables. A back-of-the-envelope quantification implies that import tariffs reduce bilateral trade deficits by substantially less when production networks exhibit strong input-output market complementarities.

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1 Introduction

Global value chains (GVCs) are an important conduit of cross-border shocks. Evaluating the economic impact of such shocks requires accurate measurement of production networks. The increasing frequency of pandemics, trade wars and geopolitical conflicts magnifies the importance of such measurement. Virtually all GVC measurement utilize input-output (IO) tables, especially, the multi-country tables connecting intermediate and final goods flows from country-industry sources to country-industry destinations.[1] These tables have been invaluable in advancing our understanding of how GVCs propagate shocks. However, they rely on proportionality assumptions that can obscure actual production linkages. A particular proportionality assumption, that we call "pairwise" proportionality, implies for example that Mexican inputs in U.S. auto production destined ultimately for Mexico is used in exactly the same proportion as in U.S. auto production destined ultimately for Germany.

In this paper, we provide the first granular estimates of U.S. production networks by connecting input sources to export destinations at the level that production takes place: the individual manufacturing establishment. By linking several confidential U.S. Census Bureau microdata, we construct comprehensive country-specific input-output linkages for U.S. manufacturers, replacing the proportionality assumptions with actual production linkages in a three-country setting. This novel perspective reveals systematic complementarities between input sources and output destinations that pairwise proportionality obscures. We find that "round-trip" GVC flows, where the same country is both the source of inputs and the destination of exports, are far more important than suggested by IO tables, with a prominent role played by multinational firms. Our newly constructed linkages also offer new insight on how regional trade agreements (RTAs) shape production linkages by showing that GVC flows are substantially higher when all three countries in the supply chain—input source, U.S., and export destination—share a RTA.

The striking round-trip pattern in GVC flows is especially important in light of contemporary U.S. trade policy that seeks to reduce bilateral trade deficits (Federal Register, 2025). When foreign inputs are embedded in a country's exports, import tariffs act as a tax on production that can decrease employment (e.g., Flaaen and Pierce, 2024) and exports (e.g., Handley, Kamal and Monarch, 2025). Our findings extend this logic to bilateral trade relationships: when foreign inputs are intensively traded in back-and-forth production networks, as is the case for the deeply integrated North American production networks, U.S. tariffs on Mexican inputs may decrease production destined back to Mexico more than to Germany, dampening the reduction in the U.S.-Mexico bilateral trade deficit. In a back-of-the-envelope quantification based on the 2025 tariff episode, we show that our Census-based

[1] Examples of multi-country IO tables include OECD (2024); WIOD (2023); Casella, Bolwijn, Moran and Kanemoto (2019) that enable industry-country GVC analysis at scale.

GVC measure implies a smaller reduction than the IO table-based GVC measure.

We measure GVC as the imported content of exports, a micro-level application of the concept of vertical specialization (Hummels, Ishii and Yi, 2001), using confidential microdata from the U.S. Census Bureau on manufacturers' trade and production for 2002, 2007, 2012, and 2017.[2] To construct our measure, we employ two administrative Census data sets: the Longitudinal Firm Trade Transactions Database (LFTTD), which contains the universe of goods export and import flows for individual U.S. firms (Bernard, Jensen and Schott, 2009; Kamal and Ouyang, 2020), and the Census of Manufactures (CMF), which contains detailed information on establishment-by-product-level output and input use (U.S. Census Bureau, 2022c). A distinctive feature of our methodology is to use supplementary establishment-level information in the CMF (the materials and product trailer files) to identify the inputs used in production and exports actually produced by the establishment. With these imported inputs linked to production and produced exports, we construct our establishment-level GVC measure.

We study the sources of variation in an aggregate version of the establishment-level GVC measure—capturing flows from a source country to the U.S. and then to a destination country—in a gravity framework. We document two novel findings. First, the round-trip effect is economically and statistically significant. Controlling for the combined distance from source-to-U.S.-to-destination, direct distance between source and destination countries, and source-year and destination-year fixed effects, round-trip GVC flows are four times larger than other GVC flows. The round-trip behavior reflects systematic complementarity between input sourcing and output destination markets. In addition, we might expect multinationals, especially those with manufacturing operations in both headquarter and affiliate countries, to contribute to this round-trip effect. Indeed, we find that round-trip GVC flows are nearly twice as large for fully intrafirm transactions (imports from, and exports to, related parties) compared to fully arm's length transactions. This suggests that common ownership deepens the complementarity between input and output markets.

Second, the three-country structure of our linkages enables a novel examination of how RTAs operate in production networks. We can identify the separate effects of RTAs between each country pair (source-U.S., U.S.-destination, source-destination), as well as when all three countries share preferential access. We find that when the United States has an RTA with both the input source country and the export destination country, GVC flows are 22 percent higher. When all three countries share an RTA, GVC flows are 55 percent higher. Strikingly, the round-trip effect persists even after controlling for RTAs, indicating that the complementarity between source and destination countries extends beyond the effects of

[2]This measure captures a good that is produced in two or more sequential stages, at least two countries contribute production value-added, and at least one country uses imported inputs in its production stage and part of the resulting output is exported.

trade policy coordination.

The input-output tables underlying most GVC measures rely on two main proportionality assumptions. One is the assumption highlighted above, which we call "pairwise" proportionality. The second is the well-known import proportionality assumption, in which, for example, the allocation of steel imports from Brazil to different U.S. manufacturing industries is assumed to be proportional to the allocation of all other imported steel to the different U.S. manufacturing industries. Taken together, these proportionality assumptions imply that if a U.S. industry uses a particular input, then imports of that input from any source country are assumed to be embodied in that industry's exports to any destination country. Thus, the proportionality assumptions generate "excess smoothing" in IO table-based GVC measures. Our establishment-level linkages show that many country pair combinations record zero GVC flows. In several manufacturing sectors more than 10 percent, and up to 37 percent, of all possible country pairs have zero flows, yet input-output tables assign positive values to these cases by construction.

We investigate the role of these two proportionality assumptions by comparing a gravity regression with our GVC measures against a gravity regression with GVC measures constructed from the World Input-Output Database (WIOD, 2023) maintaining the same country-pairs as in WIOD. Our main finding is that the round-trip effect is significantly attenuated when using IO table-based GVC measures. The round-trip effect from the IO table-based gravity regression is only about $\frac{1}{50}$ as large as the effect from the Census-based gravity regression. The IO-table assumptions mask the strong complementarities between input and output markets that we find. Indeed, the correlation between Census-based and WIOD-based bilateral GVC measures is only 0.42 for manufacturing as a whole, and as low as 0.26 for pharmaceuticals.

Finally, using a back-of-the-envelope quantification exercise based on the 2025 tariff episode, we find that import tariffs reduce bilateral trade deficits by substantially less when production networks exhibit strong round-trip linkages. A tariff on a partner country reduces not only U.S. imports from that country but also U.S. exports to it, because part of what the U.S. sells back to the partner embodies inputs sourced from that same partner. With our Census-based GVC measure, 8.4 percent of the tariff-induced import contraction is offset by lower U.S. exports; constructing round-trip shares from aggregate IO tables instead reduces the aggregate offset share to 3.9 percent. The gap is largest exactly where round-trip trade matters most: for Mexico, proportionality-based measures put the offset share at half the Census-based value, and thus overstate the deficit reduction from the 2025 tariffs by $12 billion.

Our paper makes contributions to two empirical GVC literatures. First, we contribute to the research on GVC measurement that has broadly focused on two measures, the import content (or, related, the foreign value-added) embodied in exports and the domestic

value-added embodied in exports (e.g., Hummels, Ishii and Yi, 2001; Johnson and Noguera, 2012a; Koopman, Wang and Wei, 2014; Timmer, Erumban, Los, Stehrer and de Vries, 2014; Johnson and Noguera, 2017; Borin and Mancini, 2023); see Antràs and Chor (2022) for a recent survey. This large and still growing research relies primarily on national and multi-country IO tables. Relatedly, an IO table-based GVC literature assesses the role of gravity forces, including RTAs, in explaining value-added exports (e.g., Noguera (2012); Johnson and Noguera (2017); Laget, Osnago, Rocha and Ruta (2020)). Our contribution is to construct GVC measures by replacing the pairwise and import proportionality assumptions with direct establishment-level linkages for the United States. We show that the proportionality assumptions substantially understate round-trip GVC flows and attenuate the role of trilateral RTAs.

Second, we contribute to the research using firm-level data to measure GVCs. Using firm-level linkages between production and trade, Kee and Tang (2016) and Bems and Kikkawa (2021) show that national IO tables aggregate out firm heterogeneity in export and import intensities that lead to aggregation bias in measures of GVC participation in the context of China and Belgium, respectively. A complementary approach uses "hybrid" data—firm-level trade blended with industry-level production—to introduce firm heterogeneity in IO tables: export processing status of firms in countries with large processing trade sectors like China (e.g., Koopman, Wang and Wei (2014)) and Mexico (e.g., Cruz, Koopman, Wang and Wei (2013)) and multinational status of U.S. traders (Fetzer, Highfill, Hossiso, Howells, Strassner and Young, 2023). de Gortari (2019) uses customs transactions by Mexican firms and IO production flows to show that by ignoring heterogeneity in input sourcing within an industry that varies by exports markets, GVC flows between given bilateral trading partners are significantly understated. Our contribution is to extend this micro-founded approach further by linking firm-level trade transactions with establishment-level production. Whereas prior work measures imported input use at the firm level, we allocate multi-industry firms' trade flows to the specific establishments where production occurs. This establishment-level granularity is important when trading firms operate across multiple industries: the average U.S. manufacturer that both exports and imports operate in eight different industries. Linking trade to establishments rather than firms allows us to construct bilateral GVC measures that reflect actual input-output linkages within specific production locations rather than aggregated firm-wide averages.[3]

The rest of the paper is organized as follows. Section 2 details the data and methodology

[3]Innovations linking firms' imported inputs by source using production and customs records for the United States include Boehm, Flaaen and Pandalai-Nayar (2019) who identify inputs purchased by U.S. affiliates of Japanese multinationals; Antràs, Fadeev, Fort and Tintelnot (2024) who identify inputs purchased by U.S. multinationals; and Handley, Kamal and Monarch (2025) who identify inputs purchased by U.S. exporters. Cebreros, Torres and Utar (2025) employ a similar approach for Mexican firms, examining the effects of the U.S.-China trade war on Mexican GVC participation.

for constructing establishment-level GVC measures and the resulting summary statistics. Section 3 documents the determinants of GVC trade in a gravity framework. Section 4 demonstrates the role of proportionality assumptions in shaping measurement biases in the gravity determinants of GVC trade. Section 5 discusses the impacts of tariffs on bilateral trade deficits with round-trip trade. The final section discusses avenues for extending our measures.

2 Measuring Global Value Chains in the United States

A central contribution of this paper is linking the full global value chain of U.S. manufacturers, from imported inputs to production to exports at the establishment level, the most granular unit at which production occurs. This establishment-level foundation allows us to construct GVC measures at several levels of aggregation while preserving the underlying heterogeneity that proportionality assumptions obscure.

We begin by constructing an establishment-level GVC measure—the imported input content of exports—based on the concept of vertical specialization (VS) (Hummels et al., 2001).[4] It is defined for an input product r imported from country m and used by a U.S. establishment e in industry s in its output product p for export to country n in period t as:

$$GVC_{emnrspt} = \frac{IMP^{I}_{emrt}}{GO_{est}} EXP_{enpt}, \tag{1}$$

where IMP^{I}_{emrt} denotes imported inputs (details in Appendix A.3), and EXP_{enpt} represents produced outputs (details in Appendix A.4).[5] GO_{est} is gross output of establishment e in industry s in period t.

2.1 Data Sources and Sample Construction

The construction of $GVC_{emnrspt}$ combines goods trade and production from two confidential, micro-level datasets maintained by the U.S. Census Bureau.

First, the Longitudinal Firm Trade Transactions Database (LFTTD) combines merchandise export and import transactions from confidential customs declaration forms with administrative data on the universe of U.S. firms in the non-farm, private sector in the Census Bureau's Business Register (Kamal and Ouyang, 2020). It covers the universe of import

[4] $(1 - VS)$ is closely related to the measure of value-added exports (VAX), capturing the domestic value-added embodied in a country's exports (Johnson and Noguera, 2012a, 2017; Koopman, Wang and Wei, 2014), when goods are produced in two stages (otherwise, U.S. firm imports may embody U.S. value-added). See Borin and Mancini (2023) and Baldwin, Freeman and Theodorakopoulos (2022) for a comprehensive overview of GVC measures and Baldwin and Freeman (2021) for a risks approach to GVCs.

[5] At the establishment level, s is a 6-digit NAICS industry.

shipments valued over US$2,000 and export shipments valued over US$2,500. We use the LFTTD to measure a U.S. firm's exports by 10-digit Schedule B product and destination and imports by 10-digit Harmonized Tariff System (HTS) product and source.

Second, the Census of Manufactures (CMF), collected every five years (in years ending in a 2 or 7) as part of the economic census, surveys the universe of manufacturing establishments on their production processes including output, input usage, and product-level shipments (U.S. Census Bureau, 2022c,a). We allocate a firm's exports and imports to their establishments using the CMF trailer files: the Materials Trailer File (CMF-MAT) identifies products used as material inputs in production; and the Product Trailer File (CMF-PROD) identifies products produced and/or shipped. Given our focus on production activities, our sample includes all manufacturing establishments with product-level information on inputs and output. This restriction eliminates a significant number of small manufacturing establishments that do not report product-level detail but retains firms accounting for the vast majority of shipments.

Thus, using LFTTD, CMF, CMF-MAT, and CMF-PROD, we build a comprehensive picture of establishment-level production with links to global input usage and global market access. Appendix A provides the methodological details.

2.2 Connecting Trade Flows Associated with Production Activity

GVC measurement connecting U.S. manufacturing with the rest of the world is challenging as firms undertake a variety of activities across sectors, a portion of which may be classified outside of manufacturing (e.g., Ding, Fort, Redding and Schott, 2022; Ding, 2023; Fort, 2023).[6] Manufacturers may import goods intended for direct sale downstream as part of wholesale and retail activities, and thus such shipments would not be inputs from the perspective of their U.S. production operations; similarly, not all exports by a manufacturer may be produced in-house and therefore should not be considered as manufactured exports. Even within the manufacturing sector, firms operate across multiple industries: manufacturers that both export and import have very diverse industrial footprints operating in roughly eight six-digit and five four-digit industries (Appendix Table A2). By construction, firms that both export and import contribute the most to $GVC_{emnrspt}$ and thus ignoring the industry-level heterogeneity within a firm can yield spurious assignment of imported inputs across industries.

Consistent with the complexity of modern U.S. manufacturers' activities, our methodology assigns part of firms' imports and exports as intermediate inputs and manufactured

[6] An extreme form of production fragmentation is captured by so-called "factoryless" goods-producers that outsource physical transformation activities while retaining ownership of the intellectual property and control of sales to customers (Bernard and Fort, 2015; Bayard, Byrne and Smith, 2015; Fort, 2017, 2023; Kamal, 2023).

output, respectively. Table 1 reports the matching results over the sample years. Our methodology allocates about 60% of the average firm's imports to its establishments as intermediate inputs (column 1). This share is similar to Boehm, Flaaen and Pandalai-Nayar (2019) who classify 64% of manufacturing imports as intermediates in 2007.[7] For the representative manufacturing establishment, imported inputs are about 17% of the total material costs (column 2). Our methodology allocates about 70% of the average firm's exports to its establishments as being produced (column 3). A similar finding for Belgium attributes about a third of export value to so-called carry-along trade (Bernard, Blanchard, Beveren and Vandenbussche, 2018). For the representative manufacturing establishment, produced exports as a share of shipments has increased over time and in 2017 was 10.4% (column 4).[8]

Table 1: Aggregate Match Statistics (%), 2002-2017

	Intermediate Share of		Produced Export Share of	
	Firm Imports	Establishment Cost	Firm Exports	Establishment Shipments
2002	56.9	14.0	69.8	7.7
2007	60.9	17.8	70.6	9.1
2012	62.9	16.9	69.8	10.3
2017	58.5	18.4	68.9	10.4

Notes: This table displays imports identified as inputs as a share of total firm imports (column 1) and as a share of total establishment material cost (column 2); exports identified as produced by manufacturing establishments as a share of total firm exports (column 3) and as a share of total establishment shipments (column 4).
Source: Authors' calculations using CMF and LFTTD.

There are two important data limitations we confront. First, while we have detailed product-level information on establishments' output and input in the CMF, these data do not indicate whether input usage differs by the output market. Thus, we rely on a proportionality assumption that a particular establishment's imported input use for its exported products is in proportion to overall input use. Second, while we have micro-level data for a firm's direct import and export activities, we cannot track firm-to-firm transactions within the United States—unlike countries that collect such data through VAT reporting guidelines (e.g., Belgium (Dhyne, Kikkawa, Mogstad and Tintelnot, 2021))—and thus are unable to account for indirect import and export activities through domestic supply linkages.[9] Hence, we construct a *direct* GVC measure that captures a lower bound of the true degree of foreign input usage in U.S. production.

[7] They classify goods as intermediate inputs or capital investment goods if they are not in the CMF-PROD.

[8] This is smaller than the 14% share of exports to gross output reported for the manufacturing sector in Bernard, Jensen, Redding and Schott (2007, Table 2), but the authors rely solely on the exports reported by establishments in the 2002 CMF and do not use the LFTTD or CMF-PROD.

[9] The Commodity Flow Survey (U.S. Census Bureau, 2023) tracks a select set of domestic shipments from a sending establishment to a destination zip code. However, strong assumptions are required to construct flows between establishments. For example, Atalay, Hortaçsu and Syverson (2014) use information on zip codes and industry for all establishments of a firm to probabilistically determine the receiving establishment.

2.3 Summary Statistics

2.3.1 Imported Input Content in U.S. Exports

We present trends in industry-level GVC by summing over all product-source of imports and product-destination of exports for establishment e operating in industry s in period t:

$$GVC_{est} = \frac{\sum_{m,r} IMP^{I}_{emrt}}{GO_{est}} \sum_{n,p} EXP_{enpt}, \tag{2}$$

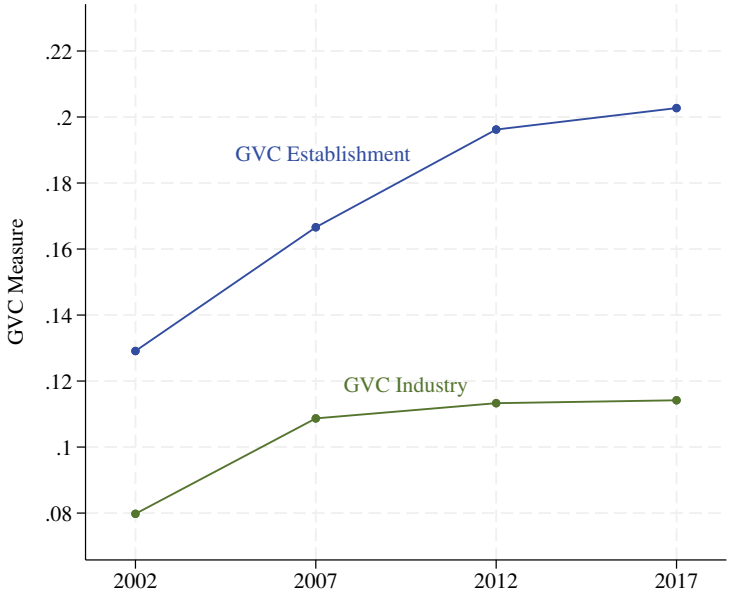
and then summing across establishments of a sector. We scale GVC_{est}, which is in dollars, by sectoral exports to create the share of imported inputs in exports:

$$gvc^{E}_{st} = \frac{\sum_{e \in E_{st}} \left[\frac{\sum_{m,r} IMP^{I}_{emrt}}{GO_{est}} \sum_{n,p} EXP_{enpt} \right]}{\sum_{e \in E_{st}} \sum_{n,p} EXP_{enpt}}, \tag{3}$$

where E_{st} is the set of establishments that are producing in industry s in year t.[10]

Figure 1 plots gvc^{E}_{st} for the U.S. manufacturing sector as the blue line. The imported content of exports rises steadily from 13 to nearly 20 cents of imported inputs embodied in each dollar of exported output between 2002 and 2012 and edges above 20 cents in 2017.

Figure 1: Imported Input Content of U.S. Exports: Establishment vs. Aggregate



Notes: This figure plots the share of imported inputs in exports (GVC measure) for the U.S. manufacturing sector. The blue line plots gvc^{E}_{st} (Equation 3) and the green line plots gvc^{I}_{st} (Equation 4).
Source: Authors' calculations using CMF and LFTTD.

Our measure stands in contrast to what would be calculated from industry-level aggre-

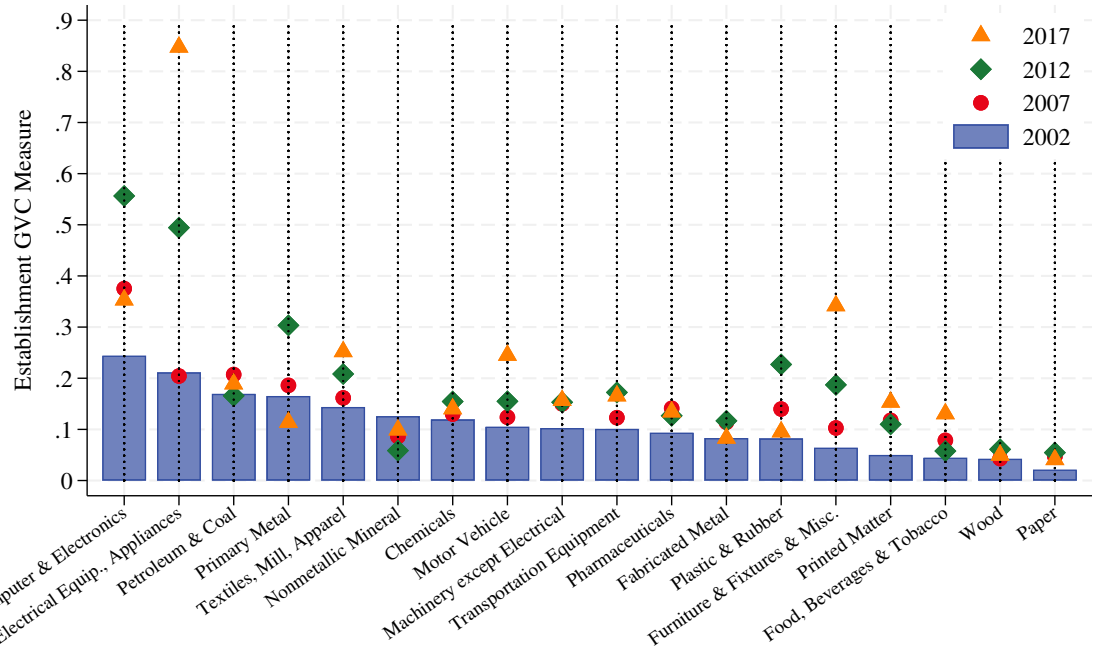
[10] Here, s is a 3-digit manufacturing sector based on WIOD industry definition to enable comparisons as discussed in Section 4.

gates of imports, output, and exports that are the primary ingredients to multi-country IO tables. As previously demonstrated (e.g., Kee and Tang, 2016; Bems and Kikkawa, 2021), GVC estimates from industry-level aggregates suffer from downward aggregation bias if export and import intensity is positively correlated at the micro level. To explore the presence of aggregation bias in U.S. data, we aggregate our establishment-level data to industries and recalculate GVC as if the establishment-level linkages between imports and exports were unobserved as follows:

$$gvc^I_{st} = \frac{\left(\sum_{e \in E_{st}} \sum_{n,p} EXP_{enpt}\right)\left(\frac{\sum_{e \in E_{st}} \sum_{m,r} IMP^I_{emrt}}{\sum_{e \in E_{st}} GO_{est}}\right)}{\sum_{e \in E_{st}} \sum_{n,p} EXP_{enpt}}. \tag{4}$$

The green line in Figure 1 plots this aggregate-based measure. It shows that both the level and trends of gvc^E_{st} would be mis-measured without establishment-level links.[11]

Figure 2: GVC Estimates for Manufacturing Sub-sectors, 2002, 2007, 2012, 2017



Notes: This figure plots gvc^E_{st} (Equation 3) by 3-digit sectors defined in WIOD.

Source: Authors' calculations using CMF and LFTTD.

Figure 2 plots gvc^E_{st} for manufacturing sub-sectors. It highlights significant heterogene-

[11] See Appendix B.4 for a discussion of how industry mis-classification can shape aggregation bias. We show that industry mis-classification is less acute if using firm-industry versus establishment aggregation compared to firm-primary industry versus establishment aggregation. This is because firm-industry data preserve the detailed establishment-level industry codes which a single firm-wide primary industry designation cannot capture. Flaaen, Kamal, Lee and Yi (2024) document that much of the increase in the aggregation bias over time arises from higher correlation between export and import intensities within establishments.

ity across industries (the bars signify values from 2002, the red dots values for 2007, the green diamonds for 2012, and the orange triangles for 2017). The industries experiencing the greatest growth in foreign linkages during this period include computer and electronics, electrical equipment, plastics and rubber, and furniture. Conversely, those industries experiencing little or negative growth in foreign linkages are non-metallic minerals, petroleum and coal, and wood products.

2.3.2 Source-specific Imported Input Content of Destination-specific Exports

The key objective of this paper is to understand the determinants of GVC trade flows in a three-country setting. To enable this analysis, we construct bilateral GVC—imported content by source country m of exports by export destination n in year t—as:

$$GVC_{mnt} = \sum_{e \in E_{mnt}} \left(\frac{\sum_r IMP^I_{emrt}}{GO_{est}} \sum_p EXP_{enpt} \right), \tag{5}$$

where E_{mnt} is the set of all manufacturing establishments that import inputs from country m and export their products to country n in year t. We first compute bilateral GVC measures for each establishment and then aggregate them across all establishments participating in a given supply chain (m, US, n). To compute the GVC share for each (m, n, t), we divide equation (5) by overall or destination-specific total manufacturing exports.

Table 2 shows the top country pairs of linked import source and export destinations based on the sum of the bilateral GVC share measure across all manufacturing sub-sectors (see Appendix B.2 for top GVC country pairs for select industries). A striking feature in Table 2 is how Canada and Mexico occupy all of the top destinations for the input-output country pairs. In addition to North America as a prominent input source in U.S. global value chains, countries such as China, Japan, Singapore, and Germany are important source countries.

3 Determinants of GVC Trade Patterns

Our newly developed establishment-level linkages between imports, production, and exports of U.S. manufacturers enable, for the first time, an exploration of the role of trade frictions as implied by bilateral distance and regional trade agreements in a three-country setting. We estimate a gravity model by linking GVC_{mnt} (defined in Equation 5) to information on country attributes from the Centre d'Etudes Prospectives et d'Informations Internationales or CEPII (Conte, Cotterlaz and Mayer, 2022).

Table 2: Top GVC Country Pairs in the Manufacturing Sector, 2012

Source	Destination	GVC Share in Exports Total	GVC Share in Exports By Destination
Mexico	Canada	0.39%	1.98%
China	Canada	0.34%	1.72%
Mexico	Mexico	0.32%	2.23%
Canada	Canada	0.27%	1.36%
Canada	Mexico	0.20%	1.37%
Japan	Canada	0.14%	0.73%
China	Mexico	0.12%	0.79%
Singapore	Canada	0.09%	0.44%
Germany	Canada	0.08%	0.43%

Notes: The table displays the top import and export country pairs, by bilateral GVC (measured in Equation (5)), for the U.S. manufacturing sector as a share of overall manufacturing exports ("Total") and as a share of manufacturing exports by the destination ("By Destination").
Source: Authors' calculations using CMF, LFTTD, and USA Trade Online (U.S. Census Bureau, 2024b).

3.1 The Role of Trade Frictions

In our three-country setting, the analogous proxy measure of trade frictions for GVC flows is the *combined* distance of each country to the United States, capturing the barriers to the flow of inputs and output in the three countries involved in production. Formally, the combined distance is $d_{m,US,n} \equiv d_{m,US} + d_{US,n}$ for imports from country m and exports to country n, where $d_{m,US}$ and $d_{US,n}$ are the distances between the U.S. and the non-U.S. countries m and n, respectively.

We also consider the role of *direct* distance between input and output markets ($d_{m,n}$)—ignoring the location of the United States in the production chain—on GVC flows. For example, Italy and Spain are relatively proximate, but a middle stage of production in the United States substantially increases the total distance and complexity of the value chain. Hence, including both resistance terms allows exploring whether on the margin, the strength of regional factors linking input and output markets outweighs the cost of processing outside the region (a negative coefficient on $d_{m,n}$) or not (a positive coefficient on $d_{m,n}$). Using our example, we can examine whether the regional factors of a particular product chain are similar enough between Spain and Italy to overcome the added cost of U.S. processing, or whether such processing could just as easily occur in a different (more proximate) country to that bilateral pair (e.g., Germany, rather than the United States).

A special case of the direct distance ($d_{m,m}$) arises when the input source m is the same

as the output destination n.[12] This illustrates another non-traditional factor affecting GVC flows: the prominence of "round-trip" production, in which a U.S. establishment imports an input from a given country and subsequently exports output to the same country. In addition to the overall impact of direct distance, we capture the round-trip effect on GVC flows by including an indicator term $\mathbb{I}(m = n)$ in the gravity specification. After controlling for both combined and direct distances, the estimated round-trip coefficient will capture the effect of having the same country as the input source and the export destination, which is not captured by proximity in input and output markets.

We formally explore these factors by estimating a gravity model, including exporter-year ($\eta_{n,t}$) and importer-year ($\delta_{m,t}$) fixed effects, as follows:

$$\log(GVC_{mnt}) = \alpha + \delta_{m,t} + \eta_{n,t} + \beta\mathbb{I}(m = n) + \gamma d_{m,US,n} + \lambda d_{m,n} + \varepsilon_{mnt}. \tag{6}$$

We report the gravity results, pooled across all years in our sample, i.e., every five years from 2002 to 2017, in Panel A of Table 3, beginning with bivariate regressions of the key variables of interest. The coefficient on the round-trip indicator is large and highly significant. The coefficient on the combined distance variable exhibits the expected negative sign and we find a negative impact of direct distance as well, with the combined distance exhibiting a larger magnitude. Columns (4) through (6) show results when the round-trip variable is included in combination with either combined or direct distances or both. The coefficient on the round-trip indicator is attenuated somewhat when controlling for direct distance, but remains large and highly significant. Given that the m to n distance measure is comparatively very small for the round-trip country pairs (reflecting CEPII's within-country distance calculation), it follows that some of the effect attributed specifically to a round-trip effect would fall instead on this distance measure. The coefficients on both distance measures are significantly negative, with the combined distance measure having roughly double the magnitude of the direct ($m \to n$) distance.

These results reveal two novel features of international supply chains connected through the U.S. manufacturing sector. First, the negative relationship between the combined distance ($m \to$US$\to n$) and bilateral GVC flows suggests that trade frictions operate along the multi-country supply chain, with the degree of production spanning three countries being attenuated as the frictions of the production chain accumulate. The negative coefficient on the direct ($m \to n$) distance after accounting for combined distance implies that greater proximity between input and output markets supports higher GVC flows. These results are consistent with strong complementarities between input and output markets. Second, the large coefficient on the round-trip indicator is an extreme example of this complementarity,

[12] In our empirical analysis, $d_{m,m}$ is not zero. The CEPII methodology takes all possible combinations of *city-pair* distances within a country and calculates a population-weighted average.

Table 3: The Role of Distance in Bilateral GVC Flows

Panel A: Pooled Estimates, 2002-2017

	Dependent Variable: Log Bilateral GVC					
	(1)	(2)	(3)	(4)	(5)	(6)
Round-trip (m=n)	2.33***			2.24***	1.32***	1.39***
	(0.112)			(0.111)	(0.119)	(0.121)
Log Distance (m →US→ n)		-1.64***		-1.42***		-0.414***
		(0.106)		(0.104)		(0.118)
Log Distance (m→n)			-0.256***		-0.194***	-0.175***
			(0.009)		(0.009)	(0.011)
Exporter-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Importer-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	117,000	117,000	117,000	117,000	117,000	117,000

Panel B: Annual Estimates

	Dependent Variable: Log Bilateral GVC			
	2002	2007	2012	2017
	(7)	(8)	(9)	(10)
Round-trip (m=n)	1.45***	1.48***	1.49***	1.14***
	(0.266)	(0.228)	(0.227)	(0.244)
Log Distance (m →US→ n)	0.316	-1.40***	-0.371	-0.516**
	(0.254)	(0.247)	(0.237)	(0.212)
Log Distance (m→n)	-0.206***	-0.147***	-0.178***	-0.174***
	(0.022)	(0.022)	(0.021)	(0.019)
Exporter FE	Yes	Yes	Yes	Yes
Importer FE	Yes	Yes	Yes	Yes
Observations	26,000	29,500	29,000	32,000

Notes: This table reports coefficients from estimating Equation 6. Round-trip ($m = n$) is an indicator for when the input source and export destination are the same country. Distance (m →US→ n) measures the sum of distance from input source to U.S. and U.S. to export destination ($d_{m,US} + d_{US,n}$). Distance ($m \to n$) measures the bilateral distance between input source and export destination countries. Panel A pools data from 2002, 2007, 2012, and 2017 with exporter-year and importer-year fixed effects. Panel B presents estimates by individual year with time-invariant exporter and importer fixed effects. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Observation counts are rounded to comply with Census Bureau disclosure avoidance rules.

Source: Authors' calculations using CMF, LFTTD, and CEPII.

highlighting the importance of back-and-forth production sharing by establishments within a given country. It also indicates that this round-trip behavior extends beyond the complementarity effects captured solely by the direct ($m \rightarrow n$) distance between source and destination countries.

We confirm that these results are not being driven by a specific year. Panel B reproduces the results in column 6 of Panel A but separately for each year in the sample. The patterns remain qualitatively similar.[13]

3.2 The Role of Regional Trade Agreements

The last few decades have been marked by a proliferation of regional trade agreements (Ruta, 2017). Evaluating the effects of these regional trade agreements (RTAs) in a world where, increasingly, a particular bilateral trade flow is just one segment of a value chain encompassing other countries is challenging. For example, the extent to which a trade agreement between the United States and any particular country, say the Republic of Korea, enhances GVC flows between the United States, Korea, and any third country (say Canada) may also depend on the state of bilateral trade agreements between the United States and Canada, the Republic of Korea and Canada, or all three countries. The granularity of our linkages allows a first exploration of the complex impacts of RTAs on global supply chains.

The study of the impacts of RTAs on gross trade flows in a gravity framework has a long history with estimates of a bilateral RTA indicator generally ranging from 0.1 to 0.3 (Larch and Yotov, 2024). Regional trade agreements and value-added exports (the domestic value-added embodied in a country's exports) exhibit a negative relationship consistent with RTAs facilitating increased production sharing between RTA partners (e.g., Noguera, 2012; Johnson and Noguera, 2017). Our establishment-level links enable an exploration of the role of RTAs in trilateral supply chain linkages. We construct indicator variables using CEPII data for whether: countries m and n have an RTA, both countries m and n have RTAs with the United States, and all three countries (m, n, and the U.S.) are in an RTA.[14] We add these variables to the gravity model in Equation (6).

The results are presented in columns (1) - (4) of Table 4, where we continue to include the round-trip indicator and combined distance as controls.[15] We find only a small positive coefficient on GVC flows from an RTA indicator that includes the import and export countries but not the United States. But the coefficient increases substantially once we focus instead on an RTA indicator capturing those importers and exporters that both have an

[13] The magnitude of the combined distance coefficient varies somewhat by year although retains a negative sign in all years except 2002.

[14] Note that the third indicator is an intersection of the other two RTA indicators. See Appendix Table C1 for the complete list of RTAs.

[15] Since CEPII also records a country as having an RTA with itself, the round-trip indicator will soak up this portion of any effect from the RTA (m and n) coefficient.

Table 4: The Role of RTAs in Bilateral GVC Flows
Pooled Estimates, 2002-2017

	Dependent Variable: Log Bilateral GVC						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Round-trip (m=n)	2.20***	2.23***	2.21***	2.19***			
	(0.112)	(0.111)	(0.112)	(0.112)			
Log Distance (m →US→ n)	-1.38***	-1.39***	-1.36***	-1.36***			
	(0.105)	(0.104)	(0.104)	(0.105)			
RTA (m & n)	0.044**			0.042**	-0.080**		
	(0.020)			(0.020)	(0.036)		
RTA (m & US, n & US)		0.198***		0.191***		0.135*	
		(0.059)		(0.059)		(0.075)	
RTA (m, n, US)			0.438***				0.196**
			(0.112)				(0.099)
Exporter-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Importer-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter-Importer FE					Yes	Yes	Yes
Observations	117,000	117,000	117,000	117,000	112,000	112,000	112,000

Notes: This table reports coefficients from estimating Equation (6) augmented with RTA indicators. Three RTA measures are examined: (1) RTA between m and n only; (2) bilateral RTAs where both m and n separately have RTAs with the U.S.; (3) trilateral RTA covering all three countries. Round-trip ($m = n$) is an indicator for when the input source and export destination are the same country. Distance (m →US→ n) measures the sum of distance from input source to U.S. and U.S. to export destination ($d_{m,US} + d_{US,n}$). Columns (1) - (4) include exporter-year and importer-year fixed effects. Columns (5) - (7) add exporter-importer pair fixed effects. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Observation counts are rounded to comply with Census Bureau disclosure avoidance rules.
Source: Authors' calculations using CMF and LFTTD.

RTA with the United States (column 2), and even further when the RTA indicator includes all three countries (column 3). The imported input content from country m of a U.S. manufacturing firm's exports to country n is nearly 55 percent higher when the three countries are collectively in an RTA (controlling for other factors) than otherwise.[16]

While we find a strong role for RTAs in increasing GVC activities, the round-trip effect remains robust. For instance, the estimated coefficient on the round-trip indicator shows virtually no change between column (4) of Table 3 and columns (1)-(4) of Table 4, with combined distance included. This finding suggests that the back-and-forth trading behavior of establishments is driven by factors affecting the coordination of overall production flows, extending beyond the influence of trade policy coordination between countries.

We provide evidence that the RTA results are not purely driven by selection by leveraging changes in RTA status and the corresponding changes in GVC activity. Although our sample period is relatively short, we operationalize this strategy in columns (5)-(7) by adding a country-pair fixed effect, thereby controlling for the endogenous adoption of RTAs based on historical ties or time-invariant features (Baier and Bergstrand, 2007). Using this approach,

[16]Calculated as $exp(\beta_{RTA(m,n,US)}) - 1 = exp(0.438) - 1 = 55\%$.

the magnitude of the effect of RTAs on GVCs is somewhat reduced relative to columns (1)-(4). The RTA indicator without any U.S. involvement actually switches from mildly positive to mildly negative. Nonetheless, for RTAs including the United States, despite the small sample and relatively few RTAs initiated during the sample period, we find a positive impact on GVC flows of between 14 and 22 percent.

3.3 The Role of Multinationals

Multinational enterprises (MNE) are a major driver of global production fragmentation (e.g., Baldwin, 2016; Antràs and Chor, 2013). In 2017, MNEs accounted for 40% of sales, 65% of goods exports, and 60% of goods imports (Kamal, McCloskey and Ouyang, 2022). Given the economic importance of MNEs, we examine multinationals' production networks by decomposing the bilateral GVC measure in Equation 5 as follows:

$$GVC_{mnt} = \underbrace{\sum_{e \in E_{mnt}} \left(\frac{\sum_r IMP^{I,AL}_{emrt}}{GO_{est}} \sum_p EXP^{AL}_{enpt} \right)}_{\equiv GVC^{(AL,AL)}_{mnt}} + \underbrace{\sum_{e \in E_{mnt}} \left(\frac{\sum_r IMP^{I,RP}_{emrt}}{GO_{est}} \sum_p EXP^{AL}_{enpt} \right)}_{\equiv GVC^{(RP,AL)}_{mnt}}$$
$$+ \underbrace{\sum_{e \in E_{mnt}} \left(\frac{\sum_r IMP^{I,AL}_{emrt}}{GO_{est}} \sum_p EXP^{RP}_{enpt} \right)}_{\equiv GVC^{(AL,RP)}_{mnt}} + \underbrace{\sum_{e \in E_{mnt}} \left(\frac{\sum_r IMP^{I,RP}_{emrt}}{GO_{est}} \sum_p EXP^{RP}_{enpt} \right)}_{\equiv GVC^{(RP,RP)}_{mnt}}, \quad (7)$$

where RP indicates whether the trade transaction takes place between related parties and AL indicates whether the trade transaction takes place between arm's-length parties. We use the related-party trade status in the LFTTD, an indicator variable that takes the value of 1 if a shipment takes place between related parties, and 0 otherwise (U.S. Census Bureau, 2025b).[17]

We begin by documenting the share of GVC trade flows by related-party status in Table 5 for each year in the sample period. We find that the share of U.S. manufacturers' GVC trade that was fully arm's-length ("AL-AL"), partially related-party (either imports or exports were related party ("RP-AL") or ("AL-RP")) and fully related-party ("RP-RP") remains fairly stable over the sample years. Overall, multinationals account for around three-quarters of total GVC flows, but these firms engage in a mix of purely intra-firm GVC (with both directions of trade flows between related parties, which account for about 30% of total GVC) and also GVC transactions with other arm's-length firms (where only one direction of the GVC flow occurs within the firm, which accounts for an additional 45% of total GVC). The

[17]For export transactions, it denotes relationships in which one firm owns a stake of at least 10% in the other as reported in the Electronic Export Information filings (U.S. Census Bureau, 2025a). For import transactions, it denotes relationships in which one firm owns a stake of at least 5% in the other as reported in customs entry filings (U.S. Customs and Border Protection, 2025).

central role of multinationals in mediating GVC flows in the U.S. manufacturing sector is corroborated by the dominance (both in terms of sales and employment) of firms that have both domestic and foreign in-house production (Fort, 2023).

Table 5: Share of GVC by Related-Party Trade Status (%)

Related-Party Relationship Imports-Exports	2002	2007	2012	2017
AL-AL	26	26	26	23
RP-AL	15	15	13	17
AL-RP	29	24	31	32
RP-RP	31	35	30	27

Notes: This table displays the share of GVC by the related-party trade status. Columns denote the sample years and shares within a column may not sum to 100 due to rounding. "AL-AL" refers to both import and export flows with arm's-length parties; "RP-AL" refers to imports from related parties and exports to arm's-length parties; "AL-RP" refers to imports from arm's-length parties and exports to related parties; "RP-RP" refers to both import and export flows with related parties.
Source: Authors' calculations using CMF and LFTTD.

To understand how multinationals influence geographic patterns of GVC linkages, we stack each of the four elements of GVC_{mnt} in Equation (7) and run the following expanded gravity specification,

$$\log(GVC^{o}_{mnt}) = \alpha + \delta^{o}_{m,t} + \eta^{o}_{n,t} + \beta\mathbb{I}(m=n) + \lambda d_{m,n} + \gamma d_{m,US,n} + \sum_{o' \in \{(RP,AL),(AL,RP),(RP,RP)\}} \left[\beta^{o'}\mathbb{I}(m=n) + \lambda^{o'} d_{m,n} + \gamma^{o'} d_{m,US,n}\right] \times \mathbb{I}(o=o') + \varepsilon^{o}_{mnt}, \tag{8}$$

with interaction terms between the related-party status of GVCs and each gravity control. The coefficients β, λ, and γ capture the baseline effect of each control for GVC flows that are fully at arm's length—i.e., (AL, AL)—while $\beta^{o'}$, $\lambda^{o'}$, and $\gamma^{o'}$ capture the additional effect of all possible combinations of related-party status other than (AL, AL). The $\delta^{o}_{m,t}$ and $\eta^{o}_{n,t}$ terms indicate country by related-party status by year fixed effects.

We report the results in Table 6, where the three coefficients associated with related-party GVC are additional effects on top of the baseline (AL, AL) coefficient for each measure. The first two rows report the coefficients on the round-trip variable and its interactions and the direct distance variable and its interactions from estimating Equation 8. These collectively show how the evidence for complementarities in GVC flows in Section 3.1 is disproportionately driven by multinational flows. While the round-trip effect is present for all types of GVC flows, it is nearly twice as strong for GVC flows entirely within a multinational firm. Similarly, the additional attenuation of GVCs where import and export countries are

Table 6: The Role of Multinationals in Bilateral GVC Flows
Pooled Estimates, 2002-2017

		Dependent Variable: Log Bilateral GVC			
		Baseline	**Additional Effect by Related-Party Type**		
		Imp=AL Exp=AL	Imp=RP Exp=AL	Imp=AL Exp=RP	Imp=RP Exp=RP
		(1)	(2)	(3)	(4)
(1)	Round-trip (m=n)	1.10***	0.124	-0.286	0.805***
		(0.115)	(0.178)	(0.190)	(0.213)
(1)	Log Distance ($m \rightarrow n$)	-0.156***	-0.019	-0.092***	-0.153***
		(0.011)	(0.016)	(0.017)	(0.019)
(2)	RTA (m & n)	0.000	0.107***	0.263***	0.485***
		(0.020)	(0.032)	(0.034)	(0.038)
(2)	RTA (m & US, n & US)	0.053	0.353***	0.361***	0.364***
		(0.054)	(0.090)	(0.095)	(0.113)
(3)	RTA (m, n, US)	0.310***	-0.029	0.577***	0.713***
		(0.100)	(0.157)	(0.173)	(0.198)

Notes: This table reports select coefficients from estimating Equation 8 (unreported coefficients on combined distance and its interactions are suppressed for display). A row number denotes a regression specification: row (1) estimates Equation 8; rows (2) and (3) augment Equation 8 with RTA indicators and their interactions with related-party status. Column (1) reports baseline coefficients for arm's-length transactions (both imports and exports with unrelated parties). Columns (2) - (4) report additional effects for transactions involving related parties: column (2) for imports from related parties and exports to arm's-length parties; column (3) for imports from arm's-length parties and exports to related parties; column (4) for both imports and exports with related parties (fully intrafirm). The reported coefficients in columns (2) - (4) are incremental effects that must be added to the baseline in column (1) to obtain the total effect for each related-party type. All specifications include importer-year and exporter-year fixed effects by related-party type. There are 354,000 observations in each regression. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Observation counts are rounded to comply with Census Bureau disclosure avoidance rules.
Source: Authors' calculations using the CMF, LFTTD, and CEPII.

distant (after controlling for the overall combined distance) suggests that proximity and coordination between input and output markets are particularly important for multinational supply chains.

In the next three rows (which come from two separate regressions), we document how regional trade agreements shape multinational GVC flows differently. The first two types of RTA (those not including the U.S., and those including the U.S. separately for import and export countries) only appear to matter for GVC flows mediated by multinationals. RTAs that span all countries in the supply chain encourage all forms of GVC flows, but once again have the strongest impact where the GVC flow is fully within the multinational firm boundary. These results are consistent with the role of RTAs in reducing coordination costs, even controlling for both combined and direct distance, for firms looking to engage in production sharing arrangements among the RTA members. Our results are also consistent

with findings in Antràs et al. (2024), who document that U.S. multinational parents are not only more likely to trade with the countries in which they have affiliates, but also with other countries within the regions where the affiliates are located, or with countries that share a free trade agreement with the affiliates' location.

4 Assessing Biases in GVC Measurement from Proportionality Assumptions

We evaluate the implications of proportionality assumptions in aggregate IO tables for GVC measurement by comparing our bilateral GVC measure to those derived from the WIOD. We use the November 2016 release spanning 43 countries (and a rest of world aggregate, RoW) and 56 sectors (18 in manufacturing) between 2000 and 2014. To compare the Census-basis estimates with what would be generated using the WIOD, we isolate the imports of inputs into the United States. We convert the NACE (Nomenclature of Economic Activities) industry classification to NAICS and then drop all inputs of services given our focus on the manufacturing activities of U.S. firms. We then collapse the Census-basis data for the 43 countries and RoW in WIOD.

4.1 Conceptual Example of Pairwise Proportionality

For a conceptual illustration of how true country-pair linkages are lost in aggregation, consider a simple economy composed of two firms that each import an identical commodity and export an identical product, but from and to different sets of countries. The import, export, and gross output values of these two firms are shown below in Figure 3.

The GVC values for the possible country-pair combinations that result from summing Equation (1) across the two firms for a given country-pair are shown in the left panel of Figure 3b. In this example, Firm 1 generates $30 of GVC from Mexico to the UK and Firm 2 generates $30 of GVC from China to Germany. Absent firm-level data, however, the researcher only observes the area highlighted in blue in Figure 3a, representing aggregate country-level import and export data. Hence, the researcher must use pair-wise combinations of import and export values to construct bilateral GVC values from this data, illustrated in the right panel of Figure 3b. This example illustrates the bias introduced from the resulting pairwise proportionality assumption.

4.2 Biases in Determinants of Bilateral GVC

How would proportionality assumptions in aggregated data impact the determinants of bilateral GVCs? To answer this question, we construct the WIOD-based bilateral GVC measure

Figure 3: Conceptual Illustration of GVC Proportionality

(a) Firm-Level and Aggregate Data

	Imports		**Exports**		**Gross**
	Mexico	China	U.K.	Germany	**Output**
Firm 1	\$100	\$0	\$150	\$0	\$500
Firm 2	\$0	\$100	\$0	\$300	\$1000
Total	**\$100**	**\$100**	**\$150**	**\$300**	**\$1500**

(b) GVC Calculations: Reality vs Aggregate

Bilateral GVC: Reality

	U.K.	Germany
Mexico	\$30	\$0
China	\$0	\$30

Bilateral GVC: Aggregated

	U.K.	Germany
Mexico	\$10	\$20
China	\$10	\$20

Notes: This figure illustrates how pairwise proportionality assumptions in aggregate data smooth out true bilateral GVC linkages. Panel (a) shows firm-level data where Firm 1 imports from Mexico and exports to the U.K., while Firm 2 imports from China and exports to Germany. Panel (b) shows that with only aggregate data (blue totals), proportionality assumptions incorrectly allocate GVC flows to all four country-pair combinations.

by aggregating the import and export data at the industry level before constructing GVC measures, rather than relying on the import-export pairs connected by establishments. Thus, instead of using the sum of the GVC measure defined in Equation (5) across s as the dependent variable, we construct:

$$GVC^{agg}_{mnst} = \frac{\sum_{e \in E_{mst}} \sum_r IMP^I_{emrt}}{\sum_{e \in E_{st}} GO_{est}} \sum_{e \in E_{nst}} \sum_p EXP_{enpt}. \tag{9}$$

4.2.1 Excess Smoothing in Allocating Trade Flows

Absent direct linkages between import sources to export destinations, the pairwise proportionality applied to aggregate IO tables will naturally understate areas of concentration in bilateral linkages. To highlight this feature—what we describe as "excess smoothing" from pairwise proportionality—we calculate the fraction of bilateral country-pairs (among countries included in the WIOD) that record $GVC^{agg}_{mnst} = 0$ in the Census data. Provided that there are non-zero commodity imports (to U.S.) and exports (from U.S.) within a given sectoral aggregation, the proportionality-based measure will record strictly positive GVC

values across the full Cartesian product of country pair links.

Without pairwise proportionality, we observe zero GVC flows for a significant number of (m, n, s, t) combinations, as shown in Table 7, since it is possible that there is no establishment in industry s that imports inputs from country m and exports to country n in year t.[18] The excess smoothing varies across manufacturing sectors: there is a greater average share of zeros in the true data among nondurable sectors, though wood and wood products (within durables) records the highest overall share of zeros at 37 percent of all possible pairwise combinations.

In the WIOD, on the other hand, we confirm that GVC flows for all (m, n, s, t) combinations are non-zero due to the pairwise proportionality assumption.

Table 7: Fraction of Zero Bilateral GVC Linkages, by Sector, 2012

NAICS	Percent	NAICS	Percent
Nondurable Sectors		*Durable Sectors*	
Food, Beverage, and Tobacco	14%	Wood and Wood Products	37%
Textiles, Apparel, Leather	11%	Non-metallic Mineral Products	13%
Paper and Paper Products	14%	Basic Metals	6%
Printing	28%	Fabricated Metal Products	1%
Coke and Petroleum Products	20%	Machinery and Equipment	0%
Pharmaceutical	4%	Computer, Electronic and Optical	0%
Chemicals and Chemical Products	2%	Electrical Equipment	0%
Rubber and Plastics	3%	Motor Vehicles and Trailers	1.6%
		Other Transport Equipment	0.2%
		Furniture and Other Mfg	0.1%

Notes: This table reports the fraction of zero GVC linkages among all possible pairwise combinations $(43^2 = 1,849)$ for select sectors.
Source: Authors' calculations using CMF and LFTTD.

4.2.2 Census vs. WIOD Bilateral GVC: Correlations

To assess the alignment of the Census (Equation 5) and WIOD (Equation 9) based measures of bilateral GVC, we begin by calculating the correlation between all bilateral import-export country-pair GVC statistics for a given industry (e.g., the GVC measure of imported inputs from Mexico in exports to France in the machinery and equipment industry). The correlations for each industry-sector are shown in Table 8, with a value of 0.42 for overall U.S. manufacturing. There is wide variation across the broad industries with correlations as low as 0.26 in "Pharmaceuticals" and as high as 0.94 in "Coke and Petroleum Products". Our

[18]The GVC-weighted average fraction of zero bilateral GVC linkages across all U.S. manufacturing, as shown in Table 7, is 3.2 percent.

findings indicate that multi-country IO tables capture broad patterns of the "true" GVC flows, yet are subject to some significant biases.

Table 8: Census-WIOD Correlations of Bilateral GVC by Sector, 2012

Broad Manufacturing Sector	Bilateral GVC
Food, Beverage, and Tobacco	0.92
Textiles, Apparel, Leather	0.56
Wood and Wood Products	0.63
Paper and Paper Products	0.76
Printing	0.64
Coke and Petroleum Products	0.94
Pharmaceutical	0.26
Chemicals and Chemical Products	0.81
Rubber and Plastics	0.49
Non-metallic Mineral Products	0.66
Basic Metals	0.69
Fabricated Metal Products	0.77
Machinery and Equipment	0.85
Computer, Electronic and Optical	0.83
Electrical Equipment	0.69
Motor Vehicles and Trailers	0.86
Other Transport Equipment	0.81
Furniture and Other Mfg	0.48
Overall Manufacturing	**0.42**

Notes: This table displays correlations, by broad sector, between Census-based (defined in Equation 5) and WIOD-based (defined in Equation 9) measures of imported input by source country as a share of exports by destination.
Source: Authors' calculations using CMF, LFTTD, and WIOD.

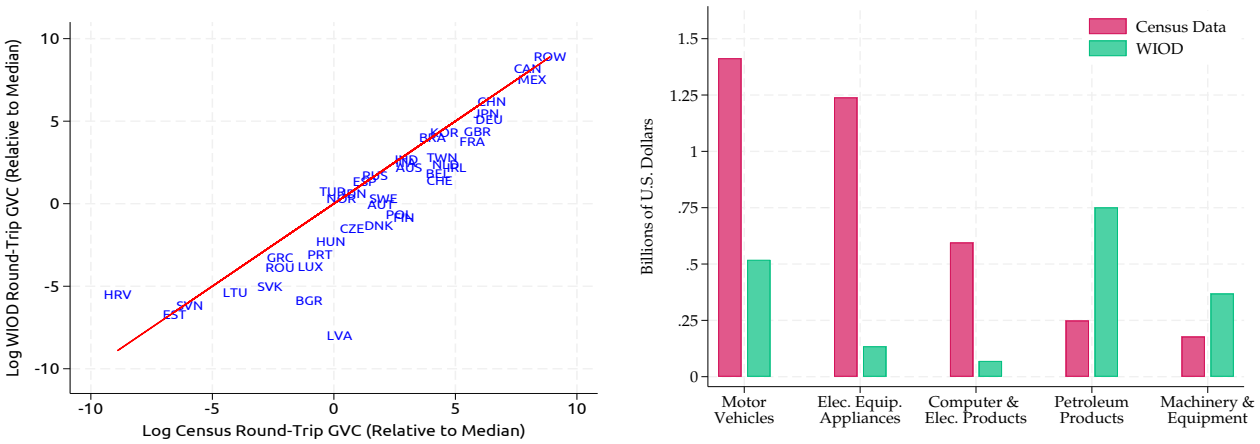
Next, we plot the round-trip GVC values—scaled relative to the median value across all GVC pairs—in our data (x-axis) relative to an equivalent measure in WIOD (y-axis) in the left panel of Figure 4. The figure reveals that nearly all WIOD countries lie below the 45-degree line, indicating significantly higher relative magnitudes of these round-trip GVC flows than would be captured in WIOD. Aggregate measures may also hide important misalignment across industries. The right panel of Figure 4 shows examples of the industry-level round-trip values for Mexico (where establishments within a given industry simultaneously import from and export to Mexico) that exhibit large differences between our data and that reported in WIOD.

4.2.3 Census vs. WIOD Bilateral GVC: Gravity Determinants

Finally, we examine the role that sample coverage, aggregation, and proportionality assumptions play in shaping the determinants of bilateral GVC flows constructed using global IO

Figure 4: Alignment of Round-Trip GVC Values, 2012

(a) Overall Country-Level Round-Trip Alignment (b) Industry-Level Alignment for Mexico



Notes: This figure plots round-trip GVC pairs (where the import country equals the export country) in Census data (x-axis) vs WIOD (y-axis). Each statistic is scaled relative to the median value across all WIOD-based GVC country pairs, and in logs.
Source: Authors' calculations using CMF, LFTTD, and WIOD.

tables. To initialize this exercise, we replicate column (3) of Table 4 in the first column of Table 9. To begin, some features of our results may be hidden because the country samples underlying many proportionality-based tables do not include sufficient variation; hence column (2) replicates our baseline regression while restricting the set of countries to be identical to that in the WIOD. As is clear, some results here are lost. Unsurprisingly, there now appears to be an insufficient number of RTA partner pairs to exhibit a positive coefficient, and the coefficient on the combined distance metric is no longer significant. Since the EU countries are disproportionately represented in the WIOD, while many smaller countries around the world are missing, neither the RTA nor the distance measure retains its explanatory power when we reduce our sample countries to match those in the WIOD. On the other hand, this sample exhibits only a modestly reduced round-trip effect, implying that the round-trip effect we observe does not depend significantly on the set of countries used in the gravity regression.

In the last four columns of Table 9, we explore the role of other differences between the two GVC measures in the gravity relationship by changing the way we measure GVCs, rather than merely restricting the sample of countries. Columns (3) and (4) of Table 9 focus on aggregation bias and pairwise proportionality. We construct $\log GVC^{agg}_{mnt} \equiv \log(\sum_s GVC_{mnst})$ for all pair-wise combinations in column (3) and only for the bilateral pairs that exist in the data in column (4) — effects that separate out the extensive margin effect of the excess smoothing identified above.

In both columns (3) and (4), we find much smaller round-trip effects. As shown in Figure 4a, the impact of aggregation bias and the pairwise proportionality assumption reduces the concentration of GVC found in round-trip pairs. More surprising is the impact this assumption has on the distance coefficient—attenuating the negative effects found in the

true data, and in the case of extrapolating to all possible pairs of countries (in Column (3)), turning the coefficient positive.[19] With the full set of countries available, the RTA coefficient continues to exhibit a positive and statistically significant sign. The fact that the magnitude is reduced by more than half relative to the establishment-based data is attributable once again to the fact that the relatively more concentrated flows associated with those pairs are smoothed out via proportionality.

Table 9: Assessing Biases in Determinants of Bilateral GVC Flows
Pooled Estimates

	Dependent Variable: Log Bilateral GVC					
	(1)	(2)	(3)	(4)	(5)	(6)
Round-trip (m=n)	2.21***	1.71***	0.173***	0.213***	0.183***	0.083***
	(0.112)	(0.119)	(0.043)	(0.040)	(0.028)	(0.015)
Log Distance (m →US→ n)	-1.36***	0.262	0.114**	-0.011	-0.283**	-0.040
	(0.104)	(0.280)	(0.049)	(0.045)	(0.114)	(0.083)
RTA (m, n, US)	0.438***	-0.132	0.158***	0.174***	0.060	-0.033
	(0.112)	(0.220)	(0.046)	(0.045)	(0.087)	(0.061)
Data	Census	Census	Census	Census	Census	WIOD
Trade-Production Links	Establishment	Establishment	IO	IO	IO	IO
Country Sample	All–Data	WIOD-43	All–Possible	All–Data	WIOD-43	WIOD-43
Observations	117,000	7,100	139,000	117,000	7,100	7,056

Notes: Column (1) replicates the baseline specification from column (3) in Table 4 using establishment-level Census data with all available countries. Column (2) restricts the Census sample to the 43 countries in WIOD to assess the role of sample composition. Columns (3) - (5) use Census data but aggregate imports, exports, and production to the industry level before constructing GVC measures (imposing pairwise proportionality), mimicking the WIOD methodology. Column (3) constructs GVC for all possible country-pair combinations (even those with zero actual flows); column (4) includes only country pairs with observed GVC flows in the data; column (5) restricts to WIOD countries. Column (6) uses WIOD-based GVC measures directly. The comparison isolates four sources of measurement bias: country sample restrictions (columns 1 vs. 2), pairwise proportionality assumptions (columns 1 vs. 4, or columns 2 vs. 5), extrapolation to zero-flow pairs (columns 3 vs. 4), and import proportionality assumptions embedded in WIOD (columns 5 vs. 6). Estimates are pooled between 2002-2017 for the Census sample and 2002-2014 for the WIOD sample. All specifications include exporter-year and importer-year fixed effects. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Observation counts are rounded to comply with Census Bureau disclosure avoidance rules.
Source: Authors' calculations using CMF, LFTTD, and WIOD.

In column (5), we use the bilateral GVC measures based on the aggregated microdata from columns (3) and (4), and also restrict the set of countries in the sample to match the WIOD. Similar to the comparison between column (1) and column (2), the round-trip effect is only marginally reduced when we restrict our sample from column (4) to column (5), confirming that the sample does not play a significant role in the round-trip effect. The RTA coefficient loses significance.

Finally, we run the gravity regression with the WIOD in column (6). When moving from the Census data in column (5) to the WIOD in column (6), we implicitly introduce the import proportionality assumption that is inherent in assigning imports to input industries

[19]This positive impact may be a result of allocating trade to country pairs that are relatively remote when in reality these pairs record zero GVC flows.

in aggregate data.[20] With the addition of this proportionality assumption, the round-trip coefficient is further reduced, albeit much less than from column (2) to column (5), and the distance and RTA coefficients lose significance. We find that the pairwise proportionality assumptions necessary to translate aggregate data into multi-country IO tables generate GVC measures that mask the round-trip and RTA effects in trilateral supply chains.

5 Bilateral Trade Deficits under Round-Trip Trade

One of the primary goals of the U.S. tariffs imposed in 2025 was to reduce bilateral trade deficits. Trade economists have long known that supply chains attenuate the impact of tariffs on trade deficits generally (Balassa, 1965; Johnson and Noguera, 2012b; Blanchard, Bown and Johnson, 2026). But the strong round-trip linkages documented in this paper indicate that the impact on *bilateral* deficits will be smaller than previously understood. A tariff on a partner country reduces not only U.S. imports from that country but also U.S. exports to that country, both because U.S. exports back to the country embody inputs sourced from that country, and because the imports embody U.S. content that was previously exported. This export offset due to bilateral tariffs is larger the more intensively the two countries are linked through round-trip production. Correctly measuring round-trip intensity is therefore central to assessing how tariffs translate into changes in bilateral deficits.

In this section we present back-of-the-envelope calculations to quantify this attenuation, treating the two channels described above separately. In the first channel, the U.S. is in the middle of the round-trip chain ($c \to \text{US} \to c$): the tariff-induced contraction in imports from c reduces the U.S. exports that embody inputs sourced from c. In the second channel, the direction is reversed, with a foreign firm in the middle and U.S. firms at *both ends* ($\text{US} \to c \to \text{US}$): the tariff on c's goods reduces the demand for the U.S. content they embody. Section 5.1 formalizes the two channels and explains how we measure each of them.

5.1 A Conceptual Framework and Measurements

Consider a change $\Delta\tau_c$ in the U.S. *ad valorem* import tariff on partner country c from the baseline-level tariff τ_c^0.[21] To a first order, the induced change in U.S. imports from c is

$$\Delta M_c = -\varepsilon \left[\frac{\Delta\tau_c}{(1+\tau_c^0)}\right] M_c, \tag{10}$$

[20] Comparisons of imported cost share measures derived from our Census data linkages and WIOD are in Appendices B.3.1 and B.3.2.

[21] Throughout this section, we report tariff levels and changes in percentage points.

where ε is a short-run trade elasticity and M_c is pre-tariff imports from c. For simplicity, we apply a common ε across countries and assume no foreign retaliation, full tariff pass-through into U.S. import prices, and a fixed production structure over the short horizon we consider.[22]

In a counterfactual world without round-trip trade, the bilateral deficit moves one-for-one with imports, $\Delta D_c = \Delta M_c$. With round-trip trade, on the other hand, U.S. exports to c would also fall. The $c \to \text{US} \to c$ channel links the contraction in imports from c to a contraction in the U.S. exports that embody those imported inputs; the $\text{US} \to c \to \text{US}$ channel links the import contraction to the U.S. content embedded in c's exports back to the United States:

$$\underbrace{\Delta X_c^{(1)} = \varphi_c \cdot \Delta M_c}_{c \to \text{US} \to c \text{ offset}}, \qquad \underbrace{\Delta X_c^{(2)} = \psi_c \cdot \Delta M_c}_{\text{US} \to c \to \text{US offset}}. \tag{11}$$

Here $\varphi_c \equiv GVC_{cc}/M_c$ is the bilateral round-trip intensity with c: the round-trip GVC value for country c relative to U.S. imports from c. Likewise, ψ_c is the U.S. value-added share of c's gross exports to the United States. Combining equations (10) and (11), the change in the bilateral deficit with c is

$$\Delta D_c \;=\; \Delta M_c - \left[\Delta X_c^{(1)} + \Delta X_c^{(2)}\right] \;=\; \Delta M_c \cdot \big(1 - \underbrace{(\varphi_c + \psi_c)}_{\equiv \text{ offset share}}\big). \tag{12}$$

The key message in equation (12) is that a dollar of tariff-induced import contraction would, mechanically, shrink the bilateral deficit by a dollar, but round-trip linkages offset part of that. We define the combined intensity $\varphi_c + \psi_c$ as the tariff deficit *offset share*: the fraction of the import contraction that is offset by a fall in U.S. exports, leaving only $\big(1 - \varphi_c - \psi_c\big)$ to reach the bilateral deficit.[23]

Measurement. We measure equations (10)–(12) for the 39 partner countries covered by both the Census microdata and the WIOD. While we focus on the smaller set of countries covered in the WIOD to match the sample used previously, we use the Asian Development Bank's Multiregional Input-Output (ADB MRIO) tables so we can leverage more recent information including 2024 values of bilateral imports to measure M_c.[24]

For the round-trip intensities, we compute two variants of the pair (φ_c, ψ_c): the input-output table variant and the Census variant. Note that the Census microdata measure

[22] These are the standard short-run, partial-equilibrium assumptions: a one-time, fully-enforced tariff shock with no exchange-rate adjustment, no income effects, no third-country diversion, and no entry/exit. Also, we capture only the direct effects of the tariff changes, with no second-round adjustments.

[23] Consider two polar cases: a partner with no round-trip linkages ($\varphi_c + \psi_c = 0$) delivers $\Delta D_c = \Delta M_c$; a partner whose trade is entirely round-trip ($\varphi_c + \psi_c = 1$) sees no deficit change at all, because the export decline exactly matches the import decline.

[24] We use the 2025 version of the 2024 tables (Asian Development Bank, 2024).

the $c \to \text{US} \to c$ channel directly, while the $\text{US} \to c \to \text{US}$ channel requires tracing U.S. content through *foreign* production and thus relies on a multi-country input-output table in either variant. The input-output table variant is simple: both φ_c and ψ_c are taken from the ADB MRIO under the standard proportionality assumptions. The Census variant is more involved, because the Census microdata do not extend to 2024. We construct it in three steps: (1) we compute a country-specific scaling factor, the ratio of the Census-based to the MRIO-based round-trip value for the $c \to \text{US} \to c$ direction in 2012; (2) the Census-variant φ_c is the MRIO-based 2024 φ_c multiplied by this scaling factor; and (3) the Census-variant ψ_c is the MRIO-based 2024 ψ_c multiplied by the same scaling factor. In other words, the Census variant assumes that the Census-MRIO wedge estimated for the direction our microdata observe applies to both directions.[25]

The tariff shock $\Delta\tau_c$ is calculated based on the actual tariff episode in 2025. We calculate the percentage-point change of the U.S. import tariff on country c based on the difference between the 2024 import-weighted average realized duty rate and the statutory tariff configuration as of June 3, 2025, both taken from the Trade War Tracker (Waugh, 2026). We use statutory rather than realized post-shock rates, because realized duty rates already embed equilibrium responses such as trade diversion. The resulting $\Delta\tau_c$'s vary significantly across partner countries: e.g., 28.4 pp for China, 9.0 and 8.8 for Mexico and Canada, and 12.2 for EU members. We set the trade elasticity as $\varepsilon = 2$, a standard short-run benchmark.[26]

5.2 Results and Discussion

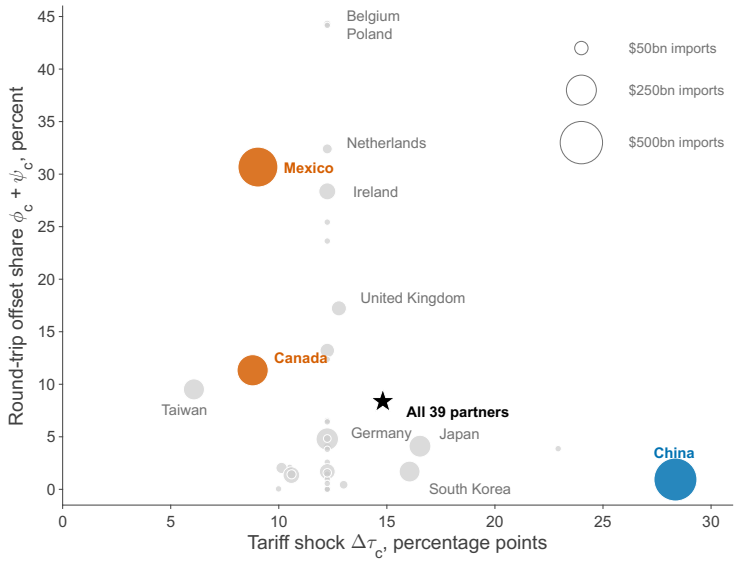
Figure 5 reports the results from the exercise using the Census-based round-trip measures for all 39 partners. Each circle represents a partner country, with the 2025 tariff shock $\Delta\tau_c$ on the horizontal axis, the offset share $\varphi_c + \psi_c$ (the Census variant) on the vertical axis, and the marker area proportional to 2024 U.S. imports from the partner. The 2025 episode raises the import-weighted average U.S. tariff on the 39 partners from 3.1% to 17.9%. With the trade elasticity $\varepsilon = 2$, imports contract by $664 billion and the aggregate deficit narrows by $609 billion in the short run. The star in the figure marks this aggregate response: an import-weighted tariff shock of 14.8 percentage points and an aggregate offset share of 8.4%. Appendix Figure D1 reports the dollar decomposition of the deficit responses for individual countries.

The modest aggregate offset, however, masks considerable heterogeneity in how much round-trip trade matters for each partner's deficit response. For Mexico, round-trip trade

[25] For two small countries (Bulgaria and Latvia), tiny MRIO-based round-trip denominators produce extreme scaling ratios. Therefore, for these two countries, we instead apply the pooled regression-based Census–IO round-trip wedge $\exp(1.71 - 0.08) \approx 5.1$ implied by columns (2) and (6) of Table 9.

[26] Because ε is common across partners, the offset shares are invariant to it while all dollar figures are proportional to it: at $\varepsilon = 1$ every dollar magnitude reported below halves, and the offset shares are unchanged.

Figure 5: Tariff Shocks vs. Round-Trip Exposure, 39 Partners



Notes: The horizontal axis is the 2025 tariff shock $\Delta\tau_c$ (June 3, 2025 statutory configuration minus the 2024 baseline); the vertical axis is the Census-based round-trip offset share $\varphi_c + \psi_c$. Marker area is proportional to 2024 U.S. imports from the partner. The star marks the aggregate across the 39 partners—the import-weighted tariff shock (14.8 percentage points) and the aggregate offset share (8.4%)—and its size is not proportional to imports.
Source: Authors' calculations using CMF, LFTTD, ADB MRIO, and the Trade War Tracker.

matters a lot: the offset share is 30.7%, so a dollar of import contraction from the 2025 tariff shock reduces the U.S. bilateral trade deficit with Mexico by only 69 cents. For Canada, round-trip trade also matters substantially, with an offset share of 11.3%. In contrast, China has minimal round-trip linkages with the United States to begin with: its offset share is below 1%, so its import contraction reduces the bilateral deficit almost one-for-one.

The heterogeneity in offset shares reshapes each partner's contribution to the aggregate deficit response. China stands out in Figure 5 with the largest import base and the highest tariff shock, yet virtually no round-trip offset: its $264 billion import contraction—the largest across the 39 partners—passes through to the bilateral deficit almost in its entirety. Mexico and Canada are the opposite case. Their combined import contraction is only about half of China's, but their deep round-trip integration means that they account for over half of the aggregate export offset despite facing much smaller tariff shocks. Round-trip trade is thus not a uniform dampening factor on the aggregate deficit response. A tariff policy aimed at bilateral deficits will see far less responsive deficits for USMCA partners than an import elasticity to tariffs would suggest. Beyond the USMCA partners, countries such as Belgium, Poland, and the Netherlands exhibit high round-trip intensities despite smaller import bases. In summary, production network structure, and not just trade volumes or tariff levels, determines how tariffs translate into bilateral deficits. Measuring each trade partner's round-trip intensity correctly is thus essential for evaluating the effect of tariff

policy on bilateral deficits.

Section 4.2.2 shows how aggregate input-output tables, such as WIOD, may systematically underestimate round-trip GVCs. To assess the potential implication of this underestimation, we compare three variants of the offset share in Table 10 for Mexico, Canada, and China: no round-trip trade at all, and the IO-table and Census variants defined in Section 5.1 (Appendix Figure D2 reports results for all partners). The comparison mirrors the heterogeneity documented above. For Mexico, where round-trip trade matters most, the bias from proportionality is also largest: IO-based measures put the offset share at 15.8%, barely half the Census-based 30.7%, and thus overstate the deficit reduction from the 2025 tariffs by $12 billion. For Canada, round-trip trade matters almost as much, but the IO-based offset share (13.9%) happens to lie close to the Census-based one (11.3%), so the bias is small.[27] For China, round-trip trade is negligible under either measure (0.7% versus 0.9%), leaving little room for an offset, or for bias, in the first place. In the aggregate, constructing round-trip shares from IO tables cuts the offset share from 8.4% to 3.9%: proportionality-based measures make tariffs look more effective at reducing bilateral deficits than the Census-based measures imply.

Table 10: Tariff Deficit Offset: Input-Output vs. Census Round-Trip Measures

	Offset share (%)			Deficit response ΔD_c ($bn)		
Partner	No round-trip	IO tables	Census	No round-trip	IO tables	Census
Mexico	0.0	15.8	30.7	−80.0	−67.4	−55.5
Canada	0.0	13.9	11.3	−47.6	−41.0	−42.2
China	0.0	0.7	0.9	−263.5	−261.6	−261.0
Aggregate	0.0	3.9	8.4	−664.0	−638.4	−608.5

Notes: The offset share is the tariff deficit offset share, $100 \times (\varphi_c + \psi_c)$. "IO tables" uses round-trip intensities φ_c and ψ_c constructed from the ADB MRIO; "Census" uses the Census microdata, scaled to 2024 as explained in the text. "No round-trip" imposes $\varphi_c = \psi_c = 0$, so the offset share is zero and $\Delta D_c = \Delta M_c$. The aggregate offset share is $100 \times (1 - \Delta D / \Delta M)$.
Source: Authors' calculations using CMF, LFTTD, ADB MRIO, and the Trade War Tracker.

6 Conclusion

An extensive body of work documenting the characteristics of and trends in GVCs in the past two decades has been driven, in large part, by development of multi-country, multi-sector input-output tables. Yet, global value chains are inherently about firms and how

[27] For Canada, the ADB MRIO suggests a somewhat higher offset share (13.9%) than our Census-based measure (11.3%), likely because our Census measure captures only direct manufacturing linkages while the MRIO includes indirect multi-stage chains, and because our 2024 Census estimates are imputed from 2012 relationships while the MRIO uses 2024 data.

they organize production, including sourcing inputs from abroad and exporting products to a new market, across their establishments. Input-output tables by construction rely on the industry-level output, exports, and imports that aggregate out export and import intensities at the establishment level and rely on import proportionality assumption that ignores heterogeneity in input sourcing within sectors. Further, pairwise proportionality leads to positive GVC measures for all import-export country pairs even if true linkages do not exist. This paper replaces proportionality assumptions with direct establishment-level linkages to measure the imported content of exports.

We develop novel linkages between origin country-specific imported inputs embodied in an establishment's destination-specific manufactured exports. Our evidence suggests that in the absence of establishment-level linked data, U.S. GVCs would be under-estimated and their growth trends substantially muted. In addition, the round-trip effect is much weaker, and the trilateral RTA effect disappears, when bilateral GVCs are constructed from input-output tables. In other words, proportionality assumptions mask an important source of complementarity between input and output markets. Back-of-the-envelope estimates based on our findings show that tariffs are less effective at reducing bilateral trade deficits when applied to partners with whom the U.S. has deep round-trip integration such as regional trade agreement partners.

The establishment-level linkages between imports and material use and between exports and output provide a comprehensive picture of U.S. manufacturers' direct involvement in global value chains. However, a salient feature of modern manufacturing firms is their involvement in a substantial amount of non-manufacturing activities. Moreover, our linkages exclude indirect GVC connections of U.S. establishments through connections to other U.S. firms. This suggests that our current methodology, while comprehensively measuring direct foreign input sourcing by U.S. manufacturing plants, provides a lower bound on U.S. establishments' contributions to global value chains. We leave extending the micro data linkage methodology to encompass indirect linkages for future research.

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Appendix

A Constructing Establishment-Level GVC Measures

A.1 Sample Criteria

Given our focus on linking firms' trade flows to their production activities, our sample includes all establishments in the manufacturing sector with non-negligible manufacturing shares of activity in terms of employment and sales. Detailed information on products produced/shipped and materials consumed contained in the CMF product and material trailer files, respectively, are collected from establishments that receive a long form. About 60% of establishments, typically accounting for over 97% of value of shipments in the manufacturing sector, are sent a report form; and about 70% of these establishments receive a long form and the rest receive a short form (U.S. Census Bureau, 2002, 2007b, 2012, 2017).

The long forms contain a pre-populated list of (i) primary and secondary products and miscellaneous services specific to a group of related industries; and (ii) list of materials generally used in the production process specific to an industry. From the list of products, establishments are asked to identify the products, value of each product (and quantity of the product for select cases) shipped during the survey year. From the list of materials consumed, establishments are asked to identify those consumed and the associated cost (and quantity consumed for select cases) during the survey year. The short form requests summary products and materials data but not detailed categories which "would increase the value of the "not specified by kind" categories" (U.S. Census Bureau, 2007a).[28]

Table A1: Number of Firms and Establishments by Trader Type and Year

Trader Type	Year	Firms	Establishments
Non-Trader	2002	118,000	126,000
Non-Trader	2007	98,000	103,000
Non-Trader	2012	86,000	91,000
Non-Trader	2017	88,500	93,000
Exporter-Only	2002	11,000	14,000
Exporter-Only	2007	24,000	29,000
Exporter-Only	2012	21,000	25,000
Exporter-Only	2017	20,500	25,500
Importer-Only	2002	13,000	18,000
Importer-Only	2007	10,000	11,000
Importer-Only	2012	10,000	12,000
Importer-Only	2017	9,500	12,500
Exporter-Importer	2002	11,000	43,000
Exporter-Importer	2007	20,000	55,000
Exporter-Importer	2012	20,000	51,000
Exporter-Importer	2017	17,500	48,500

Notes: This table displays the number of firms and establishments in the sample by type of trader and year. Numbers may not sum to total due to rounding. Observation counts are rounded to comply with Census Bureau disclosure avoidance rules.
Source: Authors' calculations using CMF and LFTTD.

[28] This implies that imported inputs would be allocated using the indirect methodology discussed below.

About 40% of manufacturing establishments, which are small single-establishment firms, are not required to file a census report and instead basic information (e.g., receipts, payroll, location) on these firms is populated using administrative records. There is no information available on products produced/shipped and materials consumed for these establishments and we drop these administrative records.[29]

The number of firms and establishments in our analysis sample is reported in Table A1. There are 153,000, 152,000, 137,000, and 135,500 firms in 2002, 2007, 2012, and 2017 respectively; there are 201,000, 198,000, 179,000, and 179,500 manufacturing establishments in 2002, 2007, 2012, and 2017, respectively. Not surprisingly, non-traders account for the largest share of firms and establishments since trading is a high-fixed-cost activity. The number of exporter-only, importer-only, and exporter-importer firms is very similar at over 10,000 each. However, exporter-importer firms have more than double the number of establishments than the other two types of traders. This is consistent with the fact that exporter-importer firms tend to be larger, accounting for about half of economy-wide employment and over 60% of employment at large (employs over 500 workers) firms in the U.S. economy (Handley, Kamal and Ouyang, 2021).

We also document the number of six and four-digit manufacturing industries (based on NAICS) that firms operate in according to their goods trading status to demonstrate the pervasiveness of multi-sector goods traders. Table A2 shows that manufacturers that both export and import have very diverse industrial footprints operating in roughly 8 six-digit and 5 four-digit industries.

Table A2: Number of Manufacturing Industries by Trader Type and Year

Trader Type	Year	4-digit Industry	6-digit Industry
Exporter-Importer	2002	5.68	9.54
Exporter-Importer	2007	4.91	8.21
Exporter-Importer	2012	4.74	7.56
Exporter-Importer	2017	4.72	7.42
Exporter-Only	2002	1.13	1.26
Exporter-Only	2007	1.12	1.24
Exporter-Only	2012	1.11	1.18
Exporter-Only	2017	1.12	1.19
Importer-Only	2002	1.32	1.52
Importer-Only	2007	1.28	1.42
Importer-Only	2012	1.26	1.35
Importer-Only	2017	1.49	1.77
Non-Trader	2002	1.08	1.12
Non-Trader	2007	1.04	1.06
Non-Trader	2012	1.03	1.04
Non-Trader	2017	1.05	1.07

Notes: This table displays the weighted average number of 4- and 6-digit NAICS industries in the manufacturing sector that firms operate in where weights are the total value of shipments by type of trader and year.
Source: Authors' calculations using CMF and LFTTD.

[29]Dropping administrative records in the CMF is a common practice in empirical research e.g., Bernard, Jensen and Schott (2006); Kehrig and Vincent (2021); White, Reiter and Petrin (2018); Hsieh and Klenow (2009).

A.2 Aligning CMF Trailer Files and LFTTD Trade Data

For reporting establishments in the CMF-PROD and CMF-MAT, we perform two main cleaning steps. First, we identify and remove aggregator codes from the set of product codes associated with each establishment. Such codes may serve as aggregates of usable product codes (77100000), or serve as "balancer" codes to ensure that the sum of product-level shipments and materials matches the total value specified elsewhere in the survey.

A feature of the CMF-MAT trailer files is that a non-trivial share of value is associated with miscellaneous codes indicating products not specified in the pre-populated survey form. These "not elsewhere specified or indicated" (NESOI) codes account for approximately 20-30 percent of the industry total (in terms of value) in our sample years, and cannot be directly linked to product codes in the LFTTD. Table A3 reports the share of costs and shipments reported to be "not elsewhere specified" as part of either the CMF-MAT (Panel A) or CMF-PROD (Panel B), respectively. This share is quite low in the CMF-PROD.

Table A3: Value of "All Other" Products as Share of Costs/Shipments

	Share of Costs/Shipments
Panel A: Material Trailer File	
2002	30.9%
2007	28.1%
2012	21.6%
2017	33.3%
Panel B: Product Trailer File	
2002	0.4%
2007	0.3%
2012	0.3%
2017	0.5%

Notes: This table displays the value of manufactured products classified as "Not Elsewhere Specified or Indicated" (NESOI) as a share of total cost of materials (Panel A) or total value of shipments (Panel B).
Source: Authors' calculations using Economic Census publications (U.S. Census Bureau, 2024a).

Second, after removing aggregate and balancing codes, we concord the Census product codes from the trailer files to a NAICS-level code that can be matched to the HTS and Schedule B codes found in import and export data, respectively. We use the concordances in Pierce and Schott (2012) that match both Census product codes and HTS/Schedule B codes to a common NAICS-Baseroot product basis.[30] This is not a straightforward match since many Census product codes in the trailer files are not found in the concordance. We apply an iterative matching process. For Census product codes that do not match to a NAICS-Baseroot code at the most disaggregated level (i.e. if no match at the 7-digit level), we attempt to match at the next level of aggregation (i.e., 6-digit level) and impute a matching 7-digit-level and associated NAICS-Baseroot based upon the existing set of disaggregated (i.e., 7-digit) matches. We iterate up to the 4-digit level until we have matched all Census

[30]Indeed, the prospect of aligning LFTTD and material/product codes at the product level for manufacturing firms was one of the primary use cases outlined by Pierce and Schott (2012) in their description of this concordance.

product codes to NAICS-Baseroots.[31]

Finally, once imports, exports, material input usage, and production are all aligned on a common product classification (6-digit NAICS-Baseroot), we proceed to the core measurement challenges: identifying intermediate input imports and allocating those imports to individual establishments, and identifying exports that are manufactured by the establishment (production-associated exports) and allocating those exports to individual establishments.

A.3 Establishment-level Intermediate Imports

For an establishment e of firm f, we calculate a set of products identified as intermediate inputs based on the set of products specified as being used as inputs by the establishment in the CMF-MAT. The set of intermediate products $\mathcal{M}_{ef}$ of establishment e of firm f is defined such that $p \in \mathcal{M}_{ef}$ if $mc_{efp} > 0$, where mc_{efp} is the material cost of product p used by establishment e of firm f as identified in the CMF-MAT.

Applying this set of products to import data is complicated by the fact that the LFTTD exists at the firm level, and thus there is the possibility for input products to match to more than one establishment. Formally, we can describe this possibility using the following notation: $\exists$ a product p and establishments e and k such that $p \in \mathcal{M}_{ef}$ and $p \in \mathcal{M}_{kf}$. In these cases, we allocate imports based on the relative material costs as defined in the CMF-MAT. Hence, the first step in our construction of an establishment-level measure of intermediate input imports from country m can be summarized as:

$$IMP^{MAT}_{efm} = \sum_{p \in \mathcal{M}_{ef}} \frac{mc_{efp}}{\sum_{e,p \in \mathcal{M}_{ef}} mc_{efp}} Imp_{fpm} \tag{A1}$$

which takes firm level imports Imp_{fpm} of firm f of product p from country m and allocates them to establishments, as intermediate inputs provided $p \in \mathcal{M}_{ef}$ and using the shares of material costs of product p across all establishments of the firm f.

Since a non-trivial share of material inputs are reported under the NESOI category, imported inputs that are not directly matched to the materials reported by establishments may belong in this category. To account for this possibility, we proceed in two steps. First, we use the CMF-PROD and identify what are likely the set of produced (or, final goods) products for establishment e following Boehm, Flaaen and Pandalai-Nayar (2019). Formally, for an establishment e of firm f, we define the set of output products to be $p \in \mathcal{P}_{ef}$ if $prod_{efp} > 0$ where $prod_{efp}$ is the shipment value of product p by establishment e of firm f as identified in the CMF-PROD.

In the second step, we exclude products identified in the CMF-PROD from the list of imported products that are not explicitly identified as inputs of establishment e. The remaining set of imported products are most likely to be included in the NESOI category reported by the establishment in the CMF-MAT, and thereby classified as intermediate inputs.

One potential concern with our approach is the possibility that an establishment reports a particular product as both an input in production *and* an element of output, hence, residing

[31] Beginning in 2017, product information was collected and published on a North American Product Classification System or NAPCS basis in the Economic Census (U.S. Census Bureau, 2003). We use concordances between 2017 NAPCS and 2012 Census product codes (U.S. Census Bureau, 2022b). Census material codes remain unchanged over the sample period.

at the "diagonal" of an input-output table.[32] Such instances represent a relatively small share of material costs using our methodology—on average around 16 percent across the sample years.

Such overlap is lower than similar statistics in Antràs, Fadeev, Fort and Tintelnot (2024, Appendix Table A.8.). While a direct comparison is difficult because of numerous differences in sample construction, basis of calculation, etc., we identify in Table A4 two areas that are consequential for separating input vs output products.

First, Panel A of Table A4 shows how aggregation of product definitions affects the ability to distinguish inputs from outputs—the average of 16% cost overlap utilizing 6-digit level of product disaggregation in the CMF-MAT and CMF-PROD rises to nearly 45% when only accessing 3-digit product codes. Second, comparing Panels A and B of Table A4 reveals that aggregating to the firm-level is also associated with significantly higher overlap, more in line with what is shown in Antràs, Fadeev, Fort and Tintelnot (2024) which also uses a firm-level basis for their calculations. Nevertheless, while these "diagonal" cases would be captured as intermediate inputs under our current methodology, further research is warranted to better understand an establishment's production function when inputs and outputs match so precisely.[33]

Table A4: Overlap Between Input Products and Output Products

	Share of Input Codes Matching Product Codes (by value)			
	2002	**2007**	**2012**	**2017**
	Panel A: Establishment-level Match			
6-digit	14.5%	16.0%	14.5%	19.4%
4-digit	25.8%	28.7%	29.6%	29.0%
3-digit	44.5%	46.8%	45.0%	44.2%
	Panel B: Firm-level Match			
6-digit	34.0%	33.5%	28.7%	33.6%
4-digit	48.8%	47.6%	46.9%	44.1%
3-digit	60.9%	59.2%	58.5%	52.5%

Notes: This table calculates the overall fraction of the value of input costs in which the input product code matches to a produced product code of the same establishment or firm. The 6-digit row is the detail available in the trailer files; the 4 and 3-digit rows re-calculate this statistic under more aggregated industry classifications.
Source: Authors' calculations using CMF and LFTTD.

Once this residual set of imported products is constructed, we allocate these imported products across establishments within the firm. In the absence of any other information, we use the NESOI product code value for establishment e as a share of total NESOI values

[32]For example, Bernard, Fort, Smeets and Warzynski (2020) find that Danish firms that offshore, produce the same detailed products in both low-wage locations and the domestic market.

[33]For example, Cox (2026) creates detailed (HS6) steel-specific input-output tables using exclusion requests filed by U.S. importers in response to the 2018 U.S. steel tariffs. However, this level of detail is not available for all products.

of the firm, denoted as η_{ef}. Hence, our final estimate of intermediate imports for a given establishment e of firm f from country m is given by:

$$IMP^{I}_{efm} = IMP^{MAT}_{efm} + \sum_{p \notin \mathcal{M}_{ef} \cup \mathcal{P}_{ef}} \eta_{ef} Imp_{fpm}. \tag{A2}$$

Of the identified intermediate imports linked to establishments, around 54% of the value on average is allocated based on direct input matching as described in Equation A1, and the remaining are linked indirectly using the CMF-PROD as described in Equation A2. These statistics are shown across the sample years in Table A5. The notable increase in the share of imported inputs allocated via the indirect method is correlated with the decrease in the number of pre-populated material codes in the Census of Manufactures, which would lead respondents to report a larger share of material use under the NESOI category.

Table A5: Share of Imported Inputs Identified via Indirect Method

	Share of Total
2002	43.5%
2007	42.3%
2012	42.4%
2017	56.8%

Notes: This table displays the share of imports identified as inputs using the indirect method described in Equation A2.
Source: Authors' calculations using CMF and LFTTD.

It is important to highlight that the intermediate input share of imports in Table 1 is not directly comparable to the statistic in Johnson and Noguera (2012a): "[t]rade in intermediate inputs accounts for as much as two thirds of international trade." The difference is between the emphasis on the establishment or the product. The output products produced by an establishment may be used downstream in further production—and thereby be classified as an input on a product-level basis—but that product should be considered a final product from the perspective of the establishment. Thus, while there should be some degree of alignment between these two definitions of input trade, they need not be identical.

A.4 Production-Associated Exports

Using a similar approach as in Section A.3, we connect the production of a manufacturing establishment to its exports. The underlying challenge here is determining whether a firm engages in exports of a particular product that it did not produce in the United States. Exports of goods where the firm exports more than it produces is referred to as "carry-along trade" in the trade literature (Bernard, Blanchard, Beveren and Vandenbussche, 2018). Examples of this could be re-exports or otherwise utilizing the wholesale/distribution services of the firm to export products made outside of its U.S. manufacturing establishments (such as agricultural or mining products), or by another firm entirely.

We construct a set of products identified as being produced by the establishment in the CMF-PROD: a product p is in the set $\mathcal{P}_{ef}$, i.e., $p \in \mathcal{P}_{ef}$, if $prod_{efp} > 0$. Once again, the challenge is how to properly account for exports where multiple establishments of the same firm record the same product as being produced. Thus, in addition to specifying the establishment-specific list of products produced by the establishment, the exports need to be

allocated across establishments when multiple establishments of the same firm report producing a given product. Our establishment-level measure of production-associated exports is therefore:

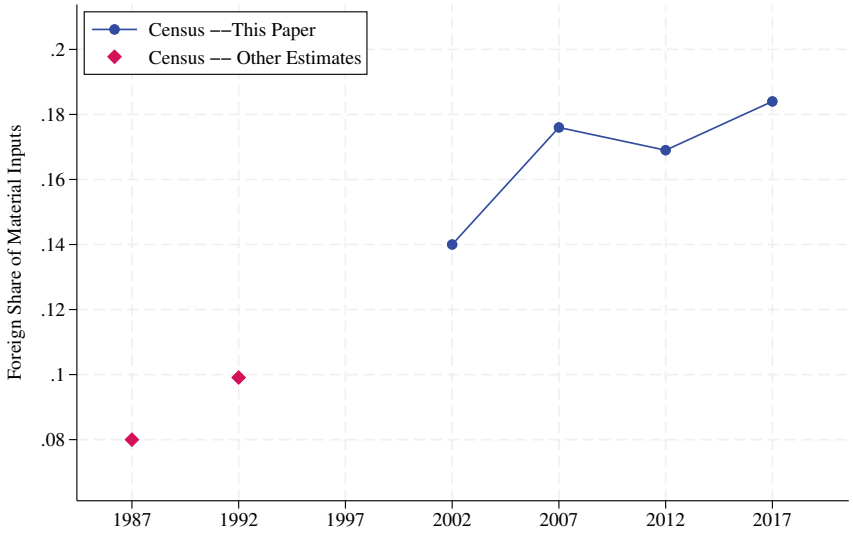
$$EXP_{efn}^{PROD} = \sum_{p \in \mathcal{P}_{ef}} \frac{prod_{efp}}{\sum_{e,p \in \mathcal{P}_f} prod_{efp}} Exp_{fpn}. \tag{A3}$$

B Additional Results

B.1 Share of Imported Inputs in U.S. Material Costs

A large literature measuring the extent of offshoring in U.S. manufacturing has focused on the share of material inputs sourced from abroad. Houseman, Kurz, Lengermann and Mandel (2011) describe how the increase of foreign-sourced inputs could lead to upward bias in manufacturing productivity statistics, as the price declines from foreign substitution are systematically under-measured due to outlet-substitution bias (when consumers shift their shopping from higher-priced to discount sources for the same product) in price index measurement. Several papers (including, for example Feenstra and Hanson (1996b), Feenstra and Hanson (1996a)) explore the specific role of outsourcing inputs abroad in labor market developments within the U.S. manufacturing sector.

Figure B1: The Foreign Input Cost Share in U.S. Manufacturing



Notes: This figure plots estimates of the foreign input cost share for U.S. manufacturing.

Source: Authors' calculations using CMF and LFTTD (blue line) and Berman, Bound and Griliches (1993) and Kurz (2006) (red diamonds).

Despite the importance of this statistic, the data limitations identified in this paper have made it difficult to quantify this basic measure of the dependence of U.S. manufacturers on foreign inputs. The blue line in Figure B1 represents new estimates of this statistic for years 2002-2017, while the red diamonds display estimates for 1987 (Berman, Bound and Griliches, 1993) and 1992 (Kurz, 2006).[34] Our establishment-level linkages indicate that foreign sources of material costs increased during the sample period, most notably between 2002 and 2007.

[34]The 1987 and 1992 CMF included a question on the cost of the foreign content of materials used in

B.2 Bilateral GVC by Sector

Specific sectors within manufacturing reveal a richer portrait of the countries that are connected through global value chains in the United States. The top ten country-pair links for a select few sectors are shown in Table B1. For example, in the Pharmaceuticals sector, Ireland is the top input source for all top ten bilateral country-pairs, with imported inputs from Ireland linked to exports to a wide range of countries in Asia, Europe, and South America.

The patterns for the three other sectors also illustrate well-known features of industry linkages. For machinery and equipment, the top bilateral country pairs reflect U.S. exports to Canada that rely on established manufacturing centers (Mexico, Germany, Japan, and Canada itself). Other top bilateral pairs link exports in the machinery and equipment sector to Australia via inputs from Canada and Mexico.

For motor vehicles and parts, USMCA countries naturally play a dominant role, with Mexico-Canada, Mexico-Mexico, and Canada-Canada occupying the top three positions. The impact of non-US automakers is evident as well, as inputs from Japan, Germany, and South Korea are connected to exports to Canada through U.S. operations. These are further direct evidence of how foreign direct investment (FDI), and, specifically, export-platform FDI, can influence patterns of global value chains (e.g., Tintelnot, 2016; Antràs, Fadeev, Fort and Tintelnot, 2024).

For "Other Transport Equipment", the patterns also align with expectations, with a few surprises along the way. Two round-trip bilateral pairs—France-to-France and Japan-to-Japan—occupy the top two ranks, with links between import sources from Japan, Canada, and the United Kingdom with exports to France also in the top ten. More surprising are imported inputs from Japan and the United Kingdom with the United Arab Emirates being prominent country-pair links. More generally, a striking feature of bilateral GVC links in other transport equipment is how distant the value chains are: nine of the top ten bilateral pairs would need to make two ocean crossings as part of the value chain moving from the source country, to the United States, and then to the destination country.

production. The question asked: "Does this establishment use materials purchased or transferred from foreign sources?".

Table B1: Top GVC Country Pairs in Selected Manufacturing Sectors, 2012

Source	Destination	GVC Share in Exports	
		Total	By Destination
	Pharmaceuticals		
Ireland	Italy	0.69%	11.04%
Ireland	Japan	0.39%	4.61%
Ireland	Belgium	0.38%	4.96%
Ireland	South Korea	0.31%	16.07%
Ireland	France	0.30%	5.05%
Ireland	Ireland	0.27%	9.74%
Ireland	Canada	0.25%	2.69%
Ireland	Brazil	0.15%	5.69%
Ireland	Mexico	0.13%	3.89%
	Machinery and Equipment		
Mexico	Canada	0.19%	0.91%
Canada	Canada	0.17%	0.82%
Germany	Canada	0.15%	0.75%
Japan	Canada	0.14%	0.68%
China	Canada	0.11%	0.54%
Mexico	Mexico	0.11%	1.00%
United Kingdom	Canada	0.10%	0.48%
Mexico	Australia	0.10%	1.72%
Mexico	Germany	0.10%	3.17%
Canada	Australia	0.09%	1.56%
	Motor Vehicles and Trailer		
Mexico	Canada	1.18%	2.73%
Mexico	Mexico	1.15%	5.95%
Canada	Canada	0.75%	1.73%
Japan	Canada	0.67%	1.54%
Germany	Mexico	0.34%	1.78%
Canada	Mexico	0.34%	1.74%
Japan	Mexico	0.22%	1.13%
Germany	Canada	0.22%	0.50%
Germany	Germany	0.17%	3.09%
South Korea	Canada	0.16%	0.37%
	Other Transport Equipment		
France	France	0.23%	3.29%
Japan	Japan	0.22%	2.88%
Japan	United Arab Emirates	0.19%	2.90%
Japan	China	0.19%	2.68%
Japan	France	0.16%	2.28%
Canada	France	0.14%	2.04%
United Kingdom	France	0.14%	2.00%
France	Brazil	0.13%	2.27%
United Kingdom	United Arab Emirates	0.11%	1.70%
France	Japan	0.11%	1.46%

Notes: The first two columns in this table display the top import and export country pairs, by bilateral GVC (measured in Equation (5), for select industries in the U.S. manufacturing sector. The last two columns display bilateral GVC as a share of overall industry exports ("Total") and as a share of industry exports by the destination ("By Destination"), respectively.
Source: Authors' calculations using CMF, LFTTD, and USA Trade Online (U.S. Census Bureau, 2024b).

B.3 Comparing Census and WIOD Measures of Input Costs

B.3.1 Sectoral Imported Input Cost Shares by Source

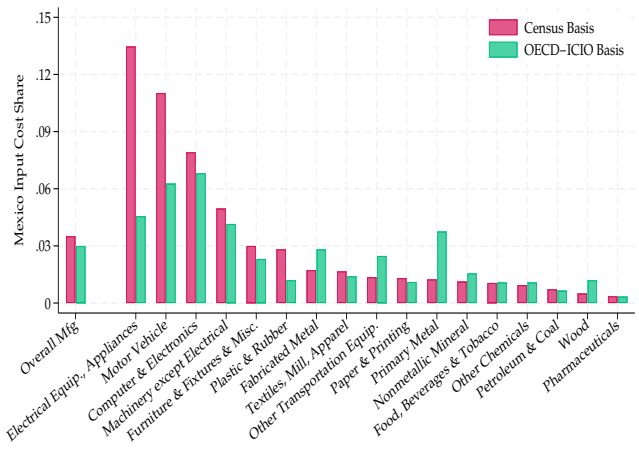
We compare the imported input cost shares for the manufacturing sector, derived from establishment-level linked data from the Census, to those derived from the WIOD. The Census-based estimates (shown in Figure B1) show a steady increase in the usage of foreign inputs through 2007, followed by a leveling off in 2012 and 2017. This contour is broadly similar to what one would obtain from the WIOD (not shown), though the level in WIOD is typically a few percentage points lower.

Next, we examine country-specific input shares. Motivated by the changes in U.S. trade policy with Mexico and Canada in the first part of 2025, we explore the dependence of U.S. manufacturers on inputs sourced within North America. In Figure B2, we plot the fraction of Mexican and Canadian input costs in total material input costs across all broad manufacturing industries—shown in (a) and (b), respectively—using newly created links from Census data (red bars) and compare them to analogous estimates derived from the OECD-ICIO (green bars), using data from 2017.[35]

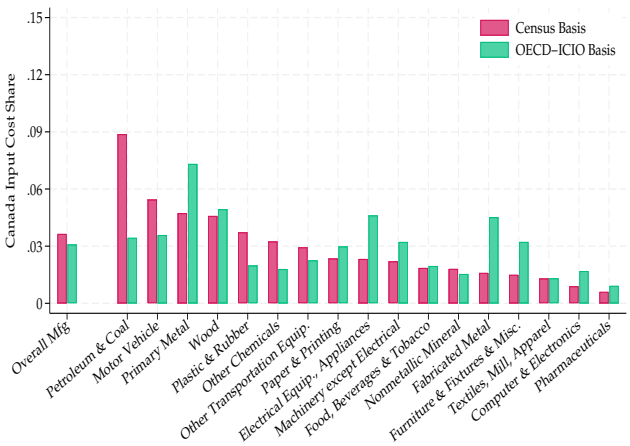
Based on the Census estimates, Mexican imported inputs represent 3.5% and Canadian imported inputs represent 3.7% of total cost of materials in the manufacturing sector. However, reliance on North American inputs varies widely by industry. "Electrical Equipment & Appliances" (13%), "Computer & Electronics" (11%), "Motor Vehicles" (8%), and "Machinery & Equipment" (5%) have Mexican input shares that are higher than the Mexican share in overall manufacturing; while "Petroleum and Coal" (9%), "Motor Vehicles" (5%), "Primary Metals" (5%), "Wood" (5%), and "Plastic & Rubber Products" (4%) have Canadian input shares that are higher than the Canadian share in overall manufacturing. These statistics confirm that North America plays a key role as a source of foreign inputs.

Figure B2: North American Input Cost Share in U.S. Manufacturing, 2017

(a) Mexican Input Cost Share



(b) Canadian Input Cost Share



Notes: This figure displays inputs imported from (a) Mexico and (b) Canada as a share of material costs in U.S. manufacturing industries.

Source: Authors' calculations using CMF, LFTTD, OECD-ICIO.

[35] We use OECD-ICIO for this comparison because the latest available year in the WIOD is 2014.

While the Canadian and Mexican input cost shares for overall manufacturing are similar between Census-based and OECD-ICIO-based measures, with a slight underestimation in the OECD-ICIO-based ones, their distribution across industries differs significantly.

The industry-level differences between our Census estimates and OECD-ICIO highlight the potential role of biases arising from import proportionality assumptions embedded in multi-country input-output tables along with other measurement issues.[36] Figure B2, thus, illustrates that a picture of the dependence of U.S. manufacturers on North American inputs derived from firm-level information compared to more aggregate tables could lead to both under- and over-estimation of the exposure of manufacturing industries to trade policy-induced cost shocks.

B.3.2 Census vs. WIOD Imported Input Cost Shares by Industry: Correlations

To assess the implications of the import proportionality assumption operative in the country import cost shares, we report a summary of the alignment between Census estimates and WIOD estimates in Table B2, using simple correlations across country shares for given industries.[37] For manufacturing as a whole, the correlation is 0.64 – a strong positive correlation indicating that the WIOD and its inherent proportionality assumption do indeed capture significant features of U.S. global value chains. Nonetheless, a correlation well below 1 reveals that there are patterns in foreign input sourcing that are not well-represented by the import proportionality assumption. All broad industries within manufacturing show a correlation well above zero. High correlations above 0.9 are seen in sectors such as "Basic Metals" and "Motor Vehicles and Trailers"; the correlation is lowest at 0.3 for "Pharmaceuticals".[38]

Delving deeper into the potential sources of mis-alignment in column 1 of Table B2, Figure B3 plots the country sources of foreign inputs for Pharmaceuticals (NAICS 3254, Panel A) and Basic Chemicals excluding pharmaceuticals (NAICS 325X, Panel B). What is immediately evident in Panel A of Figure B3 is the role that Ireland plays in the mis-measurement of foreign inputs for the Pharmaceutical sector: the Census-based measure records Ireland occupying nearly 8 percent of material input costs, whereas the WIOD has Ireland's share at less than 1 percent.[39] One can see the opposite pattern in the Basic Chemicals sector—a feature which likely reflects the proportionality assumption pushing too many Irish imports into inputs in basic chemicals rather than into inputs in pharmaceuticals.[40] The outsized role of Ireland in pharmaceuticals trade—as well as for producing measurement headaches in international statistics—has been well-documented (Setser, 2019).[41]

[36] Discrepancies could be a result of our methods of classifying imports into intermediate inputs, or how country-specific inputs are assigned to non-manufacturing sectors in multi-country input-output tables.

[37] Imported input cost share measured as $IC_{st} = \frac{\sum_{e \in E_{st}} IMP^I_{est}}{\sum_{e \in E_{st}} mc_{est}}$, which we replicate using the WIOD. Without information on E_{st} in the WIOD, we use imports and material costs for each industry s as reported in the WIOD.

[38] Our finding of a correlation of 0.64 across (roughly) three-digit NAICS industries is very close to the correlation found in Feenstra and Jensen (2012) for the year 1997, suggesting that the scope for errors in proportionality has remained somewhat stable over time, at least in the United States.

[39] Ireland is the top input source for all top ten bilateral country-pairs in the pharmaceutical sector (Table B1).

[40] The relative magnitudes are also sensible, as published data indicate that basic chemicals record nearly eight times as much material input costs as pharmaceuticals.

[41] One might worry particularly about the final vs intermediate goods classification in the pharmaceutical sector, and similarly, how the U.S. territory of Puerto Rico is recorded in the data. On the former point, we

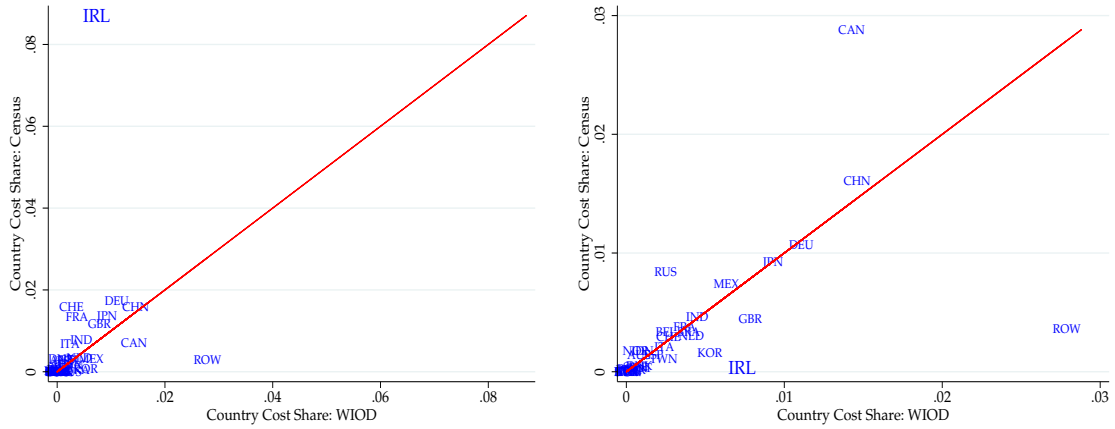
Table B2: Census-WIOD Correlations of Input Costs by Sector, 2012

Broad Manufacturing Sector	Input Costs
Food, Beverage, and Tobacco	0.83
Textiles, Apparel, Leather	0.67
Wood and Wood Products	0.87
Paper and Paper Products	0.81
Printing	0.73
Coke and Petroleum Products	0.68
Pharmaceutical	0.30
Chemicals and Chemical Products	0.62
Rubber and Plastics	0.67
Non-metallic Mineral Products	0.86
Basic Metals	0.94
Fabricated Metal Products	0.79
Machinery and Equipment	0.87
Computer, Electronic and Optical	0.62
Electrical Equipment	0.75
Motor Vehicles and Trailers	0.90
Other Transport Equipment	0.85
Furniture and Other Mfg	0.58
Overall Manufacturing	**0.64**

Notes: This table displays correlations, by broad sector, between Census-based and WIOD-based measures of imported input costs.
Source: Authors' calculations using CMF, LFTTD, and WIOD.

Figure B3: Mis-Alignment Between WIOD and Census Measures of Foreign Input Shares

(a) Pharmaceutical (NAICS 3254) (b) Basic Chemicals (NAICS 325X)



Notes: These figures display the foreign cost share of material inputs by source country within broad sectors. The red lines are at the 45 degree line, indicating perfect country-level alignment between sources.
Source: Authors' calculations using CMF, LFTTD, and WIOD.

manually re-coded any imported product beginning with "30." ("Pharmaceuticals") in the HS schedule to be a final good provided the establishment is in the pharmaceutical sector. On the latter point, we exclude

B.4 Assessing Biases in GVC Measurement from Industry Mis-classification

We highlight the role of industry mis-classification that arises due to the prevalence of multi-industry firms that mediate the vast majority of goods trade.

B.4.1 The Role of Primary Industry Definition

Establishments may not be the primary economic unit in all statistical collections that would correctly capture the heterogeneity in firms' activities across sectors. For example, statistical collections in many countries only collect input and output information at the level of the firm's main industry (e.g., Belgium studied by Bems and Kikkawa (2021)). If firms are only required to report a primary industry, it could bias GVC measures.

To explore the extent and direction of bias in GVC measurement due to industry mis-classification, we start with the establishment level information and define s as the primary sector of the firm. A primary sector is defined as the sector accounting for the highest share of the firm's payroll.[42]

We construct an analog of gvc_t^I except that we use the definition of sector based on firms' primary industries as follows:

$$gvc^{I\star}{}_t = \frac{\left[\sum_{f,e,s^\star} EXP_{fes^\star t} \frac{\sum_{f,e,s^\star} IMP^I_{fes^\star t}}{\sum_{f,e,s^\star} GO_{fes^\star t}}\right]}{\sum_{f,e,s^\star} EXP_{fes^\star t}}. \tag{A4}$$

A priori, the direction of the measurement bias introduced by using the primary industry of the firm is not obvious and is an empirical question. At the national level, we find that $gvc^{I\star}{}_t$ is 10% in 2002 and 13% in 2007 and 2012, aligning very closely with gvc_t^I.

However, the aggregate statistics mask variation in both levels and trends within sub-sectors as displayed in Figure B4 where $gvc^{I\star}{}_{st}$ is in red and gvc^I_{st} is in blue. GVC measures for Food, Furniture, Plastic and Rubber, Motor Vehicle, and Textiles are less sensitive to the choice of industry definition in both level and trend. While both measures track closely in levels over 2002 and 2007 for Computer and Electronics, Fabricated Metal, Machinery, Non-metallic Mineral, Paper, Pharmaceuticals, Primary Metal, Printed Matter, and Wood, they diverge in 2012. For the other three sub-sectors (Chemicals, Electrical Equipment, Petroleum and Coal, Transportation Equipment), broadly, the two measures track in terms of trend but differ in level.

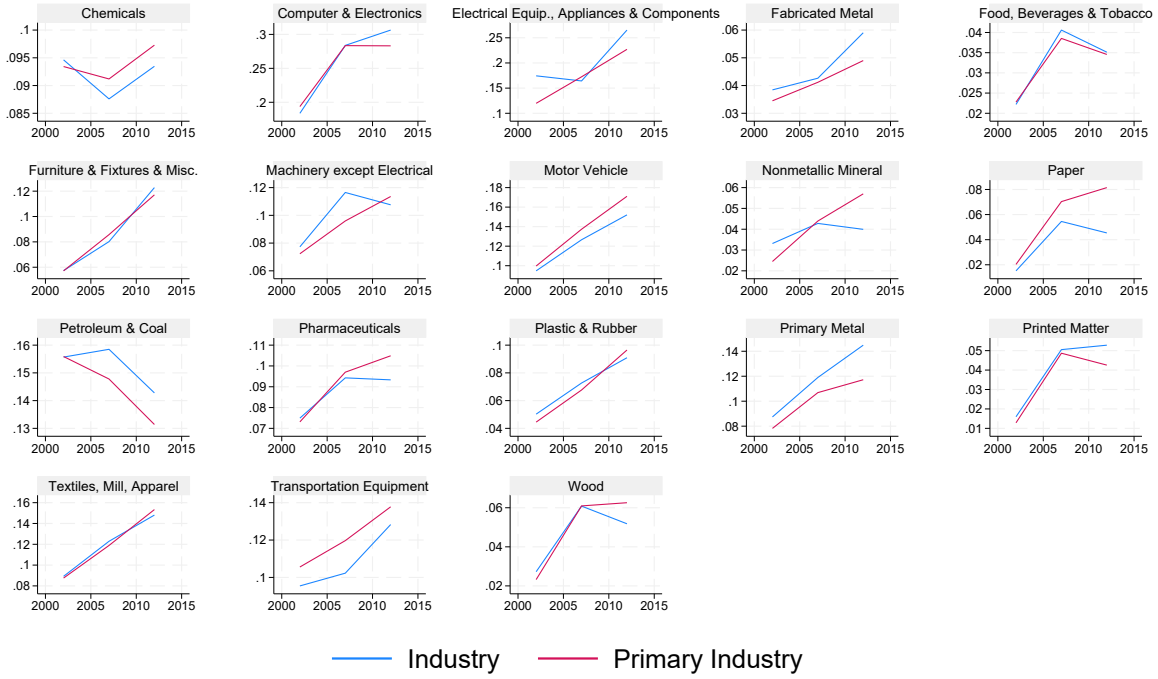
B.4.2 The Role of Establishment versus Firm-Industry Aggregation

If a firm is the most disaggregated economic unit in a statistical collection, even when industry is reported on the basis of its establishments' activities, GVC measures constructed from firm-industry data may suffer from aggregation bias. To explore the extent of aggregation bias due to ignoring establishment level heterogeneity, but not suffering from industry mis-classification, we aggregate across all establishments in a given sub-sector s for firm f

any import transactions in the LFTTD that list Puerto Rico as the district of entry.

[42] We create payroll shares by each 6-digit industry of the firm.

Figure B4: Comparison of gvc_t^I and $gvc^{I\star}{}_t$, 2002, 2007, 2012



Notes: This figure plots GVC for 3-digit manufacturing sectors. "Industry" defined in Equation 3 and "Primary Industry" defined in Equation A4.
Source: Authors' calculations using CMF and LFTTD.

to create a firm-industry based measure of sectoral GVC as follows:

$$gvc_{st}^F = \frac{1}{\sum_{f,e} EXP_{fest}} \sum_f \left[\sum_e EXP_{fest} \frac{\sum_e IMP_{fest}^I}{\sum_e GO_{fest}} \right]. \tag{A5}$$

We find that the average absolute difference between gvc_{st}^E and gvc_{st}^F across sectors is very small (0.005) and the correlation is very high (0.97).[43] This suggests that industry misclassification is a more important source of bias than availability of firm-industry information only in GVC measurement.

[43]The results are available upon request.

C RTA Data

Table C1 displays the set of bilateral and trilateral RTAs used in the analysis.

Table C1: Regional Trade Agreement Country Pairs (2017)

Panel A: RTAs with the United States (2017)

All bilateral pairs of the below form RTAs each with the U.S.

Australia	Israel
Bahrain	Jordan
Canada	Mexico
Chile	Morocco
Colombia	Nicaragua
Costa Rica	Oman
Dominican Republic	Panama
El Salvador	Peru
Guatemala	Singapore
Honduras	South Korea

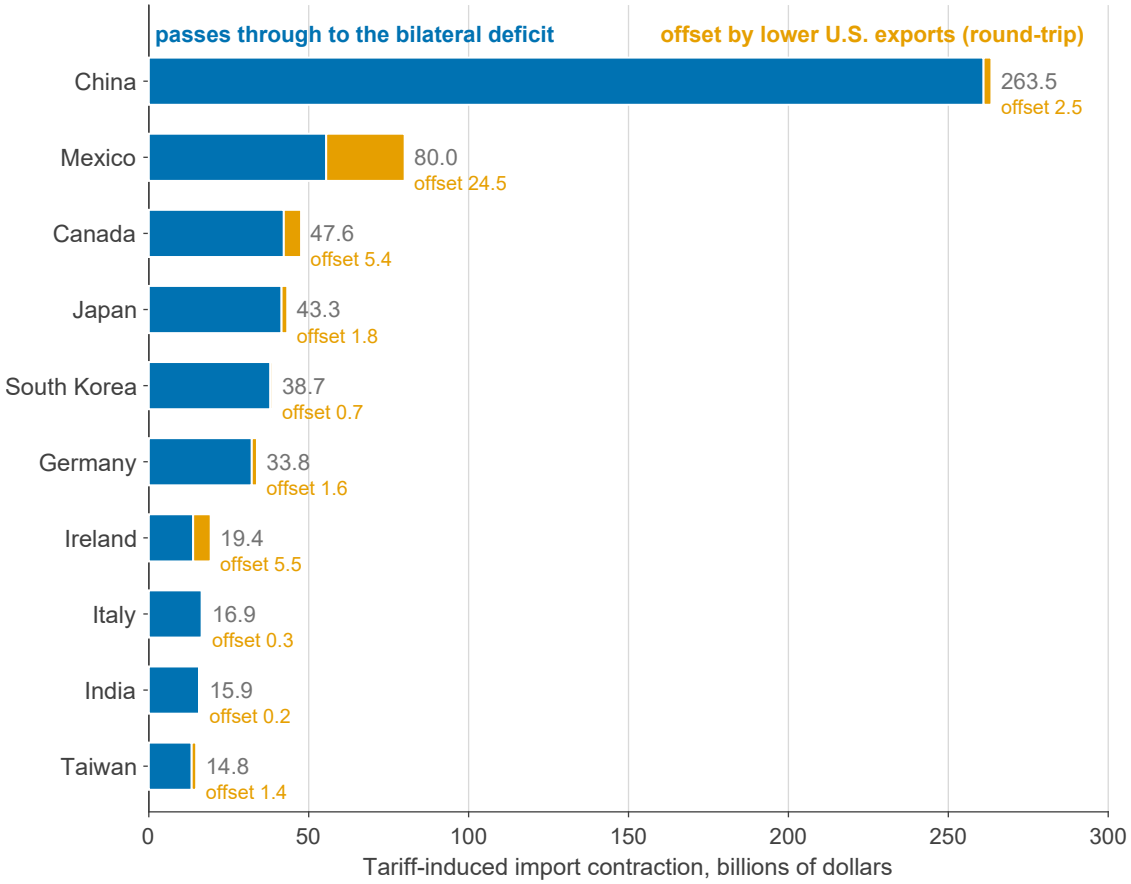
Panel B: Country-pairs where all three (including U.S.) are under an RTA (2017)

AUS-CHL	COL-SLV	ISR-CAN	OMN-SGP
AUS-KOR	CRI-CAN	ISR-MEX	PAN-CAN
AUS-SGP	CRI-CHL	JOR-BHR	PAN-CHL
BHR-JOR	CRI-DOM	JOR-CAN	PAN-CRI
BHR-MAR	CRI-GTM	JOR-MAR	PAN-HND
BHR-OMN	CRI-HND	JOR-OMN	PAN-MEX
BHR-SGP	CRI-MEX	JOR-SGP	PAN-PER
CAN-CHL	CRI-NIC	KOR-AUS	PAN-SGP
CAN-COL	CRI-PAN	KOR-CAN	PAN-SLV
CAN-CRI	CRI-PER	KOR-CHL	PER-CAN
CAN-HND	CRI-SGP	KOR-PER	PER-CHL
CAN-ISR	CRI-SLV	KOR-SGP	PER-COL
CAN-JOR	DOM-CRI	MAR-BHR	PER-CRI
CAN-KOR	DOM-GTM	MAR-JOR	PER-HND
CAN-MEX	DOM-HND	MAR-OMN	PER-KOR
CAN-PAN	DOM-NIC	MEX-CAN	PER-MEX
CAN-PER	DOM-SLV	MEX-CHL	PER-PAN
CHL-AUS	GTM-CHL	MEX-COL	PER-SGP
CHL-CAN	GTM-COL	MEX-CRI	SGP-AUS
CHL-COL	GTM-CRI	MEX-GTM	SGP-BHR
CHL-CRI	GTM-DOM	MEX-HND	SGP-CHL
CHL-GTM	GTM-HND	MEX-ISR	SGP-CRI
CHL-HND	GTM-MEX	MEX-NIC	SGP-JOR
CHL-KOR	GTM-NIC	MEX-PAN	SGP-KOR
CHL-MEX	GTM-SLV	MEX-PER	SGP-OMN
CHL-NIC	HND-CAN	MEX-SLV	SGP-PAN
CHL-PAN	HND-CHL	NIC-CHL	SGP-PER
CHL-PER	HND-COL	NIC-CRI	SLV-CHL
CHL-SGP	HND-CRI	NIC-DOM	SLV-COL
CHL-SLV	HND-DOM	NIC-GTM	SLV-CRI
COL-CAN	HND-GTM	NIC-HND	SLV-DOM
COL-CHL	HND-MEX	NIC-MEX	SLV-GTM
COL-GTM	HND-NIC	NIC-SLV	SLV-MEX
COL-HND	HND-PAN	OMN-BHR	SLV-HND
COL-MEX	HND-PER	OMN-JOR	SLV-NIC
COL-PER	HND-SLV	OMN-MAR	SLV-PAN

Notes: This table identifies the country pairs that satisfy the RTA (m & US, n & US) indicator (Panel A) and RTA (m, n, US) indicator (Panel B) used in the analysis.

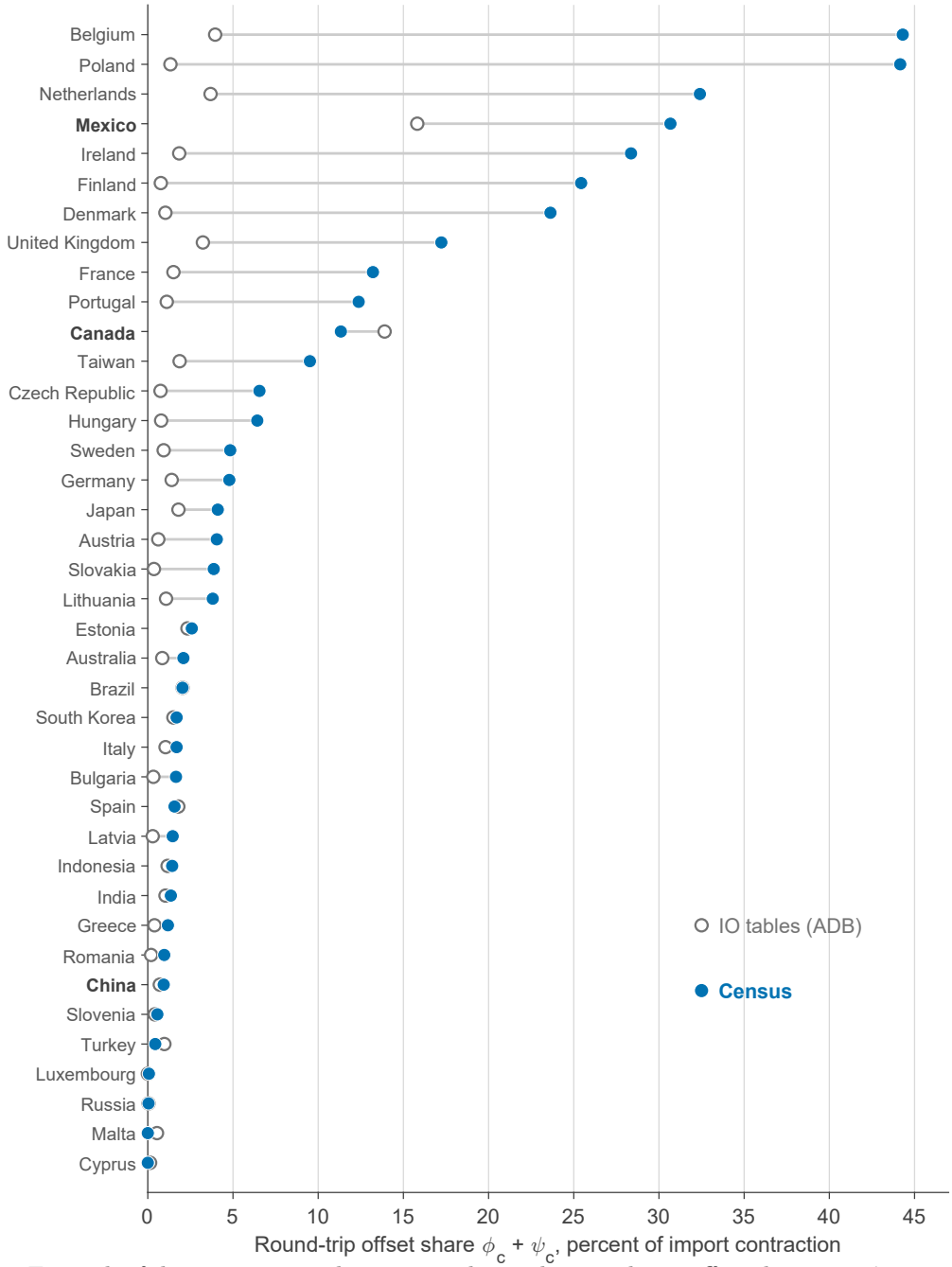
D Additional Figures from the Tariff-Deficit Exercise

Figure D1: Decomposition of the Tariff-Induced Import Contraction
Top 10 Import Sources



Notes: The ten largest 2024 U.S. import sources, sorted by the size of the import contraction. Each bar is the tariff-induced import contraction $|\Delta M_c|$ under the actual 2025 tariff shocks with $\varepsilon = 2$, split into the deficit response $|\Delta D_c|$ and the export offset $(\varphi_c + \psi_c)|\Delta M_c|$, using Census-based round-trip measures. Dollar values in billions.
Source: Authors' calculations using CMF, LFTTD, ADB MRIO, and the Trade War Tracker.

Figure D2: Round-Trip Offset Shares: IO Tables vs. Census Microdata



Notes: For each of the 39 partners, the open marker is the round-trip offset share $\varphi_c+\psi_c$ constructed from the ADB MRIO and the filled marker is the Census-based measure; partners are sorted by the Census value.

Source: Authors' calculations using CMF, LFTTD, ADB MRIO, and WIOD.