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

Aaron Flaaen
Federal Reserve Board

Fariha Kamal
U.S. Census Bureau

Eunhee Lee
Seoul National University

Kei-Mu Yi
FRB Dallas, University of Houston and NBER

September 2024

Abstract

Global value chains (GVC) are a pervasive feature of modern production, but they are hard to measure. We develop novel linkages between U.S. manufacturing establishments' imports and exports using microdata and document three new patterns in U.S. manufacturers' GVCs. First, we find that for every dollar of exports, imported inputs represent 13 cents in 2002 and over 20 cents by 2017, substantially higher than what aggregate data suggests. Second, we find strong complementarities between input and output markets reflected in "round-trip" trade linkages where an establishment sources inputs from and exports output to the same country. Third, we find a strong positive association between regional trade agreements and GVC trade flows. We further document that the presence of aggregation bias and import proportionality assumption in global input-output tables would substantially mute these relationships. Finally, we show that the "round-trip" results are consistent with the presence of firm-country-specific fixed costs with an idiosyncratic adjustment factor that is low when the source and destination countries are the same.

JEL codes: F1, F14, O51
Keywords: global value chains, manufacturing, exports, imports, establishment, microdata

*Any opinions and conclusions expressed herein are those of the authors and do not represent the views of the U.S. Census Bureau, the Federal Reserve Bank of Dallas, the Board of Governors of the Federal Reserve System, or their research staff. The Census Bureau has reviewed this data product to ensure appropriate access, use, and disclosure avoidance protection of the confidential source data used to produce this product. This research was performed at a Federal Statistical Research Data Center under FSRDC Project Number 2631 (CBDRB-FY23-0248, CBDRB-FY24-P2631-R11288, CBDRB-FY24-P2631-R11530). We thank Rudolfs Bems, Andy Bernard, Xiang Ding, Teresa Fort, Ken Kikkawa, Guillermo Noguera, T. Kirk White, and conference participants at the Dallas Fed, Census Bureau, Cowles Foundation, SEM, SED, FSRDC, Hitotsubashi-Gakushuin, Erasmus U., GEN, KATIS, NBER SI CRIW, Syracuse U., and U. of Rochester for their valuable comments. Spencer Bowdle, Grace Ozor, and Lauren Spits provided excellent research assistance.

1 Introduction

The ongoing U.S.-China trade war, the COVID-19 pandemic, Russia's invasion of Ukraine, and rising geopolitical tensions are just the latest examples of global shocks that alter prices, employment, income, and output in countries around the world. Understanding and evaluating the consequences of these shocks at both the micro and macro levels are essential for designing and implementing appropriate policies to mitigate and offset negative impacts. An increasingly important element in any such analysis is the propagation of these shocks to other countries through global value chains.

This paper argues that the appropriate foundation of global value chain (GVC) measurement is connecting imported inputs, output, and exports to individual establishments.[1] Existing research relies primarily on multi-country input-output tables that connect national input-output matrices to international trade flows. Remarkable measurement achievements in their own right, such industry-level tables have been invaluable in providing a portrait of the growth in GVCs across time and space, and in helping calibrate models with intersectoral linkages across countries. However, these aggregate resources for monitoring GVCs may provide an incomplete view of global production arrangements for two main reasons. First, integrating domestic input-output across countries relies heavily on proportionality assumptions—allocating an industry's input use as proportional to the economy-wide import share—which may distort the true industry-level exposure to foreign sources of inputs. Second, the use of industry-level data may result in aggregation bias, as the establishment-level connections of exporting and importing are replaced by industry-level assumptions, distorting the overall degree of vertical specialization, or the true picture of a particular value chain connecting an import source country to an export destination. Combined, these industry-level assumptions can lead to a biased assessment of how GVCs evolve over time and of the key determinants of GVC exposure.

Relaxing these assumptions requires establishment-level GVC measurement, but data limitations have constrained efforts to connect import and export transactions to actual production activities. In the context of the United States, goods trade transactions are collected at the firm level and do not specify the intended use of imports or whether exports were produced by the exporter of record. This complicates classification of imports as intermediate inputs and classification of exports as manufactured output. The out-sized role of multi-industry firms in U.S. goods trade further complicates ascertaining imported input

[1]The conceptualization of GVC adopted in this paper follows Hummels, Ishii and Yi (2001): a good 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. Antrás (2020) provides a generalized definition of GVCs along similar dimensions as "a series of stages involved in producing a product or service that is sold to consumers, with each stage adding value, and with at least two stages being produced in different countries".

use and production of exports at individual establishments that are the most dis-aggregated statistical unit of production. We address these well-known measurement challenges by, respectively, linking U.S. firms' exports and imports to their establishment's output and material use.

We measure the source-specific imported input content of an establishment's destination-specific exports in 2002, 2007, 2012, and 2017 by combining two confidential, micro-level datasets maintained by the U.S. Census Bureau. First, the Longitudinal Firm Trade Transactions Database (LFTTD) contains the universe of goods export and import flows for individual U.S. firms (Bernard, Jensen and Schott, 2009; Kamal and Ouyang, 2020). Second, the Census of Manufactures (CMF) contains detailed information on establishment-by-product-level output and input use (U.S. Census Bureau, 2022c) that underlie the U.S. input-output tables (U.S. Bureau of Economic Analysis, 2009). We link the products imported by a firm in the LFTTD to the products reported as inputs by its manufacturing establishment in the CMF. Similarly, we link products exported by a firm in the LFTTD to the products reported as produced or shipped by its manufacturing establishment in the CMF. Overall, our linking methodology identifies about 60 percent of a firm's imports as inputs used in production by its establishments, and about 70 percent of a firm's exports as manufactured by its establishments.

We begin by documenting GVCs for the overall U.S. manufacturing sector constructed by summing up the establishment-level GVC measures normalized by total manufacturing exports. We find that the imported input content of U.S. manufactured exports steadily increases between 2002 and 2012 with slower growth through 2017. Specifically, for every dollar of manufactured exports, imported inputs represented 13 cents in 2002 and 20 cents by 2017. We also document heterogeneity across industries and over time. For example, the imported input content of exports in the motor vehicle industry increased steadily from about 10 to 25 cents from 2002 to 2017; the electrical equipment and machinery industry shows a more dramatic increase of a more than a quadrupling between 2007 and 2017 to exceed 80 cents in 2017.

Next, we aggregate our establishment-level GVC measure to the source country–U.S.–destination country level to study the role of frictions and policy in these multi-country linkages in a gravity framework. This measure of trade flows within GVCs involve three, not the usual two, countries typically studied in gravity settings and thus provides an opportunity to evaluate the role of multiple measures of frictions, as proxied by estimates of distance. First, the combined distance between the input source country to the United States, and then from the United States to the destination country of exports, captures barriers to the physical flow of goods in value chain. Second, the direct distance from the input source country to the export destination country may reflect coordination costs of the overall production flow. Finally, magnitudes of trade flows within GVCs may be uniquely affected by the special case

of round-trip production—i.e., when the input source and export destination country is the same.

Gravity estimation results pooling all four years and exporter-year and importer-year fixed effects reveal the relative importance of the combined, direct, and round-trip distance measures. Increases in combined distance, as well as direct distance, are associated with significantly reduced GVC trade flows with the most stark result for the round-trip case. All else equal, the presence of round-trip production is associated with 3.7 times higher GVC flows. This is consistent with strong complementarity effects between source and destination countries in the supply chain.

Our framework allows a unique perspective on the well-studied role that policy plays–specifically, the role of regional trade agreements (RTAs)—in the formation of GVCs. Unlike prior work on this topic, we can examine all combinations of regional trade agreements among the source-U.S.-destination countries in a value chain. We find that bilateral RTAs between the United States and the input source country, and between the United States and the export destination country, are associated with 22 percent higher GVC flows, all else equal. A trilateral RTA between all three countries raises GVC trade by 55 percent, all else equal. Strikingly, even in the presence of RTAs, the round-trip indicator remains both economically and statistically significant, suggesting that the complementarity between source and destination countries extends beyond the effects of trade policy coordination.

We show that without the novel establishment-level linkages developed in this paper, U.S. trade within GVCs would be underestimated and the round-trip effect would be significantly muted, driven primarily by biases due to aggregation and import proportionality assumption, respectively. Aggregation may lead to downward (upward) bias in GVC measurement if establishment-level import and export intensities are positively (negatively) correlated. We document evidence of downward aggregation bias—our establishment-level measures aggregated to the industry level are significantly higher than an industry-level measure constructed from standard input-output table assumptions.[2]

Import proportionality assumes that an industry's imports of an input, relative to its total demand, is the same as the economy-wide imports of the input relative to total demand (e.g., imports of steel from Brazil are allocated to steel-using industries in the same proportion as the overall allocation of imported steel to steel-using industries). This assumption is commonly used to construct national input-output tables when industry-specific input source country information is not readily available. Proportionality, by its nature, generates "smoothing" in GVC measures. For example, under proportionality, as long as total imported inputs by a U.S. sector and exports from that sector are positive, the GVC measure at the sector-level will be positive for *all* import-export country-pairs. However, with our

[2]Flaaen, Kamal, Lee and Yi (2024) show that the aggregation bias is growing over time and driven by increase in export and import intensity at the establishment-level.

newly constructed establishment-level linkages, we show that in several sectors, more than 10 percent of import-export country pairs have zero GVC trade flows, as no single establishment participates in that particular value chain. We further demonstrate that GVC flows based on the import proportionality assumption i.e., all non-zero flows, exhibits a significantly smaller round-trip effect. Thus, in the absence of establishment-level linkages, we would miss the strong complementarities between input and output markets.

Finally, we augment a version of the "global firms" model in Bernard, Jensen, Redding and Schott (2018b) featuring fixed and variable costs of both importing and exporting. We derive the model counterpart to our GVC measure and conduct several numerical experiments with 14 symmetric countries, plus the United States and 1000 firms per country. Each experiment is characterized by a different configuration of fixed costs. We then simulate the model and run gravity regressions on our simulated data. We find that a firm-country-specific fixed cost combined with an adjustment factor that is low when the source and destination countries are the same can generate patterns consistent with our findings on round-trip GVC trade flows from the gravity regression results.

Our paper contributes to three main bodies of literature. The first is GVC measurement, which, accelerated in the 2000s thanks to the development of multi-country input-output tables. Early work by Hummels, Ishii and Yi (2001) measuring vertical specialization was followed by more intricate efforts to isolate value-added exports or VAX (Johnson and Noguera, 2012; Koopman, Wang and Wei, 2014; Timmer, Erumban, Los, Stehrer and de Vries, 2014; Dietzenbacher, Los, Stehrer, Timmer and de Vries, 2015; Johnson and Noguera, 2017).[3] These developments have been instrumental in providing a comprehensive portrait of GVCs across countries and over time, and the multi-country input-output tables themselves have been used to calibrate a large set of international trade models.[4] Despite their widespread value and use, however, input-output tables, and GVC measures constructed from these tables, reflect biases owing to import proportionality and aggregation. To our knowledge, only Kee and Tang (2016), de Gortari (2019), and Bems and Kikkawa (2021) measure GVCs by employing firm-level data for China, Mexico, and Belgium, respectively, and, in so doing, address both sources of biases.[5]

Yet, studies using firm-level data for measurement of GVCs cannot fully account for heterogeneity in industrial activities within firms. The vast majority of U.S. goods trade is

[3]International organizations and partnerships have developed a full suite of trade in value added statistics to facilitate GVC measurement for large number of countries e.g., OECD (2024); WIOD (2023). See Antràs and Chor (2022) for a survey of the GVC measurement literature.

[4]In particular, models based on Caliendo and Parro (2015) have been so calibrated.

[5]There also has been efforts to augment GVC measurement with input-output tables by introducing firm-level heterogeneity. For example, Fetzer et al. (2023) introduce multinational production heterogeneity in U.S. input-output tables to create trade in value added statistics. Input-output tables distinguishing processing from non-processing firms have also developed in countries with large processing trade sectors like China (e.g., Koopman et al. (2014)) and Mexico (e.g., De La Cruz et al. (2013)).

mediated by large, multi-industry firms (Bernard, Jensen, Redding and Schott, 2018b; Ding, 2023). While trading firms operate in many industries, each establishment within the firm is classified within a single industry (U.S. Office of Management and Budget, 2024). Our innovation is creating linkages between input and output flows at the most disaggregated statistcial economic unit – the establishment — minimizing distortion in constructing value added flows that would otherwise arise owing to the assumptions made to allocate inputs across different industries for multi-sector firms.

The second is the literature on input sourcing measurement. Early contributions pioneered use of firm-level data to relax the import proportionality assumption embodied in national input-output tables. Feenstra and Jensen (2012) is one of the first attempts to enhance U.S. input-output tables by linking information in 1997 on firms' total imports from the LFTTD to materials use reported by their establishments in the CMF. Winkler and Milberg (2009) and Puzzello (2012) account for heterogeneity in input sourcing patterns across firms in the case of Germany and set of Asian countries, respectively. These early contributions underscored the need for micro data to provide a full characterization of production arrangements, generating a rich portrait of firms' global operations. Recent contributions for the United States include Fort (2017), Fort (2023) and Antràs, Fadeev, Fort and Tintelnot (2024). Progress in identifying firms' imported inputs by source linked to U.S. exports has also been made in the context of examining U.S. firms' responses to input shocks (e.g., Boehm, Flaaen and Pandalai-Nayar (2019); Handley, Kamal and Monarch (forthcoming)).[6] We provide the first comprehensive assessment of the imported inputs embodied in U.S. manufacturing establishments' exports.

The third literature studies the effect of regional trade agreements (RTAs) on measures of GVCs in a gravity framework (see, for example, Noguera (2012); Johnson and Noguera (2017); Laget, Osnago, Rocha and Ruta (2020)). We extend this research by leveraging the *trilateral* nature of our GVC measures. In this broader context, we show that RTAs continue to augment GVCs. In addition, we show the large round-trip effect, and that this effect is significantly muted if GVC measurement is subject to biases arising from aggregation and proportionality assumption. Our findings underscore that, as trade flows and GVCs reorient within geopolitical blocs centered around the United States and China (Gopinath, Gourinchas, Presbitero and Topalova, 2024), measurement using granular data becomes especially important to capture shifts in global production networks.

The rest of the paper is organized as follows. Section 2 details the data and our methodology for constructing establishment-level GVC measures by linking administrative firm-level data on exports and imports to establishment-level data on products produced and materials consumed and presents trends in foreign inputs cost shares and GVCs in the U.S. manu-

[6] A recent study for Mexico finds that Mexican GVC firms increased their exports to the United States in response to the U.S.-China tariff war (Utar, Cebreros and Torres, 2023).

facturing sector. Section 3 presents GVC measures constructed from establishment-level linkages. Section 4 presents determinants of GVC trade in a gravity framework. Section 5 documents the role of proportionality assumption in shaping GVC measures and the gravity determinants of GVC trade. Section 6 highlights key assumptions in canonical trade models that can rationalize the observed patterns in the determinants of GVC trade. The final section concludes.

2 Measuring Global Value Chains in the United States

In this section, we describe our measure of establishment-level GVCs—imported inputs by source embodied in exports by destination. We then describe the data linking methodology and core datasets used to construct the establishment-level measures of GVC.

2.1 Establishment-Level GVC

The central contribution of this paper is moving beyond connecting imported inputs to U.S. production to connecting full value chain flow through the United States: from imported inputs to U.S. production through to U.S. exports. We construct an establishment-level GVC measure that is based on the concept of vertical specialization (VS) capturing the imported input content of exports (Hummels, Ishii and Yi, 2001).[7] 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 (see Equation A2), and EXP_{enpt} represents produced outputs (see Equation A3).[8] GO_{est} is gross output of establishment e in industry s in period t.

2.2 Data Sources and Sample Construction

The construction of establishment-level GVC measure in Equation 1 entails combining goods trade and production information from two confidential, micro-level datasets maintained by the U.S. Census Bureau.

[7] Note that the difference between the imported input content of exports and total gross exports represents value-added trade such that (1-VS) measures the domestic value-added share in exports.

[8] At the establishment level, s is measured as a 6-digit NAICS industry. When presenting GVC statistics, we use the s notation to denote 3-digit manufacturing sectors based on industry definitions from the World Input-Output Database (WIOD) (Dietzenbacher, Los, Stehrer, Timmer and de Vries, 2015). We use WIOD definitions to enable comparisons to statistics computed using the WIOD as discussed in Section 5.

First, the Longitudinal Firm Trade Transactions Database (LFTTD) links specific international trade transactions to individual firms in the United States (Bernard et al., 2009; Kamal and Ouyang, 2020). The 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. It covers the universe of imported shipments valued over US$2,000 and exported shipments valued over US$2,500 of merchandise goods. We utilize the LFTTD to measure a U.S. firm's exports and imports by detailed 10-digit Harmonized System (HS) product and destination and source country, respectively.

Second, we rely on the Census of Manufactures (CMF) to obtain detailed information on establishment-level output and inputs. The CMF is collected quinquennially (every 5 years, in years ending in a 2 or 7) as part of the economic census (U.S. Census Bureau, 2022c). The CMF is a survey sent to the universe of establishments or plants in the manufacturing sector with questions on detailed output, input usage, product-level shipments, energy usage, inventories, and other aspects of production.[9] Specifically, to allocate a firm's exports and imports to their establishments, we use the trailer files of the Census of Manufactures: the Materials Trailer File (CMF-MAT) identifies the individual products used as material inputs in production; and the Product Trailer File (CMF-PROD) identifies the individual products produced and/or shipped.

Given our focus on the linkages in manufacturing production activity in the United States, our sample includes all establishments in the manufacturing sector 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 on inputs and output but retains firms accounting for the vast majority of shipments. We further restrict our sample to only those firms with non-negligible manufacturing shares of activity in terms of employment and sales.[10]

2.3 Connecting Trade Flows Associated with Production Activity

Measurement of global value chains 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.[11] A direct implication is that manufacturers may import goods intended for direct sale downstream as part of wholesale and retail activities,

[9] See the full set of questions on the survey forms at U.S. Census Bureau (2022a).

[10] Appendix Section A.1 provides details on sample construction.

[11] For example, many automakers produce some models in the United States with a wide variety of imported input content, while also importing finished cars to be sold to U.S. consumers. Indeed, an extreme form of production fragmentation is captured by so-called "factoryless" goods-producing firms 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).

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. Without detailed industry information, restrictive assumptions would be needed to allocate firm-level inputs and output. We 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 1 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 1: 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.

By construction, firms that both export and import contribute the most to measures of GVC and thus ignoring the industry-level heterogeneity within a firm can yield spurious assignment of imported inputs across industries. To illustrate this challenge, suppose a firm imports steel from China and axles from Vietnam, while at the same time exports engines to Mexico and finished cars to Canada. Should some fraction of steel and axles be assigned to both engines and finished cars or should all the steel be assigned to engines and all the axles assigned to finished cars?

Our methodology takes an establishment-level perspective to split the firm's production by distinct industries. To identify imported inputs, we utilize the set of inputs products reported by establishments in the CMF-MAT. To identify produced exports, we utilize the set of products reported by establishments in the CMF-PROD.[12] Thus, using LFTTD, 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.1 provides the methodological details.

Table 2: Aggregate Match Statistics (%)

	Intermediate Share		Produced Export Share	
	of Firm Imports	of Firm Cost	of Firm Exports	of Firm 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 firm material cost (column 2); exports identified as being produced by manufacturing establishments as a share of total firm exports (column 3) and as a share of total firm shipments (column 4).
Source: Authors' calculations using CMF and LFTTD.

Consistent with the complexity of modern U.S. manufacturers' activities, our methodology assigns part of firms' imports and exports as intermediate inputs and manufactured output, respectively. Table 2 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.[13] 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 as so-called carry-along trade (Bernard, Blanchard, Beveren and Vandenbussche, 2018a). For the representative manufacturing establishment, produced exports are about 9% of the total value of shipments (column 4).[14]

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

[12]This builds on Boehm, Flaaen, Pandalai-Nayar and Schlupp (2021) to link LFTTD-based exports to individual establishments.

[13]Their methodology differs somewhat as theyclassify goods as intermediate inputs or capital investment goods if they are not on the list of products on the CMF-PROD.

[14]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 utilize the LFTTD or CMF-PROD.

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.[15] Hence, we view our measures as *direct* GVC measures and a lower bound of the true degree of foreign input usage in U.S. production activity.

3 Trends in GVC Activity within U.S. Manufacturing

This section derives industry-level GVC statistics based on the establishment-level linkages described in Section 2.3 that are novel in their detail and scope. We begin by reporting the imported input share in total material cost for the U.S. manufacturing sector over our sample years. We then derive industry level measures of imported input content embedded in U.S. export to highlight how aggregation bias mutes both the level and trend in the U.S. manufacturing sector's participation in global value chains.

3.1 Share of Imported Inputs in U.S. Material Costs

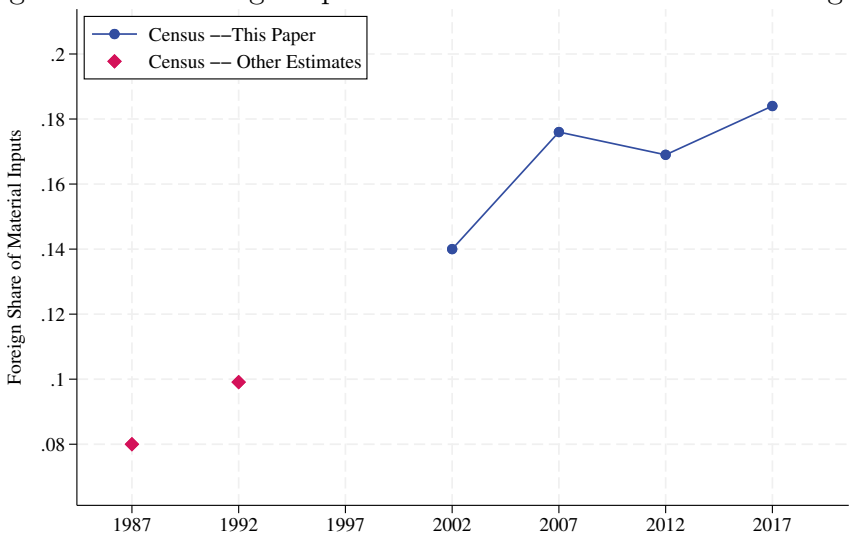
A large literature measuring the extent of offshoring in U.S. manufacturing has focused on the share of material inputs sourced from abroad. Houseman, Kurz, Lengermann and Mandel (2011) describe how the increase of foreign-sourced inputs could lead to upward bias in manufacturing productivity statistics, as the price declines from foreign substitution are systematically under-measured due to the well-known outlet-substitution bias in price index measurement. In another strand, many papers (including, for example Feenstra and Hanson (1996b), Feenstra and Hanson (1996a)) explore the specific role "outsourcing" of inputs abroad has had in labor market developments within the U.S. manufacturing sector.

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 1 represent 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).[16] Our establishment-level linkages indicate that foreign sources

[15]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.

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

Figure 1: 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).

of material costs increased during the sample period, most notably between 2002 and 2007.

3.2 Imported Input Content in U.S. Exports

We construct sector level measures of GVC from the establishment-level linkages between imports and exports by summing over all country-sector sources of imports and country destinations for exports to arrive at a measure for an individual establishment e operating in industry s in period t as:

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

and then sum across establishments of a sector (or across all establishments in our sample). We then scale GVC_{est} (which is in units of dollars) by overall (or sectoral) exports to arrive at a ratio as follows:

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

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

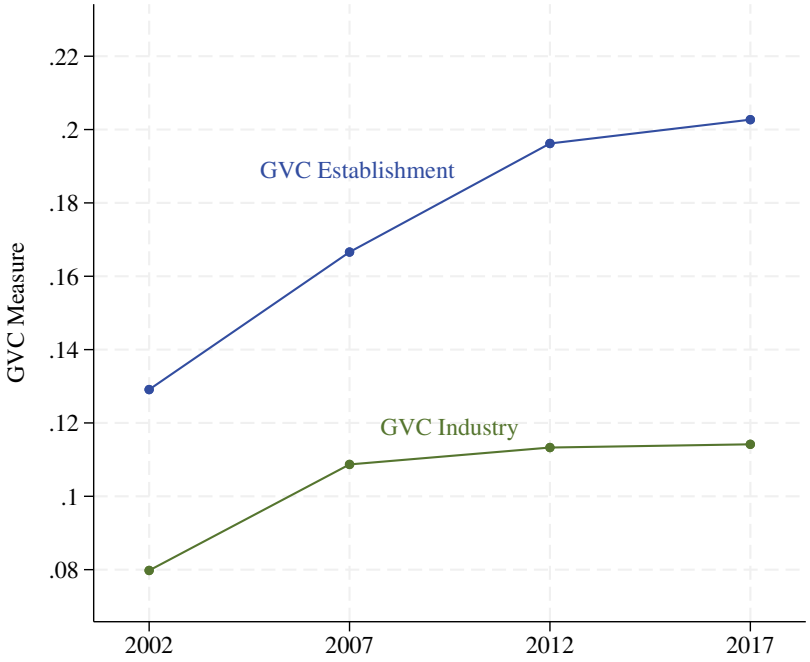
The GVC and gvc measures are closely related to well-known measures of value-added exports (hereafter, VAX) (Johnson and Noguera, 2012, 2017; Koopman, Wang and Wei,

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

2014). VAX captures the domestic value-added embodied in a country's exports. Over the past decade, these measures have become widely used for capturing global value chain behavior. There are three points worth mentioning. First, as with our measure, VAX is a useful way to measure international production chains in which a good-in-process crosses multiple borders. Second, when aggregate VAX is reported as a share, i.e., total value-added exports as a share of total exports, then it is roughly equivalent to $1 - gvc$.[17] From these first two points, it is clear that VAX and GVC are "cousins", in some sense. Third, VAX can be split into components by destination country, by sector, and even by sector and destination. However, by its nature, its focus is on the export side, while our measure captures both the imported inputs and exports. This motivates much of our regression analysis in Section 4.

We plot the gvc^E_{st} measures for U.S. manufacturing as a whole—i.e., where s denotes the entire U.S. manufacturing sector—as the blue line in Figure 2. There are steady gains in the reliance on global value chains in the United States between 2002 and 2012 such that by the year 2012 there were nearly 20 cents of imported inputs embodied in each dollar of exported output. In 2017 the increase in GVC activity moderates somewhat, to slightly over 20 cents, relative to the trend in previous years.

Figure 2: GVC in Manufacturing: Establishment-based vs. Aggregate



Notes: This figure plots GVC measures for the manufacturing sector as a whole.

Source: Authors' calculations using CMF and LFTTD.

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

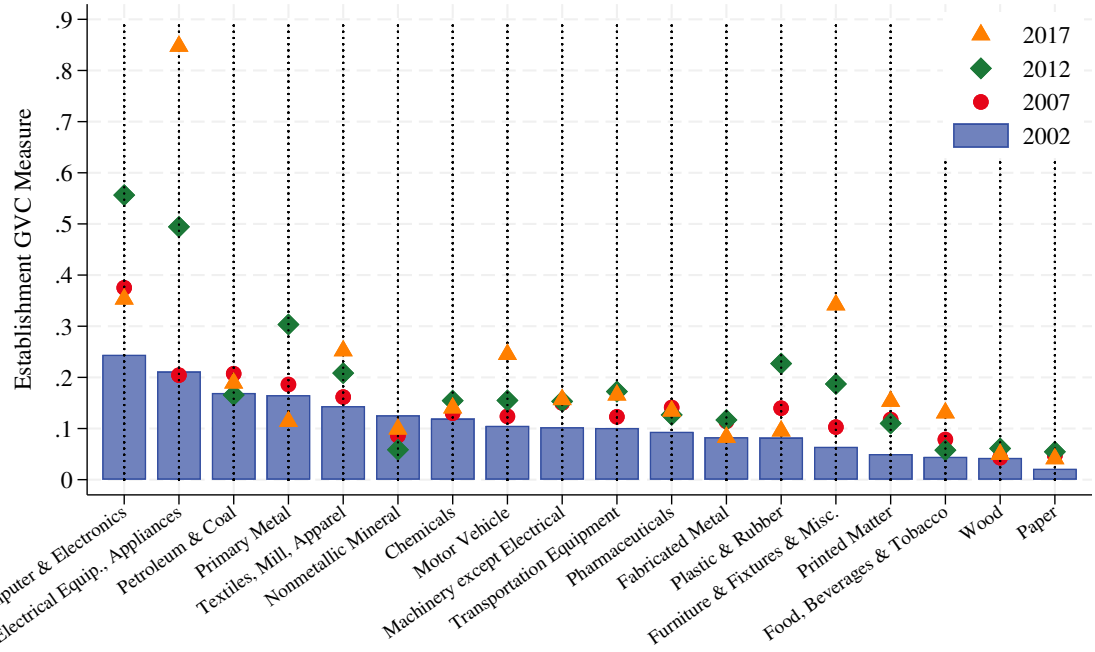
[17]The term $1 - gvc$ captures the domestic value-added embodied in exports as a share of total exports, subject to one caveat. If there is a great deal of back-and-forth trade, then some imports by U.S. firms may embody U.S. value-added. Hence, in this case $1 - gvc$ will underestimate the VAX share. This is relevant if goods are produced in more than two stages.

aggregates of imports, output, and exports. As previously demonstrated by Kee and Tang (2016), using data on Chinese firms, and Bems and Kikkawa (2021), using data on Belgian firms, estimates of GVC from industry-level aggregates are subject to non-trivial aggregation bias that can distort trends in the fragmentation of global production.[18] To highlight such aggregation bias, we calculate industry-level GVCs using industry-level aggregates from our newly linked data (essentially ignoring the establishment-level mappings between imports and exports) as in:

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

The green line in Figure 2 plots this aggregate-based measure, highlighting the important role that aggregation bias plays in this measure. Indeed, it is not only the level of GVC that would be mis-measured without establishment-level links, but also the trends. As shown in the green line, the aggregate-based measure slowed considerably in 2012, and then remained flat in 2017.

Figure 3: GVC Estimates for Manufacturing and sub-sectors, 2002, 2007, 2012, 2017



Notes: This figure plots GVC for 3-digit sectors consistent with industry definitions in WIOD.

Source: Authors' calculations using CMF and LFTTD.

Our GVC estimates, gvc^E_{st}, for manufacturing as a whole masks significant heterogeneity

[18] Another source of aggregation bias may arise from using *firm* versus *establishment* level data. GVC estimates using firm-level aggregates indicate that they align closely with GVC estimated from establishment-level information at both the national (correlation of 0.99) and sub-sector (correlation of 0.97) levels. See discussion in Appendix Section B.4.

across industries. We plot the industry-level GVC values from Equation (3) in Figure 3, where 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.

4 Determinants of GVC Trade Patterns

We now turn to a systematic analysis of the integrated flows of imports, domestic production, and foreign exports. Because the data provide a complete accounting of how import countries are linked to export countries through the United States – all coming from a granular, establishment-level production basis, rather than industry-level input-output tables – we can, for the first time, explore the determinants of global value chain connections across multiple trading partners. This analysis sheds light on the trends in the broad patterns of global value chains in the United States shown in Figure 2.

For this analysis, we define a bilateral GVC measure for import source country m and export destination country n in year t as follows:

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

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. Thus, we first compute bilateral GVC measures for each establishment and then aggregate them across all establishments participating in a given supply chain (m, n).

We examine the determinants of GVC_{mnt} in a gravity framework, which typically relates bilateral gross trade flows to bilateral determinants that include proxies for trade costs such as distance. GVC_{mnt} captures country-pairs connected via the the United States, and thereby enables an examination of the role of distance and regional trade agreements in a three-country setting. We implement the gravity estimation by linking our bilateral GVC measures to information on country attributes (distance, trade agreements, etc.) sourced from the Centre d'Etudes Prospectives et d'Informations Internationales or CEPII (Conte, Cotterlaz and Mayer, 2022). For each combination of the bilateral GVC, the country-level information can vary according to the pairs of countries involved (import country to U.S., U.S. to export country, and import country to export country).

4.1 Gravity in Global Value Chains

In our context, the traditional measure of distance between two non-U.S. countries does not capture any direct trade flow; here, the analog proxy measure of trade frictions for GVC flows would be the *combined* distance of each country to the United States, capturing the flow of inputs and output in the three countries involved in production. Formally, this is defined as $d_{m,US,n} = d_{m,US} + d_{US,n}$ for imports from country m and exports to country n.

While the combined distance is more directly linked to GVC flows, the *direct* distance between import (input) and export (sale) countries (that is, $d_{m,n}$)—ignoring the location of the United States in the production chain—may also have an impact on GVC flows. This measure of distance should be interpreted differently than traditional measures, in particular when included on top of the combined distance measure.[19] Whether the proximity of input and output markets increases or decreases the scale of global value chain activity may also depend on their joint distance away from the United States. 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 may yield important insights on a number of questions, such as whether 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 whether value chains of such proximate input-output countries would be unlikely to be paired with a country that adds significant cost (a positive coefficient on $d_{m,n}$). Returning to our example, are the regional factors of a particular product chain similar enough between Spain and Italy to overcome the added cost of U.S. processing, or could such processing 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 arises when country m equals country n. 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.[20] In addition to the overall impact of the 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 distance measures, 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.

[19] Note that the distance measure for round-trip production (for $d_{m,m}$) is not measured as zero in gravity datasets such as CEPII. For population-weighted, within-country distance measures, the CEPII methodology is to take all possible combinations of *city-pair* distances within a country and calculate a weighted average.

[20] This feature was highlighted in the model constructed in Johnson and Moxnes (2023), though it is not considered prominent in the data in Johnson and Noguera (2017).

To explore these ideas, we estimate a novel form of the gravity model connecting these bilateral pairs of production flows through the United States as below:

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

where the dependent variable is $\log(GVC_{mnt}) \equiv \log(\sum_s GVC_{mnst})$.[21] All specifications also include exporter-year ($\eta_{n,t}$) and importer-year ($\delta_{m,t}$) fixed effects. As discussed above, the foreign value content of U.S. exports captured in our measure is similar but distinct from the VAX measure considered in the gravity model results in Noguera (2012). It is important to note, however, that the results in Noguera (2012), Johnson and Noguera (2017), and others rely on the industry-level proportionality assumptions to back out VAX measures that we evaluate in Section 5.

Table 3: Gravity Model of GVC, 2002-2017

	Dependent Variable: Log Bilateral GVC						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Round-trip (m=n)	2.33***			2.24***	1.32***	1.39***	0.08***
	(0.112)			(0.111)	(0.119)	(0.121)	(0.020)
Log Distance (m →US→ n)		-1.64***		-1.42***		-0.414***	-0.01
		(0.106)		(0.104)		(0.118)	(0.061)
Log Distance (m to n)			-0.26***		-0.194***	-0.175***	0.00
			(0.009)		(0.009)	(0.002)	(0.004)
Data	Census	Census	Census	Census	Census	Census	WIOD
Exporter-Year F.E.	yes	yes	yes	yes	yes	yes	yes
Importer-Year F.E.	yes	yes	yes	yes	yes	yes	yes
Observations	117,000	117,000	117,000	117,000	117,000	117,000	7,100
R-squared	0.861	0.860	0.861	0.861	0.861	0.861	0.99

Notes: The Census sample consists of years 2002, 2007, 2012, and 2017. The WIOD sample consists of the same years except the last which is given by the end year, 2014, in the WIOD. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.
Source: Authors' calculations using the CMF, LFTTD, CEPII (Columns 1-6); WIOD and CEPII (Column 7).

We report the gravity results in the first six columns of Table 3, beginning with bi-variate regressions of the key variables of interest.[22] The coefficient on the round-trip indicator is large and highly significant, and coefficients on the combined and direct distance variables exhibit the expected negative sign, with the direct trade cost proxy (combined distance) exhibiting a far greater magnitude. Columns (4) through (6) show results when these variables are included in combination (we discuss results in column (7) in Section 5.4). 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

[21] GVC_{mnst} is defined in Equation A4. See Appendix Section B.1 for summary statistics.
[22] The results in Table 3 are pooled across all years in our sample i.e., every five years from 2002 to 2017; Appendix Table A8 provides estimates by year.

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. Second, 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. This result points to strong complementarities between input and output markets. The large coefficient on the round-trip indicator is an extreme example of this complementarity, 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 ($m \to n$) distance between source and destination countries. This complementarity between input and output markets is an under-explored topic, which we return to in greater detail in Section 5.4, in the context of biases that arise when measuring GVCs with aggregate input-output tables.

4.2 The Impact of Regional Trade Agreements on Value Chains

The last few decades have been marked by a proliferation of regional trade agreements (RTAs) and production chains increasingly crossing multiple borders before final consumption (Ruta, 2017). Hence, it is increasingly difficult to connect the effects of a specific regional trade agreement to a particular trade flow when that shipment is only one part of a broader value chain encompassing other countries. 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 structure of our data 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). The impact of regional trade agreements on value added trade has also received close attention. For example, Noguera (2012) and Johnson and Noguera (2017) find a negative relationship between RTAs and VAX (the domestic value-added embodied in a

country's exports) consistent with RTAs facilitating increased production sharing between RTA partners. Our establishment-level links provide the opportunity to extend this finding beyond a relationship between RTAs and overall production sharing in a country's exports, to specific trilateral supply chain linkages.

Hence, we construct several indicator variables for whether regional trade agreements are in place between all possible combinations of the GVC countries. Using data from CEPII, we construct indicators for whether countries m and n have an RTA, whether both countries m and n have RTAs with the United States, and finally whether all three countries (m, n, and the U.S.) are all under an RTA.[23] We add these variables to the existing gravity regression variables in Equation (6), and present the results in columns (1) - (4) of Table 4.

Table 4: The Impact of RTAs on GVC Linkages, 2002-2017

	Dependent Variable: Log Bilateral GVC				
	(1)	(2)	(3)	(4)	(5)
Round-trip (m=n)	2.20***	2.23***	2.21***	2.19***	0.08***
	(0.112)	(0.111)	(0.112)	(0.112)	(0.015)
Log Distance (m →US→ n)	-1.38***	-1.39***	-1.36***	-1.36***	-0.04
	(0.105)	(0.104)	(0.104)	(0.105)	(0.083)
RTA (m & n)	0.044**			0.042**	
	(0.020)			(0.204)	
RTA (m & US, n & US)		0.198***		0.191***	
		(0.059)		(0.059)	
RTA (m, n, US)			0.438***		-0.03
			(0.112)		(0.061)
Data	Census	Census	Census	Census	WIOD
Exporter-Year F.E.	yes	yes	yes	yes	yes
Importer-Year F.E.	yes	yes	yes	yes	yes
Observations	117,000	117,000	117,000	117,000	7,056
R-squared	0.861	0.861	0.861	0.861	0.997

Notes: The Census sample consists of years 2002, 2007, 2012, and 2017. The WIOD sample ends in 2014, and so we substitute 2014 in for 2017 to replicate a similar number of years. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.
Source: Authors' calculations using the CMF and LFTTD (Columns 1-4) and WIOD (Column 5).

We display results in columns (1) - (4) of Table 4, where we continue to include the round-trip indicator and combined distance as controls.[24] Perhaps unsurprisingly, there is only a small positive coefficient on GVC flows from an RTA indicator that includes the import and export countries but not the United States.[25] But the coefficient increases substantially once we focus instead on those importers and exporters (separately) that have an RTA with the United States (column 2), and even further when the RTA includes all three countries

[23]Note that the third indicator is a linear combination of the other two RTA indicators.

[24]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.

[25]The European Union plays an important role in this indicator.

(column 3).[26] In terms of magnitudes, we find that the imported input content from country m of a U.S. manufacturing firm's exports to country n is nearly 44 percent higher when the three countries are collectively in an RTA (controlling for other factors) than otherwise.

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, where combined distance is controlled. 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.

Further evidence in support of a causal interpretation to our RTA results would leverage *changes* in RTA status and the corresponding changes in GVC activity. Although our sample period is relatively short for such an analysis, we operationalize this strategy in Table 5 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, the magnitude of the effect of RTAs on GVCs is somewhat reduced relative to Table 4; indeed, the RTA indicator without any U.S. involvement actually switches from mildly positive to mildly negative. Yet, for those RTAs including the United States–despite the small sample and relatively few RTAs initiated during our sample period–our results suggest a positive impact of RTAs on GVC flows of between 14 and 20 percent.

Table 5: Additional Results on the Impact of RTAs on GVC Linkages, 2002-2017

	Dependent Variable: Log Bilateral GVC		
	(1)	(2)	(3)
RTA (m & n)	-0.08**		
	(0.036)		
RTA (m & US, n & US)		0.14*	
		(0.075)	
RTA (m, n, US)			0.20**
			(0.099)
Data	Census	Census	Census
Exporter-Year F.E.	yes	yes	yes
Importer-Year F.E.	yes	yes	yes
Exporter-Importer F.E.	yes	yes	yes
Observations	112,000	112,000	112,000
R-squared	0.920	0.920	0.920

Notes: The sample consists of years 2002, 2007, 2012, and 2017. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.
Source: Authors' calculations using CMF and LFTTD .

At face value, this approach looks similar to the findings in Johnson and Noguera (2017) that examines the role of RTAs in value-added trade. While the results in that paper are

[26] See Appendix Table A7 for a listing of all countries included in these RTAs.

complementary to this work– the authors find that the overall value-added share of gross exports declines (overall foreign inputs usage increase) between a bilateral pair when they are engaged in an RTA–our results directly link the adoption of RTAs between a three-country pair to the actual GVC activity among those same countries.

5 Assessing Biases in GVC Measurement from Import Proportionality

This section demonstrates the measurement biases arising from the well-known import proportionality assumption—an individual country's imports are allocated as inputs across industries in the same proportion as their overall imports—typically utilized in national input-output tables. We compare the imported input cost share and imported input content of exports (i.e. imported inputs from Mexico in exports to France) derived from establishment-level linked data versus measures derived from aggregate input-output data harmonized across countries. Specifically, we rely on the World Input-Output Database or WIOD (Dietzenbacher, Los, Stehrer, Timmer and de Vries, 2015; Timmer, Los, Stehrer and de Vries, 2016) spanning 44 countries and 56 sectors (18 in manufacturing) between 2000-2014.[27] 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 to align with our focus on only the manufacturing activities of U.S. firms. We then collapse the Census-basis data to match the 43 countries and a Rest of World (RoW) aggregate and at the same level of NAICS classification.

5.1 Biases in Imported Input Cost Shares by Source

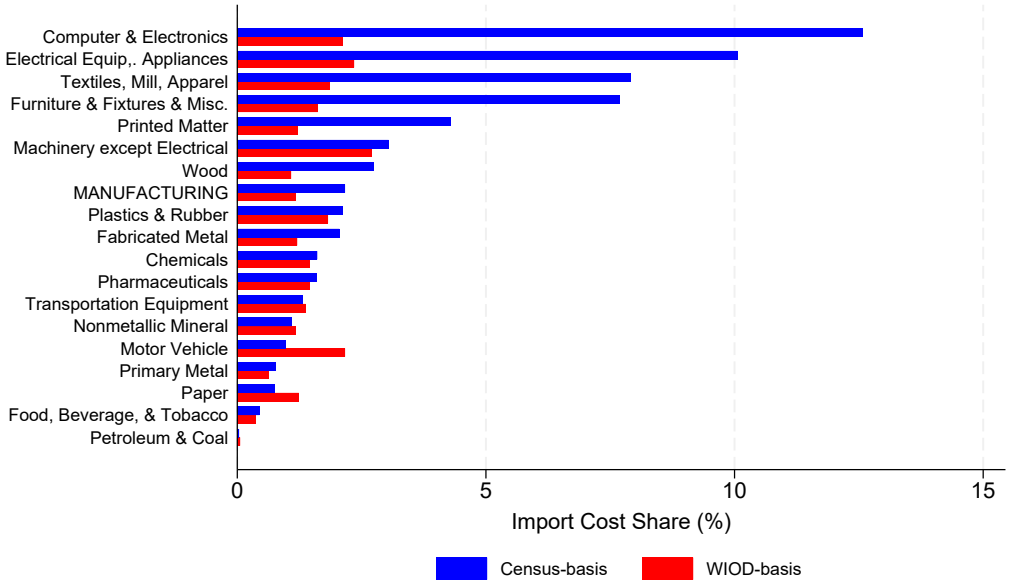
We begin by comparing the imported input cost shares for the manufacturing sector derived from establishment-level linked data from the Census and compare these estimates to those derived from the WIOD. The Census-based estimates (shown in Figure 1) show steady increases in the usage of foreign inputs through 2007 with 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 is typically a few percentage points lower.

Next, we examine the dependence of U.S. manufacturers on inputs sourced from China, the top import source in 2012, as a share of total cost of materials across all broad manufacturing industries using the newly created links from Census data (blue bars) compared to analogous estimates derived from the WIOD (red bars) in Figure 4. Based on the Census

[27]The most current available version is the November 2016 release.

estimates, Chinese imported inputs represent 2.2% of total cost of materials in the manufacturing sector. However, reliance on Chinese imported inputs varies widely by industry: "Computer & Electronics" and "Electrical Equipment & Appliances" have the highest shares, 13% and 10%, respectively; "Food, Beverage, & Tobacco" and "Petroleum & Coal" have the lowest shares, 0.46% and 0.04%, respectively. In contrast, the WIOD estimates indicate much lower dependence on China as a source of inputs across manufacturing industries, except "Motor Vehicles" and "Paper" where the WIOD estimates are about double that of the Census estimates. This comparison highlights the importance of using establishment-level linkages between imports and production to draw a more complete picture of imported input dependence in the U.S. manufacturing sector.

Figure 4: Chinese Input Cost Share in U.S. Manufacturing, 2012



Notes: This figure displays the Chinese input cost share for U.S. manufacturing sectors.

Source: Authors' calculations using CMF, LFTTD, WIOD.

5.2 Correlations of Census-based and WIOD-based GVC Measures

A summary of the alignment of the country import cost share measures between the WIOD and our Census-based data is described in the first column of Table 6, based on simple correlations.[28] 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

[28]Imported input cost share measured as $IC_{st} = \frac{\sum_{e \in E_{st}} IMP^I_{est}}{\sum mc_{est}}$, which we replicate in the WIOD.

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".[29]

Table 6: Census-WIOD Correlations by Sector, 2012

	Correlations of	
Broad Manufacturing Sector	Input Costs	Bilateral GVC
Food, Beverage, and Tobacco	0.83	0.92
Textiles, Apparel, Leather	0.67	0.56
Wood and Wood Products	0.87	0.63
Paper and Paper Products	0.81	0.76
Printing	0.73	0.64
Coke and Petroleum Products	0.68	0.94
Pharmaceutical	0.30	0.26
Chemicals and Chemical Products	0.62	0.81
Rubber and Plastics	0.67	0.49
Non-metallic Mineral Products	0.86	0.66
Basic Metals	0.94	0.69
Fabricated Metal Products	0.79	0.77
Machinery and Equipment	0.87	0.85
Computer, Electronic and Optical	0.62	0.83
Electrical Equipment	0.75	0.69
Motor Vehicles and Trailers	0.90	0.86
Other Transport Equipment	0.85	0.81
Furniture and Other Mfg	0.58	0.48
Overall Manufacturing	**0.64**	**0.42**

Notes: This table displays correlations, by broad sector, between Census-based and WIOD-based measures of: imported input by source country as a share of total cost of materials (column 1); imported input by source country as a share of exports by destination (column 2).
Source: Authors' calculations using CMF, LFTTD, and WIOD.

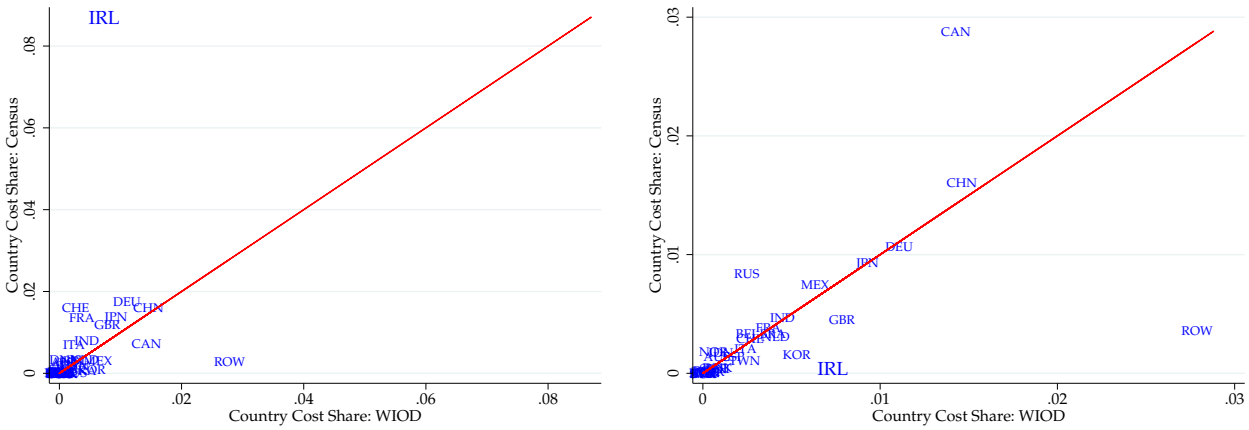
The second column of Table 6 considers the alignment of the WIOD with Census data on a bilateral basis. That is, the second column calculates the correlation between all *bilateral* import-export country-pair GVC statistics for a given industry (i.e. the GVC measure of imported inputs from Mexico in exports to France in the machinery and equipment industry) using the WIOD and Census-based measures. For the Census-based measure, we use Equation (5). For the WIOD-based bilateral GVC measures, we use intermediate imports from country m and exports to country n as reported in the WIOD. As shown in the table, these correlations are typically—though not always—lower than the overall cost-share measures. Across all industries, this correlation stands at 0.42 for U.S. manufacturing.

[29]Our finding of a correlation of 0.64 across (roughly) three-digit NAICS industries is in fact remarkably 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.

Delving deeper into the potential sources of mis-alignment in column 1 of Table 6, Figure 5 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 5 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.[30] 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.[31] The outsized role of Ireland in pharmaceuticals trade—as well as for producing measurement headaches in international statistics—has been well-documented (Setser, 2019).[32]

Figure 5: 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.

5.3 Excess Smoothing in Proportional Measures

Without direct linkage of import sources to export destinations, one source of the misalignment in GVC linkages identified in Table 6 (Column 2) is the smooth distribution of import sources across all export destinations. To highlight one example of what we describe as

[30] For more details, see the top ten import-export country pairs for the pharmaceuticals sector in Table A6. Ireland is remarkably the top input source for all top ten bilateral country-pairs.

[31] The relative magnitudes also make sense, as published data indicate that basic chemicals record nearly 8 times as much material input costs as pharmaceuticals.

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

"excess smoothing" in proportionality-based measures, we calculate the fraction of bilateral country-pairs (among WIOD countries) that record zero GVC linkages 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—a feature which does hold for the 18 manufacturing sectors in WIOD countries—then the proportional-based measure will naturally record strictly positive GVC values across the full cartesian product of country pair links.

Table 7 shows evidence of excess smoothing of GVC linked pairs as evidenced by a significant share of zero bilateral linkages in Census data, though the extent of the excess smoothing varies widely by manufacturing sector. On the whole, 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.

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.

Naturally, measures of such excess smoothness will increase substantially when additional periphery countries are included in proportional measures. Indeed, one could glimpse this issue by recognizing that the "Rest of World" category tends to record a considerably higher share (on average, nearly 1.5 percentage points) of costs in the WIOD-based measure than in our Census-based measure. Amid very low shares, the possibility of errors relative to zero go up substantially. On the other hand, one might worry about the role of missing inputs in our Census-based measure that are imported *indirectly* through other firms. As explained in Section 2.3 above, our Census-based measures are not able to capture such indirect import content. If firms disproportionately use third-party firms—such as importer-exporters or

wholesale firms—to import inputs from such small countries, then our Census-based measure may underestimate the cost share of these small countries. We hope to explore the role of indirect imported inputs in future work.

All told, whether excess smoothing presents an issue to the researcher will depend on the specific question being addressed. From a quantitative perspective, the issue naturally applies to a small share of overall GVC activity: The GVC-weighted average of the zero share from Table 7 across all U.S. manufacturing is 3.2 percent.

5.4 Biases in Determinants of Bilateral GVC

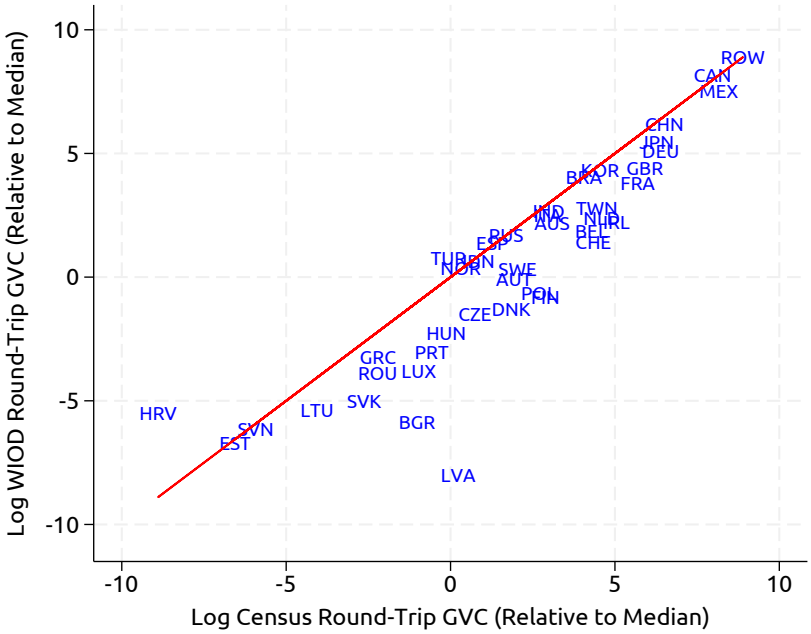
Aggregated data are unable to replicate the patterns we have uncovered in Section 4. We show this by replicating the gravity regressions by constructing the bilateral GVC measure using the WIOD. As is shown in column (7) of Table 3 and column (5) of Table 4, the WIOD-based results do not capture – even in a qualitative sense – the patterns discussed in the previous section.

Figure 6 shows this disconnect directly, focusing on the robust feature of round-trip GVC linkages apparent in our Census-based GVC measures identified above. The figure plots 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). 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. A comparison of columns (6) and (7) of Table 3 is another way of seeing this disconnect.

The data highlighted in this paper provides new insights into the patterns and determinants of global supply chain linkages. We conclude by examining the layers of measurement where these features may reside, and the role that proportionality, sample coverage, and aggregation play in their disclosure in publicly available input-output tables.

To initialize this exercise, we replicate column (7) of Table 3 in the first column of Table 8. 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

Figure 6: Alignment of Round-Trip GVC Values, 2012



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.

regression.

As discussed extensively above, the difference between the GVC measure based on microdata and that based on aggregate input-output tables is not solely due to sample criteria. In the last four columns of Table 8, 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. Columns (3) and (4) of Table 8 focus on the role of aggregation. Rather than relying on the import-export pairs connected by establishments, we instead aggregate the import and export data at the industry level before constructing GVC measures. In other words, instead of using the sum of the GVC measure defined in equation (5) across s as the dependent variable, we use the following GVC measure, which is subject to aggregation bias by design:

$$GVC^{agg}_{mnt} = \sum_{s} \left(\frac{\sum_{e \in E_{mnst}} \sum_{r} IMP^{I}_{emrt}}{\sum_{e \in E_{mnst}} GO_{est}} \sum_{e \in E_{mnst}} \sum_{p} EXP_{enpt} \right). \tag{7}$$

As we discussed in the previous section, without proportionality in play, we observe zero GVC flows for a significant number of (m, n, s, t) combinations, since it is possible that E_{mnst} is an empty set. In the WIOD, on the other hand, GVC flows for all (m, n, s, t) combinations are non-zero. With this in mind, we compute Equation (7) for all pair-wise combinations in column (3) and only for the bilateral pairs that exist in the data in column (4).

In both columns (3) and (4), we find much smaller round-trip effects. As discussed in Flaaen, Kamal, Lee and Yi (2024), a positive correlation between exports and imports at the establishment level leads to a downward bias in GVC measurement when using aggregate data. The significant reduction of the round-trip effect in the aggregated microdata implies that this bias is pronounced relatively more in round-trip trading behavior. Introducing aggregation bias to the GVC measures also diminishes the strong explanatory power of distance and RTAs found in microdata.

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. Finally, we run the gravity regression with the WIOD in column (6). By construction, the GVC measure computed with the WIOD is subject to aggregation bias. Additionally, compared to columns (3)-(5), where we hypothetically introduced aggregation bias with our microdata, the WIOD table is also subject to the proportionality assumption. With both aggregation bias and the proportionality assumption in play, we find a very small round-trip effect and lose significance for both the distance and RTA coefficients.

Table 8: Gravity Model Comparisons 2002-2017

	Dependent Variable: Log Bilateral GVC					
Variable	(1)	(2)	(3)	(4)	(5)	(6)
Log Distance ($m \rightarrow$US$\rightarrow n$)	-1.36***	0.26	0.11**	-0.011	-0.28**	-0.04
	(0.104)	(0.280)	(0.049)	(0.045)	(0.114)	(0.083)
Round-trip (m=n)	2.21***	1.71***	0.17***	0.21***	0.18***	0.08***
	(0.112)	(0.119)	(0.0426)	(0.0396)	(0.0282)	(0.015)
RTA (m, n, US)	0.44***	-0.13	0.16***	0.17***	0.06	-0.03
	(0.112)	(0.220)	(0.046)	(0.045)	(0.087)	(0.061)
Data	Census	Census	Census	Census	Census	WIOD
Basis	Estab	Estab	Agg.	Agg.	Agg.	Agg.
Country Sample	All–Data	WIOD-43	All–Poss.	All–Data	WIOD-43	WIOD-43
Observations	117,000	7,100	139,000	117,000	7,100	7,056
R-Squared	0.86	0.94	0.96	0.96	0.99	0.99

Notes: Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Includes Exporter-Year F.E. and Importer-Year F.E.
Source: Authors' calculations using CMF, LFTTD, and WIOD.

6 A Simple Framework of Global Value Chains

Model frameworks for global value chains (GVCs) have evolved in various forms to reflect the complex structure of GVCs in reality, including roundabout production, multi-stage production with specific inputs, multinational activities, and more. In this paper, we adopt and modify a straightforward framework of firm-level GVCs from the existing literature to reconcile our empirical findings from microdata, while delegating the development of a fully fledged model of GVCs to future research.

6.1 Model Framework

We build a framework in which firms solve sourcing and selling problems jointly. Firms can source intermediate inputs domestically or internationally and sell their output products in domestic or foreign markets. We assume firms are heterogeneous in productivity. The input market is assumed to be perfectly competitive, while the output market is characterized by monopolistic competition. This framework draws from Bernard, Jensen, Redding and Schott (2018b), combining the firms' sourcing problem of Antrás, Fort and Tintlenot (2017) with the production location choice problem and export problem as in Melitz (2003). We simplify their framework by abstracting from firms' endogenous choice of production location and assuming all firms are single-industry, single-establishment, and single-product firms. Therefore, the notation f, which denotes a firm in this section, effectively corresponds to establishment e in the notation used to describe the Census microdata earlier in the paper.

6.1.1 Basic Setup

Final goods consumers in country n have the following CES utility:

$$U_n = \left[\sum_{i \in \Omega_n^N} \sum_{f \in \Omega_{in}^F} (C_{ifn})^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}},$$

where C_{ifn} denotes the country-n consumers' consumption quantity of the product made by firm f in country i; Ω_{in}^F is the set of firms from country i selling products to consumers in country n; Ω_n^N is the set of countries where there is at least one firm that serves the destination market n. The term σ is a constant elasticity of substitution. Denote the price that consumers in country n pay for the product sold by firm f in country i as P_{ifn}^F. With monopolistic competition in the final goods market, market-n consumers' expenditure share for firm f's product is

$$S_{ifn}^F = \frac{(P_{ifn}^F)^{1-\sigma}}{\sum_{i' \in \Omega_n^N} \sum_{f' \in \Omega_{i'n}^F} (P_{i'f'n}^F)^{1-\sigma}}.$$

Production of final goods is done by combining labor with intermediate inputs. Firm f in country i has the following Cobb-Douglas production technology:

$$Q_{if}^F = \varphi_{if} \left(\frac{L_{if}^F}{\alpha} \right)^{\alpha} \left(\frac{Y_{if}^F}{1-\alpha} \right)^{1-\alpha},$$

where φ_{if} is firm f's productivity; L_{if}^F is labor input used in final goods production; α is the labor cost share. We assume that there is a continuum of input varieties on a unit interval and denote Y_{if}^F as the CES aggregate of intermediate inputs—i.e., $Y_{if}^F = \left[\int_0^1 Y_{if}^F(l)^{\frac{\eta-1}{\eta}} dl \right]^{\frac{\eta}{\eta-1}}$ with η being the elasticity of substitution between input varieties.

Sourcing of intermediate inputs follows Antràs, Fort and Tintlenot (2017). We assume that producers of intermediate inputs use only labor as a production input. With the assumption of a perfectly competitive input market, the variable sourcing cost of input variety l from source country m for firm f in country i is given by

$$a_{ifm}(l) = \frac{w_m d_{mi}^I}{z_{ifm}(l)}.$$

w_m is the wage in country m under the assumption that labor is perfectly mobile within a country. $d_{mi}^I \geq 1$ is variable input trade cost from country m to country i. Finally, $z_{ifm}(l)$ is an intermediate input productivity that is randomly drawn from a Fréchet distribution $G_m(z) = \exp\left(-T_m z^{-\theta}\right)$. $T_m > 0$ is the scale parameter governing the absolute advantage of country m as the source of intermediate inputs, and $\theta > 0$ is the shape parameter that is inversely related to the dispersion of the distribution.

6.1.2 Sourcing and Exporting Decisions

We derive the equilibrium of this model in two steps. First, we derive the intensive margins of sourcing and exporting, conditional on the set of countries from which each firm sources intermediate inputs and to which it sells its final goods. In the second step, we solve for the set of import source countries and export destination countries—Ω_{if}^{NI} and Ω_{if}^{NX}, respectively—that maximize a firm's profit.

Firms source each intermediate input variety from the lowest-cost supplier among the countries in Ω_{if}^{NI}. Following Eaton and Kortum (2002) and Antràs, Fort and Tintlenot (2017), the equilibrium probability that firm f in country i sources intermediate inputs from country $m \in \Omega_{if}^{NI}$ is

$$\mu_{ifm}(\Omega_{if}^{NI}) = \frac{T_m (w_m d_{mi}^I)^{-\theta}}{\sum_{m' \in \Omega_{if}^{NI}} T_{m'} (w_{m'} d_{m'i}^I)^{-\theta}}.$$

Then, the variable unit cost function for firm f in country i is given by

$$\delta_{if}(\varphi_{if}, \Omega_{if}^{NI}) = \frac{1}{\varphi_{if}} w_i^{\alpha} \left[\Gamma \left(\frac{\theta + 1 - \eta}{\theta} \right) \right]^{\frac{1-\alpha}{1-\eta}} \left[\sum_{m' \in \Omega_{if}^{NI}} T_{m'} (w_{m'} d_{m'i}^{I})^{-\theta} \right]^{-\frac{1-\alpha}{\theta}}.$$

We assume $\theta+1 > \eta$ so that the cost function is well-defined. Under monopolistic competition in the final goods market, consumers in country n pay the following price for the product of firm f, if the firm exports to country n:

$$P_{ifn}^{F} = \frac{\sigma}{\sigma - 1} d_{in}^{X} \delta_{if}(\varphi_{if}, \Omega_{if}^{NI}),$$

where $d_{in}^{X} \geq 1$ is a variable trade cost for final goods from country i to country n. For convenience, we refer to $d_{in}^{X} \geq 1$ as the variable export cost and $d_{mi}^{I} \geq 1$ as the variable import cost.

In the next step, we derive how firms decide on the extensive margins of sourcing and exporting—i.e., how firms determine which countries to include in Ω_{if}^{NI} and Ω_{if}^{NX}. In addition to the variable costs of sourcing and exporting, we assume there are also fixed costs associated with these activities, denoted by F_{ifm}^{I} and F_{ifn}^{X}, respectively. For example, if firm f in country i sources intermediate inputs from country m and exports their product to country n, it must pay both F_{ifm}^{I} and F_{ifn}^{X}. We normalize the fixed cost of production to zero. All fixed costs are assumed to be paid in terms of labor. Firm f chooses the countries to be included in Ω_{if}^{NI} and Ω_{if}^{NX} to maximize the following profit:

$$\Pi_{if}^{F} = \sum_{n \in \Omega_{if}^{NX}} \left(\frac{1}{\sigma} \right) E_{ifn}^{F} - \sum_{n \in \Omega_{if}^{NX}} w_i F_{ifn}^{X} - \sum_{m \in \Omega_{if}^{NI}} w_i F_{ifm}^{I},$$

where $E_{ifn}^{F} \equiv S_{ifn}^{F} w_n L_n$ denotes the total sales of firm f in destination market n.

6.1.3 GVC Measures

This simple model framework provides a measure of global value chains that we can compare with the measures derived from Census microdata. Using the Cobb-Douglas structure of the production technology, the imports of intermediate inputs from country m are given by $IMP_{ifm}^{M} = \mu_{ifm}(\Omega_{if}^{NI})(1-\alpha)GO_{if}^{M}$, where the subscript M denotes variables derived from the model, which have direct data counterparts used earlier in the paper. With this expression, the dollar-value GVC measure for a country-i firm f's imports of intermediate inputs from

country m and exports to country n from the model can be written as

$$\begin{aligned} GVC^{M}_{ifmn} &= \frac{IMP^{M}_{ifm}}{GO^{M}_{if}} EXP^{M}_{ifn} \\ &= \mu_{ifm}(\Omega^{NI}_{if})(1-\alpha)E^{F}_{ifn}. \end{aligned} \tag{8}$$

This expression is the model counterpart of the term inside the summation in equation (5). We aggregate this firm-level trilateral GVC measure across firms to compute a measure equivalent to that defined in equation (5), allowing us to use it in the gravity analysis. Country i's aggregate GVC measure for import source country j and export destination country j is defined as follows:

$$GVC^{M}_{imn} = \sum_{f \in F_{imn}} \mu_{ifm}(\Omega^{NI}_{if})(1-\alpha)E^{F}_{ifn}, \tag{9}$$

where we define F_{imn} as $F_{imn} \equiv \{f \mid m \in \Omega^{NI}_{if} \text{ and } n \in \Omega^{NX}_{if}\}$. In other words, F_{imn} is the set of firms located in country i that import intermediate inputs from country m and export their output to country n. The only difference between equation (5) and its model counterpart (8) is that i is omitted in equation (5) as we consider only the case of $i = US$.

6.2 Numerical Simulations

We can numerically simulate this model framework to see if it can generate the empirical patterns documented with the Census microdata, with a particular focus on the gravity relationship for GVCs. Although the numerical exercise presented in this section is not a full calibration to real-world data, the results highlight the determinants of GVCs and the model features needed to reconcile the strong roundtrip effect observed in the microdata.

6.2.1 A New Feature to Reconcile the Round-trip Effect

The model framework we present includes firms' endogenous selection into GVC participation, with the fixed costs of sourcing and exporting playing a key role in their decisions. However, the baseline framework may not capture systematic complementarity between input source countries and export destination countries, because the size of the import (export) fixed cost is independent of the set of export destinations (import source) countries. In other words, the baseline model does not systematically reduce a firm's fixed cost of importing inputs from country A, even if the firm exports to the same country A, or vice versa.

We can modify the baseline model with a new feature that helps reconcile the roundtrip effect. Note that in the model, both export and import fixed costs are firm-specific. We assume that these costs include both common and idiosyncratic components. Specifically,

for each firm f, we assume that its export and import fixed costs take the following form:

$$\begin{aligned} F^X_{ifn} &= F^X_{in}\varepsilon^X_{ifn}(\Omega^{NI}_{if}) \\ F^I_{ifm} &= F^I_{mi}\varepsilon^I_{ifm}(\Omega^{NX}_{if}), \end{aligned}$$

where F^X_{in} and F^I_{mi} represent the fixed cost components common to all firms. These common components are adjusted for each firm by an idiosyncratic factor $\varepsilon^X_{ifn}(\Omega^{NI}_{if}) > 0$ for exporting and $\varepsilon^I_{ifm}(\Omega^{NX}_{if}) > 0$ for importing. The adjustment to the fixed exporting cost for firm f and export destination n depends on whether country n is included in the set Ω^{NI}_{if}. Similarly, the fixed importing cost for firm f and import source country m is adjusted based on whether m is included in Ω^{NX}_{if}.

In the numerical simulation, we implement this adjustment by lowering both export and import fixed costs if a firm exports to and imports from the same country. Specifically, we set the two idiosyncratic factors $\varepsilon^X_{ifn}(\Omega^{NI}_{if})$ and $\varepsilon^I_{ifm}(\Omega^{NX}_{if})$ as follows.

$$\begin{aligned} \varepsilon^X_{ifn}(\Omega^{NI}_{if}) &\equiv \bar{\varepsilon}^X_{ifn} \times \left(1 - \xi_f \mathbf{1}(n \in \Omega^{NI}_{if})\right) \\ \varepsilon^I_{ifm}(\Omega^{NX}_{if}) &\equiv \bar{\varepsilon}^I_{ifm} \times \left(1 - \xi_f \mathbf{1}(m \in \Omega^{NX}_{if})\right) \end{aligned}$$

In the expressions above, $\bar{\varepsilon}^X_{ifn} > 0$ and $\bar{\varepsilon}^I_{ifm} > 0$ are firm-country-specific draws that are exogenously fixed. ξ_f is a firm-specific roundtrip adjustment factor which reduces a firm's export and import fixed costs for the country that is included in both the set of sourcing countries and that of export destinations of the firm. We randomly draw ξ_f for each firm from a uniform distribution on $[0, 1]$.

6.2.2 Parameter Values

We construct a hypothetical economy under which we simulate the model to assess the behavior of the model numerically. The simulation is done for a partial equilibrium model for given country-level wages. We assume that there are 15 countries, each of which is populated by 1,000 firms. Firms are heterogeneous in their productivities. We randomly draw each firm's productivity from a Pareto distribution with the shape parameter equal to 3 and the lower bound 1. We simplify the country-level comparative advantage structure by assuming that all countries have identical wages (w_i), labor endowment (L_i), and average productivity (T_i), except for country 1, which has double the values for each. The value-added share is set at 1/3 for all countries. In the remainder of this section, we will report simulation results for GVC flows with country 1 at the center of the chain, similar to how our GVC measure is constructed from the data, with the U.S. at the center. Lastly, the elasticity of substitution in the CES utility function and the shape parameter θ in the Fréchet distribution for intermediate input productivity are both set to be 4.

To generate bilateral trade frictions, we first randomly draw variable export costs d_{in}^X for each country pair (i, n) such that $i \neq n$ from a uniform distribution on $[1, 1.4]$ under the restriction of $0 \leq \mid d_{in}^X - d_{ni}^X \mid \leq 0.03$ in order to implement the symmetric nature of variable trade costs. We adopt a simpler symmetry between variable export costs and variable import costs by assuming $d_{in}^X = d_{in}^I$—i.e., variable trade costs are identical for trade flows from country i to country n regardless of whether they are intermediate inputs or final goods. A similar symmetry is also imposed for the common component of the fixed costs.

While variable trade costs include many country-specific trade barriers, most notably distance, we can also explore the role of regional trade agreements in influencing these costs. We randomly sample 40% of country pairs as having regional trade agreements with each other, independent of the initial assignment of variable trade costs. If a country pair is selected to have an RTA, we eliminate both export and import variable costs by setting d equal to one for that pair.

6.2.3 Gravity with Simulated Data

After simulating the model using the parameter values described above, we obtain firm-level simulated GVC flows, as derived in equation (8). For $i = 1$, we aggregate this measure across firms to arrive at the bilateral GVC measure in equation 9, with country 1 at the center of the supply chain. The log of this bilateral GVC measure serves as the dependent variable in the simulated gravity exercise, which is specified similarly to its empirical counterpart in equation (6). Various distance measures in (6) are replaced by the values of d's drawn for the simulation. RTA indicators are constructed based on whether two countries are randomly selected to have an RTA, thereby having no variable trade costs in the simulation. Source and country fixed effects are included in all regressions.

We simulate our model under three scenarios. The first scenario uses the parameter values described in Section 6.2.2, including non-degenerate draws of ξ_f to account for the adjustment of fixed costs related to roundtrip behavior. In the second scenario, we assume no adjustment of fixed costs for roundtrip behavior by setting $\xi_f = 0$ for all f. The last scenario keeps $\xi_f = 0$ as in the second scenario and further restricts the model by assuming that fixed export and import costs have no idiosyncratic components—i.e., $\bar{\varepsilon}_{ifn}^X = \bar{\varepsilon}_{ifm}^I = 1$ for all countries and firms. In other words, the last scenario assumes that the fixed costs for each are exogenously given and independent of one another.

We present the gravity estimation results using simulated data in Table 9. For each scenario, we report the results corresponding to the specifications in column (6) of Table 3 and column (3) of Table 4.[33] We find a positive and significant roundtrip effect in scenario

[33]Since we do not calibrate this model framework to the actual data, the magnitude of the coefficients cannot be directly compared to those in Tables 3 and 4. We interpret the results from this simulated gravity exercise qualitatively and leave the full calibration of the model to future research.

1, where fixed costs are adjusted for roundtrip flows. The combined distance has a strongly negative effect on GVC flows, while the direct distance between the source and destination shows no significant effect. GVC flows are larger when all three countries have an RTA with one another. However, when the roundtrip adjustment of fixed costs is removed in scenarios 2 and 3, not only does the roundtrip effect disappear, but distance and RTAs also lose their significance in affecting GVC flows. This holds true regardless of whether we introduce idiosyncratic components in fixed export and import costs as in the baseline (scenario 2) or not (scenario 3).

Table 9: Gravity Estimation with Simulated Data

	Dependent Variable: Log Simulated Bilateral GVC					
	Scenario 1		Scenario 2		Scenario 3	
Variable	(1)	(2)	(3)	(4)	(5)	(6)
Round-trip (m=n)	0.57***	0.58***	0.13	0.15**	-0.03	-0.05
	(0.021)	(0.019)	(0.081)	(0.073)	(0.076)	(0.068)
Log Distance (m →US→ n)	-7.24***	-6.94***	11.20	11.43	-1.22	-0.88
	(2.559)	(2.461)	(7.456)	(7.582)	(10.131)	(10.033)
Log Distance (m to n)	-0.02		-0.10		0.04	
	(0.057)		(0.198)		(0.179)	
RTA (m, n, US)		0.09***		0.00		-0.12
		(0.030)		(0.107)		(0.083)
Exporter F.E.	yes	yes	yes	yes	yes	yes
Importer F.E.	yes	yes	yes	yes	yes	yes
Observations	196	196	196	196	196	196
R-squared	0.99	0.99	0.91	0.91	0.90	0.90
Round-trip Adjustment	yes	yes	no	no	no	no
Idiosyncratic Fixed Costs	yes	yes	yes	yes	no	no

Notes: "Round-trip adjustment" indicates whether fixed export and import costs are lowered for the country that appears in both the set of import sources and that of export destinations. "Idiosyncratic fixed costs" indicates whether fixed export and import costs have firm-specific components. Each scenario is described in the text in detail. The number of observations is equal to the square of the number of partner countries for country 1. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.
Source: Model simulated data.

In summary, we find that a model feature introducing complementarity between import sources and export destinations is crucial for capturing the roundtrip effect observed in the gravity relationship documented by the microdata. Omitting such a feature leads to a gravity relationship that is inconsistent with the data. As an example of a model feature that can introduce this complementarity, we propose endogenous fixed costs for exporting and sourcing, where fixed costs are lower for a firm's roundtrip behavior due to potential spillovers of knowledge about a particular foreign market. The development and quantification of a fully fledged model will be addressed in future research.

7 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 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 industry-level output, exports, and imports that aggregates out export and import intensities at the establishment-level and rely on import proportionality assumption that ignores heterogeneity in input sourcing within sectors. This paper measures GVCs for the U.S. manufacturing sector greatly minimizing biases due to aggregation and import proportionality.

We develop novel linkages between origin country-specific imported inputs embodied in an establishment's destination-specific manufactured exports. We show that in the absence of establishment-level linked data, U.S. GVCs would be under-estimated and their growth trends substantially muted. Further, bilateral GVCs measured using input-output tables do not feature a round-trip effect or strong role of RTAs in facilitating trade flows within U.S. GVCs and thus misses an important source of complementarity between input and output markets.

The establishment-level linkages between imports and material use and between exports and output provide a complete picture of U.S. manufacturer's 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 (Ding, Fort, Redding and Schott, 2022; Ding, 2023; Fort, 2023). Moreover, our methodology misses the indirect connections of U.S. establishments to global value chains through connections to other U.S. firms. This suggests that out current methodology, while comprehensively measuring direct foreign input sourcing by U.S. manufacturing plants, could be excluding other dimensions of how U.S. establishments contribute to global value chains. We leave extending the micro data linkage methodology to encompass such features for future research.

References

Antrás, Pol, "Conceptual Aspects of Global Value Chains," *World Bank Economic Review*, 2020, *34* (3), 551–5742514–2564.

Antràs, Pol and Davin Chor, "Global Value Chains," in Gita Gopinath, Elhanan Helpman, and Kenneth Rogoff, eds., *Handbook of International Economics, Vol. 5*, Elsevier, 2022, chapter 5, pp. 297–376.

Antrás, Pol, Evgenii Fadeev, Teresa Fort, and Felix Tintelnot, "Global Sourcing and Multinational Activity: A Unified Approach," 2022. mimeo.

_ , Teresa C. Fort, and Felix Tintlenot, "The Margins of Global Sourcing: Theory and Evidence from U.S. Firms," *American Economic Review*, 2017, *107* (9), 2514–2564.

Antràs, Pol, Evgenii Fadeev, Teresa C. Fort, and Felix Tintelnot, "Exporting, Global Sourcing, and Multinational Activity: Theory and Evidence from the United States," *The Review of Economics and Statistics*, 04 2024, pp. 1–48.

Atalay, Enghin, Ali Hortaçsu, and Chad Syverson, "Vertical Integration and Input Flows," *American Economic Review*, 2014, *104* (4), 1120–1148.

Baier, Scott L. and Jeffrey H. Bergstrand, "Do Free Trade Agreements Actually Increase Members' International Trade?," *Journal of International Economics*, 2007, *71*, 72–95.

Bayard, Kimberly, David Byrne, and Dominic Smith, "The Scope of US Factoryless Manufacturing," in Susan Houseman and Michael Mandel, eds., *Measuring Globalization: Better Trade Statistics for Better Trade Policy*, Kalamazoo: W.E. Upjohn Institute for Employment Research, 2015, chapter 2, pp. 81–120.

Bems, Rudolfs and Ayumu Ken Kikkawa, "Measuring Trade in Value Added with Firm-Level Data," *Journal of International Economics*, 2021, *129.*

Berman, Eli, John Bound, and Zvi Griliches, "Changes in Demand for Skilled Labor Within U.S. Manufacturing: Evidence from the Annual Survey of Manufacturers," 1993. NBER Working Paper w4255.

Bernard, Andrew B. and Teresa C. Fort, "Factoryless Goods Producing Firms," *American Economic Review Papers and Proceedings*, May 2015, *105* (5), 518–523.

_ , Emily J. Blanchard, Ilke Van Beveren, and Hylke Vandenbussche, "Carry-Along Trade," *Review of Economic Studies*, 2018, *86* (2), 526–563.

_ , J. Bradford Jensen, and Peter K. Schott, "Survival of the best fit: Exposure to low-wage countries and the (uneven) growth of U.S. manufacturing plants," *Journal of International Economics*, 2006, *68*, 219–237.

_ , _ , and _ , "Importers, Exporters and Multinationals: A Portrait of Firms in the U.S. that Trade Goods," in Timothy J. Dunne, J. Bradford Jensen, and Mark J. Roberts, eds., *Producer Dynamics: New Evidence from Micro Data*, Chicago, IL: University of Chicago Press, 2009, chapter 14, pp. 513–522.

_ , _ , **Stephen J. Redding, and Peter K. Schott**, "Firms in International Trade," *Journal of Economic Perspectives*, 2007, *21* (3), 105–130.

_ , _ , _ , **and** _ , "Global Firms," *Journal of Economic Literature*, 2018, *56* (2), 565–619.

Boehm, Christoph E., Aaron Flaaen, and Nitya Pandalai-Nayar, "Input Linkages and the Transmission of Shocks: Firm-level Evidence from the 2011 Tohoku Earthquake," *Review of Economics and Statistics*, 2019, *101* (1), 60–75.

_ , _ , _ , **and Jan Schlupp**, "The Local Area Incidence of Exporting," 2021. mimeo.

Caliendo, Lorenzo and Fernando Parro, "Estimates of the Trade and Welfare Effects of NAFTA," *Review of Economic Studies*, January 2015, *82* (1), 1–44.

Conte, Maddalena, Pierre Cotterlaz, and Thierry Mayer, "The CEPII Gravity Database," 2022. CEPII Working Paper 2022-05.

Cruz, Justino De La, Robert B Koopman, Zhi Wang, and Shang-Jin Wei, "Estimating foreign value-added in Mexico's manufacturing exports," 2013.

de Gortari, Alonso, "Disentangling Global Value Chains," 2019. NBER Working Paper 25868.

Dhyne, Emmanuel, Ayumu Ken Kikkawa, Magne Mogstad, and Felix Tintelnot, "Trade and Domestic Production Networks," *Review of Economic Studies*, 2021, *88* (2), 643–668.

Dietzenbacher, Erik, Bart Los, Robert Stehrer, Marcel Timmer, and Gaaitzen J. de Vries, "An Illustrated User Guide to the World Input-Output Database: the Case of Global Automotive Production," *Review of International Economics*, 2015, *23* (3), 575–605.

Ding, Xiang, "Industry Linkages from Joint Production," 2023. mimeo.

_ , **Teresa C. Fort, Stephen J. Redding, and Peter K. Schott**, "Structural Change Within Versus Across Firms: Evidence from the United States," 2022. NBER Working Paper 30127.

Eaton, Jonathan and Samuel Kortum, "Technology, geography, and trade," *Econometrica*, 2002, *70* (5), 1741–1779.

Feenstra, Robert C. and Gordon H. Hanson, "Foreign Investment, Outsourcing, and Relative Wages," in Robert Feenstra, Gene M. Grossman, and Douglas A. Irwin, eds., *Essays in Honor of Jagdish Bhagwati*, Cambridge, MA: MIT Press, 1996, pp. 89–127.

_ **and** _ , "Globalization, Outsourcing, and Wage Inequality," *The American Economic Review*, 1996, *86* (2), 240–245.

_ **and J. Bradford Jensen**, "Evaluating Estimates of Materials Offshoring from US Manufacturing," *Economic Letters*, 2012, *117*, 170–173.

Fetzer, James J., Tina Highfill, Kassu W. Hossiso, Thomas F. Howells III, Erich H. Strassner, and Jeffrey A. Young, "Accounting for Firm Heterogeneity within US Industries: Extended Supply-Use Tables and Trade in Value Added Using Enterprise and Establishment Level Data," in Nadim Ahmad, Brent Moulton, J. David Richardson, and Peter van de Ven, eds., *Challenges of Globalization in the Measurement of National Accounts*, Chicago, IL: University of Chicago Press, 2023, chapter 9, pp. 311–342.

Flaaen, Aaron, Fariha Kamal, Eunhee Lee, and Kei-Mu Yi, "Analyzing Aggregation Bias in the Measurement of U.S. Global Value Chains," *American Economic Review: Papers and Proceedings*, 2024.

Fort, Teresa, "The Changing Firm and Country Boundaries of US Manufacturers in Global Value Chains," *Journal of Economic Perspectives*, 2023, *37* (3), 31–58.

Fort, Teresa C., "Technology and Production Fragmentation: Domestic versus Foreign Sourcing," *Review of Economic Studies*, 2017, *84* (2), 650–687.

Freund, Caroline and Martha Denisse Pierola, "Export Superstars," *Review of Economics and Statistics*, 2015, *97* (5), 1023–1032.

Gopinath, Gita, Pierre-Olivier Gourinchas, Andrea F. Presbitero, and Petia Topalova, "Changing Global Linkages: A New Cold War?," 2024. IMF WP/24/76.

Handley, Kyle, Fariha Kamal, and Ryan Monarch, "Rising Import Tariffs, Falling Exports: When Modern Supply Chains Meet Old-Style Protectionism," *AEJ: Applied Economics*, forthcoming.

_ , _ , and Wei Ouyang, "A Long View of Employment Growth and Firm Dynamics in the United States: Importers vs. Exporters vs. Non-Traders," 2021. U.S. Census Bureau Center for Economic Studies Working Paper 21-38.

Houseman, Susan, Christopher Kurz, Paul Lengermann, and Benjamin Mandel, "Offshoring Bias in U.S. Manufacturing," *Journal of Economic Perspectives*, June 2011, *25* (2), 111–32.

Hsieh, Chang-Tai and Peter J. Klenow, "Misallocation and Manufacturing TFP in China and India," *Quarterly Journal of Economics*, 2009, *124* (4), 1403–1448.

Hummels, David, Jun Ishii, and Kei-Mu Yi, "The Nature and Growth of Vertical Specialization in World Trade," *Journal of International Economics*, 2001, *1* (54), 75–96.

Johnson, Robert and Guillermo Noguera, "Accounting for Intermediates: Production Sharing and Trade in Value Added," *Journal of International Economics*, 2012, *82* (2), 224–236.

_ and _ , "A Portrait of Trade in Value-Added Over Four Decades," *Review of Economics and Statistics*, 2017, *99* (5), 896–911.

Johnson, Robert C. and Andreas Moxnes, "GVCs and trade elasticities with multistage production," *Journal of International Economics*, 2023, *145*, 103796.

Kamal, Fariha, "A Portrait of US Factoryless Goods Producers," in Nadim Ahmad, Brent Moulton, J. David Richardson, and Peter van de Ven, eds., *Challenges of Globalization in the Measurement of National Accounts*, Chicago, IL: University of Chicago Press, 2023, chapter 12, pp. 425–447.

_ **and Wei Ouyang**, "Identifying U.S. Merchandise Traders: Integrating Customs Transactions with Business Administrative Data," 2020. U.S. Census Bureau Center for Economic Studies Working Paper 20-28.

Kee, Hiau Looi and Heiwai Tang, "Domestic Value Added in Exports: Theory and Firm Evidence from China," *American Economic Review*, 2016, *106* (6), 1402–1436.

Kehrig, Matthias and Nicolas Vincent, "The Micro-Level Anatomy of the Labor Share Decline," *Quarterly Journal of Economics*, 2021, *136* (2), 1031–1087.

Koopman, Robert C., Zhi Wang, and Shang-Jin Wei, "Tracing Value-Added and Double Counting in Gross Exports," *American Economic Review*, 2014, *104* (2), 459–494.

Kurz, Christopher, "Outstanding Outsourcers: A Firm- and Plant-level Analysis of Production Sharing," 2006. Finance and Economics Discussion Series (FEDS) Working Paper.

Laget, Edith, Alberto Osnago, Nadia Rocha, and Michele Ruta, "Deep trade agreements and global value chains," *Review of Industrial Organization*, 2020, *57*, 379–410.

Larch, Mario and Yoto V. Yotov, "Estimating the Effect of Trade Agreements: Lessons from 60 Years of Methods and Data," *The World Economy*, 2024, *forthcoming*.

Melitz, Marc J, "The impact of trade on intra-industry reallocations and aggregate industry productivity," *Econometrica*, 2003, *71* (6), 1695–1725.

Noguera, Guillermo, "Trade Costs and Gravity for Gross and Value Added Trade," 2012. mimeo.

OECD, "Trade in Value-Added (TiVA)," https://www.oecd.org/en/topics/sub-issues/trade-in-value-added.html 2024.

Pierce, Justin and Peter Schott, "A Concordance Between U.S. Harmonized System Codes and SIC/NAICS Product Classes and Industries," *Journal of Economic and Social Measurement*, 2012, *37* (1-2), 61–96.

Puzzello, Laura, "A Proportionality Assumption and Measurement Biases in the Factor Content of Trade," *Journal of International Economics*, 2012, *87* (1), 105–111.

Ruta, Michele, "Preferential Trade Agreements and Global Value Chains: Theory, Evidence, and Open Questions," 2017. World Bank Policy Research Working Paper 8190.

Setser, Brad, "When Tax Drives the Trade Data," https://www.cfr.org/blog/when-tax-drives-trade-data 2019. Accessed: 2023-04-04.

Timmer, Marcel, Bart Los, Robert Stehrer, and Gaaitzen J. de Vries, "An Anatomy of the Global Trade Slowdown based on the WIOD 2016 Release," 2016. GGDC Research Memorandum Number 162, University of Gronigen.

Timmer, Marcel P., Abdul Azeez Erumban, Bart Los, Robert Stehrer, and Gaaitzen J. de Vries, "Slicing up the Global Value Chain," *Journal of Economic Perspectives*, 2014, *28*, 99–118.

Tintelnot, Felix, "Global Production with Export Platforms*," *The Quarterly Journal of Economics*, 10 2016, *132* (1), 157–209.

U.S. Bureau of Economic Analysis, "Concepts and Methods of the U.S. Input-Output Accounts," https://www.bea.gov/sites/default/files/methodologies/IOmanual_092906.pdf 2009. (Accessed September 15, 2024).

U.S. Census Bureau, "Procedural History of the 2002 Economic Census," https://www2.census.gov/library/publications/economic-census/2002/ec02-00r-hist.pdf 2002. accessed August, 2024.

_ , "Overview of NAPCS Objectives, Guidance, and Implementation Strategy and Goals: A United States Perspective," https://www.census.gov/naics/napcs/papers/overviewobj.pdf 2003. accessed August, 2024.

_ , "2007 Census of Manufactures: Sources of the Data," https://www2.census.gov/econ2007/Reference_materials/htm%20files/ec31mdesc.htm 2007. accessed August, 2024.

_ , "History of the 2007 Economic Census," https://www.census.gov/history/pdf/2007econhistory.pdf 2007. accessed August, 2024.

_ , "2017 Economic Census Methodology," https://www.census.gov/programs-surveys/economic-census/year/2012/technical-documentation/methodology/basis.html 2012. accessed August, 2024.

_ , "2017 Economic Census Methodology," https://www.census.gov/programs-surveys/economic-census/year/2017/economic-census-2017/technical-documentation/methodology.html#sample-design 2017. accessed August, 2024.

_ , "2022 Economic Census Survey Repository," https://bhs.econ.census.gov/ombpdfs2022/ 2022. accessed April 4, 2023.

_ , "Economic Census: NAPCS-Based Codes Understanding Product Classification Systems," https://www.census.gov/programs-surveys/economic-census/year/2022/guidance/understanding-napcs.html 2022. accessed August, 2024.

_ , "Economic Census Technical Documentation," https://www.census.gov/programs-surveys/economic-census/year/2022/technical-documentation.html 2022. accessed April 4, 2023.

_ , "Commodity Flow Survey," https://www.census.gov/programs-surveys/cfs.html 2023. (Accessed April 3, 2023).

_ , "Economic Census (2002 – 2022)," https://www.census.gov/data/developers/data-sets/economic-census.html 2024. accessed August, 2024.

_ , "USA Trade Online," https://usatrade.census.gov/ 2024.

U.S. Office of Management and Budget, "North American Industrial Classification System: United States 2022," https://www.census.gov/naics/reference_files_tools/2022_NAICS_Manual.pdf 2024. accessed September, 2024.

Utar, Hale, Alfonso Cebreros, and Luis Bernardo Torres, "The US-China Trade War and the Relocation of Global Value Chains to Mexico," CESIfo Working Paper 10638 2023.

White, T. Kirk, Jerome P. Reiter, and Amin Petrin, "Imputation in U.S. Manufacturing Data and Its Implications for Productivity Dispersion," *Review of Economics and Statistics*, 2018, *100* (3), 502–509.

Winkler, Deborah and William Milberg, "Errors from the Proportionality Assumption in the Measurement of Offshoring: Application to German Labor Demand," 2009. SCEPA WP 2009-12, Schwartz Center for Economic Policy Analysis and Department of Economics, New School for Social Research.

WIOD, "World Input-Output Database," https://www.rug.nl/ggdc/valuechain/wiod/?lang=en 2023. (Accessed April 3, 2023).

A Data Appendix

A.1 Constructing Establishment-Level GVC Measures

A.1.1 Sample Criteria

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. Counts are rounded to comply with Census Bureau disclosure avoidance rules.
Source: Authors' calculations using CMF and LFTTD.

Given our focus on linking firms' trade flows to their production activities, our sample includes all establishments in the manufacturing sector. 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).[34]

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

About 40% of manufacturing establishments, that 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 are populated using administrative records. However, there is no information available on detailed product and materials for these establishments and we drop these administrative records.[35]

We report the number of firms and establishments in each year in our analysis sample 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 are 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).

A.1.2 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 typically account for 20-30 percent of the industry total (in terms of value), and cannot be directly linked to product codes in the LFTTD. Table A2 reports the share of costs and shipments reported to be "not elsewhere specified" as part of either the CMF-MAT (Panel A) and CMF-PROD (Panel B), respectively. This share is quite low in the CMF-PROD.

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 utilize 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.[36] 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

[35] 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).

[36] 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.

Table A2: 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).

of disaggregated (i.e. 7-digit) matches. We iterate up to the 4-digit level until we have matched all Census product codes to NAICS-Baseroots.[37]

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.1.3 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:

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

[37]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 utilize concordances between 2017 NAPCS and 2012 Census product codes (U.S. Census Bureau, 2022b). Census material codes remain unchanged over the sample period.

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 utilize 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 CM-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 at the "diagonal" of an input-output table. We show in Panel A of Table A3 that such instances represent a relatively small share of our material costs, due in part to the availability of establishment-level product data at the 6-digit level of disaggregation in the CMF-MAT and CMF-PROD. At the establishment-level, the overlap is less than 20 percent in any sample year, and typically closer to 15 percent as shown in Panel A, Table A3. However, if only 3-digit level detail of product codes were available, the overlap would be double or more. 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.

The overlap identified in Panel A, Table A3 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 highlight the important role of aggregation when using these trailer files. Panel B replicates the calculations of Panel A of Table A3, by aggregating the data to the level of the firm. Here we see *much* higher rates of 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.

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

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

Of the identified intermediate imports linked to establishments, 60% of the value 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 in column (1), Table A4 across the sample years.

Table A3: Overlap Between Input Products and Output Products

	Share of Input Codes Matching 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-calculates this statistic under more aggregated industry classifications.
Source: Authors' calculations using CMF and LFTTD.

Table A4: 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 2 is not directly comparable to the statistic in Johnson and Noguera (2012): "[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 in 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.1.4 Production-Associated Exports

Using a similar approach as in Section A.1.3, 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, 2018a).

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 Appendix: Additional Results

B.1 The Import Source Content of U.S. Exports: Overall Patterns

This section documents core patterns in the embedded import source countries of U.S. exports by export destination. This measures how countries are connected through the United States based on actual establishment-level input and output measures that does not rely on proportionality assumptions or aggregation bias.

We first modify Equation (5) to notate bilateral GVC measures by sector as follows:

$$GVC_{mnst} = \sum_{e \in E_{mnst}} \left(\frac{\sum_r IMP_{emrt}^I}{GO_{est}} \sum_p EXP_{enpt} \right), \tag{A4}$$

where E_{mnst} is the set of establishments in industry s that import inputs from country m and export products to country n in year t. Thus, we first compute bilateral GVC measures for each establishment and then aggregate them across all establishments in industry s participating in a particular supply chain of (m, n). To compute the GVC share for each (m, n, s, t), Equation (5) is divided by $\sum_{e \in E_{mnst}} \sum_{n,p} EXP_{enpt}$.

Table A5 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. A striking feature in Table A5 is how Canada and Mexico occupy all of the top destinations for the input-output country pairs. We see evidence of "round-trip" behavior in the aggregate for both Canada and Mexico. While North America is a prominent input source in U.S. global value chains, countries such as China, Japan, Singapore, and Germany also occupy top bilateral positions as source countries.

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 A6. For example, in the Pharmaceuticals sector, Ireland is remarkably 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,

Table A5: Top GVC Country Pairs in the Manufacturing Sector, 2012

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

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 some well-known 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 (see Tintelnot (2016) and Antrás, Fadeev, Fort and Tintelnot (2022)).

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 imports 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 cross two oceans as part of the value chain moving from the source country, to the United States, and then to the destination country.

Table A6: 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 displays 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.2 Regional Trade Agreements and Additional Gravity Results

Table A7: 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 sample criteria that satisfy the RTA (m & US, n & US) indicator (Panel A) and RTA (m, n, US) indicator (Panel B) as described in the text.

Table A8: Gravity Model of GVC, Annual Estimates 2002-2017

	Dependent Variable: Log Bilateral GVC			
	2002	2007	2012	2017
Variable	(1)	(2)	(3)	(4)
Round-trip (m=n)	1.45***	1.48***	1.49***	1.139***
	(0.266)	(0.228)	(0.227)	(0.244)
Log Distance ($m \rightarrow$US$\rightarrow n$)	0.316	-1.401***	-0.371	-0.516**
	(0.254)	(0.247)	(0.237)	(0.212)
Log Distance (m to n)	-0.206***	-0.147***	-0.178***	-0.174***
	(0.0220)	(0.0217)	(0.0210)	(0.0194)
Exporter F.E.	yes	yes	yes	yes
Importer F.E.	yes	yes	yes	yes
Observations	26,000	29,500	29,000	32,000

Notes: Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.
Source: Authors' calculations using the CMF, LFTTD, and WIOD.

B.3 The Role of Industry Definition in GVC Measures

In addition to exploring the role of aggregation bias in GVC measurement we also highlight the role of industry mis-classification that arises due to choice of the source data for identifying industry. Large firms play an out-sized role in mediating goods trade (e.g., Freund and Pierola (2015)). These traders also tend to operate across multiple sectors (e.g., Handley et al. (2021)). However, 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 misclassification, 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 firms' payroll.[38] We construct an analog of gvc^I_t except that we use the definition of sector based on firms' primary industries as follows:

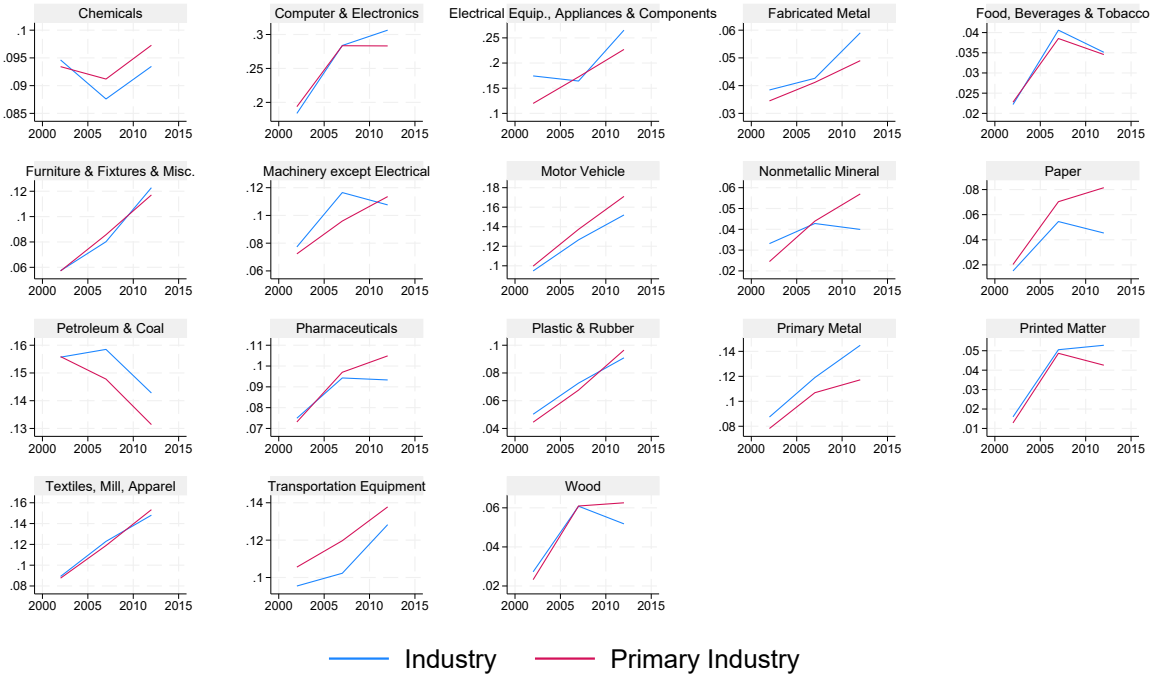
$$gvc^{I\star}{}_t = \frac{\left[\sum_{f,e,s^\star} EXP_{fes^\star t} \frac{\sum_{f,e,s^\star} IMP^I_{fes^\star t}}{\sum_{f,e,s} GO_{fes^\star t}}\right]}{\sum_{f,e,s^\star} EXP_{fes^\star t}}. \tag{A5}$$

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^I_t.

However, the aggregate statistics mask variation in both levels and trends within subsectors as displayed in Figure A1 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.

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

Figure A1: 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 A5.

Source: Authors' calculations using CMF and LFTTD.

B.4 The Role of Establishment versus Firm Aggregation in GVC Measures

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

$$gvc_{st}^{F} = \frac{1}{\sum_{f,e} EXP_{fest}} \sum_{f} \left[\sum_{e} EXP_{fest} \frac{\sum_{e} IMP_{fest}^{I}}{\sum_{e} GO_{fest}} \right]. \tag{A6}$$

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).[39] This suggests that industry mis-classification is a more important source of bias than availability of firm-industry information only in GVC measurement.

[39]The results are available upon request.