# Aggregation Bias in the Measurement of U.S. Global Value Chains

**by**

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**CES 24-49** **September 2024**

**Abstract**

This paper measures global value chain (GVC) activity, defined as imported content of exports, of U.S. manufacturing plants between 2002 and 2012. We assesses the extent of aggregation bias that arises from relying on industry-level exports, imports, and output to establish three results. First, GVC activity based on industry-level data underestimate the actual degree of GVC engagement by ignoring potential correlations between import and export activities across plants within industries. Second, the bias grew over the sample period. Finally, unlike with industry-level measures, we find little slowdown in GVC integration by U.S. manufacturers.

**Keyword:** global value chains, aggregation bias

**JEL Classification:** F1, F14, O51

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# 1 Introduction

Decades of empirical and theoretical research on global value chains (GVCs) have shown their importance in understanding the causes and consequences of globalization. More recently, there is widespread agreement that GVCs have figured prominently in the slowdown of globalization, as well as the U.S.-China tariff conflict, the Covid-19 pandemic and subsequent monetary and fiscal stimulus, and the Russia-Ukraine war.

The measures of GVCs employed in existing studies are typically derived from multi-country input-output tables.[1] While these measures have been enormously useful, the construction of such tables from industry-level data makes them potentially susceptible to aggregation bias. Of course, GVCs are fundamentally a firm or establishment-level concept.

This paper assesses the significance of aggregation bias in measuring GVC activity – the bias that arises when an entire industry is essentially treated as a single firm or establishment. To do so, we employ U.S. Census microdata to construct measures of establishment-level GVCs from data on imported inputs, exports, and gross output. We aggregate our establishment-level measures to the industry-level (all of manufacturing) and compare them to a measure constructed from industry aggregates of imported inputs, exports, and gross output.

We find that there is negative aggregation bias; that is, our establishment-level measures aggregated to the industry level are greater than an industry-level measure constructed from standard input-output (IO) table assumptions. Moreover, this bias grew between 2002 and 2007, and between 2007 and 2012. Finally, unlike with industry-level measures, we see little slowdown in GVC integration by U.S. manufacturers during this time period.

In addition, we show that the bias, and the growth of the bias, is dominated by establishments that are both exporters and importers. We conduct a bias decomposition following the approach of Bems and Kikkawa (2021); our results show that most of the increase in the bias between 2002 and 2012 is from "Within-GVC" bias, i.e., within establishments for which high export intensities are also associated with high import intensities. Our results suggest that GVC measures constructed at a granular level will provide further understanding into how firms, and economies, adjust to shocks such as those mentioned above.

# 2 GVC Estimates from Plant-Level Data

In recent work, Flaaen, Kamal, Lee and Yi (2024) describe new efforts to measure global value chain participation using U.S. microdata. While a full description of these data efforts is available in that paper, we highlight several important features here. The emphasis of this work is on how U.S. *production* activity is linked in global value chains; therefore we focus

[1] See, for example, the World Input-Output Database (WIOD). and similar tables produced by the OECD.

attention on U.S. establishments in the manufacturing sector and identify their linkages to foreign countries through 1) their use of imported inputs in U.S. production, and 2) their reliance on foreign export markets.

Despite the richness of the transaction-level export and import data linked to U.S. firms in the Census Longitudinal Foreign Trade Transactions (LFTTD) microdata, there are two crucial measurement challenges in linking these LFTTD transactions to actual production activity in the United States. A first challenge involves removing imports not used as inputs in production, while also removing exports that are not produced in U.S. manufacturing (non-manufactured goods like agriculture and mining, or exported goods from wholesale operations). An extreme example of this are the "factoryless" goods producers highlighted in Bernard and Fort (2015). Second, given the prevalence of multi-industry firms, our production-oriented approach requires bringing the firm-level trade data from the LFTTD down to the level of the individual establishment.

The approach described in Flaaen, Kamal, Lee and Yi (2024) to filter trade transactions associated with U.S. production relies on product-level trailer files provided in the U.S. Census of Manufacturing (CMF). These trailer files allow the researcher to link inputs used in production to imported products and also link produced outputs to exported products. Moreover, since these trailer files provide this product-level information at the level of individual plants comprising a firm, they also allow for a strategy to split the relevant import and export products from the level of the firm down to individual establishments, thus further linking trade transactions to actual production activity in the U.S. The result is an accurate view of global value chains with unprecedented micro-level detail for the U.S. economy.

Our measure of global value chain activity is based on the share of imported content in exports, or the vertical specialization ($VS$) measure following Hummels, Ishii and Yi (2001).[2] Hence, at the most detailed level possible, our GVC measure is defined for an establishment $e$ at time $t$ for an input product $r$ imported from country $m$ and an export product $s$ exported to country $n$ as:

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

where $IMP^{I}_{emrt}$, $GO_{est}$, and $EXP_{enst}$ represent imported inputs, gross output, and exports, respectively. As previously discussed, we use imports of inputs and produced exports when measuring imports and exports from the U.S. data to ensure an accurate depiction of how each establishment's GVC engagement is centered around its actual production activity.

We refer to this as a "direct" GVC measure to emphasize that it captures trade only in goods that are directly mediated by the manufacturing establishment itself. Two further

[2]The difference between total gross exports and the imported content of exports represents value-added trade; hence, $(1-VS)$ is the domestic value-added share of exports. If production takes three or more stages, $(1-VS)$ is an approximate measure; see Johnson and Noguera (2017) and Koopman, Wang and Wei (2014).

GVC concepts are excluded from this measure. First, the direct GVC measure does not reflect imported inputs or exported products that are processed through a separate firm, such as a wholesaler. Second, this measure does not incorporate upstream imported content from domestic suppliers, or downstream exported content from domestic customers.[3]

For a micro-based estimate of GVC for overall manufacturing that is the focus of this paper, we sum equation (1) across all source and destination countries and across all input and output products for a given establishment, and then across all establishments in manufacturing.[4] For ease of comparison, we convert the dollar-value of these GVC measures into shares by dividing them by an aggregate measure of exports. Specifically, the aggregate establishment-based GVC measure is

$$gvc_t^E = \frac{\sum_{e \in E_t} \left[ EXP_{et} \frac{IMP_{et}^I}{GO_{et}} \right]}{\sum_{e \in E_t} EXP_{et}}, \tag{2}$$

where $E_t$ denotes the set of establishments in the manufacturing sector; $EXP_{et}$, $IMP_{et}^I$, and $GO_{et}$ represent establishment $e$'s total produced exports, input imports, and gross output, respectively, aggregated over all source and destination countries as well as all products. Importantly, this measure calculates the $VS$ measure *first* at the establishment level before aggregating it across all establishments.

# 3 Aggregation Bias in GVC Measurement

Without our establishment-based perspective on global value chains, researchers would rely on measures that combine exports, imports, and output that are harmonized at the industry level. In contrast to equation (2), such measures would be constructed in the following way:

$$gvc_t^I = \frac{\left( \sum_{e \in E_t} EXP_{et} \right) \left( \frac{\sum_{e \in E_t} IMP_{et}^I}{\sum_{e \in E_t} GO_{et}} \right)}{\sum_{e \in E_t} EXP_{et}}, \tag{3}$$

where the share of imported input content in exports is calculated at the industry level, rather than the establishment level.

Such industry-based measures of global value chains can inaccurately capture the magnitude and growth of U.S. firms' participation in GVCs. One main source of this inaccuracy is aggregation bias. Bems and Kikkawa (2021) is the first paper, to our knowledge, that

[3] Using Belgian data, Dhyne, Kikkawa, Mogstad and Tintelnot (2023) show that such indirect trade activity is important.

[4] Flaaen, Kamal, Lee and Yi (2024) examine industry-level heterogeneity in GVC measurement and aggregation bias, by aggregating equation (1) by output industry.

presents micro-level evidence for aggregation bias with GVC measurement.[5] They do this for Belgium. Our paper documents the bias for the United States, and it extends and enhances our understanding of this aggregation bias along several fronts.

Table 1: Example of GVC Aggregation Bias

| | Imports | Gross Output | Exports | GVC |
|---|---|---|---|---|
| Estab 1 | 20 | 50 | 20 | 8 |
| Estab 2 | 5 | 50 | 10 | 1 |
| Estab Aggregate | | | | 9 (0.3) |
| Industry Aggregate | 25 | 100 | 30 | 7.5 (0.25) |

We illustrate aggregation bias with a simple two-establishment example in Table 1.[6] Given the import, output, and export values of the two establishments in the economy, one results in a GVC value of \$8 while the other results in a value of \$1. Hence, the total GVC in this economy is \$9, and when scaled by aggregate exports, we arrive at 30 cents of each dollar of exports is embodied imports. The answer would be different without the establishment-level data. With only aggregate information of \$25 of imports, \$30 of exports, and \$100 of output, the GVC measure would be \$7.50, or a scaled 25 cents for each dollar of exports. This is downward, or negative, aggregation bias.

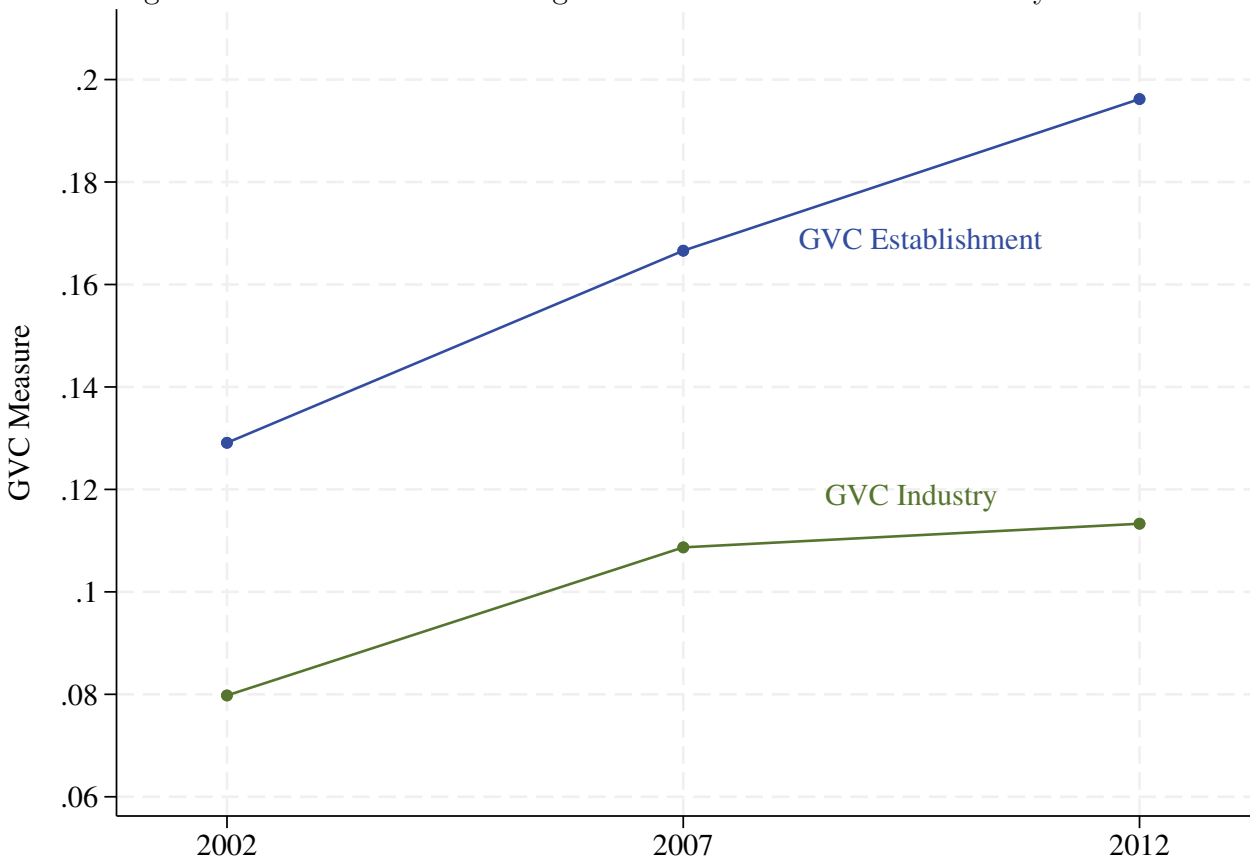
To isolate the role of aggregation bias, we compare the establishment-based measure to a derived measure that uses the same data but mirrors what is used by industry-based measures in equation (3). Figure 1 plots these two distinct measures of U.S. manufacturing establishments' involvement in global value chains.

The figure shows that our micro-level measure grew more between 2002 and 2012 than the industry-based measure. The bias is downward and increasingly so over time. Specifically, our GVC measure increased by about 7 percentage points, or more than 50 percent, between 2002 and 2012, so that by 2012, almost 20 cents of imported inputs is embodied in every \$1 of U.S. exports. The industry-based measure, on the other hand, is smaller in magnitude, and the growth slowed sharply between 2007 and 2012 relative to the preceding five-year period. While this slowdown is consistent with evidence on the slowing of globalization, our micro-based evidence conveys a different message of little slowing in globalization trends, at least through 2012.

[5] Koopman, Wang and Wei (2012) do sector-level analysis, and account for processing activity as a separate sector, which reduces the aggregation bias.

[6] Our example is similar to that in Bems and Kikkawa (2021).

Figure 1: GVC in Manufacturing: Establishment-based vs. Industry-based




**Source:** Authors' calculations using CMF and LFTTD.

# 4 Decomposing the GVC Aggregation Bias

This section decomposes the aggregation bias in two ways. We begin by defining the unweighted and the gross output-weighted averages of export and import intensities:

$$\bar{\alpha}_t^X \equiv \frac{1}{N_t^E}\sum_{e\in E_t}\left(\frac{EXP_{et}}{GO_{et}}\right) \quad ; \quad \tilde{\alpha}_t^X \equiv \frac{\sum_{e\in E_t} EXP_{et}}{\sum_{e\in E_t} GO_{et}}$$
$$\bar{\alpha}_t^M \equiv \frac{1}{N_t^E}\sum_{e\in E_t}\left(\frac{IMP_{et}^I}{GO_{et}}\right) \quad ; \quad \tilde{\alpha}_t^M \equiv \frac{\sum_{e\in E_t} IMP_{et}^I}{\sum_{e\in E_t} GO_{et}},$$

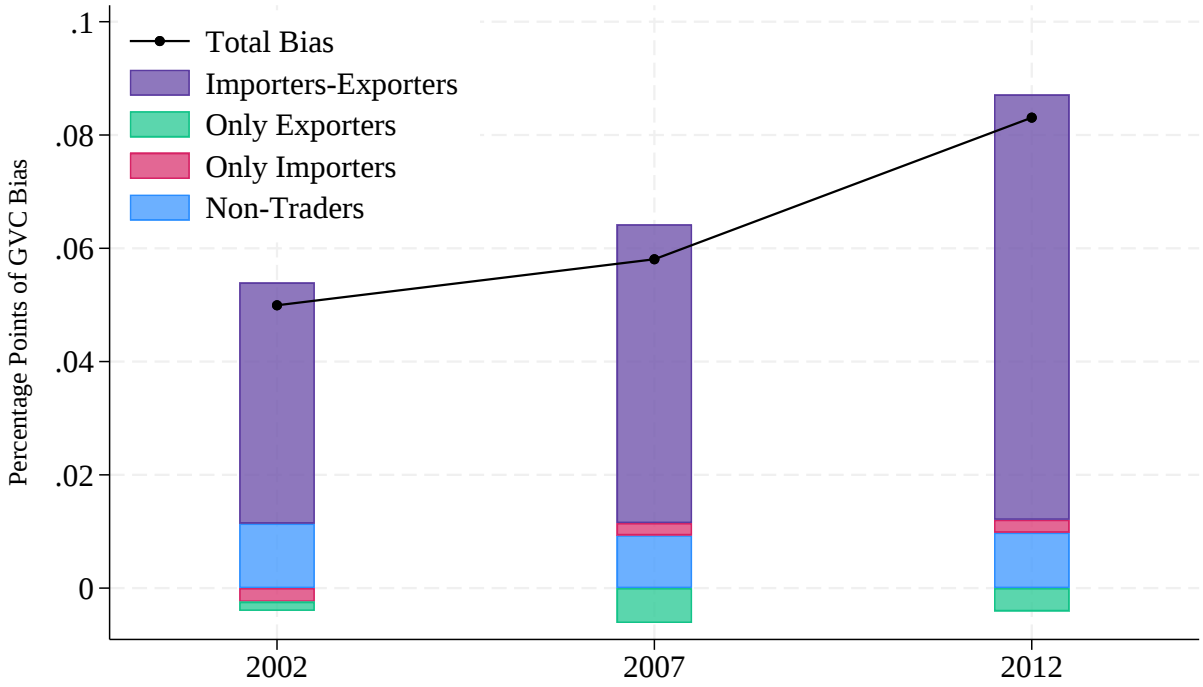
where $N_t^E$ is the total number of establishments in U.S. manufacturing. We also denote the simple average of gross output by $\bar{GO}_t \equiv \frac{1}{N_t^E}\sum_{e\in E_t} GO_{est}$. With these notations in hand, we can write the establishment-industry aggregation bias ($B_t^{EI}$) as:

$$\begin{aligned} B_t^{EI} &\equiv gvc_t^E - gvc_t^I \\ &= \frac{\sum_{e\in E_t} \Delta\alpha_{et}^X \Delta\alpha_{et}^M GO_{et}}{\sum_{e\in E_t} EXP_{et}}, \end{aligned} \tag{4}$$

where $\Delta\alpha_{et}^{X}$ and $\Delta\alpha_{et}^{M}$ represent the deviations of each establishment's export and import intensities from their respective weighted averages.

Equation (2) shows that an establishment must have positive values of both imports and exports to register a non-zero value of the direct establishment-based GVC measure. An establishment with zero exports but positive imports will record an establishment-level GVC ($GVC_{et}$) of zero, yet the imports of that establishment will nevertheless contribute to the industry-based measure of GVC (and similarly for establishments with positive exports but zero imports). Even non-trading establishments will affect the bias, because the gross output of these establishments will still be a part of total gross output of the manufacturing sector in equation (3), while their contribution to the establishment-based measure in equation (2) is zero.

Figure 2: GVC Bias by Establishment Type in U.S. Manufacturing




**Source:** Authors' calculations using CMF and LFTTD.

By grouping establishments in $E_t$ based on their trading status, we can decompose the overall bias in equation (4) into contributions made by importer-exporters, only-exporters, only-importers, and non-traders. Figure 2 illustrates the decomposition results. Importer-exporters account for the majority of the aggregation bias, and their contribution grew during the period 2002-2012. Perhaps surprisingly, non-traders contribute a non-trivial share of the overall aggregation bias; while these establishments do not trade and have lower than average values of output, they represent roughly half the establishments (in 2012) in our data – hence their combined impact is significant. By contrast, the contribution of only-importers and

only-exporters to the aggregation bias is relatively small. Indeed, those establishments that only export actually reduce the bias throughout our sample.

Part of the increased contribution of importer-exporters during our sample period reflects an increasing share of establishments that import and export—from 21 percent in 2002 to 28 percent in 2012. Conversely, the share of establishments with no trading activity at all declines from 63 percent in 2002 to 51 percent in 2012.

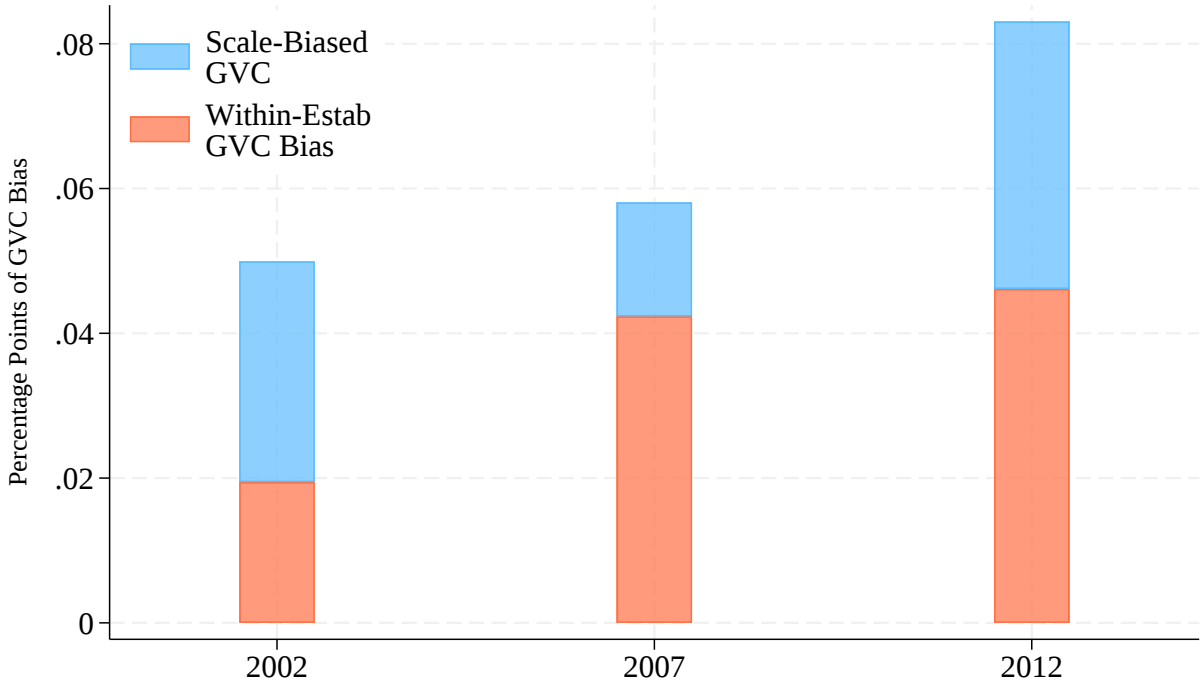
A more nuanced perspective on the micro-level features underlying the aggregation bias is found from expanding the numerator of equation (4) in a way similar to that in Bems and Kikkawa (2021):

$$\begin{aligned}\sum_{e\in E_t}\Delta\alpha_{et}^{X}\Delta\alpha_{et}^{M}GO_{et} &= N_t^E\bar{GO}_t cov(\alpha_{et}^{X},\alpha_{et}^{M})\ldots \\ &+\sum_{e\in E_t}\left(GO_{et}-\bar{GO}_t\right)\left(\alpha_{et}^{X}-\bar{\alpha}_t^{X}\right)\left(\alpha_{et}^{M}-\bar{\alpha}_t^{M}\right)\ldots \\ &-\left(\bar{\alpha}_t^{X}-\tilde{\alpha}_t^{X}\right)\left(\bar{\alpha}_t^{M}-\tilde{\alpha}_t^{M}\right)N_t^E\bar{GO}_t. \qquad (5)\end{aligned}$$

As a whole, equation (5) helps to interpret the aggregation bias as reflecting the weighted covariance structure between export and import intensities across the size distribution of manufacturing establishments. There are two components to equation (5) that provide further intuition for micro-level features underlying the bias. The first term, which we refer to as the "Within-Establishment GVC Bias", reflects the overall unweighted covariance between export and import intensities among all establishments. This effect captures the overall extent of GVC activity occurring within establishments (both importing *and* exporting).

The second component (combining the second and third terms of equation (5)) reflects the extent to which correlated export and import intensities scale with overall establishment size. This second component, which we refer to as "Scale-Biased GVC", captures whether GVC activity *within* the establishment – where imported inputs are processed into output for export at the same plant — occurs disproportionately at large establishments. This bias is larger when larger establishments directly import a greater amount of inputs for the production of output, and a larger share of their output is subsequently exported downstream. Alternatively, the bias is lower where larger establishments tend to specialize in either importing inputs or in exporting output, but not both. Recall that industry-based GVC measures do not account for the correlations of export and import intensities across establishments (the "Within-GVC Bias"), with this omission being more consequential (creates a larger bias) if the highest correlations of export and import intensities occur at the largest establishments ("Scale-Biased GVC"). Figure 3 shows the decomposition of the aggregation bias into the Within-Estab Bias and Scale-Biased GVC. Two features of this decomposition contrast with what was found for the case of Belgium in Bems and Kikkawa (2021). First,

Figure 3: Sources of GVC Aggregation Bias in U.S. Manufacturing




**Source:** Authors' calculations using CMF and LFTTD.

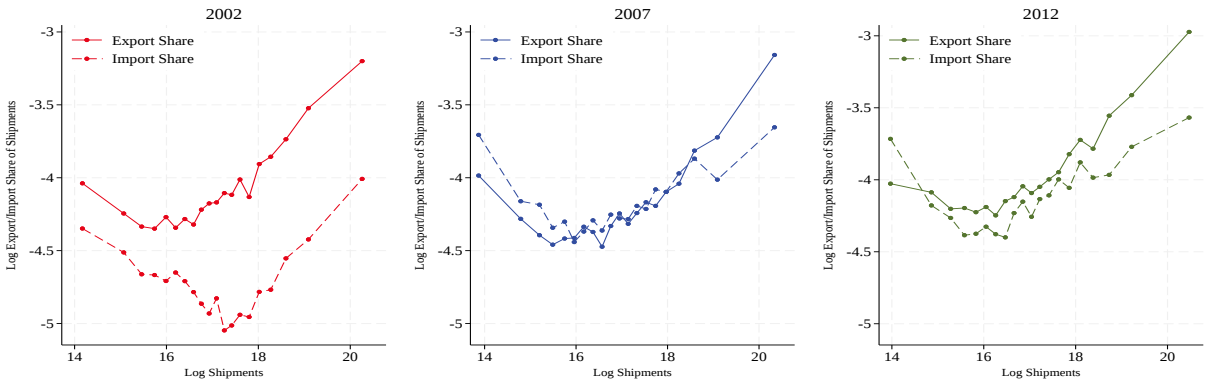
while the aggregation bias in Belgium was driven almost exclusively by the within-estab bias, for the U.S. we find that both components contribute significantly to the overall bias during our sample period. Second, the relative contributions of these two components in the U.S. change significantly over time, unlike what was found in the case of Belgium.

As Figure 3 shows, the one percentage point increase in the bias between 2002 and 2007 comes from a large increase in the within-estab bias, even as the scale bias declines. Then, between 2007 and 2012, the within-estab bias remains flat while the scale bias more than doubles in size. These movements in the aggregation bias reflect real micro-level dynamics of exporting and importing establishments. To confirm the increased role of within-estab GVC in 2007 and 2012 we regress log import intensity on log export intensity across all trading establishments, controlling for 3-digit NAICS industry fixed effects. This bilateral coefficient rises from 0.1 in 2002 to 0.15 in 2007 and 0.13 in 2012.[7]

Another illustration of the role of underlying micro-level dynamics of GVC activities in the evolution of aggregation bias is shown in Figure 4, which plots the relationship between establishment size and export and import intensities. Specifically, we divide establishments into 20 equal-sized bins along the distribution of log shipments and then plot the average log

[7]The within-estab bias in equation (5) also reflects changes in overall gross output, which has expanded rapidly during our sample. This feature may explain the modestly larger within-estab bias in 2012 even though the bilateral coefficient declined.

Figure 4: Export and Import Intensity Along the Establishment Size Distribution




**Source:** Authors' calculations using CMF and LFTTD as explained in the text.

export and import intensities for each bin.[8] The resulting heterogeneity in trade intensity across the establishment size distribution provides a useful illustration for unpacking the components of the aggregation bias highlighted above. Indeed, among other features, Figure 4 reveals an intriguing U-shaped relationship between establishment size and both export and import intensities that is evident in all years of our sample. The determinants of this shape will be a subject of our future research.

The most striking change between 2002 and 2007 is the large upward shift in import intensity *across all establishment-size bins*, consistent with the substantial increase in input imports during this period. This significant expansion of imported input use by U.S. manufacturers is likely linked to the expanded role of China in the global trading system during this time period. Such a broad-based expansion of imported inputs that results in a more closely aligned import and export intensity raises GVC activity in a way that increases the within-estab GVC bias, which was evident in Figure 3. Moreover, when comparing the left and middle panels of Figure 4, it appears that the largest establishments by size actually saw the smallest increase in alignment between export and import intensity, consistent with the relative reduction in the scale bias between 2002 and 2007.

Finally, from 2007 to 2012 the slope of the export and import intensities relative to size steepens somewhat, with increases in export intensity that are not quite matched by increases in import intensity, especially for larger plants. These modest shifts in the trade profiles of the establishment size distribution in 2012 are consistent with an increase in the scale bias even as the within-estab bias remains high.

In summary, we provide a new and detailed accounting of the changes in how U.S. manufacturers interacted with global supply chains during this period while also pointing to how industry-level estimates provide a misleading picture of these changes. This exploration

[8]For this illustration it is useful restrict the sample underlying Figure 4 to be all importer-exporter establishments. Moreover the binscatter figures also control for three-digit industry fixed effects to net out features solely driven by industry composition.

provides clues for what additional basic statistics could be regularly disclosed to supplement industry-level data, correcting for these aggregation biases in the future.

# 5 Concluding Remarks

Contrary to what industry-level data would reveal, we find that U.S. manufacturers' participation in GVCs increased at a steady pace between 2002 and 2012. Improved measurement of such basic statistics describing globalization is one benefit of a new production-oriented dataset linking imported inputs, output, and export activity, all at the level of individual plants. Future work will explore other potential pitfalls of more aggregate data and suggest ways that such industry-based measures could be improved without access to confidential microdata.

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