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Trade and Domestic Production Networks

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We examine how many and what kind of firms ultimately rely on foreign inputs, sell to foreign markets, and are affected by trade shocks. To capture that firms can trade indirectly by buying from or selling to domestic firms that import or export, we use Belgian data with information on both domestic firm-to-firm sales and foreign trade transactions. We find that most firms use a lot of foreign inputs, but only a small number of firms show that dependence through direct imports. While direct exporters are rare, a majority of firms are indirectly exporting. In most firms, however, indirect export is quantitatively modest, and sales at home are the key source of revenue. We show that what matters for the transmission of foreign demand shocks to a firm's revenue is how much the firm ultimately sells to foreign markets, not whether these sales are from direct or indirect export.

Key words: Production Networks, International Trade.

JEL Codes: F14, L14

1. INTRODUCTION

The increased availability of micro datasets on firms' foreign trade has shifted the focus of research on international trade from countries and industries to firms. One important insight from these data is that importers and exporters represent a very small fraction of firms across many developed and developing economies (Tybout, 2003; Melitz and Redding, 2014). Another important insight is that firms that import or export tend to be larger, more productive, and pay higher wages, even prior to their entry into international markets (Bernard and Jensen, 1999; Bernard *et al.*, 2007). These empirical insights have spurred the development of new theories of trade emphasizing firm heterogeneity and self-selection (Bernard *et al.*, 2003; Melitz, 2003; Antràs and Helpman, 2004). In these models, only the most productive firms are able to overcome the costs of entering foreign markets. Thus, it is argued, a reduction in trade barriers or transportation costs makes the productive firms that trade internationally expand while less productive non-trading firms shrink or exit.

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The fact that only a small and selective set of firms are directly exporting or importing does not necessarily imply that few firms are relying on foreign inputs or producing goods that end up in foreign markets. Even if firms themselves do not import or export, they may buy from or sell to domestic firms that trade internationally. However, accurately capturing this notion of *indirect trade* is difficult since domestic firm-to-firm transactions are rarely observed. As a result, there is little direct evidence on how many and what kind of firms ultimately rely on foreign inputs, sell to foreign markets, or are affected by changes in trade barriers or transportation costs.

The goal of this article is to help close this knowledge gap and broaden the empirical perspective on international trade to include all firms, including those that do not directly import or export. To this end, we combine data on domestic firm-to-firm sales with information on firms' foreign trade transactions. Our analyses employ a unique panel dataset of Belgian firms, which is based on several micro data sets that we have linked.[1] Annual accounts provide data on input factors and output, custom records and intra-EU declarations give information on imports and exports, and a value-added tax (VAT) registry provides information on domestic firm-to-firm transactions.

Using these data, we construct measures of import and export which capture that firms may choose to access foreign markets both directly and indirectly. In particular, we measure the total import and export of a firm as the total share of inputs that it buys directly or indirectly from abroad (*i.e.* the *total import share*) and the total share of output that it sells directly or indirectly to foreign markets (*i.e.* the *total export share*). The key assumption we make to compute these measures is that the firm's composition of inputs in production does not vary across its buyers. Under this assumption, it follows that the total import share is high if much of the firm's inputs are imported either directly from abroad or indirectly via purchases from domestic suppliers with high import shares. By comparison, the total export share is high if a lot of the firm's output is exported directly to foreign markets or indirectly via sales to domestic buyers with high export shares.

Our article offers five sets of results. First, we show that most firms rely a lot on foreign inputs, but only a small number of firms show that dependence through the direct imports observed in trade transaction data. Indeed, many of the firms with high total import shares do not directly import. Moreover, the total import shares tend to be high even in industries with little direct import, such as the service sector. We show that indirect import remains important even if one excludes the inputs that are directly imported by wholesalers or retailers.

Second, while direct exporters are rare, a majority of firms are indirectly exporting through sales to domestic buyers that subsequently trade internationally. Still, the total export share is relatively small in a majority of firms. This finding shows that sales at home are the key source of revenue for most firms, even in a small open economy such as Belgium.

Third, accounting for indirect import and export not only increases the fraction of firms that participate in international trade but also makes the trading firms much more comparable to non-trading firms in terms of size, productivity, and wages. In particular, the key difference between large and small firms is *how* they import and export, rather than whether or how much the firms ultimately rely on foreign inputs or sell to foreign markets. Firms that directly trade are systematically larger than the firms that only trade indirectly; this finding holds true even if we look within industries and condition on the total import or export shares. Yet, in many small firms, their total import or export shares are as high as those of large firms. Taken together, these findings suggest that smaller and less productive firms overcome the costs of entering foreign markets by selling to or buying from domestic firms that trade internationally.

1. The micro data sets come from the National Bank of Belgium. In Supplementary Appendix E, we report key moments of the data with the hope that other researches may use this information to study and model international trade and production networks.

Our fourth set of results are informative about the structure of the domestic production network and the persistence of the foreign trade behaviour of firms. As we show, the way in which firms import and export is highly persistent: both firms that trade directly and those that only trade indirectly are likely to continue to do so in the future. Indeed, a small set of individual buyer–supplier links explain most of the indirect trade, and these links are highly persistent over time. In other words, the Belgian economy can be described as a sparse production network in which most firms have a handful of important and relatively long-lasting buyer–supplier links.

The final set of results demonstrate that what matters for the transmission of foreign demand shocks to a firm's revenue is how much it ultimately sells to foreign markets, not whether these sales are from direct or indirect export. Following Hummels *et al.* (2014), we measure the direct export shock to a firm through the changes in world demand of country-product combinations with which the firm had a previous trade relationship. To measure the total export shock to the firm, we take into account both its direct sales to foreign markets and its indirect export through sales to domestic buyers that subsequently trade internationally. When estimating the transmission of these trade shocks to revenues, we find that two firms with the same total export shock are equally affected, regardless of whether the sales to foreign markets are from direct or indirect export.

Taken together, these sets of results highlight that data on domestic production networks are key to understanding how many and what kind of firms ultimately rely on foreign inputs, sell to foreign markets, and are affected by trade shocks. Huneeus (2018) is arguably the closest study to ours.[2] He uses firm-to-firm transaction data to model and estimate how trade shocks during the Great Recession propagated in Chile. By comparison, Barrot and Sauvagnat (2016), Boehm *et al.* (2015), and Carvalho *et al.* (2016) use natural disasters as exogenous variation to demonstrate the propagation of shocks in production networks. Acemoglu *et al.* (2016a) and Acemoglu *et al.* (2016b) study the propagation of supply and demand shocks through industry input–output networks.

The research on production networks and firm-to-firm connections naturally connects to a recent literature on the role of intermediation in trade (see *e.g.* Bernard *et al.*, 2010; Ahn *et al.*, 2011; Fujii *et al.*, 2017; Ganapati, 2018; Bernard *et al.*, 2019a). In this work, intermediaries are firms that are exploiting economies of scale or scope in trading abroad and, thus, are able to lower the per-product fixed costs of import or export. To date, most empirical work on intermediation in trade is centred on the direct import and export of wholesalers or retailers, and we have little if any direct evidence on how many and what kind of firms buy from or sell to these intermediaries. At the same time, the work on firm-to-firm connections typically does not distinguish between producers and intermediaries. Making this distinction, we find that indirect trade remains important even if one excludes import and export by wholesalers or retailers. Thus, indirect trade is more than just the channelling of import or export through pure intermediaries.

The remainder of the article proceeds as follows. Section 2 discusses the data sources, the sample selection, and the key variables. Section 3 describes how we construct measures of import and export that capture that firms may choose to access foreign markets both directly and indirectly. In the next four sections, we use these measures to develop several empirical findings. Sections 4 and 5 show how many and what kind of firms ultimately rely on foreign inputs or sell to foreign markets. Section 6 examines the structure of the domestic production network and the persistence of the foreign trade behaviour of firms. In Section 7, we explore the consequences of indirect trade for the transmission of foreign demand shocks to firms. The final section concludes with a

2. Several other papers have used firm-to-firm transactions to study a wide array of topics ranging from taxation to the effects of infrastructure (see *e.g.* Atalay *et al.*, 2011; Magerman *et al.*, 2016; Bernard *et al.*, 2018, 2019b; Gadenne *et al.*, 2019; Kikkawa *et al.*, 2019).

discussion of how our findings both challenge existing views and raise new questions about the role and behaviour of different types of firms in international trade.

2. DATA SOURCES AND SAMPLE SELECTION

Our analyses draw on three administrative data sources from Belgium for the period 2002–14. These data sources can be linked through unique identifiers, assigned and recorded by the government for the purpose of collecting value-added taxes (VAT). Below we briefly describe our data and sample selection; additional details are given in Supplementary Appendix C.

The first data source is the Business-to-Business (B2B) transactions database (National Bank of Belgium, 2002–2014b. For details, see Dhyne *et al.*, 2015). By law, all Belgian firms are required to file the amount of annual sales to each buyer (provided that the amount of annual sales to a given buyer exceeds 250 euro). Thus, the B2B dataset allows us to accurately measure the identity of the firms' suppliers and buyers. The second data source is the annual accounts that Belgian firms are required to file (National Bank of Belgium, 2002–2014a). These data contain detailed information from the firm's balance sheets on sales, revenues, costs of inputs (such as capital, labour, and intermediates), as well as four-digit (NACE) industry codes and geographical identifiers at the zip code level. In addition, the annual accounts include information about ownership shares in other enterprises. The third data source consists of the Belgian customs records and the intra-EU trade declarations (National Bank of Belgium, 2002–2014c). These data contain information about the international trade transactions of firms.[3] Both imports and exports are disaggregated by product and origin or destination.

One challenge with using the Belgian data is that all the information is recorded at the level of the VAT identifier. This creates a challenge because a firm may have several VAT identifiers (for accounting or tax reasons).[4] While organizational choices and transactions across units within a firm are of interest, our article is centred on trade between firms. Thus, if a firm has multiple VAT identifiers, we aggregate the data up to the firm level using information from the balance sheets about ownership structure. Details of the aggregation are outlined in Supplementary Appendix C.4. In 2012, for example, the aggregation converts 896,000 unique VAT identifiers into 860,000 unique firms. Of these firms, 842,000 had a single VAT identifier. However, the 18,000 firms with multiple VAT identifiers are important, accounting for around 60 percent of the total output in the dataset.

After constructing the firm-level dataset, we impose a few sample restrictions. We restrict our analysis to firms in the private and non-financial sectors with positive labour costs, at least one full-time-equivalent employee, and positive output. Following De Loecker *et al.* (2014), we also restrict our analysis to firms with tangible assets of more than 100 euro and positive total assets in at least one year during our sample period. Applying these criteria reduces the number of firms significantly. In 2012, for example, only 98,745 firms satisfy the above criteria. The large reduction in sample size is mostly driven by the exclusion of Belgian firms without employees (self-employed) from the sample (750,100 firms in 2012). These criteria also remove from the sample foreign firms with no local economic activity in Belgium.

As evident from Table 1, our selected estimation sample of firms covers most of the aggregate value added, gross output, exports, and imports.[5] Consistent with this finding, we show, in

3. See Supplementary Appendix C.2 for reporting thresholds for these international good transactions and Supplementary Appendix C.3 for the concordance between the B2B dataset and the customs records.

4. Existing papers tend to ignore this issue, analysing the data as if each firm has a single unique VAT identifier. See, for example, Amiti *et al.* (2014), Magerman *et al.* (2016), and Bernard *et al.* (2019a).

5. The amount of total sales in our sample is larger than that reported in the national statistics because the output of trade intermediaries in the national statistics is measured by their value added instead of their total sales. The amount of total

TABLE 1
Coverage of selected sample

	Aggregate statistics				Selected sample						
Year	GDP	Output (Excl. Gov. and Fin.)	Imp	Exp	Count	V.A.	Sales Total	Sales Netw.	Labour cost	Imp	Exp
2002	181	458	178	194	88,301	119	565	199	75	175	185
2007	229	593	255	269	95,941	152	729	206	89	277	265
2012	248	672	310	311	98,745	164	796	225	100	292	292

Notes: All numbers except for count are denominated in billion euro in current prices. Belgian gross domestic product (GDP) and output are for all sectors excluding the public and financial sectors. See Supplementary Appendix C.5 for the statistics of the sample of all Belgian firms. Data for Belgian GDP, output, imports, and exports are from Eurostat (2002–2012). Firms' value added is from the reported values from the annual accounts. Firms' sales consist of their sales to firms in the selected sample (network sales), sales to households at home, and direct export to foreign markets. See Supplementary Appendix C.1 for the definition and construction of each variable.

Supplementary Appendix D.3, the robustness of our results to including purchases from and sales to the excluded firms.

3. MEASURING DIRECT AND INDIRECT TRADE

In this section, we construct measures of import and export that capture that firms may choose to access foreign markets both directly and indirectly. The key assumption we make is that the firm's composition of inputs in production does not vary across its buyers. Even with our exceptionally rich data, it is not possible to directly examine whether the assumption is in strong disagreement with the data. However, the predictive power of measures of trade that rely on this assumption might be a good indication. In Section 7, we show that measures of indirect export (which rely on this assumption) are as predictive as measures of direct export (which is directly observed) for the transmission of foreign demand shocks to the revenues of domestic firms. It is also useful to observe that our assumption is weaker than what is assumed in previous work using industry input–output tables. This research assumes the composition of inputs in production is the same for all firms in a given industry.[6]

Under the assumption that the firm's composition of inputs in production does not vary across its buyers, we can measure the total import and export of a firm by the total share of inputs that it buys directly or indirectly from abroad (*i.e.* the *total import share*) and the total share of output that it sells directly or indirectly to foreign markets (*i.e.* the *total export share*). Formally, firm j's total import share, s_{Fj}^{Total}, is defined as the share of inputs that it directly imports, s_{Fj}, plus the share of inputs that it buys from other domestic firms, multiplied by the total import shares of those firms:

$$s_{Fj}^{\text{Total}} = s_{Fj} + \sum_{i \in Z_j^D} s_{ij} \underbrace{\left[s_{Fi} + \sum_{k \in Z_i^D} s_{ki} \left(s_{Fk} + \cdots \right) \right]}_{s_{Fi}^{\text{Total}}}, \tag{1}$$

where Z_j^D denotes the set of domestic suppliers of firm j and s_{ij} is the share of j's inputs that it buys from firm i. The denominator of the input shares is the sum of the firm's labour costs,

sales is even larger in the sample of all Belgian firms (see Supplementary Appendix C.5). Supplementary Appendix C.6 shows the sectoral composition of our sample.

6. See de Gortari (2019) and Bems and Kikkawa (2020) for analyses of the problems with assuming the composition of inputs in production is the same for all firms in a given industry.

purchases from other domestic firms, and direct imports. In the same fashion, the total export share of firm j, r_{jF}^{Total}, is defined as the share of revenue from direct export, r_{jF}, and the share of revenue coming from sales to other domestic firms, multiplied by the total export shares of those firms:

$$r_{jF}^{\text{Total}} = r_{jF} + \sum_{i \in W_j^D} r_{ji} \underbrace{\left[r_{iF} + \sum_{k \in W_i^D} r_{ik} \left(r_{kF} + \cdots \right) \right]}_{r_{iF}^{\text{Total}}}, \tag{2}$$

where W_j^D denotes the set of domestic buyers of firm j and r_{ji} is the share of j's revenue that comes from sales to firm i. The denominator of the export shares is the total revenue of the firm, which consists of sales to other domestic firms, sales to households, and direct exports.

Note that the definitions in equations (1) and (2) are recursive. For example, a firm's total import share is the sum of its direct import share and the share of its inputs from other domestic firms multiplied by the total import shares of those firms. In other words, the expression s_{Fj}^{Total} reflects the direct import share of firm j's suppliers, suppliers' suppliers, and so forth, each weighted by the share of inputs that each firm buys from other domestic firms. Thus, the total import share is high if much of the firm's inputs are imported either directly from abroad or indirectly via purchases from domestic suppliers with high import shares. By comparison, the total export share is high if a lot of the firm's output is exported directly to foreign markets or indirectly via sales to domestic buyers with high export shares.

It is important to observe that we do not add the user cost of capital to the denominator of the input shares. This is because we do not observe how much of the input costs come from purchases of capital goods. Thus, adding the user cost of capital goods as another input could lead to double counting of capital goods. As a robustness check, we nevertheless include the user cost of capital in the construction of the input shares. This check is described in greater detail in Supplementary Appendix D.2. Reassuringly, we find that including the user cost of capital does not materially change the comparison of total versus direct import shares across firms.

A natural question is whether our measures of total import and export shares can be motivated or justified by economic theory. To answer this question, we consider, in Appendix A, a broad class of models with fixed firm-to-firm linkages and constant markups. In these models, our measures of total import and export shares are key to quantifying the costs and benefits of trade shocks. For example, if the production functions have constant returns to scale, then—to a first-order approximation—how firms' costs are affected by a change in the foreign price is a weighted average of the change in the foreign price and the change in the domestic wage. The weight assigned to the change in the foreign price is the firm's total import share, not its direct import share. Another example arises if one assumes a Cobb–Douglas functional form for both the utility and production functions. Then, we can express how the firm's revenue is affected by a change in the aggregate expenditures as a weighted average of the changes in aggregate foreign and domestic expenditures. The weight assigned to the change in the foreign expenditure is the firm's total export share, not the direct export share.

4. DIRECT AND TOTAL TRADE OF FIRMS

This section uses the measures defined in the previous section to examine how many and to what extent firms ultimately rely on foreign inputs and sell to foreign markets.

4.1. *Direct and total import shares*

Figure 1(a) shows the distributions of direct and total import shares across firms. It is evident that most firms rely a lot on foreign inputs, but only a small number of firms show that dependence through the direct imports observed in trade transaction data. While only 19% of firms import directly, nearly all firms use some foreign inputs in production.[7] Indeed, most firms are heavily relying on foreign inputs once indirect import is taken into account. For example, the median firm in the distribution of total import shares is, directly or indirectly, importing about 39% of its inputs. By comparison, if we look at the 20th and 80th percentiles, the total import shares are 20% and 58%, respectively. In Appendix B.2, we plot the distribution of total import shares separately for the firms that directly import (19% of the sample) and those that only indirectly import (81% of the sample). The distributions display considerable overlap, implying that a substantial number of firms with relatively high total import shares do not directly import.

In Supplementary Appendix D.1, we break down the direct and total import shares by sector. Interestingly, foreign inputs are important in all sectors once one accounts for indirect import. Indeed, the total import shares are sizable even in industries with little direct import, such as the service sector. Breaking down the data by sector also reveals that indirect import is more than just the channelling of foreign inputs through pure intermediaries. In Supplementary Appendix D.4, we exclude direct imports that come from wholesalers and retailers (which account for 29% of aggregate imports) and then recalculate the total import shares of firms in the other sectors. We find that many firms rely heavily on foreign inputs even after excluding the goods that are directly imported by wholesalers or retailers.

4.2. *Direct and total export shares*

Figure 1(b) displays the distributions of direct and total export shares of firms. While only 12% of firms are exporting directly, an additional 75% of firms are indirectly exporting through sales to domestic buyers that subsequently trade internationally.[8] Still, the total export share is relatively small in a majority of firms. For example, the median firm in the distribution of total export shares is, directly or indirectly, exporting only 3% of its output. In fact, the total export share remains low across most of the distribution, reaching only 23 percent at the 80th percentile. These findings show that sales at home are the key source of revenue for most firms, even in a small open economy such as Belgium. In Appendix B.2, we plot the distribution of total export shares separately for the firms that directly export and those that only indirectly export. These results reveal that most firms with relatively high total export shares are directly exporting.

In Supplementary Appendix D.1, we investigate the total and direct export shares by sectors. The results show that in certain sectors, such as services, nearly all the export shares come from sales to domestic buyers that subsequently trade internationally. In Supplementary Appendix D.4, we exclude direct exports that come from wholesalers and retailers (which account for 18% of aggregate exports) and then recalculate the total export shares of firms in the other sectors. The main findings about direct and total export shares do not change: while a majority of firms are indirectly exporting, most of their sales are at home.

Comparing the results in Panel (a) with those in Panel (b) of Figure 1, we find that a majority of firms are relying heavily on foreign inputs but relatively few are selling a lot to foreign markets.[9]

7. Note that most, if not all, firms are likely to use certain types of materials, such as gasoline, that are not produced in Belgium. We may not observe all these purchases because of the 250 euro reporting threshold for domestic firm-to-firm transactions. Still, the use of certain essential inputs that are not produced in Belgium could be a key reason why we find that virtually all firms are using some foreign inputs.

8. The rest of the firms, 12% of the sample, are not exporting either directly or indirectly.

9. This finding does not reflect a trade deficit in Belgium, as aggregate imports are comparable to aggregate exports.

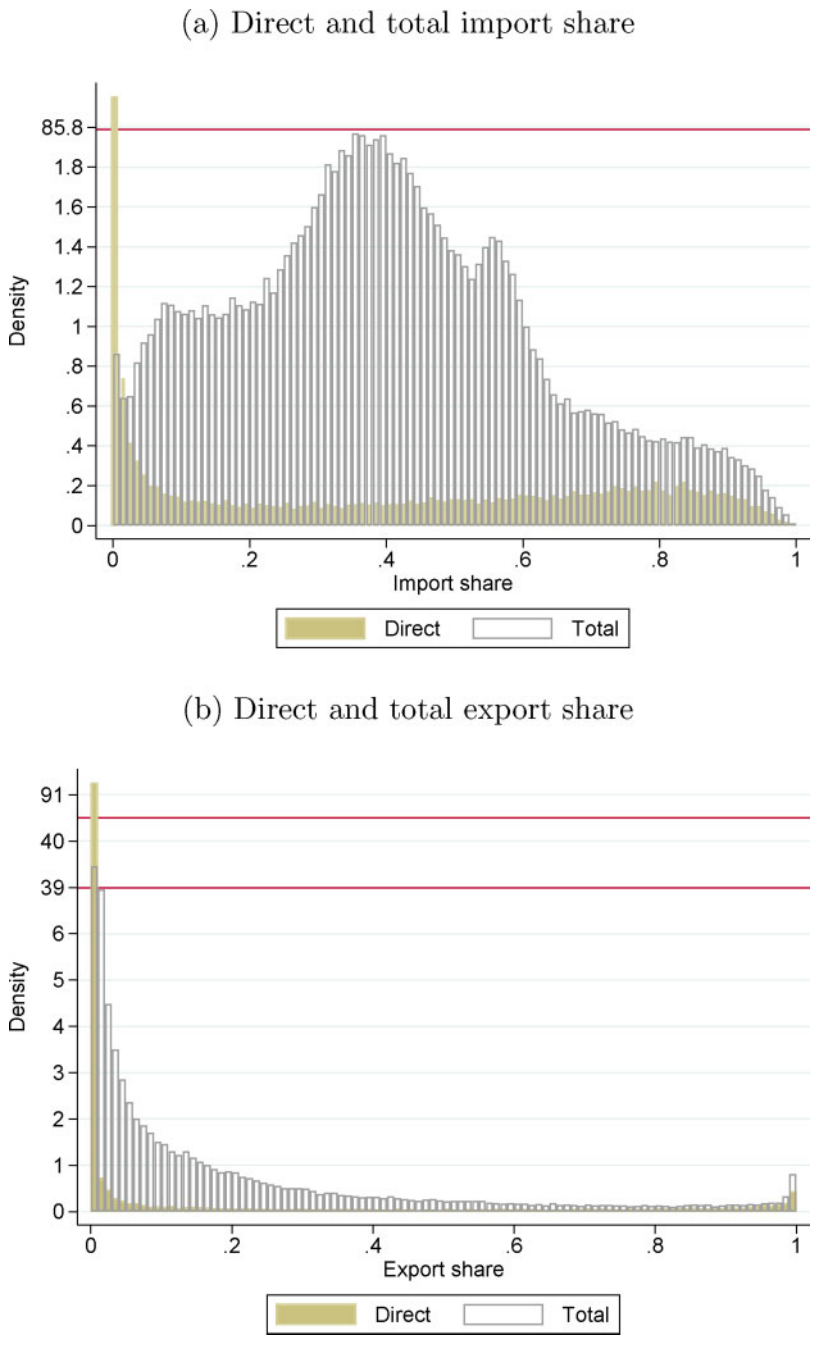

FIGURE 1

Distributions of direct and total trade across firms

Notes: The total import share of firm i, s_{Fj}^{Total}, is calculated by solving $s_{Fj}^{\text{Total}} = s_{Fj} + \sum_{i \in Z_j^D} s_{ij} s_{Fi}^{\text{Total}}$ where s_{Fj} is firm j's direct import share and s_{ij} is firm i's share among firm j's inputs. The total export share of firm j, r_{jF}^{Total}, is calculated by solving $r_{jF}^{\text{Total}} = r_{jF} + \sum_{i \in W_j^D} r_{ji} r_{iF}^{\text{Total}}$ where r_{jF} is firm j's direct export share and r_{ji} is the share of firm j's revenue that arises from sales to firm i. The figures are based on the analysis of 98,745 private sector firms in Belgium in 2012. The horizontal lines represent scale breaks on the vertical axis.

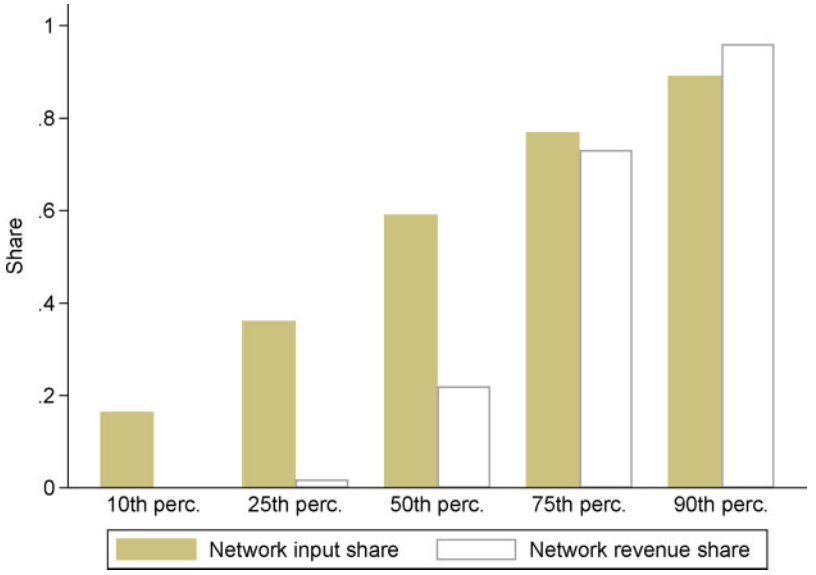

FIGURE 2

Percentiles of the network input and revenue shares

Notes: The figure shows the percentiles of firms' network input shares and their network revenue shares. The network input share is defined as the share of inputs purchased from domestic suppliers, $\sum_{i \in Z_j^D} s_{ij}$. The network revenue share is defined as the share of output sold to domestic buyers, $\sum_{i \in W_j^D} r_{ji}$. The figure is based on the analysis of 98,745 private sector firms in Belgium in 2012.

This finding reflects that the network revenue share, $\sum_{i \in W_j^D} r_{ji}$, is much smaller than network input shares, $\sum_{i \in Z_j^D} s_{ij}$, for most firms, as shown in Figure 2. In other words, a typical Belgian firm purchases a lot of its inputs from domestic suppliers but sells relatively little of its output to domestic firms. Since any indirect participation in foreign trade comes through transactions with other domestic firms, the network input share of a firm is an upper bound for its share of indirect imports, whereas the network revenue share is an upper bound for its share of indirect exports.[10]

4.3. *Import and export shares within and across industries*

The above findings point to the importance of measuring indirect trade to accurately estimate how many and to what extent firms rely on foreign inputs and sell to foreign markets. In the absence of data on domestic firm-to-firm sales, it is necessary to approximate production networks. One possible approach is to use information on aggregate sales across industries, as reported in industry input–output tables (see *e.g.* Caliendo and Parro, 2015; Acemoglu *et al.*, 2016a,b). This approach gives an accurate description of the *firm-level* indirect and total trade insofar as the firms within each industry are homogeneous in the total import and export shares of the goods they buy from and sell to other domestic firms.

In Appendix B.3, we show that this homogeneity restriction is grossly at odds with the data. In this appendix, we decompose the variation across firms in import and export shares into between-industry and within-industry components (where industry is defined rather narrowly at

10. See equations (1) and (2). We refer to the second terms of the equations as firms' shares of indirect imports and exports.

the level of four-digit NACE codes). We find that most of the variation in total import and export shares arises from differences within industries, not between industries. The large within-industry variation does not reflect heterogeneity in direct import and export shares across firms. In fact, the explanatory power of the within-industry component is even larger if we restrict attention to the variation across firms in indirect import and export shares.

In Supplementary Appendix D.5, we investigate further the errors that arise if one uses industry input–output tables to draw inference about firm-level indirect and total trade. Using the Belgian input–output table for 2010 (provided by Eurostat, 2010), we impute the total import and export shares of each firm in every industry. To perform this imputation, we maintain the above assumption that firms within each industry are homogenous in the total import and export shares of the goods they buy from and sell to other domestic firms. We then compare the distributions of imputed total import and export shares from the input–output tables to the distributions of the baseline measures of total import and export shares based on the data on domestic firm-to-firm sales.

The distribution of the imputed import shares differs considerably from the distribution of the baseline import shares. While the median (0.34 for imputed versus 0.39 for baseline) and the mode (0.40 for imputed versus 0.33 for baseline) of the distributions are fairly similar, the variances differ considerably (0.01 for imputed versus 0.05 for baseline). In fact, the correlation between the two measures of import shares is as low as 0.09. The distribution of the imputed export shares is also noticeably different from the distribution of the baseline export shares. For instance, the mode (0.09 for imputed versus 0.00 for baseline) and especially the median (0.38 for imputed versus 0.03 for baseline) are materially higher for the imputed export shares. This finding shows that the input–output data completely miss that most firms export little if anything, directly or indirectly. Indeed, data on domestic firm-to-firm sales are needed to learn that sales at home are the key source of revenue for most firms, even in a small open economy such as Belgium. Taken together, our findings suggest that input–output tables may be a poor substitute to data on firm-to-firm sales if the goal is to accurately estimate how many and to what extent firms rely on foreign inputs and sell to foreign markets.

4.4. *Degrees of separation from foreign markets*

The findings so far have shown the importance of indirect trade that firms do through the entire production network of domestic buyers and suppliers. We now examine how many domestic firm-to-firm connections the indirect trade goes through before reaching the direct importers or exporters. Our findings suggest that for a large majority of firms the indirect trade is within four degrees of separation from foreign markets.

To arrive at these findings, we decompose the firms' total import and export shares into the direct trade and several components of the indirect trade. This is done by rearranging equations (1) and (2) to get the expressions:

$$s_{Fj}^{\text{Total}} = \underbrace{s_{Fj}}_{\text{Direct}} + \underbrace{\sum_{i\in Z_j^D} s_{ij}s_{Fi}}_{\text{1st}} + \underbrace{\sum_{i\in Z_j^D}\sum_{k\in Z_i^D} s_{ij}s_{ki}s_{Fk}}_{\text{2nd}} + \underbrace{\sum_{i\in Z_j^D}\sum_{k\in Z_i^D}\sum_{\ell\in Z_k^D} s_{ij}s_{ki}s_{\ell k}s_{F\ell}}_{\text{3rd}} + \underbrace{\cdots}_{\text{4th and higher}} \tag{3}$$

$$r_{jF}^{\text{Total}} = \underbrace{r_{jF}}_{\text{Direct}} + \underbrace{\sum_{i\in W_j^D} r_{ji}r_{iF}}_{\text{1st}} + \underbrace{\sum_{i\in W_j^D}\sum_{k\in W_i^D} r_{ji}r_{ik}r_{kF}}_{\text{2nd}} + \underbrace{\sum_{i\in W_j^D}\sum_{k\in W_i^D}\sum_{\ell\in W_k^D} r_{ji}r_{ik}r_{k\ell}r_{\ell F}}_{\text{3rd}} + \underbrace{\cdots}_{\text{4th and higher}}. \tag{4}$$

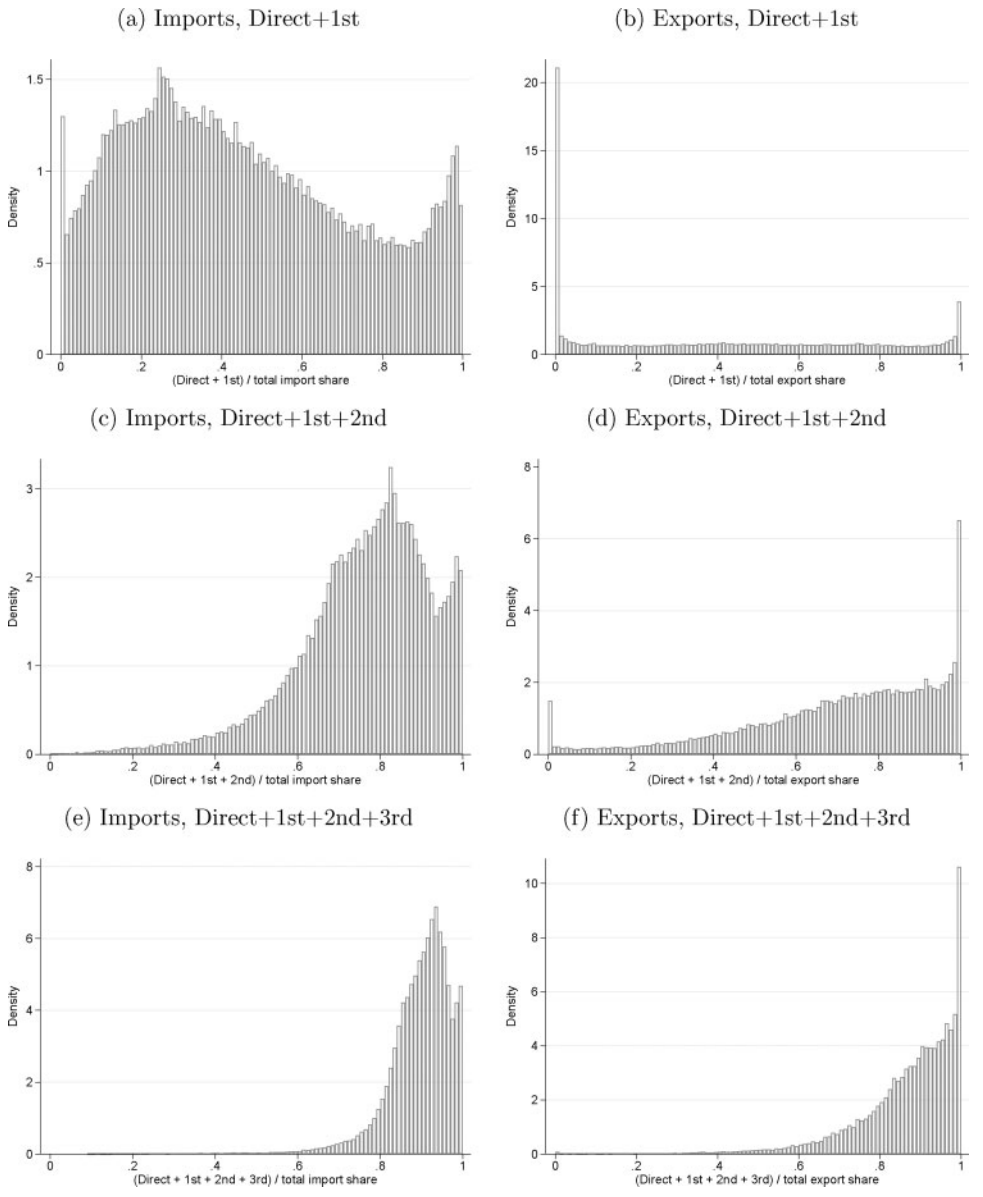

FIGURE 3

Degrees of separation from foreign markets

Notes: The figure presents the results from the decomposition in equations (3) and (4). In each panel, we plot the distribution of the share of the firm's total import or export that are due to direct import or export from either the firm itself or from closely connected domestic suppliers or buyers. The top panels report the shares of total import or export that reflect the direct and the first components. The middle panels add the contribution from the second component, and the bottom panels add the contribution from both the second and third components. The figures are based on the analysis of 98,745 private sector firms in Belgium in 2012.

In each equation, we then divide the components on the right hand side by the total shares on the left hand side. Once this normalization is made, the components can be interpreted as the shares of the firm's purchases from or sales to foreign markets that are due to direct import or export from the firm itself (Direct), direct import or export from the firm's suppliers (1st component), direct import or export from the firm's suppliers' suppliers (2nd component), and so on.

Figure 3 presents the results from the decomposition in equations (3) and (4). In each panel, we plot the distribution of the share of the firm's total import or export that are due to direct import or export from either the firm itself or from closely connected domestic suppliers or buyers. The top panels report the shares of total import or export that reflect the direct and the first components. The middle panels add the contribution from the second component, and the bottom panels add the contribution from both the second and third components. The results suggest that a vast majority of firms are buying most of the inputs from foreign markets either directly or through just a few domestic firm-to-firm connections. Indeed, the direct, first, second, and third components account for most of the total import in a large majority of firms. In fact, the degree of separation to foreign markets is not only low for inputs but also for sales. For nearly all firms, most of the sales to foreign markets are either done directly or through no more than three domestic firm-to-firm connections.

Taken together, the results in Figure 3 suggest that the structure of indirect trade is best described a so-called "small world" type network characterized by short path lengths to foreign markets. In Supplementary Appendix D.6, we extend the decomposition exercise to analyse whether or not these paths cross industries. We find that most purchases from or sales to foreign markets are either done directly or through transactions with firms in different industries.

5. COMPARING FIRMS THAT TRADE DIRECTLY AND INDIRECTLY

This section examines the importance of incorporating indirect trade for drawing conclusions about what kind of firms rely (the most) on foreign inputs or sell (a lot) to foreign markets.

5.1. *Exporter premia*

We start this section by investigating the extensive margin of trade. Table 2 shows that accounting for indirect trade not only increases the fraction of firms that participate in international trade but also makes the trading firms much more comparable to non-trading firms in terms of size, productivity, and wages.

Each cell of Table 2 reports an estimate from a regression of a characteristic of a firm on an indicator variable for whether the firm is exporting and a full set of fixed effects for industry. The variables listed on the left are the two measures of export participation that we consider: one is an indicator variable for having a positive direct export share, while the other is an indicator variable for having a positive total export share. We do not look at import participation as nearly all firms have positive import shares once one takes indirect trade into account. The firm characteristics listed in the columns are the dependent variables. For each column, we run one regression per measure of export participation. Thus, comparing the regression results across panels allows us to infer how the so-called exporter premium depends on whether one includes indirect exports. In Panel (a), we include all firms in the sample and consider the premium of direct exporting, and in Panel (b), we exclude direct exporters from the sample and consider the premium of indirect exporting. By contrast, comparing the results across columns tells us how these exporter premia vary from one firm characteristic to the other.

The estimates reported in Panel (a) show that direct exporters tend to be larger, have higher sales and productivity, and pay more than other firms. The results reported in columns (1), (2),

TABLE 2
Exporter premia

(a) Sample: all firms

	(1) Log emp.	(2) Log sales	(3) Log sales	(4) Log v.a./worker	(5) Log v.a./worker	(6) Log avg. wage	(7) Log avg. wage	(8) Log TFP	(9) Log TFP
Direct export share >0	1.17 (0.01)	1.88 (0.01)	0.87 (0.01)	0.25 (0.01)	0.29 (0.01)	0.22 (0.00)	0.13 (0.00)	0.49 (0.01)	0.25 (0.01)
Industry fixed effects (FE)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log emp. control	No	No	Yes	No	Yes	No	Yes	No	Yes

(b) Sample: excluding direct exporters

	(1) Log emp.	(2) Log sales	(3) Log sales	(4) Log v.a./worker	(5) Log v.a./worker	(6) Log avg. wage	(7) Log avg. wage	(8) Log TFP	(9) Log TFP
Total export share >0	0.41 (0.01)	0.75 (0.01)	0.41 (0.01)	0.19 (0.01)	0.21 (0.01)	0.09 (0.00)	0.07 (0.00)	0.19 (0.01)	0.11 (0.01)
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log emp. control	No	No	Yes	No	Yes	No	Yes	No	Yes

Notes: Standard errors are in parentheses. All results are from ordinary least squares regressions of the firm characteristics noted at the top of each column, on dummy variables listed on the left, as well as industry (four-digit) fixed effects. Firms' TFPs are estimated based on Wooldridge (2009). The regression results are based on the analysis of 98,745 private sector firms in Belgium in 2012. See Supplementary Appendix D.8 for the results for years 2002 and 2007.

(4), (6), and (8) suggest that direct exporters have 222% more employment, 555% more sales, 28% higher value added per worker, 25% higher wages, and 63% higher total factor productivity (TFP).[11] As shown in columns (3), (5), (7), and (9) the observed differences between direct exporters and other firms are not driven solely by size.

The findings in Panel (a) of Table 2 are emblematic of what is typically found in empirical work on the exporter premia (*e.g.* Bernard and Jensen, 1999; Bernard *et al.*, 2007). Firms that export look very different from non-exporters along a number of important dimensions. The findings in Panel (b) are novel, showing that exporter premia are smaller but still significant once indirect export is included in the definition of export participation. For example, the exporter premia in employment, sales, and wages are about half as large if one includes indirect export. We can thus conclude that by including indirect exports, firms that sell to foreign markets become more—but not completely—comparable to firms that only sell at home.

5.2. *Direct and indirect trade in large and small firms*

We now shift attention from the extensive margin of export to examining what kind of firms are heavily involved in trade.

In Figure 4, we graph the estimated relationships between our measures of total and direct trade (defined in Section 3) and firm size (as measured by log sales). To adjust for differences across industries, we first demean the log of firm sales using the firm's four-digit industry average. Thus, a firm with log sales of zero has the size of an average firm in its industry. Next, we use local polynomial regressions to non-parametrically estimate the relationships between our measures

11. Since the outcome variables are in logs, the coefficients can be interpreted as an approximation of a percentage change. Given the size of the estimated changes, however, the approximation will be poor, and we choose to report the exact percentage change instead.

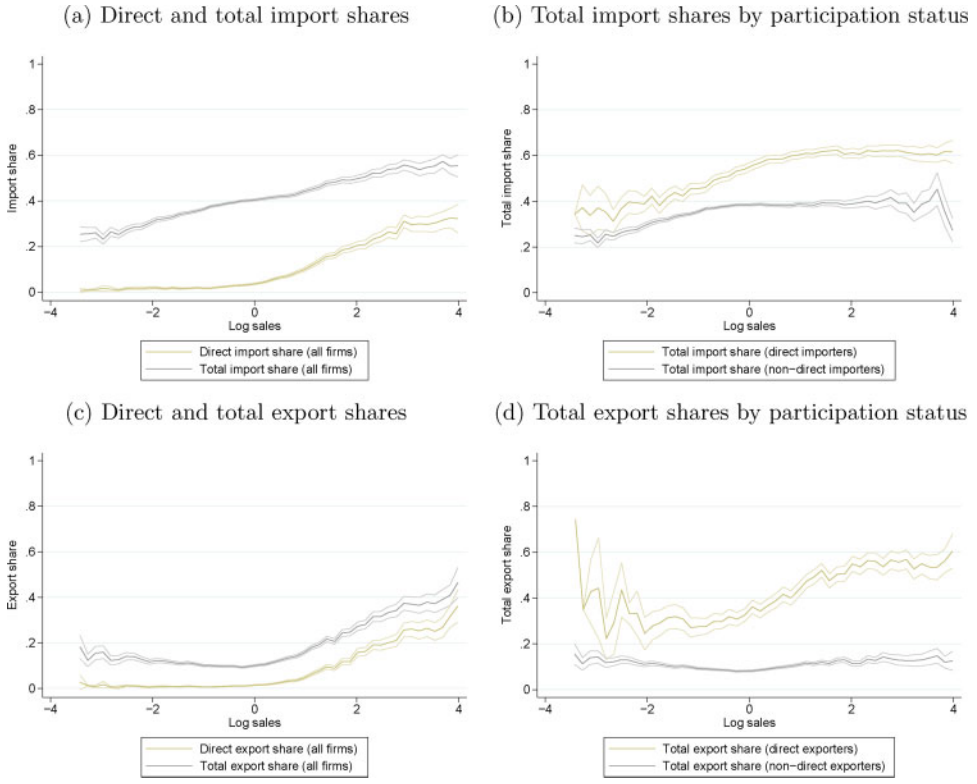

FIGURE 4

Relationship between firm size and direct and indirect trade

Notes: The figure displays the relationship between firms' levels of participation in foreign trade and their sales, using the smoothed values of kernel-weighted local polynomial regression estimates with 95 percent confidence intervals. We use the Epanechnikov kernel function with kernel bandwidth of 0.05, pilot bandwidth of 0.02, degree of polynomial smooth at 0, and smooth obtained at 50 points. Log sales are demeaned with four-digit industry fixed effects, and trimmed at the top and bottom 1 percentiles. The figures are based on the analysis of 98,745 private sector firms in Belgium in 2012.

of trade and firm size. Figure 4(a) reports estimates for firm size and direct and total import shares, while Figure 4(c) presents estimates for firm size and direct and total export shares. By comparison, Figure 4(b) and (d) display the relationships between firm size and the measures of total import and export for the firms that trade directly and for the rest of the firms.

The results in Figure 4(a) and (c) show that both the import and export shares are increasing in firm size regardless of whether we include or exclude indirect trade. As shown in Figures 4(b) and (d); however, the positive relationships between firm size and total import and export shares are almost entirely driven by the firms that trade directly. Indeed, the small indirect exporters are selling as much of their output to foreign markets as the large indirect exporters.

In Supplementary Appendix D.9, we investigate in greater detail the relationship between firm size and indirect and direct trade. We begin by using local polynomial regressions to non-parametrically estimate the relationships between firm size and our measures of trade for direct importers and non-direct importers. We find that firms that directly trade tend to be larger. This finding holds true even if we look within industries and condition on the total import or export shares. This result is consistent with the extensive margin estimates of the exporter premia in Table 2.

Motivated by this finding, we next assign the firms into groups depending on the extent of their direct and indirect trade. As explained in that appendix, we consider three groups of importers: firms that directly import, firms that do not directly import but indirectly import a large share of their inputs, and the remaining firms that neither directly import nor import a lot indirectly. In the same fashion, we assign firms to three groups of exporters. We then plot the firm size distribution for the groups of importers and exporters. We find that direct importers and exporters are much larger than other firms. However, the firms that do not trade directly but indirectly import or export a lot are very similar in size to the firms that trade little if anything.

6. PERSISTENCE OF INDIRECT TRADE

So far, we have used the cross sections of the data to demonstrate that indirect trade is empirically important for many firms, especially those that are small and less productive. In this section, we take advantage of the panel nature of our data to examine the structure of the domestic production network and the persistence of the foreign trade behaviour of firms.

In Table 3, we explore the persistence of indirect and direct trade over time. We use a balanced sample of firms over the period 2002–14. In the left panel, we assign firms into three groups based on their import behaviour in a given year. The groups are mutually exclusive and collectively exhaustive. One of the groups (Direct) consists of the firms that directly import. The other firms that do not directly import are classified as having high indirect participation in imports (HIP) if they are in the top quintile in the distribution of total import shares within their industry. The remainder of the firms that do not directly import are assigned to the group with low indirect participation in imports (non-HIP). We then compute the probability that a firm stays in the same group from one year to the next. The results show that the way in which firms import is highly persistent: both firms that directly import and those that have high indirect imports are likely to continue to do so in the future.

In the right panel of Table 3, we perform the same type of analysis for the persistence in export behaviour. The results mirror those for import behaviour: whether and how firms export are strongly persistent over time. As shown in Supplementary Appendix D.10, the broad conclusions from Table 3 about the persistence of trade behaviour also hold true if we look at persistence across five-year periods or across broad sectors.

The strong persistence of the way in which firms trade does not necessarily imply that individual buyer–supplier links are persistent over time. To examine this, it is useful to describe the structure of the production network and how it changes over time. As evident from Appendix B.1, the Belgian economy can be described as a sparse production network in which firms have

TABLE 3
Persistence in trade behaviour of firms

	Importers				Exporters		
	Direct_{t+1}	HIP_{t+1}	Non-HIP_{t+1}		Direct_{t+1}	HIP_{t+1}	Non-HIP_{t+1}
Direct_t	0.89	0.02	0.09	Direct_t	0.82	0.05	0.13
HIP_t	0.04	0.70	0.25	HIP_t	0.05	0.77	0.18
Non-HIP_t	0.04	0.05	0.90	Non-HIP_t	0.04	0.05	0.91

Notes: The two panels report the one-year Markov matrices among the sets of three mutually exclusive and collectively exhaustive groups classified according to firms' direct and indirect foreign trade. On the importing side, for each two-digit industry we group firms as follows: the first group is the firms that directly import (Direct). Firms that do not directly import are classified as having high indirect participation in imports (HIP) if they are in the top quintile in the distribution of total import shares. The remainder of the firms that do not directly import are assigned to the group with low indirect participation in imports (non-HIP). We use the same criteria for the exporting side. We use a balanced sample of firms from 2002 to 2014.

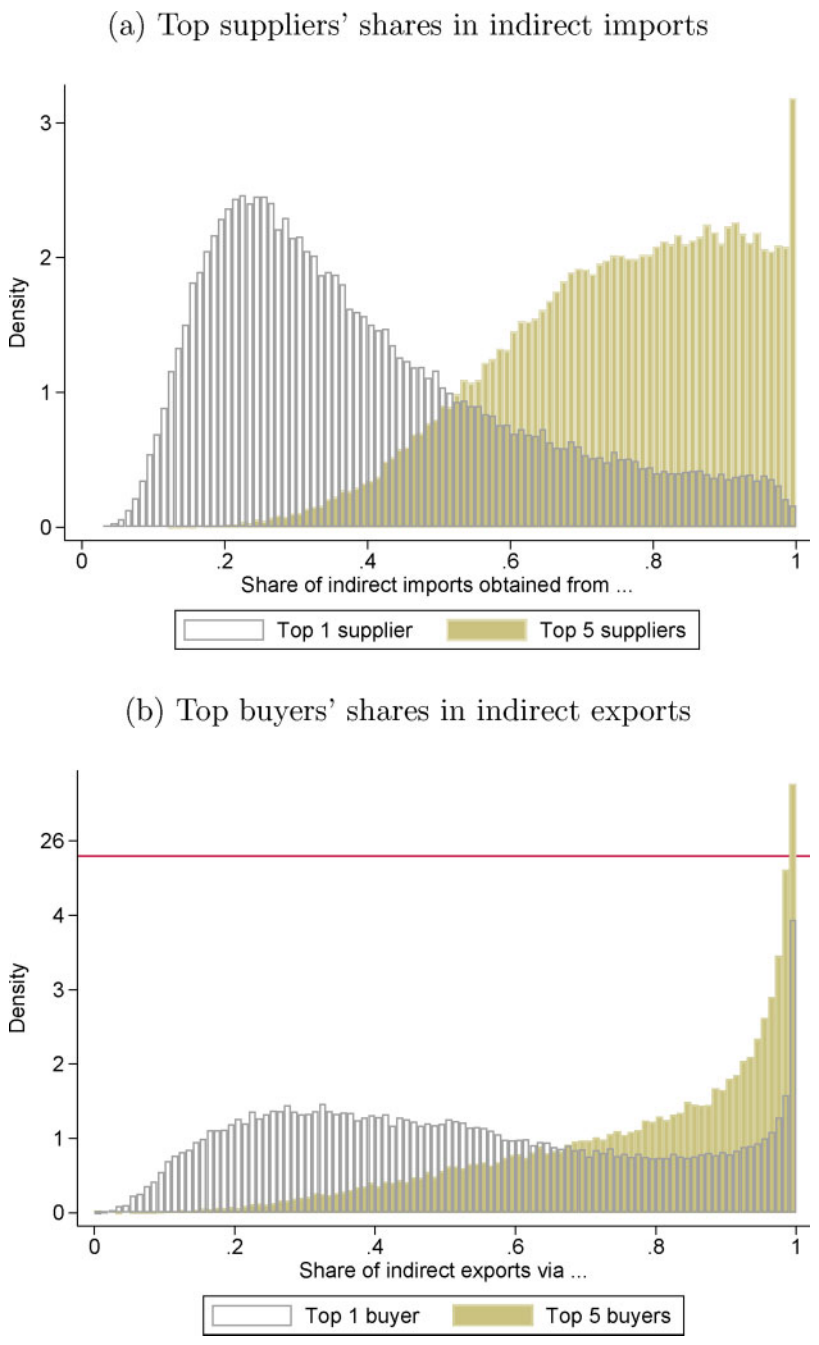

FIGURE 5

Top links' shares in firms' indirect trade

Notes: The figure displays the distributions of the shares that top suppliers and buyers account for in firms' indirect import and export shares. Supplier i's share in firm j's indirect imports is computed by $s_{ij}s_{Fi}^{\text{Total}}/\sum_k s_{kj}s_{Fk}^{\text{Total}}$. Buyer i's share in firm j's indirect exports is computed by $r_{ji}r_{iF}^{\text{Total}}/\sum_k r_{ji}r_{kF}^{\text{Total}}$. The figures are based on the analysis of 98,745 private sector firms in Belgium in 2012.

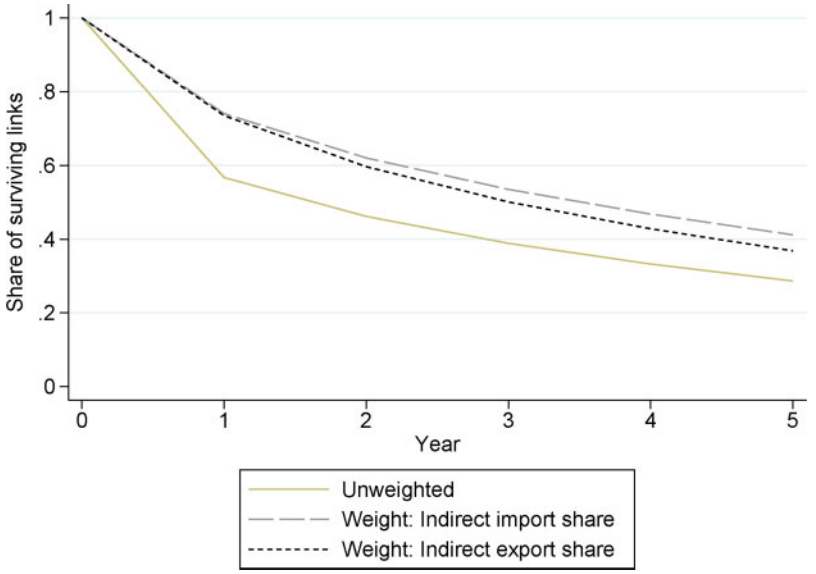

FIGURE 6

Share of surviving firm-to-firm links

Notes: The figure reports the share of surviving firm-to-firm links over time. In addition to the unweighted fraction of surviving links, we also plot the weighted fraction of surviving links, using as weights the shares of indirect import or export associated with the buyer–supplier links. The weights are the buyer firm's indirect import share from the supplier at the initial year, $s_{ij}s_{Fi}^{\text{Total}}/\sum_k s_{kj}s_{Fk}^{\text{Total}}$, or, the supplier firm's indirect export share through the buyer at the initial year, $r_{ji}r_{iF}^{\text{Total}}/\sum_k r_{jk}r_{kF}^{\text{Total}}$, respectively. The results are pooled for all cross-sections of links from 2002 to 2009.

much fewer links than the possible maximum number. Indeed, a small set of individual buyer–supplier links explain most of the indirect trade, as shown in Figure 5. This finding is consistent with Kikkawa *et al.* (2019), who show that the largest supplier for the typical firm accounts for around 30% of the input purchases.

Another interesting finding from the Belgian network data is that the key buyer–supplier links are relatively persistent over time. To illustrate the persistence of the key buyer–supplier links, Figure 6 plots the share of firm-to-firm links that survive from one year to the next. Starting from the cross section of links in a given year, we show the fraction of links that survive over the subsequent five years. In addition to the unweighted share of surviving links, we also plot the weighted share of surviving links. The weights are given by the indirect import or export shares associated with the buyer–supplier links. While there is a significant amount of churning in the buyer–supplier relationships (only 57% of the links persist from one year to the next), we find that the links that are associated with a high share of indirect trade are much more persistent (74% of the weighted links persists from one year to the next). This finding is consistent with Huneeus (2018). Using Chilean data on domestic firm-to-firm transactions, he finds that key buyer–supplier links are much more likely to persist over time.

7. TRANSMISSION OF FOREIGN DEMAND VIA INDIRECT TRADE

We conclude the empirical analyses with an investigation of how indirect trade affects the transmission of foreign demand shocks. This analysis shows that what matters for the transmission of foreign demand shocks to a firm's revenue is how much the firm ultimately sells to foreign market, not whether these sales are from direct or indirect export.

Before we present the empirical results, we derive an estimating equation that relates changes in firm revenue to changes in foreign demand. We denote firm j's sales at time t by $X_{j,t}$. The goods the firm produces can be sold to three types of buyers: domestic firms, households at home, or direct export to foreign markets. Therefore, the first-order approximation of the change in firm j's sales can be written as

$$d\log X_{j,t} = \sum_i r_{ji,t-1} d\log X_{ji,t} + r_{jH,t-1} d\log X_{jH,t} + r_{jF,t-1} d\log X_{jF,t}, \tag{5}$$

where $X_{ji,t}$ denotes firm j's sales to domestic firm i, $X_{jH,t}$ denotes firm j's sales to households at home, $X_{jF,t}$ denotes firm j's direct export, and $r_{jH,t}$ denotes the share of revenue of firm j that comes from sales to households at home.

Assuming that each firm's inputs change proportionally to its output, $d\log X_{ji,t} = d\log X_{i,t}$, and that sales to households change proportionally to aggregate household expenditure, $d\log X_{jh,t} = d\log E_t$, we can obtain the following equation:[12]

$$d\log X_{j,t} = \sum_i \tilde{H}_{ji,t-1} r_{iH,t-1} d\log E_t + \sum_i \tilde{H}_{ji,t-1} r_{iF,t-1} d\log X_{iF,t}. \tag{6}$$

Equation (6) illustrates that a firm's sales are absorbed by one of two final destinations: direct or indirect sales to domestic households and direct or indirect export to foreign markets. Note that $\tilde{H}_{t-1} = \left(I - R_{t-1}\right)^{-1}$, where the i,j element of matrix R_{t-1} is the share of revenue of firm i that is sold to firm j, $r_{ij,t-1}$. The term $\sum_i \tilde{H}_{ji,t-1} r_{iH,t-1}$ captures the share of firm j's sales that is exposed to changes in the demand from domestic households, $d\log E_t$, directly or indirectly. The term $\tilde{H}_{ji,t-1} r_{iF,t-1}$ captures firm j's total sales to foreign markets through firm i and is multiplied by firm i's change in exports, $d\log X_{iF,t}$.

Of course, it is difficult to draw causal inferences from a regression of firm sales on its total export because of simultaneity bias and correlated unobservables (*e.g.* firm productivity). To obtain plausible exogenous variation in foreign demand, we instead follow Hummels *et al.* (2014) and construct changes in world import demand for each direct exporter j, $d\log X_{jF,t}^{\text{shock}}$,

$$d\log X_{jF,t}^{\text{shock}} = \sum_{c,p} r_{j,c,p,t-1}^{\text{EX}} d\log WID_{c,p,t}, \tag{7}$$

where c denotes countries, p denotes products, and $r_{j,c,p,t-1}^{\text{EX}}$ denotes the share of j's exports to country-product c,p in j's total exports at time $t-1$. The term $WID_{c,p,t}$ represents country c's imports of product p from all other countries excluding Belgium, obtained from United Nations (2002–2014). To empirically examine how firm sales depend on foreign demand shocks, we estimate the following regression model:

$$d\log X_{j,t} = \alpha + \beta_{Et} \sum_i \tilde{H}_{ji,t-1} r_{iH,t-1} + \beta \sum_i \tilde{H}_{ji,t-1} r_{iF,t-1} d\log X_{iF,t}^{shock} + \varphi_{j,t}. \tag{8}$$

The estimating equation captures that foreign demand shocks may affect the firm's revenue through both direct and indirect export. Since firms may also be affected by changes in the

12. The assumption of $d\log X_{ji,t} = d\log X_{i,t}$ is consistent with a model in which firms' production functions have a Cobb–Douglas structure. The assumption of $d\log X_{jh,t} = d\log E_t$ is consistent with a model in which there is a representative household with Cobb–Douglas preferences. See Appendix A.2 for related results.

TABLE 4
Firms' response to foreign demand shocks

	(1) Δln Sales	(2) Δln Sales	(3) Δln Sales	(4) Δln Sales
Direct export shock	0.178***			
	(0.0270)			
Total export shock		0.283***	0.311***	0.311***
		(0.0326)	(0.0428)	(0.0261)
N	143,572	143,572	839,881	995,739
Sample	Direct exporter	Direct exporter	Non-direct exporter	All firms
Ind.-Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses. Variables are winsorized at the top and bottom 0.5 percentiles. The total export shock for firm j is defined as $\sum_i \tilde{H}_{ji,t-1} r_{iF,t-1} d\log X^{\text{shock}}_{iF,t}$, and the direct export shock for firm j is defined as $r_{jF,t-1} d\log X^{\text{shock}}_{jF,t}$. The assignment to the direct exporter or non-direct exporter sample is made based on the export status in $t-1$. All specifications include the lagged share of firms' sales exposed to household demand, $\sum_i \tilde{H}_{ji,t-1} r_{iH,t-1}$, as a control, with a time-varying coefficient. Standard errors are clustered at the NACE four-digit level. * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

demand from households at home, we control for the share of firms' sales that is exposed to household demand in every year. The change in household demand is captured by the time-varying coefficient β_{Et}. In addition, we include fixed effects for industry-year and a full set of firm fixed effects. Hence, our regression specification controls for industry-year-specific shocks and allows for firm-specific time trends.

Table 4 presents the estimation results from this regression model. The first two columns restrict the sample to direct exporters. The next column looks at the firms that do not directly export. For completeness, the final column includes all firms. In the first column, we only take into account the foreign demand shocks that operate through direct export. Consistent with previous studies, we find a significant and sizable pass-through of direct export shocks to the firm's revenue.[13] In the second column, we continue to focus on direct exporters but now take into account both direct and indirect export when measuring the firm's exposure to foreign demand shocks. The exposure that occurs through the indirect export reflects the export of firm's domestic buyers, buyers' buyers, and so forth. These firms are themselves affected by foreign demand shocks through changes in world demand of country-product combinations with which the firms had previous trade relationships. When we combine these indirect shocks with the direct export shock in the measure of total export shock, we find that the pass-through to the firm's revenue increases from 0.18 to 0.28.

In column (3), we estimate the same regression as in column (2), except we now consider the firms that do not directly export. These firms are exposed to foreign demand shocks only through their indirect export. For those firms, we find that the pass-through of indirect export shocks to their revenue is 0.31. Comparing the results in columns (2) and (3) reveals a new and interesting finding: when estimating the transmission of foreign demand shocks to revenues, two firms with the same total export shock are equally affected, regardless of whether the sales to foreign markets are from direct or indirect export. Finally, column (4) obtains a similar estimate for the sample of all firms, with a pass-through of 0.31.

13. Hummels *et al.* (2014) estimate a coefficient of similar magnitude when relating firms' exports to world import demand.

In Supplementary Appendix D.11, we show that the results in Table 4 are robust to a number of alternative specifications—including adding controls for firms' pre-period direct export shares and network revenue shares.

8. CONCLUSION

In this article, we examined how many and what kind of firms ultimately rely on foreign inputs, sell to foreign markets, and are affected by trade shocks. To do so, it is necessary to capture that many firms access foreign markets indirectly by buying from or selling to domestic firms that trade internationally. To measure this notion of indirect trade, we used Belgian data with information on both the domestic firm-to-firm sales and the firms' foreign trade transactions.

Our findings may be summarized with five broad conclusions. First, most firms use a lot of foreign inputs, but only a small number of firms show that dependence through the direct imports observed in trade transaction data. Second, while direct exporters are rare, a majority of firms are indirectly exporting. In most firms, however, indirect export is quantitatively modest, and sales at home are the key source of revenue. Third, foreign trade is common not only at large and productive firms but also among those that are smaller and less productive. However, large firms differ in that they often enter foreign markets directly, whereas small firms tend to trade indirectly. Fourth, the way in which firms import and export is highly persistent over time. Both firms that trade directly and those that only trade indirectly are likely to continue to do so in the future. Fifth, what matters for the transmission of foreign demand shocks to a firm's revenue is how much the firm ultimately sells to foreign markets, not whether these sales are from direct or indirect export.

Taken together, our findings suggest that data on and modelling of domestic production networks are essential to understand the role and behaviour of different types of firms in international trade. Our empirical findings also raise a number of important questions: What determines how firms choose to access foreign markets? Are the gains from trade concentrated among the large and productive firms that access foreign markets directly? Or are these gains shared with smaller and less productive firms that only indirectly import or export? How do demand and supply shocks transmit from one firm to the next in the domestic production network, and what are the effects of such shocks for workers, firms, and the economy? Is it necessary to observe firm-to-firm transactions to accurately estimate these effects?

To answer these questions, it is necessary to develop and estimate a model of production networks and international trade. In Appendix A, we develop such a model, assuming fixed firm-to-firm linkages and constant markups.[14] This simple model offers a justification for the way we measure total import and export shares, and it illustrates how data on firm-to-firm transactions can be used to draw inferences about the costs of and benefits from trade. At the same time, it is important to observe that the model we considered falls short of both explaining all our empirical findings and analysing all the above questions. Doing so is an important task for future research. To help facilitate such research, we report key moments of both trade and the domestic production network in Supplementary Appendix E.[15]

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14. Assuming a fixed network structure prevents one from capturing how buyer–supplier relationships may respond to changes in the price of foreign goods. In an earlier version of this article (Tintelnot *et al.*, 2019), we therefore developed and estimated a model of trade with endogenous network formation. Other approaches to endogenous formation of the domestic production network include Oberfield (2018), Lim (2018), Huneeus (2018), and Taschereau-Dumouchel (2018).

15. We thank the editor for suggesting this.

Harry Li, Alejandra Lopez Espino, Ferdinando Monte, and Andrei Nagornyi for useful comments and suggestions. The views expressed in this article are those of the authors and do not necessarily reflect the views of the National Bank of Belgium or any other institution with which one of the authors is affiliated.

Supplementary Data

Supplementary data are available at *Review of Economic Studies online*. And the replication packages are available at https://dx.doi.org/10.5281/zenodo.3997900.

Data Availability Statement

The code and public access data used to produce the figures and tables are available on Zenodo, at https://dx.doi.org/10.5281/zenodo.3997900. Confidential datasets from the National Bank of Belgium are not made available on Zenodo and were used by permission under a contract between the researchers and the National Bank of Belgium.

A. THEORETICAL MOTIVATIONS FOR THE MEASURES OF TOTAL TRADE

A.1. *Theoretical motivation for* s_{Fj}^{Total}

This section shows that, in a class of models, the firm-level cost changes and aggregate price changes in response to foreign price changes depend on the firms' total import shares, s_{Fj}^{Total}, not the direct import shares.

We consider a small open economy where the price of foreign goods, p_F, is taken as given. We assume fixed linkages between firms, fixed markups in firm-to-firm trade, and constant returns to scale production technologies. In their production, firms use domestic labour (with wage rate w) and inputs from their domestic suppliers. If they are directly importing from abroad, the imported inputs are also used as production inputs.

Denote firm j's cost function to produce y units of output with $c(\{p_{kj}\}_{k\in Z_j}, w, y)$, where Z_j denotes the set of firm j's domestic suppliers, and p_{kj} denotes the price that firm k charges firm j. Taking the total derivatives of the cost function yields:

$$\mathrm{d}c(\{p_{kj}\}_{k\in Z_j}, w, y) = \sum_{k\in Z_j} \frac{\partial c(\{p_{kj}\}_{k\in Z_j}, w, y)}{\partial p_{kj}} \mathrm{d}p_{kj} + \frac{\partial c(\{p_{kj}\}_{k\in Z_j}, w, y)}{\partial w} \mathrm{d}w + \frac{\partial c(\{p_{kj}\}_{k\in Z_j}, w, y)}{\partial y} \mathrm{d}y.$$

Dividing both sides with $c(\{p_{kj}\}_{k\in Z_j}, w, y)$, we obtain:

$$\frac{\mathrm{d}c(\{p_{kj}\}_{k\in Z_j}, w, y)}{c(\{p_{kj}\}_{k\in Z_j}, w, y)} - \frac{y \frac{\partial c(\{p_{kj}\}_{k\in Z_j}, w, y)}{\partial y}}{c(\{p_{kj}\}_{k\in Z_j}, w, y)} \frac{\mathrm{d}y}{y} = \sum_{k\in Z_j} \frac{p_{kj} \frac{\partial c(\{p_{kj}\}_{k\in Z_j}, w, y)}{\partial p_{kj}}}{c(\{p_{kj}\}_{k\in Z_j}, w, y)} \frac{\mathrm{d}p_{kj}}{p_{kj}} + \frac{w \frac{\partial c(\{p_{kj}\}_{k\in Z_j}, w, y)}{\partial w}}{c(\{p_{kj}\}_{k\in Z_j}, w, y)} \frac{\mathrm{d}w}{w}.$$

By Shephard's lemma, we also have $\frac{\partial c(\{p_{kj}\}_{k\in Z_j}, w, y)}{\partial p_{kj}} = x_{kj}(\{p_{kj}\}_{k\in Z_j}, w, y)$ and $\frac{\partial c(\{p_{kj}\}_{k\in Z_j}, w, y)}{\partial w} = \ell_j(\{p_{kj}\}_{k\in Z_j}, w, y)$. In addition, from the constant returns to scale assumption, $c(\{p_{kj}\}_{k\in Z_j}, w, y) = yc(\{p_{kj}\}_{k\in Z_j}, w, 1)$. Rearrange and obtain:

$$\frac{\mathrm{d}c(\{p_{kj}\}_{k\in Z_j}, w, 1)}{c(\{p_{kj}\}_{k\in Z_j}, w, 1)} = \sum_{k\in Z_j} s_{kj} \frac{\mathrm{d}p_{kj}}{p_{kj}} + s_{Lj} \frac{\mathrm{d}w}{w}, \forall y.$$

The term s_{Lj} represents firm j's share of labour cost in inputs. The above equation says that if the production function is constant returns to scale, the percentage change in the unit cost equals a weighted average of percentage change in factor prices, with a factor's weight equal to the expenditure share on the factor.

We can further arrange the equation by leveraging the fixed markup assumption, $\frac{\mathrm{d}p_{kj}}{p_{kj}} = \frac{\mathrm{d}c_k}{c_k}$, to obtain

$$\frac{\mathrm{d}c_j}{c_j} = \left(1 - s_{Fj}^{\text{Total}}\right) \frac{\mathrm{d}w}{w} + s_{Fj}^{\text{Total}} \frac{\mathrm{d}p_{F.}}{p_{F.}}. \tag{A.1}$$

Equation (A.1) implies that for small changes to the foreign price, the first-order approximated changes in the firm-level costs are a weighted aggregate of the change in the foreign price and the change in the domestic wage. While one needs more structure to solve for the general equilibrium and obtain the change in the domestic wage, the weights are firm-specific and summarized by the firm's total import share.

One can obtain similar results for the aggregate price index changes. We now further assume a constant returns to scale utility function and describe it as $e(\{p_{jH}\}, U) = Ue(\{p_{jH}\}, 1)$. That is, the minimized expenditure to achieve utility level U equals U times the minimized expenditure to obtain a unit utility. Furthermore, with homothetic preferences, the ideal price index P is the minimized cost of buying one unit of utility, i.e., $P = e(\{p_{jH}\}, 1)$.

Take the total derivative of $e(\{p_{jH}\}, U)$ and obtain:

$$\frac{\mathrm{d}e(\{p_{jH}\}, U)}{e(\{p_{jH}\}, U)} = \sum_j \frac{p_{jH} \frac{\partial e(\{p_{jH}\}, U)}{\partial p_{jH}}}{e(\{p_{jH}\}, U)} \frac{\mathrm{d}p_{jH}}{p_{jH}} + \underbrace{\frac{U \frac{\partial e(\{p_{jH}\}, U)}{\partial U}}{e(\{p_{jH}\}, U)}}_{=1} \frac{\mathrm{d}U}{U}.$$

Then total differentiate $Ue(\{p_{jH}\}, 1)$:

$$\frac{\mathrm{d}e(\{p_{jH}\}, U)}{e(\{p_{jH}\}, U)} = \frac{\mathrm{d}P}{P} + \frac{\mathrm{d}U}{U}.$$

By Shephard's Lemma, $\frac{\partial e(\{p_{jH}\}, U)}{\partial p_{jH}} = x_{jH}(\{p_{jH}\}, U)$. Equating the previous two equations and dropping $\frac{\mathrm{d}U}{U}$, the first-order approximated change in the ideal price index for any level U is:

$$\frac{\mathrm{d}P}{P} = \sum_j s_{jH} \frac{\mathrm{d}p_{jH}}{p_{jH}}, \tag{A.2}$$

where s_{jH} denotes the share of household consumption that is produced by firm j. Leveraging the fixed markup assumption, $\frac{\mathrm{d}p_{jH}}{p_{jH}} = \frac{\mathrm{d}c_j}{c_j}$, the change in aggregate price index is a weighted average of firm-level cost changes, which in turn are functions of their total import share.

A.2. *Theoretical motivation for* r_{jF}^{Total}

This section shows that the response of firm-level total sales to domestic and foreign demand shocks depends on the total export shares, r_{jF}^{Total}, not the direct export shares.

We consider a class of models in which production functions are Cobb–Douglas in inputs (labour, intermediate goods supplied by domestic firms, and foreign inputs) and utility functions of domestic and foreign consumers are Cobb–Douglas in consumption goods made by domestic firms. As in Section A.1, we also assume fixed linkages between firms and fixed markups in firm-to-firm trade, though here we require a firm's markup to be the same across its buyers.

Denote firm j's total sales by X_j. Firms sell to domestic final consumers (X_{jH}), foreign consumers (X_{jF}) and its downstream firms (X_{ji}):

$$X_j = \sum_{i \in W_j^D} X_{ji} + X_{jH} + X_{jF}.$$

Taking first difference and dividing both sides by X_j:

$$\frac{dX_j}{X_j} = \sum_{i \in W_j^D} r_{ji} \frac{dX_{ji}}{X_{ji}} + r_{jH} \frac{dX_{jH}}{X_{jH}} + r_{jF} \frac{dX_{jF}}{X_{jF}},$$

where r_{ji}, r_{jH}, and r_{jF} denote the share of sales to firm i, to domestic consumers, and to foreign consumers in firm j's total output, respectively.

Under the Cobb–Douglas assumption across firms' goods, we have $X_{ji} = \gamma_{ji} C_i$, $X_{jH} = \gamma_{jH} E$, and $X_{jF} = \gamma_{jF} E_F$, where C_i is the total cost of firm i, E is the aggregate domestic expenditure of households at home, and E_F is the aggregate foreign expenditure. We also have $\frac{dC_i}{C_i} = \frac{dX_i}{X_i}$ under constant markups where a firm's markup is the same across its buyers. The results in changes then follow: $\frac{dX_{ji}}{X_{ji}} = \frac{dX_i}{X_i}$, $\frac{dX_{jH}}{X_{jH}} = \frac{dE}{E}$, and $\frac{dX_{jF}}{X_{jF}} = \frac{dE_F}{E_F}$. Plugging these in to the above, we have:

$$\frac{dX_j}{X_j} = \sum_{i \in W_j^D} r_{ji} \frac{dX_i}{X_i} + r_{jH} \frac{dE}{E} + r_{jF} \frac{dE_F}{E_F}.$$

Rearranging this further, we obtain:

$$\frac{dX_j}{X_j} = (1 - r_{jF}^{\text{Total}}) \frac{dE}{E} + r_{jF}^{\text{Total}} \frac{dE_F}{E_F}$$

which shows that the change in a firm's sales is a weighted average of the changes in aggregate foreign and domestic expenditures, and the weight associated with the change in foreign demand is the total export share, r_{jF}^{Total}. With the Cobb–Douglas assumption, this result also holds globally for large changes in foreign demand.

B. ADDITIONAL EMPIRICAL RESULTS

B.1. *Firms' numbers of suppliers and buyers*

Figure B.1 plots the distributions of the number of domestic suppliers and buyers in year 2012. The domestic production network in Belgium can be characterized as a sparse network, as the median number of domestic suppliers is 33, and the median number of domestic buyers is 9.

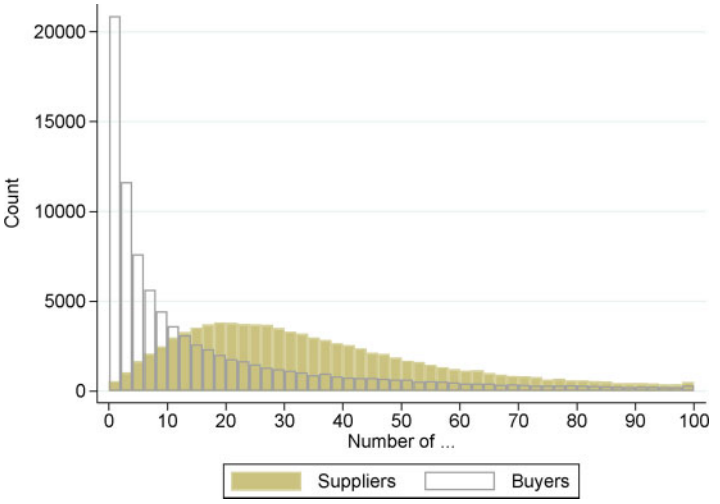

FIGURE B.1

Distributions of number of domestic suppliers and buyers

Notes: The figure plots the density distributions of firms' number of domestic suppliers and buyers in 2012. The distributions are truncated at 100. Out of the 98,745 private sector firms in 2012, we drop 9,034 firms with more than 100 domestic suppliers for the supplier distribution, and 10,052 firms with more than 100 domestic buyers for the buyer distribution.

B.2. *Total import and export shares by participation status*

Figure B.2 plots the distributions of firms' total import and export shares, separately for those that directly sell to and buy from foreign markets and for those that only trade indirectly.

We find that the distributions for the two sets of firms overlap to a large extent, especially for imports. For example, 27% of direct importers have s_{Fj}^{Total} that is below the median s_{Fj}^{Total} for indirect importers. On the export side, 36% of direct exporters have r_{jF}^{Total} that is below the 80th percentile r_{jF}^{Total} for indirect exporters.[16]

B.3. *Variance decompositions of import and export shares*

In Table A1, we calculate how much of the variation in the total participation in foreign trade is within versus between industries. We find that even at the four-digit industry level, within-industry variation in the total import share accounts for 64% of the variation, and the number—68%—is even higher for the total export share. We obtain similar results when decomposing the variance of the indirect import and export shares, where we define firm j's indirect import share as $s_{Fj}^{\text{Total}} - s_{Fj}$, and its indirect export share as $r_{jF}^{\text{Total}} - r_{jF}$. We also investigate to what extent the import (export) content within domestic purchases (sales) varies within and between industries. Industry input–output tables assume homogeneity in the import content of domestic intermediate purchases within industries. Our calculations suggest, however, that more than 70% of the variation in the import content of firms' domestic input purchases arises within industries.

16. These numbers do not change much even when we define the median s_{Fj}^{Total} and 80th percentile r_{jF}^{Total} at the two-digit level. We find that 26% of direct importers have s_{Fj}^{Total} that is below the median s_{Fj}^{Total} for indirect importers, and 38 percent of direct exporters have r_{jF}^{Total} that is below the 80th percentile r_{jF}^{Total} for indirect exporters.

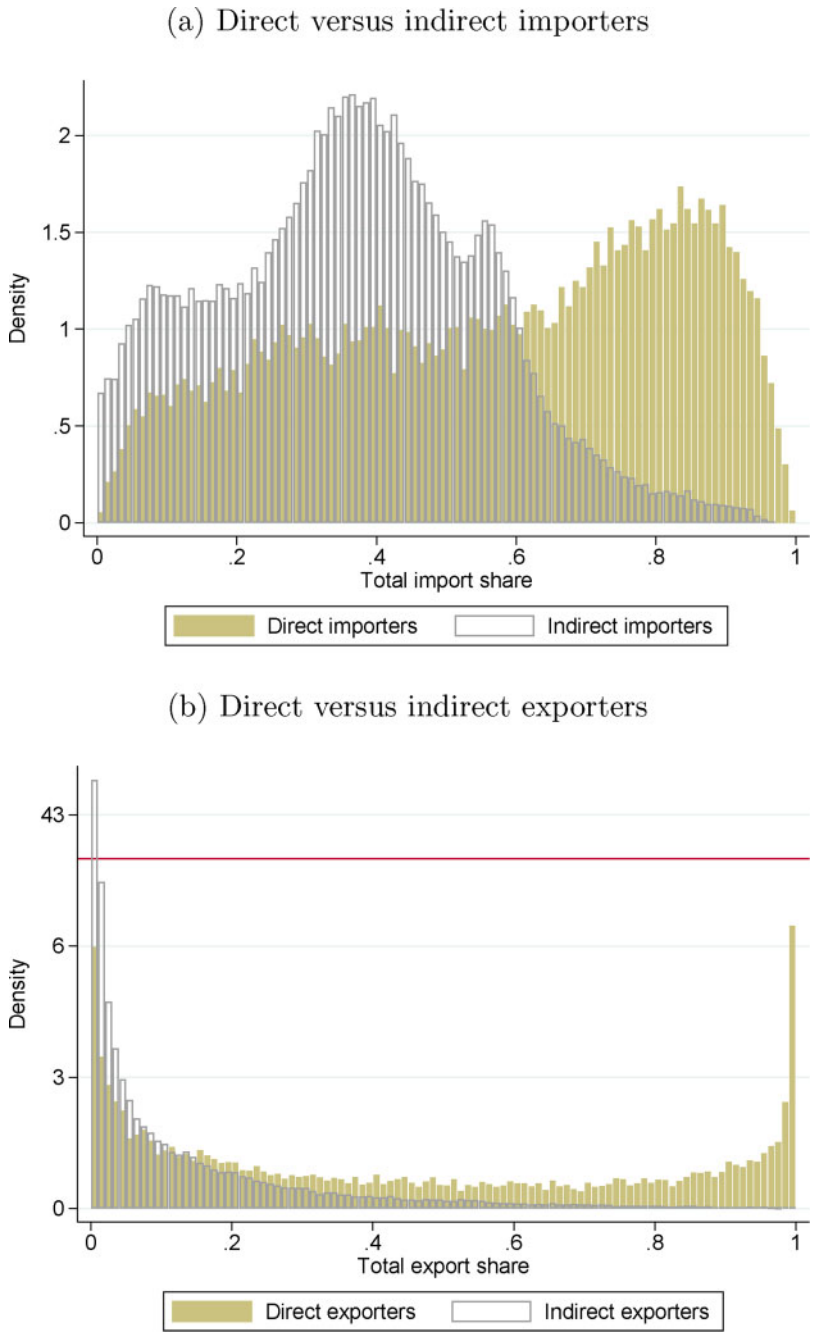

FIGURE B.2

Total import and export shares by participation status

Notes: The figure shows the densities of total import shares, s_{Fj}^{Total}, and total export shares, r_{jF}^{Total}, for direct importers and exporters, as well as for indirect importers and exporters. The figures exclude firms with zero total import or export shares.

TABLE A1
Variance decomposition of indirect participation to foreign trade

Aggregation	Two-digit		Four-digit	
	within	between	within	between
Total import share	0.71	0.29	0.64	0.36
Total export share	0.77	0.23	0.68	0.32
Indirect import share	0.76	0.24	0.67	0.33
Indirect export share	0.80	0.20	0.70	0.30
Import share in domestic network inputs	0.77	0.23	0.70	0.30
Export share in domestic network sales	0.84	0.16	0.76	0.24

Notes: This table reports the results of a variance decomposition analysis for various measures of total and indirect participation in foreign trade, in year 2012. See equations (1) and (2) for variable definitions. Firm j's indirect import share is defined as $s_{Fj}^{\text{Total}} - s_{Fj}$, and its indirect export share is defined as $r_{jF}^{\text{Total}} - r_{jF}$. The import share in domestic network inputs is calculated as $\left(s_{Fj}^{\text{Total}} - s_{Fj}\right) / \sum_{i \in Z_j^D} s_{ji}$. The export share in domestic network sales is calculated as $\left(r_{jF}^{\text{Total}} - r_{jF}\right) / \sum_{i \in W_j^D} r_{ji}$.

REFERENCES

ACEMOGLU, D., AKCIGIT, U. and KERR, W. (2016a), "Networks and the Macroeconomy: An Empirical Exploration", *NBER Macroeconomics Annual*, **30**, 273–335.

ACEMOGLU, D., AUTOR, D., DORN, D. et al. (2016b), "Import competition and the great US employment sag of the 2000s", *Journal of Labor Economics*, **34**, S141–S198.

AHN, J., KHANDELWAL, A. K. and WEI, S.-J. (2011), "The Role of Intermediaries in Facilitating Trade", *Journal of International Economics*, **84**, 73–85.

Amiti, M., Itskhoki, O. and Konings, J. (2014), "Importers, Exporters, and Exchange Rate Disconnect", *American Economic Review*, **104**, 1942–1978.

ANTRÀS, P. and HELPMAN, E. (2004), "Global Sourcing,", *Journal of Political Economy*, **112**, 552–580.

ATALAY, E., HORTACSU, A., ROBERTS, J. and SYVERSON, C. (2011), "Network structure of production,", *Proceedings of the National Academy of Sciences United States of America*, 108, 5199–5202.

BARROT, J. N. and SAUVAGNAT, J. (2016), "Input Specificity and the Propagation of Idiosyncratic Shocks in Production,", *Quarterly Journal of Economics*, 131, 1543–1592.

BEMS, R. and KIKKAWA, A. K. (2020), "Measuring Trade in Value Added with Firm-level Data".

BERNARD, A. B., BLANCHARD, E. J., VAN BEVEREN, I. and VANDENBUSSCHE, H. (2019a), "Carry-Along Trade", *Review of Economic Studies*, **86**, 526–563.

BERNARD, A. B., DHYNE, E., MAGERMAN, G. et al. (2018), "The Origins of Firm Heterogeneity: A Production Network Approach".

BERNARD, A. B., EATON, J., JENSEN, J. B. et al. (2003), "Plants and Productivity in International Trade,", *American Economic Review*, **93**.

BERNARD, A. B. and JENSEN, J. B. (1999), "Exceptional Exporter Performance: Cause, Effect, or Both?", *Journal of International Economics*, **47**, 1–25.

BERNARD, A. B., JENSEN, J. B., REDDING, S. J. et al. (2007), "Firms in International Trade", *Journal of Economic Perspectives*, **21**, 105–130.

——— (2010), "Wholesalers and Retailers in US Trade", *American Economic Review*, **100**, 408–413.

BERNARD, A. B., MOXNES, A. and SAITO, Y. U. (2019b), "Production Networks, Geography and Firm Performance", *Journal of Political Economy*, **127**, 639–688.

BOEHM, C., FLAAEN, A. and PANDALAI-NAYAR, N. (2015), "Input Linkages and the Transmission of Shocks : Firm-Level Evidence from the 2011 Tohoku Earthquake,", *Review of Economics and Statistics*, **101**, 60 – 75.

CALIENDO, L. and PARRO, F. (2015), "Estimates of the Trade and Welfare Effects of NAFTA", *Review of Economic Studies*, **82**, 1–44.

CARVALHO, V. M., NIREI, M., SAITO, Y. et al. (2016), "Supply Chain Disruptions: Evidence from the Great East Japan Earthquake", (mimeo).

DE GORTARI, A. (2019), "Disentangling Global Value Chains", (mimeo).

DE LOECKER, J., FUSS, C. and VAN BIESEBROECK, J. (2014), "International Competition and Firm Performance: Evidence from Belgium", *(NBB Working Paper Series*, 269).

DHYNE, E., MAGERMAN, G. and RUBINOVA, S. (2015), "The Belgian Production Network 2002-2012", *(National Bank of Belgium Working Paper Series*, 288).

EUROSTAT (2002–2012), "National Accounts", https://ec.europa.eu/eurostat/web/national-accounts/data/database, accessed July 28 2020.

——— (2010), "ESA Supply, Use and Input-Output Tables", https://ec.europa.eu/eurostat/web/esa-supply-use-input-tables/data/database, accessed July 22 2020.
FUJII, D., ONO, Y. and SAITO, Y. U. (2017), "Indirect Exports and Wholesalers: Evidence from Interfirm Transaction Network Data", *Japan and the World Economy*, **44**, 35–47.
GADENNE, L., T. K. NANDI, and R. RATHELOT (2019), "Taxation and Supplier Networks: Evidence from India".
GANAPATI, S. (2018), "The Modern Wholesaler: Global Sourcing, Domestic Distribution, and Scale Economies", (mimeo).
HUMMELS, D., JØRGENSEN, R., MUNCH, J. et al. (2014), "The Wage Effects of Offshoring: Evidence from Danish Matched Worker-Firm Data", *American Economic Review*, **104**, 1597–1629.
HUNEEUS, F. (2018), "Production Network Dynamics and the Propagation of Shocks", (mimeo).
KIKKAWA, A. K., DHYNE, E. and MAGERMAN, G. (2019), "Imperfect Competition in Firm-to-Firm Trade", (mimeo).
LIM, K. (2018), "Endogenous Production Networks and the Business Cycle", (Working Paper).
MAGERMAN, G., DE BRUYNE, K., DHYNE, E. and VAN HOVE (2016), "Heterogeneous Firms and the Micro Origins of Aggregate Fluctuations", *(National Bank of Belgium Working Paper Series*, 312).
MELITZ, M. J. (2003), "The Impact of Trade on Intra-industry Reallocations and Aggregate Industry Productivity", *Econometrica*, **71**, 1695–1725.
MELITZ, M. J. and REDDING, S. J. (2014), "Heterogeneous firms and trade", in Gopinath, G., Helpman, E. and Rogoff, K. (eds) *Handbook of International Economics* (Oxford, UK: Elsevier, vol. 4) 1–54.
NATIONAL BANK OF BELGIUM (2002–2014a), "Annual Account Filings", (Confidential Dataset).
——— (2002–2014b), "Business-to-Business Transactions Dataset", (Confidential Dataset).
——— (2002–2014c), "International Trade Dataset", (Confidential Dataset).
OBERFIELD, E. (2018), "A Theory of Input–Output Architecture", *Econometrica*, **86**, 559–589.
TASCHEREAU-DUMOUCHEL, M. (2018), "Cascades and Fluctuations in an Economy with an Endogenous Production Network".
TINTELNOT, F., KIKKAWA, A. K., MOGSTAD, M. et al. (2019), "Trade and Domestic Production Networks" (Working Paper Series, No. 25120, National Bureau of Economic Research).
TYBOUT, J. R. (2003), "Plant-and Firm-level Evidence on "New" Trade Theories", *Handbook of International Trade*, **1**, 388–415.
UNITED NATIONS (2002–2014), "Comtrade Database", https://comtrade.un.org/, accessed July 27 2020.
WOOLDRIDGE, J. M. (2009), "On Estimating Firm-level Production Functions using Proxy Variables to Control for Unobservables", *Economics Letters*, **104**, 112–114.