Imperfect Competition in Firm-to-Firm Trade*

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Abstract

This paper studies the implications of imperfect competition in firm-to-firm trade. Exploiting data on the universe of sales relationships between Belgian firms, we document that firms' markups increase in the average input shares among their buyers. Given this fact, we develop a model where firms charge supplier-buyer specific markups, which depend on the bilateral input shares. The estimated model suggests large distortions due to double marginalization: Reducing all markups in firm-to-firm trade by 20 percent increases welfare by 10 percent. We also highlight the importance of accounting for endogeneities in bilateral markups in predicting the effects of shock transmissions.

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1 Introduction

Firms largely operate and compete in relationships with other firms. Firms often deliver their output to multiple firms, and they often purchase inputs from other firms. These buyer-supplier relationships generate a network of complex interactions. One such complexity is that the set of firms that a firm competes against when supplying to a certain buyer may be different from those when supplying to a different buyer. This paper studies the nature of this competition in firm-to-firm trade and analyzes its implications.

We examine detailed administrative data on all domestic firm-to-firm relationships in Belgium. A typical Belgian firm is connected with only a handful of suppliers, making the firm-to-firm network extremely sparse. Moreover, among these small set of suppliers, firms often concentrate purchases from very few suppliers. These concentration in firms' input sourcing may generate opportunities for supplier firms to exert market power over their buyers. In addition, the degree of supplier firms' market power can vary across buyers due to heterogeneities in buyers' sourcing patterns.

The data indeed points out to the importance of this firm-to-firm dimension when studying firms' competition. We find that firms charge higher average markups when they have larger input shares amongst their buyers. Firm-level average markups are measured by either computing accounting markups or by estimating markups following De Loecker and Warzynski (2012). This positive relationship between firms' markups and input shares holds even after controlling for the firms' sectoral market shares. We interpret this fact as firms competing as oligopolies to supply inputs to each buyer. In addition to the *firm-level* market share within a sector, the firm's pairwise input shares for each buyer capture the *pair-level* pricing power the firm has for each of its buyers.

Motivated by this fact, we build a model of oligopolistic competition in firm-to-firm trade. With a nested CES structure in the production function that builds on Atkeson and Burstein (2008), firms charge different markups to each buyer firm. The more conventional implementation is where a firm's total sales share among same-sector firms determines its firm-level markup; in our model, the markup a firm charges a buyer depends on the firm's share in the buyer's intermediate goods purchases. As firms compete with different sets of firms when selling to each buyer, the shares that firms have in each buyer's intermediate goods vary across buyers. Therefore, the model puts emphasis on firms' pricing powers that are different depending on which firm they sell to.

Mapping our model to the data, we employ a procedure similar to that of Edmond, Midrigan, and Xu (2015) and estimate the CES parameters in both preference and production functions. We obtain these estimates so that the firm-level average markups – averages of the model implied markups on sales to other producers and to the final consumer – provide the best fit of those implied by the data. The estimated CES parameters reveal that firms generally charge higher markups in their sales to other firms than in their sales to final demand.

Equipped with these estimates, we conduct two separate counterfactual exercises that explore the implications of oligopolistic competition in firm-to-firm trade. In the first counterfactual exercise, we quantify the distortionary impact of double marginalization. With each firm along the production chain charging markups to each individual buyer, the degree of double marginalization in the aggregate depends on the structure of the firm-to-firm network. To this end, we compare the results obtained by using the observed network structure to those obtained by using an approach that assumes a particular network structure, which one would take when information on the underlying firm-to-firm network is not available.

From the estimated model, we first back out markups for each buyer-supplier pair in the data and consider the reduction in those markups in firm-to-firm trade as the shock. We find that in response to a 20 percent reduction in firm-to-firm markups, aggregate welfare – measured as the level of household consumption – increases by 10 percent. Real wages – measured as the nominal wage over the aggregate price index – increases by 7 percent. As comparison, we consider a sectoral roundabout production economy. In the sectoral roundabout production economy we impose a simple network structure in which there are two sets of common composite goods, one of which is used as intermediate goods and the other as final consumption goods. To make the comparison consistent, we keep the initial firm-level sales, firm-level inputs, firms' markups charged on sales to final demand, and firm-level average markups on intermediate goods sales the same with our model. The impact of the markup reduction on welfare turns out to be smaller under the sectoral roundabout production economy. In response to a 20 percent reduction in markups charged on common composite intermediate goods, the aggregate welfare gains are less than two-thirds relative to the benchmark case. The increase in real wage is also smaller, by around a sixth. Failing to fully account for the observed firm-to-firm trade network leads to a smaller magnitude of aggregate distortion because the sectoral roundabout production economy cannot capture the heterogeneity in cost reductions that firms face. Under the observed firm-to-firm trade network, some firms that are downstream experience extreme cost reductions leading to greater movements in the aggregate due to non-linearities in the system.

In the second counterfactual exercise we explore how oligopolistic competition in firm-to-firm trade affects predictions of the transmission of shocks both at the firm-level and at the aggregate level. We shock an exogenous parameter in the model – the price of foreign goods – and see how the model's predictions differ from those without endogenous markups in firm-to-firm trade. As a comparison, we consider an economy that are identical to the baseline economy, but having heterogeneous firm-to-firm markups that are fixed.

Implementing endogenous markups leads to two counteracting effects on top of the effects predicted under fixed markups. First, endogenous markups imply an incomplete pass-through from a change in the supplier's input price to the change in its output price. When the price of foreign goods fall, firms may increase their markups in response to reductions in their input costs. We call this the "attenuation effect," as firms' cost changes are not fully passed on to their buyers, attenuating both downstream firms' and aggregate responses. Second, when a firm faces a reduction in its input costs, the other suppliers that sell goods to the firm's buyers may reduce their markups in the face of increased competition. We call this the "pro-competitive effect," as this amplifies the downstream effects of cost reductions.

We characterize the magnitudes of these two counteracting effects operating within each buyer-supplier pair. Overall, under the uniform foreign price reduction that reduces the costs of all importers directly and of almost all firms indirectly, we find that accounting for endogeneity of firm-to-firm markups has quantitatively small effects on aggregate variables. However, we find it important to account for endogenous markups in firm-to-firm trade to understand cost changes at the firm-level. In response to a foreign price change, around half of the firms face higher markups from their suppliers on average while the rest face lower markups. We demonstrate that a measure capturing the firms' respective positions in the production chain is a key metric in explaining this heterogeneity. The more exposed a firm is to foreign inputs through its domestic suppliers, the higher markups the firm faces from its suppliers on average.

This paper contributes to the literature studying the implications of imperfect competition in intermediate goods markets. Grassi (2018) develops a model in which firms engage in oligopolistic competition in an economy with sectoral input-output linkages and studies the contribution of firm-level shocks on the aggregate dynamics.[1] Effects similar to our attenuation and pro-competitive effects are studied extensively in other contexts. For example, Feenstra, Gagnon, and Knetter (1996) study how the degree of price pass-through varies with the firm's export market share. Atkeson and Burstein (2008) focus on incomplete price pass-through to explain deviations of international relative prices from relative PPP. Amiti, Itskhoki, and Konings (2019) study how firms' prices respond to changes in the prices of their competitors. These papers analyze oligopolistic competition where firms compete with others within the same sector, implying that the firm's market power is captured by its market share in its sector.[2] In contrast, we propose a more granular view on the competition between firms. In addition to the *firm-level* market share within the sector being the determinant of the firm's market power, we suggest that the *pair-level* input shares across its buyers are also relevant metrics in capturing the firm's ability to charge markups.[3]

[1]As in Grassi (2018), we focus on strategic complementarities across suppliers in the style of Atkeson and Burstein (2008). See Neiman (2011) for a similar model of variable markups that allows for arm's length and intra-firm transactions. Mongey (2018) studies inflation and output responses to monetary shocks in oligopolistic market structures. Morlacco (2019) and Macedoni and Tyazhelnikov (2018) cast attention to firms' market power as buyers of goods in international markets. For imperfect competition where complementarities arise from the demand side, see also Krugman (1979), Ottaviano, Tabuchi, and Thisse (2002), Melitz and Ottaviano (2008), and Zhelobodko, Kokovin, Parenti, and Thisse (2012).

[2]There are also cases in which aggregate volatilities can be captured by the distribution of market shares. See for example Gabaix (2011), where the Herfindahl-Hirschman Index (HHI) is the main metric that captures aggregate volatility.

[3]This is consistent with the notion of "pricing to firm," proposed by Halpern and Koren (2007).

This paper is also related to the vast literature investigating the implications of distortions. Our approach to assess the quantitative impact of distortions is similar to those in Restuccia and Rogerson (2008) and Hsieh and Klenow (2009), in which they compute the aggregate counterfactuals upon hypothetical reductions of wedges.[4] We focus on a particular source of distortions, imperfect competition in firm-to-firm trade, and quantify how much distortion it creates in the aggregate. Focusing on imperfect competition in firm-to-firm trade also connects our paper to research on firm boundaries and vertical relationships. Our findings that reducing markups in firm-to-firm transactions can substantially lower firms' costs relate our paper to the literature studying incentives of firms to vertically integrate. The efficiency motive for vertical integration has been intensively studied and empirically investigated for selected sectors (see Lafontaine and Slade, 2007, for a survey on this literature).[5]

An important work by Baqaee and Farhi (2018) provides a framework for aggregating micro shocks at the first-order or second-order approximation, using a general model with distortions such as markups.[6] Using U.S. firm-level data, they find that eliminating firm-level markups would increase aggregate TFP by around 20 percent.[7] In this paper we capture the heterogeneous markups firms potentially charge different buyers and investigate the distortions created by markups in firm-to-firm trade. The markups we back out using the structure of the model are generally higher in firm-to-firm trade than in firms' sales to final demand. This implies that we consider the reductions in markups that are initially at higher levels than the firm-level markups one obtains by imposing them to be the same across destinations. We impose more structure on the production functions and the competition environment, and focus on the global firm-level and aggregate outcomes in response to large shocks. In doing so, we employ the technique developed by Dekle, Eaton, and Kortum (2007), which enables us to compute the counterfactual outcomes with just the observed input shares and the estimated CES parameters.

[4]Other papers that investigate misallocations arising from imperfect competition, resource misallocations, and financial frictions include Hopenhayn and Rogerson (1993), Chari, Kehoe, and Mcgrattan (2007), Epifani and Gancia (2011), Fernald and Neiman (2011), Buera, Kaboski, and Shin (2011), Oberfield (2013), Bartelsman, Haltiwanger, and Scarpetta (2013), Midrigan and Xu (2014), Asker, Collard-wexler, and De Loecker (2014), Sandleris and Wright (2014), Hopenhayn (2014), Moll (2014), Edmond, Midrigan, and Xu (2015), Buera and Moll (2015), Peters (2016), Dhingra and Morrow (2016), Gopinath, Kalemli-Ozcan, Karabarbounis, and Villegas-Sanchez (2017), Haltiwanger, Kulick, and Syverson (2017), Sraer and Thesmar (2018), Edmond, Midrigan, and Xu (2018), Bilbiie, Ghironi, and Melitz (2018), and Behrens, Mion, Murata, and Suedekum (2018).

[5]Antras (2003) investigates the relationship between vertical integration and trade, and develops a model with incomplete-contracting and allocation of property rights. For empirical investigations on the efficiency motives of vertical integration, see for example Grimm, Winston, and Evans (1992), Waterman and Weiss (1996), Chipty (2001), Hastings and Gilbert (2005), and Hortaçsu and Syverson (2007).

[6]An important benchmark in this literature is the work by Hulten (1978), which shows that the information on the structure of the production network is irrelevant in an efficient and closed economy up to a first order approximation. Building on this result, Baqaee and Farhi (2019) analyze the importance of second order effects of firm-level TFP shocks in an efficient economy. For other papers that investigate the effects beyond Hulten (1978)'s network irrelevance result, see Altinoglu (2015), Liu (2016), and Bigio and La'o (2017), which model firms facing financial constraints, and Pasten, Schoenle, and Weber (2017), which constructs a model with price rigidities.

[7]Consistent with the findings from De Loecker and Eeckhout (2017), they find the distortions that firms' markups create to increase over time.

Lastly, this paper also contributes to the literature on domestic production networks.[8] The empirical literature has investigated shocks transmission through production networks. By examining firms sourcing from Japanese firms impacted by the 2011 Tohoku earthquake, Carvalho, Nirei, Saito, and Tahbaz-Salehi (2016) and Boehm, Pandalai-Nayar, and Flaaen (2019) have found that shocks to suppliers transmit to buyer firms. Barrot and Sauvagnat (2016) have also found shock transmission through production linkages by looking at firms sourcing from firms located in places hit by natural disasters in the U.S. In the context of sector-to-sector linkages, Acemoglu, Akcigit, and Kerr (2015) study the propagation of demand and supply shocks. Motivated by this evidence, we focus on how shocks transmit through the production network once oligopolistic competition in firm-to-firm trade is accounted for.[9]

This paper proceeds as follows. Section 2 describes the data. This section also shows that suppliers charge higher markups if their input shares to buyers are higher. Section 3 outlines the model of oligopolistic competition in firm-to-firm trade along with several alternative models for comparison to the counterfactual results. In Section 4 we estimate the model's underlying parameters. With the estimated model we quantify how distortionary markups in firm-to-firm trade are in Section 5. Section 6 investigates accounting for endogenous markups in firm-to-firm trade affects predictions of the transmission of shocks. Finally, Section 7 concludes.

[8] For works studying the structure of domestic production networks, see Atalay, Hortacsu, Roberts, and Syverson (2011). Bernard, Dhyne, Magerman, Manova, and Moxnes (2018) explore the importance of firm-to-firm relationships in generating observed firm-size heterogeneity. Miyauchi (2019) studies firm agglomeration through returns to scale in firm-to-firm matching. For works on production networks in international trade, see handbook chapter of Chaney (2016).

[9] In one of our counterfactual exercises, we consider the change in the foreign price as the shock and look at its firm-level and aggregate consequences. See, for example, Gopinath and Neiman (2014), Halpern, Koren, and Szeidl (2015), Magyari (2016), Antras, Fort, and Tintelnot (2017), Furusawa, Inui, Ito, and Tang (2017), and Dhyne, Kikkawa, Mogstad, and Tintelnot (2019) for papers studying the effects of import shocks on firms. On how such firm-level or other micro shocks lead to aggregate fluctuations, Gabaix (2011) and Carvalho and Gabaix (2013) show that firm-level shocks may not wash out in the aggregate if the firm-size distributions are fat-tailed. Acemoglu, Carvalho, Ozdaglar, and Tahbaz-Salehi (2012) illustrate that firm-level shocks may lead to aggregate fluctuations if input-output structures are asymmetric. Di Giovanni, Levchenko, and Mejean (2014) and Magerman, De Bruyne, Dhyne, and Van Hove (2016) study the two potential sources of aggregate fluctuations together. Yeh (2016) points out that large firms tend to be less volatile, leading to mitigated effects of fat-tailed firm size distributions in the aggregate. Papers that study the importance of micro shocks on aggregate volatility include Jovanovic (1987), Durlauf (1993), Bak, Chen, Scheinkman, and Woodford (1993), Horvath (1998), Horvath (2000), Carvalho (2010), Foerster, Sarte, and Watson (2011), Di Giovanni, Levchenko, and Mejean (2014), Stella (2015), Atalay (2017), and Acemoglu, Ozdaglar, and Tahbaz-Salehi (2017).

2 Data and evidence

2.1 Dataset and sample selection

Our main dataset is the National Bank of Belgium (NBB) Business-to-Business (B2B) transactions database, which is a panel of VAT-ID to VAT-ID transactions among the universe of Belgian VAT-IDs from 2002–2014. As explained in detail in Dhyne, Magerman, and Rubinova (2015), all enterprises in Belgium are assigned unique VAT-IDs and are required to report total yearly sales exceeding 250 Euro to other VAT-IDs. We also make use of the VAT declarations where we observe their total sales and total purchases.

We merge the datasets with the annual account filings and the international trade dataset. From the annual accounts we observe the primary sector of each VAT-ID (NACE Rev. 2, 4-digit), total sales, labor cost, ownership relations to other VAT-ID's, location (ZIP code), and other variables that are standard in the annual accounts. The international trade dataset contains the values of imports and exports of goods at the VAT-country-product (CN 8-digit)-year level.

One firm can have multiple VAT-IDs. We focus on competitions and pricing decisions that occur across firm boundaries. The nature of these may be different from those within firm boundaries. Thus, we aggregate VAT-IDs up to the firm-level using ownership filings in the annual accounts and foreign ownership filings in the Balance of Payments survey. The Balance of Payments survey reports each VAT-ID, the name, and the country of a foreign firm that owns at least 10 percent of the shares, along with the associated ownership share. We group all VAT-IDs into firms if they are linked with more than or equal to 50 percent of ownership, or if they share the same foreign parent firm that holds more than or equal to 50 percent of their shares. See Appendix A.1 for further details.

We select private and non-financial sector Belgian firms that report positive sales, labor cost, and at least one full-time equivalent employee as our sample for analysis. Following De Loecker, Fuss, and Van Biesebroeck (2014), we select firms that report tangible assets of more than 100 Euro and positive total assets for at least one year throughout our sample period.[10] Table 1 describes the coverage of our selected sample compared to the Belgian aggregate statistics.[11] The numbers in Table 1 are identical to those in Table 1 in Dhyne, Kikkawa, Mogstad, and Tintelnot (2019), as we follow the same sampling and aggregation procedures. Note that the total sales in our sample turn out to be larger than those in the aggregate statistics. The differences can be explained by the fact that the output values in the aggregate statistics sum up value added for trade intermediaries instead of gross output, hence the smaller numbers in the aggregate statistics.

[10] For example in 2012, out of 860,000 firms only 98,745 firms satisfy these criteria. Most of this reduction is driven by the exclusion of self-employed firms without employees, which drops around 750,100 firms.

[11] In Appendix A.2 we also report the coverage of the full sample constructed in Dhyne, Magerman, and Rubinova (2015). There we also provide the sectoral composition of our sample, the aggregate statistics of the B2B dataset, and some descriptive statistics of the production network.

Table 1: Coverage of selected sample

Year	Aggregate statistics				Selected sample				
	Private, non-financial		Imports	Exports	Count	V.A.	Sales	Imports	Exports
	GDP	Output							
2002	182	458	178	193	88,301	119	501	175	185
2007	230	593	254	267	95,941	152	692	277	265
2012	248	671	317	319	98,745	164	767	292	292

Note: All numbers except for Count are in billions of Euro in current prices. Belgian GDP and output are for all private and non-financial sectors. Data for Belgian aggregate statistics are from Eurostat. Firms' value added is from the reported values from the annual accounts. Total sales in our selected sample are larger than total output in the aggregate statistics because the output values in the aggregate statistics sum up the value added for trade intermediaries instead of their gross output.

In this paper we focus on firms from the Table 1 sample and on the firm-to-firm network among those in the selected sample. For the transactions between the selected firms and the non-selected firms, we treat the sales of selected firms that go to non-selected firms as sales to domestic final demand. On the input side, we classify input purchases to selected firms from non-selected firms as labor costs. Thus labor costs can be interpreted as composite goods that come from outside the selected firms. In Appendix A.2 we report the fractions of firms' inputs that are affected by these classifications.

Table 2 shows the aggregate statistics using our selected sample. The number of firm-to-firm links in the economy is much smaller than the number of all possible links among all firms, indicating that the production network is extremely sparse.

Table 2: Aggregate statistics of the B2B dataset

Year	Num. links	Num. links / Possible links	Total B2B sales
2002	4,187	0.05%	199
2007	4,848	0.05%	206
2012	5,026	0.05%	225

Note: This table shows aggregate statistics of the firm-to-firm network, among the firms selected from the procedure described in Section 2.1. Number of links are in the thousands and the total B2B sales are in billions of Euro in current prices.

2.2 Skewed input shares across suppliers

With the data sample described, we first point to the fact that the distribution of the shares that suppliers have in a buyer's input purchases is very skewed. For each buyer-supplier pair, we define s_{ij}^m as the supplier firm i's sales share among the buyer firm j's total input purchases:

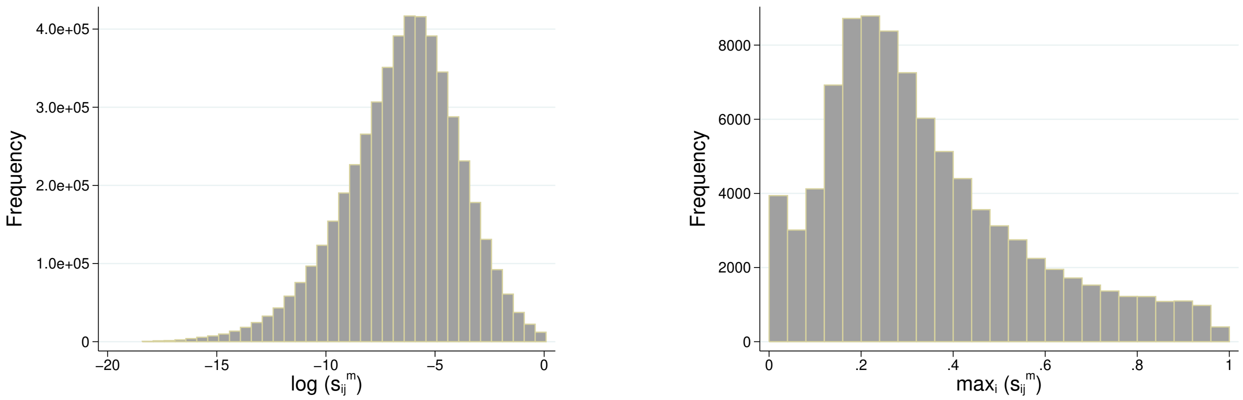
$$s_{ij}^m = \frac{\text{Sales}_{ij}}{\text{InputPurchases}_j}. \tag{1}$$

Input purchases here includes all purchases from other Belgian firms in our sample and imports, hence the superscript of m for intermediates.

Figure 1a plots the histogram of $\log\left(s_{ij}^m\right)$ for all supplier-buyer pairs. We find that the distribution of s_{ij}^m can be roughly approximated by a log-normal distribution. Figure 1b displays a histogram of the input shares to the largest suppliers for all buyer firms in 2012. This figure restricts scope to firms with at least 10 suppliers. The input share of the largest supplier for the median firm in this figure is 29 percent.

Figure 1: Distribution of input shares

(a) Histogram of $\ln s_{ij}^m$ (b) Input shares of the largest suppliers



Note: s_{ij}^m is defined as firm i's goods share among firm j's input purchases from other Belgian firms and abroad. The left histogram shows the distribution of $\ln s_{ij}^m$ for all firm-to-firm pairs in 2012. The right histogram shows the distribution of $\max_i\left(s_{ij}^m\right)$, which is the maximum value of s_{ij}^m for each buyer firm j in 2012 that has at least 10 suppliers. The median value is 0.29.

Together with the fact that the median firm has 33 suppliers, the figure reveals that suppliers' input shares are highly skewed throughout the economy. For each buyer, few suppliers tend to account for most input purchases. Appendix A.3 presents the Herfindahl-Hirschman Index (HHI) of s_{ij}^m for the same set of firms with at least 10 suppliers. There we find that 50 percent of firms have a HHI above 0.15 and 26 percent of firms have a HHI above 0.25.[12]

2.3 Markups and input shares

We then explore if these heterogeneities across buyer-supplier pairs are important when considering firms' markups. Since we do not observe pair-level prices but only values of firm-to-firm trade flows, we investigate firm-level markups as a function of the network. We determine if firm-level markups and firms' average buyer input shares are positively associated with each other, after controlling for

[12] In Appendix A.4 we also present the analogous figures for the revenue shares, r_{ij}, which is defined as the share of firm i's sales to j out of firm i's total sales.

firm-level sectoral market shares. A positive relationship, while it cannot be interpreted causally, suggests that firms' market power contains pair-level components that come from each individual buyer in addition to firm-level components that are captured by sectoral market shares.

Firm-level markups, $\mu_{i,t}$, are measured as the ratio of firms' total sales over input costs (the sum of input purchases and labor costs). This measure captures average markups or profit shares for each firm. It is consistent with the model we construct in Section 3, in which we consider a static model without fixed costs, featuring CRS production technologies.[13]

However, if firms' production technologies do not exhibit constant returns or if part of the inputs are spent as fixed costs, then the accounting markups measure, $\mu_{i,t}$, may not capture markups over marginal costs. To address this concern, we also consider an alternative measure of firm-level markups following the method introduced by De Loecker and Warzynski (2012). This method estimates production functions to identify markups from the wedge between the output elasticity of a variable input and its expenditure share out of total revenue.[14]

Firm-level sectoral market shares, $\text{SctrMktShare}_{i,t}$, are computed at the NACE 4-digit level. This measure captures firms' market power in models that feature oligopolistic competition where firms' outputs are aggregated at the sectoral level. This measure, a variable that captures firms' size, also controls for the potential returns to scale in firms' production functions. It allows us to see the correlation between firms' markups and average input shares, controlling for their overall scale.

We construct a measure that captures the input shares firms have within their buyers. Using the pairwise input shares defined in equation (1), we compute firm i's weighted average input shares to its buyers at year t, $\overline{s^m_{i\cdot,t}}$, as

$$\begin{aligned}\overline{s^m_{i\cdot,t}} &= \sum_{j\in W_{i,t}} \frac{\text{InputPurchases}_{j,t}}{\sum_{k\in W_{i,t}} \text{InputPurchases}_{k,t}} s^m_{ij,t} \\ &= \frac{\sum_{j\in W_{i,t}} \text{Sales}_{ij,t}}{\sum_{j\in W_{i,t}} \text{InputPurchases}_{j,t}},\end{aligned}$$

where $W_{i,t}$ is the set of i's buyers at year t. Total input purchases are assigned as weights for each buyer firm.

With these variables, we run the following regression:

$$\mu_{i,t} = \beta\,\text{SctrMktShare}_{i,t} + \gamma\,\overline{s^m_{i\cdot,t}} + \varphi X_{i,t} + \delta_t + \epsilon_{i,t}, \tag{2}$$

[13] We exclude the user cost of capital in the calculation of markups in our baseline case. This is because the firm-to-firm trade data may capture purchases of capital goods. Since it is impossible to identify which transaction were capital purchases, adding a measure of user cost of capital may lead to double counting of capital inputs. Nevertheless, in Appendix A.7 we account for capital usage costs as additional input costs.

[14] See Appendix A.7 for the details of this method.

where firm-level controls and year fixed effects are included. The first three columns of Table 3 report the results where firms' average accounting markups are on the LHS, and the last three columns consider firm-level markups from De Loecker and Warzynski (2012). All coefficients are X-standardized. The specification of the first and fourth columns include sector fixed effects, and the other columns include firm fixed effects. First, unsurprisingly, in all specifications we see a positive relationship between markups and firm-level market shares. The result in the third column, for example, indicates that within each firm, an increase of one standard deviation in the firm's sectoral market share is associated with an increase of around 2.2 percentage points in the firm's average markup.

More interestingly, even after controlling for these sectoral market shares, the coefficients on the firms' average input shares to buyers are positive. The third column indicates that within each firm a single standard deviation increase in average input shares to buyers corresponds to around an increase of 3.9 percentage points in the firm's average markup. We find similar results when using markups from De Loecker and Warzynski (2012) on the LHS. Controlling for firms' size in each sector, firms have greater ability to charge markups if they have higher shares within their buyers' inputs.[15]

Table 3: Firm-level markups and input shares

	Average markups			De Loecker and Warzynski (2012)		
	(1)	(2)	(3)	(4)	(5)	(6)
$\text{SctrMktShare}_{i,t}$ (4-digit)	0.0219	0.0154	0.0221	0.00996	0.00749	0.0144
	(0.00280)	(0.00174)	(0.00201)	(0.00522)	(0.00324)	(0.00333)
Average input share $\overline{s^m_{i\cdot,t}}$	0.0524	0.0412	0.0391	0.0745	0.0680	0.0653
	(0.00395)	(0.00300)	(0.00290)	(0.0213)	(0.0183)	(0.0183)
N	809722	781627	781627	90736	89305	89305
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Sector FE	4-digit	No	No	4-digit	No	No
Firm FE	No	Yes	Yes	No	Yes	Yes
Controls	Yes	No	Yes	Yes	No	Yes
R2	0.105	0.638	0.639	0.138	0.747	0.748

Note: Standard errors in parentheses. The coefficients are X-standardized. Standard errors are clustered at the NACE 2-digit-year level. The regression exclude outliers in the top and bottom 1 percent of the markup distribution. Controls include firms' number of suppliers, number of buyers, employment, total assets, and age. The first three columns consider firms' average accounting markups as the LHS variable. The last three columns consider firm-level markups from De Loecker and Warzynski (2012) for manufacturing sector firms as the LHS variable.

It is worth noting that potential confounding factors such as productivity shocks will affect only the coefficient on the sectoral market shares and not the coefficient on the average input shares, as

[15] Though beyond the scope of this paper, one natural question is how firms' ability to charge markups depend on the oligopsonistic power of their buyers. One conjecture may be that if firm i's output is concentrated to the sales to a particular buyer j, firm i may charge lower markup to j. Because we do not observe firm-to-firm prices, we proxy these quantity output shares with revenue output shares, r_{ij}, and construct averages across buyers, $\overline{r_{i\cdot}}$. When correlated with firms' average markups, μ_i, we find that the coefficient is either insignificant or even positive.

long as they are at the firm-level.[16] The positive coefficient on the average input shares indicate that firms' sectoral market shares are not perfectly collinear with their average input shares to buyers. Appendix A.5 illustrates that this is indeed the case. In particular, we demonstrate that a firm with a high input share in a particular buyer is not necessarily large in terms of total sales. Therefore, in generating the observed distributions of pairwise input shares, s^m_{ij}, pairwise match components play a large role in addition to firm-level components. The relative size of the two coefficients is also worth discussing. Across the specifications, we see larger coefficients on the average input shares compared to those on the firm-level market shares. Additionally, we show in Table 12 in Appendix A.6 that the R-squared tends to increase more when adding the average input shares on the RHS, as opposed to adding the firm-level market shares. These results indicate that both the variations in the average input shares and the variations in the sectoral market shares are important for firms' ability to charge markups.

While our results show that buyer-supplier match specific components play an important role in explaining firm-level markups, there are several forces that can be driving these results. One can interpret these match specific components as firms customizing deliveries across buyers or selling goods of different qualities. One may also rationalize in line with theories in which these match specific components develop over time, such as relation-specific sunk costs. To partly account for these time-varying components, we control for the firm's age and also for the average relationship age across its buyers. The positive correlation between markups and average input shares is robust even after these additional controls are added, meaning that there are also time-invariant aspects in the match specific components.[17] Another explanation could be non-homotheticities in buyers' production functions, as in Blaum, Lelarge, and Peters (2018). However, the positive correlation between markups and average input shares is robust after adding an additional buyers' size control variable. Finally, one can view our results as potentially coming from firms' sales to final demand. A firm may be charging a high average markup because it has a large share in final demand. It can also be because a large share of its sales is delivered to final demand, which may have higher markups. However, the positive coefficient of average markups on average input shares is virtually unaffected even when we control for firm-level sales share in final demand market, or for shares of firms' sales that go to final demand.

In the static model we construct later, we do not take an explicit stand on the potential sources that drive these components but treat them as pair-specific constant variables in the production functions,

[16]Nevertheless, there may be confounding factors at the pair-level. To address this issue we consider a specification in which we instrument the average input shares with the sales from other suppliers, $\log\left(\sum_{j\in W_{i,t}} \text{InputPurchases}_{j,t} - \sum_{j\in W_{i,t}} \text{Sales}_{ijt}\right)$. This specification only considers the variations of a firm's average input share that come from the changes in the purchases the firm's buyers made from other suppliers. As reported in Appendix A.6, the coefficients on average input shares in the second stage results remain positive.

[17]This is consistent with the time-invariant firm-country specific factors determining the exporters' distribution of sales across countries, documented in Bernard, Moxnes, and Ulltveit-Moe (2018).

that reflect how suitable goods from each supplier are as inputs for the buyer.

The positive correlation is robust to different average measures of $\overline{s^m_{i\cdot,t}}$, such as taking simple averages or median values. Furthermore, it is also robust when using other measures of pairwise input shares. For example, instead of using s^m_{ij} we use s_{ij}, which is the firm i's sales share in j's total variable inputs (input purchases plus labor costs). Another alternative share we use is the supplier's sales share among the buyer's goods inputs that are classified the same as the supplier's, either at the 2-digit or 4-digit level. We report these results and those of other robustness checks in Appendix A.6.

3 Model

In this section, we set up a model of oligopolistic competition in firm-to-firm trade. With our focus being on the effects of imperfect competition in firm-to-firm trade, we take a stylized approach in modeling consumption and labor supply, abstracting from heterogeneities in final demand and imperfect competition in factor markets. We assume a representative household inelastically supplying a fixed amount of labor. We also model the economy as a small, open economy, where we take the foreign price and the foreign demand shifter as given. Finally, we take the firm-to-firm linkages as given and fixed and consider the implications of oligopolistic competition within the observed network. While a growing number of papers consider the role of extensive margins in firm-to-firm linkages, many assume rigid surplus splitting rules between suppliers and buyers to obtain tractability (for example, see Lim, 2015, Bernard, Moxnes, and Saito, 2019, Oberfield, 2018, Dhyne, Kikkawa, Mogstad, and Tintelnot, 2019, Taschereau-Dumouchel, 2018, and Huneeus, 2018).

3.1 Preferences

There is a representative household providing L units of labor. Households have CES preferences over all firms' goods with a substitution parameter σ. We assume that firms' goods are substitutes, $\sigma > 1$. We also assume that households do not directly consume foreign goods. The household's preference is denoted as

$$U = \left(\sum_{i\in\Omega} \beta_{iH} q_{iH}^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}, \tag{3}$$

where Ω denotes the set of domestic firms. q_{iH} denotes the quantity of goods that firm i sells to the household. Given the price that i charges to the household, p_{iH}, the quantity q_{iH} can be written as

$$q_{iH} = \beta_{iH}^{\sigma} \frac{p_{iH}^{-\sigma}}{P^{1-\sigma}} E, \tag{4}$$

where E denotes the aggregate expenditure. P denotes the aggregate price index:

$$P = \left(\sum_{i\in\Omega} \beta_{iH}^{\sigma} p_{iH}^{1-\sigma}\right)^{\frac{1}{1-\sigma}}. \tag{5}$$

Demand from abroad is modeled with the same structure as the domestic household. Let I_{iF} be an indicator of whether firm i is an exporter or not. Given a price that i charges on exported goods, p_{iF}, export quantity, q_{iF}, can be written as

$$q_{iF} = I_{iF} p_{iF}^{-\sigma} D^*, \tag{6}$$

where D^* is the exogenous demand shifter from abroad.

3.2 Technology and market structure

Each firm produces a single differentiated good with a constant returns production technology. In addition to labor inputs, they purchase goods from other firms and/or purchase imported goods as intermediate goods. On the output side, they sell goods directly to final demand, to other domestic firms, and/or export. We treat firms to be infinitesimal in the final demand market and assume Dixit and Stiglitz (1977) monopolistic competition. Thus firms charge constant markups on their goods when selling to the final consumer. We also assume that firms apply the same markups when exporting.

When considering firm-to-firm trade markets, the assumption of infinitesimal suppliers for each buyer is not consistent with the data. In Section 2.2, we showed that firms tend to have highly concentrated input share distributions. A handful of top supplier firms account for the majority of firms' goods purchases. Moreover, in Section 2.3, we found that firms charge higher markups when they have higher input shares to buyers. Therefore, we assume oligopolistic competition in firm-to-firm trade, where firms charge different markups to different buyers depending on the shares they have in each buyer's goods purchases. In doing so, we apply the framework of Atkeson and Burstein (2008) to firms' pricing decisions in the relationships with each buyer.

Let Z_i be firm i's set of domestic suppliers and let I_{Fi} be the indicator for the importing status of firm i. We denote i's sector as u and j's sector as v. We assume nested CES structures in firms' production functions. A firm first combines domestically supplied goods into sector-level intermediate goods bundles. Then it combines these sectoral goods and imported goods into a different intermediate goods bundle. Finally, the firm combines labor inputs and the intermediate goods bundle to produce its output. We denote the elasticity of substitution across firms' goods in sector u as σ_u. The substitution parameter across sectoral goods and imported goods is ρ, and the substitution parameter across labor inputs and the intermediate goods bundle is η. We assume all substitution parameters to be above one.[18]

The implied unit cost of firm i is

$$c_i = \phi_i^{-1} \left(\omega_l^{\eta} w^{1-\eta} + \omega_m^{\eta} p_{mi}^{1-\eta} \right)^{\frac{1}{1-\eta}}, \tag{7}$$

where ϕ_i is i's core productivity. The terms ω_l and ω_m denote CES weights in the production function on labor and intermediate goods. Nominal domestic wage normalized by the foreign wage is denoted by w, and p_{mi} is the firm-specific price index of intermediate goods. p_{mi} is another aggregate of firm

[18] We do not impose any restrictions concerning the relative magnitudes among $\{\sigma_u\}$, ρ, and η when we estimate them in Section 4.

i's sector-level domestic intermediate price indices, p^m_{vi}, and the foreign price, p_F. p_{mi} and p^m_{vi} vary with firms' sourcing strategy, Z_i and I_{Fi}, along with the saliency parameters, α_{ji} and α_{Fi}:

$$p_{mi} = \left(\sum_v \alpha_v^\rho \left(p^m_{vi}\right)^{1-\rho} + I_{Fi}\alpha_{Fi}^\rho p_F^{1-\rho} \right)^{\frac{1}{1-\rho}}$$

$$p^m_{vi} = \left(\sum_{j \in Z_i, j \in \mathscr{V}} \alpha_{ji}^{\sigma_{v(j)}} p_{ji}^{1-\sigma_{v(j)}} \right)^{\frac{1}{1-\sigma_{v(j)}}}. \tag{8}$$

$\mathscr{V}$ denotes the set of firms in sector v. The term p_{ji} denotes the price that firm j charges for its goods when selling to firm i. p_F is the exogenous price of the foreign good. The terms α_{ji} and α_{Fi} reflect how suitable goods from firm j and foreign imports are as inputs for firm i.[19]

Before discussing the market structures of the final demand market and of the firm-to-firm markets, we derive the firms' shares on inputs implied by the above CES structures. The share of firm i's variable costs spent on labor, s_{li}, is

$$s_{li} = \frac{\omega_l^\eta w^{1-\eta}}{c_i^{1-\eta}\phi_i^{1-\eta}}. \tag{9}$$

The intermediate goods' share, s_{mi}, becomes

$$s_{mi} = 1 - s_{li} = \frac{\omega_m^\eta p_{mi}^{1-\eta}}{c_i^{1-\eta}\phi_i^{1-\eta}}. \tag{10}$$

Among i's variable costs spent on intermediate goods, the share of sector v goods, s^m_{vi}, and the share of foreign goods, s^m_{Fi}, are, respectively,

$$s^m_{vi} = \alpha_v^\rho \frac{\left(p^m_{vi}\right)^{1-\rho}}{p_{mi}^{1-\rho}},$$

$$s^m_{Fi} = I_{Fi}\alpha_{Fi}^\rho \frac{p_F^{1-\rho}}{p_{mi}^{1-\rho}}. \tag{11}$$

Among i's variable costs spent on sector v goods, the share of firm j's goods, $s^{v(j)}_{ji}$, is

$$s^{v(j)}_{ji} = \alpha_{ji}^{\sigma_{v(j)}} \frac{p_{ji}^{1-\sigma_{v(j)}}}{\left(p^m_{v(j)i}\right)^{1-\sigma_{v(j)}}}. \tag{12}$$

Analogously, we can write s_{ji} and s_{Fi} respectively as the shares of j's goods and foreign goods out of

[19] We rule out arbitrage opportunities by firms or households. All purchases made by firms are assumed to be used as inputs to their own production, and the pair specific saliency term in the production function, α_{ji}, allows firms output to be customized for each buyer firm.

i's total variable costs, $s_{ji} = s_{ji}^{v(j)} s_{v(j)i}^{m} s_{mi}$ and $s_{Fi} = s_{Fi}^{m} s_{mi}$.

Finally, we turn to the market structures. We assume monopolistic competition when firms sell to final demand. We take this stylized approach in the final demand markets, as we do not observe the identity of foreign buyers or households. When firms export or sell to domestic households, they charge a constant markup over marginal cost:

$$p_{iH} = p_{iF} = \frac{\sigma}{\sigma - 1} c_i. \tag{13}$$

We introduce oligopolistic competition in firm-to-firm trade in the following way. When selling to firm i, firm j sets price p_{ji} that maximizes variable profits by taking as given prices of all other firms including those of i's other suppliers, i's unit cost and output, c_i and q_i, as well as the domestic wage rate, aggregate consumption price and quantity. Firm j does not internalize the effect that its price, p_{ji}, may affect other firms' prices. However, firm j does recognize that the buyer i's intermediate input costs and quantities vary when changing the price, p_{ji}. Solving the firm's profit maximization problem yields the following price:

$$\begin{aligned} p_{ji} &= \mu_{ji} c_j = \frac{\varepsilon_{ji}}{\varepsilon_{ji} - 1} c_j \\ \varepsilon_{ji} &= \sigma_{v(j)} \left(1 - s_{ji}^{v(j)}\right) + \rho s_{ji}^{v(j)} \left(1 - s_{v(j)i}^{m}\right) + \eta s_{ji}^{v(j)} s_{v(j)i}^{m}. \end{aligned} \tag{14}$$

The price implies that the markup firm j charges on firm i, μ_{ji}, depends on the input shares that j's goods have in i's intermediate goods, $s_{ji}^{v(j)}$ and $s_{v(j)i}^{m}$.[20] If the supplier j in sector v has an infinitesimally small share in buyer i's intermediate goods bundle ($s_{ji}^{v(j)} \to 0$), then all the competition the supplier j engages in are with the other suppliers in sector $v(j)$ sharing the same buyer i. The price converges to the value obtained assuming monopolistic competition, a constant markup of $\frac{\sigma_{v(j)}}{\sigma_{v(j)}-1}$. As the supplier's input share on the buyer increases, then not only does the supplier compete with the other suppliers, but also with other suppliers in sectors other than v and the labor input that buyer firm i employs. Thus, the demand elasticity the supplier faces, ε_{ji}, is a weighted average of $\sigma_{v(j)}$, ρ, and η. These weights are constructed from the shares $s_{ji}^{v(j)}$ and $s_{v(j)i}^{m}$. When the supplier j is the only firm supplying the buyer ($s_{ji}^{v(j)}, s_{v(j)i}^{m} \to 1$), the markup converges to $\frac{\eta}{\eta-1}$. The intuition of how pairwise markups depend on pairwise shares are identical to what is described in Atkeson and Burstein (2008). The key difference is that here the relevant shares and markups are defined for each buyer-supplier pair.

As aforementioned, we assume that the supplier takes as given the buyer's unit cost and output, while all aggregations in the production functions are made with finite sums. This is consistent with the assumption of Bertrand competition, where firms take as given all others' prices, including the prices of their buyers. A plausible alternative would be to assume that the supplier firm internalizes

[20] See Appendix B.1 for firm j's maximization problem.

the change in demand for the buyer's good when determining price. In this case, the supplier needs to know the output composition of the buyer firm to infer the elasticity of demand the buyer is facing. As firms are unlikely to observe the flow of goods distant in the production chain, we find our assumption to be reasonable. Nevertheless, in Appendix B.2 we discuss in detail the optimal prices that firms charge their buyers when relaxing this assumption.[21]

This assumption is also consistent with the empirical evidence. Section 2.3 confirmed that firms' markups are correlated with the firms average input shares within their buyers. We further investigate if firms' markups are correlated with the average input shares their buyers have within those buyers' buyers. We find that the coefficient on these second-degree average input shares is not significant and close to zero. These results indicate that although firms charge higher markups when possessing have higher input shares in their buyers, this is not necessarily the case when their buyers have higher input shares. See Table 20 in Appendix A.6 for details.

Finally, we describe firms' output and profits. A firm sells goods to households, abroad (if the firm is an exporter), and also to other domestic firms. Therefore we have

$$q_i = q_{iH} + q_{iF} + \sum_{j \in W_i} \alpha_{ij}^{\sigma_{u(i)}} \frac{p_{ij}^{-\sigma_{u(i)}}}{\left(p_{u(i)j}^m\right)^{1-\sigma_{u(i)}}} s_{u(i)j}^m s_{mj} c_j q_j, \tag{15}$$

where W_i is the set of i's buyers. Firm i's profits come from three sources: sales to households, exports, and sales to other domestic firms. So the variable profit of firm i can thus be described as

$$\begin{aligned}\pi_i =& \frac{1}{\sigma} \underbrace{\beta_{iH}^{\sigma} \left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} c_i^{1-\sigma} \frac{E}{P^{1-\sigma}}}_{\text{Sales to HH}} + I_{iF} \frac{1}{\sigma} \underbrace{\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} c_i^{1-\sigma} D^*}_{\text{Exports}} \\ &+ \sum_{j \in W_i} \frac{1}{\varepsilon_{ij}} \underbrace{\alpha_{ij}^{\sigma_{u(i)}} \frac{p_{ij}^{1-\sigma_{u(i)}}}{\left(p_{u(i)j}^m\right)^{1-\sigma_{u(i)}}} s_{u(i)j}^m s_{mj} c_j q_j}_{\text{Sales to } j}. \end{aligned} \tag{16}$$

[21]The assumption that firms have incomplete information about firms that are distant in the production chain is similar to that considered by Antràs and de Gortari (2017). In Appendix B.2, we show that when a firm internalizes the effect of its price on the demand for the buyer's goods, the markup it charges not only depends on $s_{ji}^{v(j)}$ and $s_{v(j)i}^m$ but also on quantities that the buyer sells to other firms and the quantities that it sells to final demand. One can also assume that firms take as given a constant demand elasticity buyers are presumed to face. In this case, if one assumes the value of the demand elasticity is η, the pricing equation collapses to that of equation (14). We also discuss optimal prices when firms engage in Cournot competition instead of Bertrand competition.

3.3 Equilibrium

We close the model by assuming that firms' profits are ultimately distributed back to the households. We also assume balanced trade. The household's budget constraint becomes

$$E = wL + \sum_{i \in \Omega} \pi_i. \tag{17}$$

The trade balance and labor market clearing conditions are the following:

$$[\text{TB}] : 0 = \underbrace{\sum_{i \in \Omega} I_{iF} p_{iH}^{1-\sigma} D^*}_{\text{Exports}} - \underbrace{\sum_{i \in \Omega} I_{Fi} s_{Fi} c_i q_i}_{\text{Imports}}, \tag{18}$$

$$[\text{LMC}] : wL = \sum_{i \in \Omega} s_{li} c_i q_i. \tag{19}$$

We then characterize the equilibrium.

Definition (Equilibrium)**.** Take as given the foreign demand shifter, D^*, and the foreign price, p_F. Normalize prices with the foreign wage. An equilibrium is a set of variables, $\{w, P, E, q_i\}$, that satisfy equations (4)–(19).

3.4 Alternative models as benchmarks

Before estimating the CES parameters and conducting counterfactual exercises, we provide with variations of alternative modeling assumptions useful in benchmarking the counterfactual results of Sections 5 and 6.

Sectoral roundabout production economy

In Section 5 we consider reductions in firm-to-firm markups and quantify the distortions arising from double marginalization in firm-to-firm trade. To evaluate the results, we compare them with those from a sectoral roundabout production economy, in the spirit of Eaton and Kortum (2002). In this economy there are two sets of sector-level composite goods; one that is used as intermediate goods, the other as final consumption goods. Note that this sectoral roundabout economy is different from a standard roundabout economy in which goods from all sectors are pooled into one single intermediate good that is used by all firms in all sectors. Our sectoral roundabout economy is able to match the sector-to-sector linkages, whereas a standard roundabout economy is not. We specify the firms' cost function as the following:

$$
\begin{aligned}
c_i &= \phi_i^{-1}\left(\omega_l^{\eta} w^{1-\eta} + \omega_m^{\eta} p_{mi}^{1-\eta}\right)^{\frac{1}{1-\eta}} \\
p_{mi} &= \left(\sum_v \alpha_{vu(i)}^{\rho} P_{vB}^{1-\rho} + \alpha_{Fi}^{\rho} p_F^{1-\rho}\right)^{\frac{1}{1-\rho}} \\
P_{vB} &= \left(\sum_{j\in\mathcal{V}} \alpha_{jv}^{\sigma_v} p_{jB_R}^{1-\sigma_v}\right)^{\frac{1}{1-\sigma_v}}.
\end{aligned}
\tag{20}
$$

P_{vB} is the price index of the sector-v-specific composite good that is used as an intermediate good. It is an CES aggregate of prices that all firms in that sector charge in the intermediate goods market, p_{jB_R}. Unlike the technology presented in equation (8), here we assume that output of all firms in each sector are aggregated up to a sector-specific composite good.[22]

As in the baseline model, we assume firms charge monopolistic competitive markups, $\mu_{iH_R} = \frac{\sigma}{\sigma-1}$, to the composite goods used for final consumption. Due to the roundabout structure in intermediate goods market, firms now charge firm-level markups, μ_{iB_R}, to the composite goods used as intermediate goods. To make the results comparable with the baseline model, we set these firm-level markups, μ_{iB_R}, to be consistent with the average markups firms charge on intermediate goods sales in our baseline model.[23] With these markups, we can write the prices firms charge to the two composite goods as $p_{iB_R} = \mu_{iB_R} c_i$ and $p_{iH_R} = \mu_{iH_R} c_i$.

This sectoral roundabout production economy is useful as a benchmark because it assumes a simple network structure while keeping firm-level variables (such as firms' sales, firms' inputs, firms' markups on final demand) and firm-level average markups on intermediate goods sales still consistent with the baseline model. The only difference is that this sectoral roundabout economy has fewer production layers of intermediate goods, whereas the real firm-to-firm network features a much more complex production network structure. See Appendix B.4 for the system of equations solving for the changes in equilibrium variables under this sectoral roundabout production economy.

Economy with fixed markups

In Section 6 we consider changes in the price of foreign goods as the shock and analyze whether accounting for oligopolistic competition in firm-to-firm trade alters predictions of the transmission of shocks. To this end, we consider as a benchmark an economy where firms charge heterogeneous but fixed markups in firm-to-firm trade. To make the comparison as consistent as possible, we assume

[22]For other papers using similar approaches of having sector-specific composite intermediate goods but mostly with Cobb-Douglas aggregates, see for example Caliendo and Parro (2015), Carvalho, Nirei, Saito, and Tahbaz-Salehi (2016), Blaum, Lelarge, and Peters (2016), Grassi (2018), and Dhyne, Kikkawa, Mogstad, and Tintelnot (2019).

[23]Specifically, we set $\mu_{iB_R} = \frac{\sum_j p_{ij} q_{ij}}{c_i q_i - \frac{p_{iH} q_{iH} + p_{iF} q_{iF}}{\mu_{iH_R}}}$.

firms charge the same heterogeneous markups that are implied by the baseline economy. However, here we assume markups are fixed and do not change in response to shocks. This alternative model with fixed markups is close to what is considered in Dhyne, Kikkawa, Mogstad, and Tintelnot (2019), but with sectoral layers in the production functions. We present the system of equations solving for the changes in equilibrium variables in Appendix B.6.

4 Estimation

The counterfactual exercises using the model setup in the previous section require estimates of the CES parameters in the preference and production functions, $\{\{\sigma_u\}, \rho, \eta, \sigma\}$, and observables from the Belgian firm-to-firm trade data. In this section we describe the estimation procedures for the CES parameters.

We estimate the CES parameters, $\{\{\sigma_u\}, \rho, \eta, \sigma\}$, by exploiting the variations of sales and input shares at the firm-to-firm level in the data. Recall that in equation (14), pairwise markups, $\mu_{ij} = \frac{\varepsilon_{ij}}{\varepsilon_{ij}-1}$, are functions of parameters, $\{\{\sigma_{u(i)}\}, \rho, \eta\}$, and observable input shares, $s_{ij}^{u(i)}$ and $s_{u(i)j}^{m}$. We have also assumed markups firms charge on goods sold to domestic households and on exports, μ_{iH}, to be $\frac{\sigma}{\sigma-1}$.

In our static model without fixed costs, a firm's total input cost — sum of labor costs, purchases from other firms, and imports, $c_i q_i$ — has to equal the firm's total sales, each deflated by destination-specific markups, $\sum_j \frac{V_{ij}}{\mu_{ij}} + \frac{V_{iH}}{\mu_{iH}} + \frac{V_{iF}}{\mu_{iH}}$, where we denote firm i's sales to firm j by V_{ij}, firm i's sales to households by V_{iH}, and firm i's exports by V_{iF}. Denote also the total input costs implied from the model by $C_i = \sum_j \frac{V_{ij}}{\mu_{ij}} + \frac{V_{iH}}{\mu_{iH}} + \frac{V_{iF}}{\mu_{iH}}$. Represent the difference between the observed input costs, $c_i q_i$, and the model implied input costs, C_i, relative to the observed input costs as

$$\epsilon_i = \frac{c_i q_i - C_i}{c_i q_i}. \tag{21}$$

We assume that the accounting identity $c_i q_i = C_i$ holds in the data up to a measurement error, ϵ_i:

Assumption 1. *ϵ_i are measurement errors and constant variables for each firm.*

In the Belgian dataset we observe the input costs, $c_i q_i$, firm i's sales to firm j, V_{ij}, firm i's sales to households, V_{iH}, and firm i's exports, V_{iF}, for all firms and input shares at the buyer-supplier level, $s_{ij}^{u(i)}$ and $s_{u(i)j}^{m}$. Using these observables, we estimate the CES parameters, $\{\{\sigma_u\}, \rho, \eta, \sigma\}$, by minimizing the squared sum of the measurement errors, ϵ_i:

$$\min_{\{\sigma_u\},\rho,\eta,\sigma} \sum_i \left[\frac{c_i q_i - C_i\left(\{\sigma_{u(i)}\}, \rho, \eta, \sigma, s_{ij}^{u(i)}, s_{u(i)j}^{m}\right)}{c_i q_i} \right]^2. \tag{22}$$

Since firms' markups to final demand, μ_{iH}, are constants of $\frac{\sigma}{\sigma-1}$, the variations in the ratio of firms' sales to final demand and exports ($V_{iH} + V_{iF}$) over firms' total inputs ($c_i q_i$) pin down the value of σ. Firm-to-firm markups, μ_{ij}, are functions of pair specific shares, $s_{ij}^{u(i)}$ and $s_{u(i)j}^{m}$, and parameters, $\{\sigma_u\}$, ρ, and η. Thus the ratio of firm-to-firm sales $\left(V_{ij}\right)$ over suppliers' input costs ($c_i q_i$), and the input shares $s_{ij}^{u(i)}$ and $s_{u(i)j}^{m}$, jointly determine the value of the two parameters.

Edmond, Midrigan, and Xu (2015) use a similar procedure with sectoral market shares to infer one of the CES parameters in models with endogenous markups. Note that this estimation strategy relies on key assumptions. The CRS feature of the production function allows us to interpret the deviations between revenues and input costs as markups over marginal costs, along with measurement errors. Moreover, we are not able to distinguish fixed costs from variable costs in the data. Consistent with the static model's assumption that there are no fixed costs, we use observed labor costs and input purchases as input costs.

We use the data for the year 2012, and use the categorization of "intermediate SNA/ISIC aggregation A*38" in NACE Rev.2 classification. This leaves us to estimate 29 sectoral substitution parameters of σ_u and three parameters of σ, ρ, and η.[24]

We highlight that our theory of firm-to-firm markups cannot accommodate firms with total sales less than their input costs. We drop these firms from the estimation sample, losing around 13 percent of firms that account for around 28 percent of output.[25] In the counterfactual analysis in Section 5 where we consider an exogenous reduction in firm-to-firm markups, we only consider markup reductions of firms which sales are larger than input costs. For firms which firm-level average markups are negative, we hold these negative markups as fixed. We report the estimation results in Table 4.[26]

[24]See European Commission (2008) for details. We aggregate two A*38 codes, CD and CE, into one sector.

[25]One explanation that firms' sales are lower than input costs may be that firms are charging lower markups for some time to attract buyers before they raise markups in the future (Gourio and Rudanko, 2014). Our static framework is not able to capture such dynamic aspects of firms' markups. See Appendix A.2 for descriptive statistics on firms that are dropped.

[26]To evaluate the sensitivity of estimates to firms in the network, for each sector we draw firm-level samples from the data with replacements and compute the standard deviations of the estimates from the re-sampled data. However, as these firm-level observations are interdependent on the activities of their suppliers and buyers, standard asymptotic properties may not hold with the re-sampled data. See Chandrasekhar (2015) for discussions on conducting inference using network data.

Table 4: Estimated CES parameters

(a) η, ρ, and σ

	η	ρ	$\frac{\sigma}{\sigma-1}$
Estimate	1.92	2.16	1.28
s.e.	0.18	0.22	0.07
	η (Labor and goods)	ρ (Sectoral goods and imports in production)	σ (Firms' goods in consumption)
Implied value	1.92	2.16	4.55

(b) Sectoral estimates of σ_u

Description of sector	Estimate	s.e.
Agriculture, forestry, and fishing	2.45	0.28
Mining and quarrying	2.40	0.28
Manufacture of food products, beverages, and tobacco products	3.37	0.46
Manufacture of textiles, apparel, leather, and related products	2.27	0.24
Manufacture of wood and paper products, and printing	3.08	0.40
Manufacture of coke, refined petroleum products, chemicals, and chemical products	2.69	0.32
Manufacture of pharmaceuticals, medicinal chemical, and botanical products	5.11	2.80
Manufacture of rubber and plastics products, and other non-metallic mineral products	3.53	0.48
Manufacture of basic metals and fabricated metal products, except machinery and equipment	2.98	0.38
Manufacture of computer, electronic, and optical products	2.33	0.25
Manufacture of electrical equipment	3.58	0.49
Manufacture of machinery and equipment n.e.c.	2.93	0.37
Manufacture of transport equipment	2.44	0.74
Other manufacturing, and repair and installation of machinery and equipment	2.41	0.27
Electricity, gas, steam and air-conditioning supply	2.05	0.70
Water supply, sewerage, waste management, and remediation	2.30	0.25
Construction	3.59	0.50
Wholesale and retail trade, repair of motor vehicles and motorcycles	2.27	0.25
Transportation and storage	3.00	0.39
Accommodation and food service activities	3.48	0.48
Publishing, audiovisual and broadcasting activities	2.50	0.29
Telecommunications	2.07	0.40
IT and other information services	2.24	0.24
Real estate activities	1.76	0.15
Legal, accounting, management, architecture, engineering, technical testing, and analysis activities	1.70	0.13
Scientific research and development	4.76	2.94
Other professional, scientific and technical activities	2.60	0.31
Administrative and support service activities	2.41	0.27
Other services	2.63	0.74

Note: Standard errors are based on 25 bootstrap samples drawn with replacements. The samples are drawn at the firm-level for each sector.

In the production function the substitution parameter across labor and goods is 1.92. Within intermediate goods, the substitution parameter across sectoral goods and imported inputs is 2.16. In the preference function, the substitution parameter across goods is 4.55. Note that these parameters should be interpreted as long-term elasticities of substitution among the set of labor and suppliers that we observe in the network.

The estimated values fall in ranges not far from the findings of different approaches. Chan (2017) finds labor and intermediates to be gross substitutes. The survey of Anderson and van Wincoop (2004) finds that, within sectors, the elasticity of substitution across goods in the production function ranges from around 5 to 10 depending on the aggregation. Our estimates of σ_u are slightly lower than this because our estimates pick up the substitutability of firms' goods among the small set of suppliers that firms source from in each sector instead of the substitutability of goods among all firms in each sector.[27]

We turn to the estimates under alternative setups. In our model, firms engage in Bertrand competition in firm-to-firm trade. As an alternate specification one can assume that firms engage in Cournot competition, which leads to a different formula for pairwise markups μ_{ij}:

$$p_{ji} = \frac{\varepsilon_{ji}}{\varepsilon_{ji} - 1} c_j$$

$$\varepsilon_{ji} = \left(\frac{1}{\sigma_{v(j)}} \left(1 - s_{ji}^{v(j)}\right) + \frac{1}{\rho} s_{ji}^{v(j)} \left(1 - s_{v(j)i}^{m}\right) + \frac{1}{\eta} s_{ji}^{v(j)} s_{v(j)i}^{m} \right)^{-1} .$$

We estimate the three parameters in this setup and report the results in Appendix C.2.

We assumed monopolistic competition when firms export or sell to households, since we do not observe in the data the identity of foreign firms or households that the Belgian firms sell to. When we instead assume oligopolistic competition in these final goods markets, our estimates for the parameters are not affected.

Finally, it is worth highlighting the lack of capital goods in our model. We sum firms' total labor costs, purchases from other domestic firms, and imported goods in our measurement of firms' total inputs, $c_i q_i$. As mentioned in footnote 13, some firm-to-firm transactions may capture purchases of capital goods and adding computed measures of user cost of capital will lead to double counting. Nevertheless, in Appendix C.3 we account for firms' user cost of capital in two alternative ways: scaling up labor costs of firms uniformly by assuming a common labor-to-capital share; computing firm-level capital costs from balance sheets data.

[27] Our approach of estimating CES parameters is different from that of other papers that estimate substitution parameters at higher frequencies. For example Boehm, Pandalai-Nayar, and Flaaen (2019), Barrot and Sauvagnat (2016), and Atalay (2017) find much lower estimates in the production function parameters.

5 How distortionary are markups in firm-to-firm trade?

With the estimated parameters, in this section we explore how distortionary markups in firm-to-firm trade are. We consider two economies with different firm-to-firm network structures: one with the observed firm-to-firm network and another with the sectoral roundabout production structure described in Section 3.4. We quantify the losses from double marginalization in the two economies by fixing the two sets of firm-to-firm linkages, and characterize how the production network structure affects aggregate distortions coming from firm-to-firm markups.

We do so by solving for the equilibrium changes in firm-level costs and aggregate welfare, using the system of equations defining the equilibrium outlined in Section 5. We implement the technique developed by Dekle, Eaton, and Kortum (2007), which enables us to compute the counterfactual outcomes with only the shares directly observed in the data, $\left\{s_{li}, s_{mi}, s^m_{vi}, s^{v(j)}_{ji}, s^m_{Fi}, s_{iH}\right\}$, and the estimated CES parameters, while keeping all firm-level or pair-level primitives fixed.[28]

The observed input shares at the buyer-supplier level, $s^{v(j)}_{ji}$ and $s^m_{v(j)i}$, and the CES parameters enable us to back-out the pair-specific markups implied by the model (see equation (14)). We consider a reduction in those markups in firm-to-firm trade, μ_{ij}, as the shock. Because firms' outputs pass through many other firms until reaching final demand, the effect of a reduction in a markup that firm i charges to firm j, $\hat{\mu}_{ij}$, will be amplified when firm j reduces markups to its buyers. We feed in a shock of exogenous changes in markups, $\hat{\mu}_{ij}$, where the initial levels of firm-to-firm markup, μ_{ij}, are the markups backed-out from the data. We consider the following system of counterfactual changes:

$$
\begin{aligned}
\hat{c}_i^{1-\eta} &= s_{li}\hat{w}^{1-\eta} + s_{mi}\hat{p}_{mi}^{1-\eta} \\
\hat{p}_{mi}^{1-\rho} &= \sum_v s^m_{vi}\left(\hat{p}^m_{vi}\right)^{1-\rho} + s^m_{Fi} \\
\left(\hat{p}^m_{vi}\right)^{1-\sigma_v} &= \sum_{j\in Z_i, j\in\mathcal{V}} s^{v(j)}_{ji}\hat{\mu}_{ji}^{1-\sigma_v}\hat{c}_j^{1-\sigma_{v(j)}} \\
\hat{C}_i &= \frac{1}{C_i}\frac{V_{iH}}{\mu_{iH}}\hat{s}_{iH}\hat{E} + \frac{1}{C_i}\frac{V_{iF}}{\mu_{iH}}\hat{V}_{iF} + \frac{1}{C_i}\sum_j \frac{V_{ij}\hat{s}_{ij}}{\mu_{ij}\hat{\mu}_{ij}}\hat{C}_j \\
\hat{E} &= \frac{1}{1-\sum_i \frac{1}{E}\frac{\mu_{iH}-1}{\mu_{iH}}V_{iH}\hat{s}_{iH}}\left(\frac{wL}{E}\hat{w} + \sum_i \frac{\pi_i}{E}\left(\sum_k \frac{1}{\pi_i}V_{ik}\frac{\hat{\mu}_{ik}\mu_{ik}-1}{\hat{\mu}_{ik}\mu_{ik}}\hat{s}_{ik}\hat{C}_k + \frac{1}{\pi_i}\frac{\mu_{iH}-1}{\mu_{iH}}V_{iF}\hat{V}_{iF}\right)\right) \\
\hat{w} &= \frac{1}{wL}\sum_i s_{li}c_i q_i \hat{s}_{li}\hat{C}_i.
\end{aligned} \tag{23}
$$

C_i denotes the total input values of firm i implied by the model: $C_i = \sum_j \frac{V_{ij}}{\mu_{ij}} + \frac{V_{iH}}{\mu_{iH}} + \frac{V_{iF}}{\mu_{iH}}$. Furthermore, $\hat{s}^{v(j)}_{ji} = \hat{\mu}_{ji}^{1-\sigma_{v(j)}}\hat{c}_j^{1-\sigma_{v(j)}}\left(\hat{p}^m_{v(j)i}\right)^{\sigma_{v(j)}-1}$, $\hat{s}^m_{vi} = \left(\hat{p}^m_{vi}\right)^{1-\rho}\hat{p}_{mi}^{\rho-1}$, $\hat{s}_{mi} = \hat{p}_{mi}^{1-\eta}\hat{c}_i^{\eta-1}$, $\hat{s}_{ji} = \hat{s}^{v(j)}_{ji}\hat{s}^m_{v(j)i}\hat{s}_{mi}$, $\hat{s}_{li} = \hat{w}^{1-\eta}\hat{c}_i^{\eta-1}$, $\hat{s}_{iH} = \hat{c}_i^{1-\sigma}\hat{P}^{\sigma-1}$, $\hat{P}^{1-\sigma} = \sum_i s_{iH}\hat{c}_i^{1-\sigma}$, $\hat{V}_{iF} = \hat{c}_i^{1-\sigma}$.

[28] See Appendix B.3 for the full system of equilibrium changes.

Taking the data into the system above reveals that firms' total input values implied by the model, C_i, do not necessary match the observed input values, $c_i q_i$. While we minimized the difference between the two when estimating the CES parameters, the model under the estimated parameters is still not entirely consistent with the data. For some firms the observed inputs, $c_i q_i$, are larger than the model implied values, C_i. For other firms, the observed input values seem lower than is necessary to produce what is sold. To be consistent with the estimation strategy, in the counterfactual analyses we take the error term in equation (21), $\epsilon_i = \frac{c_i q_i - C_i}{c_i q_i}$, as constants. We designate ξ_i as the difference between the observed input values and model implied input values, $\xi_i = c_i q_i - C_i$. With this assumption, the changes in the observed inputs, $\widehat{c_i q_i}$, are equal to the changes in the model implied inputs, $\hat{C}_i$, and are also equal to the changes in the difference between the two, $\hat{\xi}_i$. One may alternatively take the values of ξ_i as constant numbers, and solve for both $\widehat{c_i q_i}$ and $\hat{C}_i$ using the relationship $\widehat{c_i q_i} = \frac{C_i}{c_i q_i}\hat{C}_i + \frac{\xi_i}{c_i q_i}$. However, for firms with negative values of ξ_i and under extreme cases where the values of $\hat{C}_i$ are low, $\widehat{c_i q_i}$ can become negative and not well defined. We also treat the observed trade balance as fixed, assuming that foreign asset holdings are not affected in the counterfactual analyses. We outline the detailed steps solving the system of counterfactual changes in Appendix B.3.

To evaluate the results, we contrast them with the results from the sectoral roundabout production economy described in Section 3.4. The sectoral roundabout production economy imposes a particular structure on the production network. There are two distinct composite goods, one of which is used as intermediate goods and the another is used as a final consumption good. The sectoral roundabout production economy does not match the observed firm-to-firm transactions but matches the firm-level exports, imports, domestic sales, labor costs, domestic purchases, value added, markups charged to final demand sales, and firm-level average markups charged to sales to intermediate goods. Therefore, this comparison with the roundabout production economy is useful for evaluating the implications of markup distortions that account for the real firm-to-firm network. We consider the reduction in the markups firms charge to the composite good used as intermediate goods as the shock. We outline the system of counterfactual changes under the sectoral roundabout production economy in Appendix B.4.

We focus on a 20 percent reduction in markups under the two models.[29] That is, we feed in the shock of $\hat{\mu}_{ij} = \frac{(\mu_{ij}-1)\times 0.8+1}{\mu_{ij}}$ for the baseline economy and $\hat{\mu}_{iB_R} = \frac{(\mu_{iB_R}-1)\times 0.8+1}{\mu_{iB_R}}$ for the sectoral roundabout production economy. Ideally, one would consider an elimination of markups which would give the counterfactual results in which firms operate in intermediate goods markets under perfect competition. However, eliminating markups under the observed firm-to-firm network generates substantial heterogeneity in firm-level cost changes, and some firms will face extreme cost reductions. Because of these firms with $\hat{c}_i$ so close to zero, numerical solution is not obtained when markups reductions

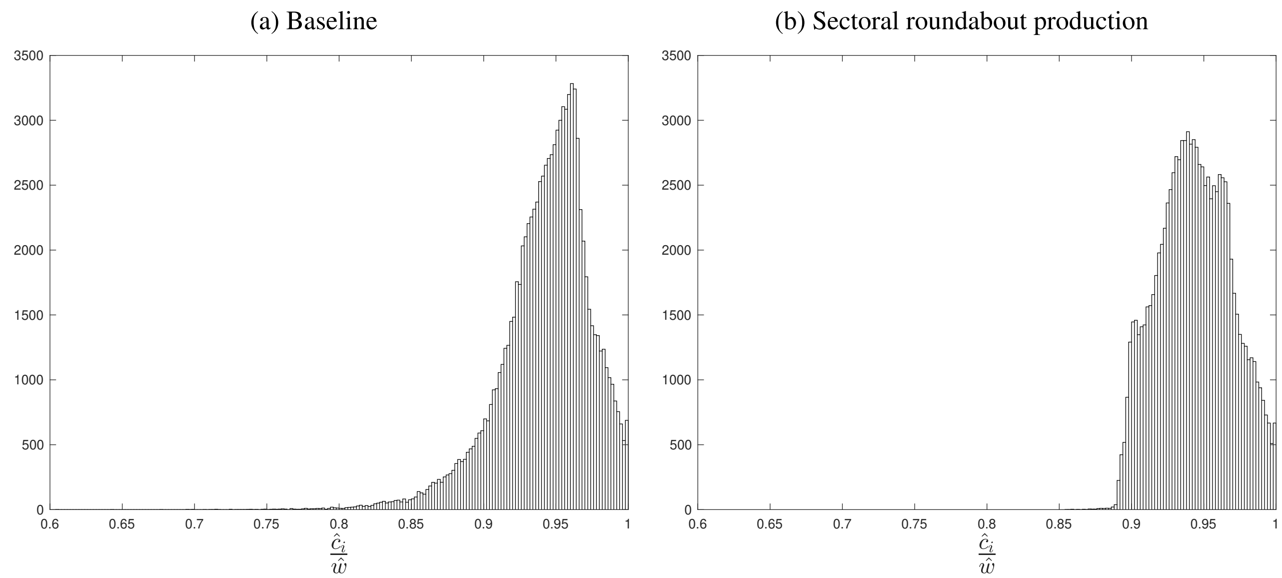
[29] We present results for the other magnitudes of markup reductions in Appendix D.4.

are larger than 50 percent. Therefore when we present the results of how aggregate variables respond, in addition to discussing how welfare increases, we describe how real wage changes since the latter is not affected by changes in profits that firms make.

We also note that our model predicts strictly positive markups on all sales. For firms which total sales are less than total input costs, we substitute their markups with the negative firm-level average markups and hold them fixed throughout this counterfactual analysis.

We first present the results of firm-level cost changes under the two economies. In both economies the cost changes are bounded from above by the increases in the nominal wage, $\hat{w}$, which are 3.8 percent in the baseline economy and 3.5 percent in the sectoral roundabout production economy.[30] Therefore in Figure 2 we present the firm-level cost changes relative to the nominal wage changes. While the distribution of the cost changes in the baseline economy seem to exhibit more concentration around cost decline of 5 percent relative to the nominal wage, it exhibits a thicker left tail. In the baseline economy some firms' costs decrease by up to 39 percent relative to the nominal wage change, the largest decline in firm-level costs relative to the nominal wage change in the sectoral roundabout production economy is only by 14 percent. This is because the sectoral roundabout production economy cannot capture the within sector heterogeneities in firms' exposure to other firms' goods.[31]

Figure 2: Histograms of cost changes relative to wage change, $\hat{c}_i/\hat{w}$, under 20 percent reduction in markups



[30]The nominal wage increases because the export demand is relatively elastic compared to import demand.

[31]Figure 2 presents results where markups of firms with sales less than input costs are held fixed. Once we remove this condition and consider reductions of all firm-to-firm markups, the pattern where cost changes in the baseline economy being more dispersed is more pronounced. See Appendix D.1 for details.

We find that the magnitudes of firm-level cost reductions in the baseline economy are correlated with measures that capture how downstream or upstream firms are positioned. One way to measure the downstreamness of firms is to compute firms' revenue share of sales to domestic final demand, $r_{iH} = \frac{V_{iH}}{V_i}$. Another approach is to compute the upstreamness measure by Antràs, Chor, Fally, and Hillberry (2012). Firm-level cost changes, $\hat{c}_i$, are negatively correlated with r_{iH} with correlation of -0.13, and are positively correlated with the upstreamness measure with correlation of 0.08. See Appendix D.2 for details.

We next turn to the effects on the aggregate variables. Table 5 reports the aggregate welfare effects of a 20 percent reduction in firm-to-firm markups in the baseline economy using the observed firm-to-firm transaction data, and of a 20 percent reduction in markups on the composite good used as intermediate goods in the sectoral roundabout production economy. We also report the changes in the real wage, $\hat{w}/\hat{P}$, aggregate expenditures, $\hat{E}$, and aggregate profits, $\hat{\Pi}$. The aggregate welfare goes up by 10.2 percent in the baseline case, but the sectoral roundabout production economy can only capture less than two-thirds of this welfare movement (6.0 percent). We also see that the baseline economy predicts larger magnitudes in the movements of all other aggregate variables. The same pattern can be seen for the real wage: it increases by 7.0 percent in the baseline case, while in the sectoral roundabout case we see an increase of around 6.0 percent.

We note that the aggregate expenditures, $E = wL + \Pi - \sum_i \xi_i - TB$, are not only affected by the change in the nominal wage, w, but also by the change in aggregate profits, Π, and the change in the sum of firm-level differences in observed input costs and model implied input costs, $\sum_i \xi_i$. The baseline economy exhibits a larger increase in the aggregate profits, contributing to the larger increase in the aggregate expenditure. When firms set prices to buyers, firms do so by maximizing profits taking as given the demand shifters they face. But here we consider the case where all firms reduce their markups at the same time, leading to changes in the demand shifters firms face through the general equilibrium. In the observed firm-to-firm network, firms' outputs go through multiple firms until final demand, resulting in larger magnitudes of these general equilibrium effects. On the other hand, in the sectoral roundabout production economy all firms' output reach final demand through a layer of the composite goods, resulting in smaller magnitudes of changes in the demand shifters.

In addition to these changes in profits, as markups go down and firms use greater amount of inputs, the differences in observed input costs and model implied input costs, $\sum_i \xi_i$, will change and affect aggregate expenditures. This stems from the assumption that we keep the firm-level ratio of $\epsilon_i = \xi_i / c_i q_i$ fixed instead of the values of the differences, ξ_i. In order to only take into account the effects of the changes in the nominal wage and the aggregate profits on the changes in aggregate welfare, in Appendix D.3 we present results on the aggregate changes from three different approaches. First, we compute the changes in aggregate welfare without considering the change in $\sum_i \xi_i$. We define $\tilde{E}$ as

$wL + \Pi - TB$ and present the aggregate changes that come from the changes in $\tilde{E}$. Second, we present counterfactual results in which we treat ξ_i as fixed instead of treating ϵ_i as fixed.[32] Third, we follow the approach by Ossa (2014) and first eliminate the differences between the observed and model implied input values, ξ_i. We solve for the counterfactual changes by forcing the observed differences, ξ_i, to zero. The resulting economy becomes fully consistent with the model, with which we can solve for the counterfactual changes under $\hat{\mu}_{ij}$. In all three approaches the aggregate movements in the two economies yield quantitatively similar results.

Table 5: Aggregate effects of a 20 percent reduction in markups

	Baseline	Sectoral roundabout
$\hat{U} = \hat{E}/\hat{P}$	1.102	1.060
$\hat{w}/\hat{P}$	1.070	1.060
$\hat{E}$	1.070	1.035
$\hat{\Pi}$	1.124	1.072

Note: In the baseline case we take the baseline model using the observed firm-to-firm trade network in 2012. We feed a 20 percent reduction in markups in firm-to-firm trade as the shock, $\hat{\mu}_{ij} = \frac{(\mu_{ij}-1)\times 0.8+1}{\mu_{ij}}$. In the sectoral roundabout case we take the sectoral roundabout production economy using the observed firm-level sales and inputs in 2012. We feed a 20 percent reduction in markups charged to the composite good used as intermediate goods, $\hat{\mu}_{iB_R} = \frac{(\mu_{iB_R}-1)\times 0.8+1}{\mu_{iB_R}}$.

It is worthwhile to put these numbers in context with other papers in the literature. Baqaee and Farhi (2018) use firm-level data with sectoral Input-Output data from the U.S. and find that eliminating firm-level markups would lead to an increase in the TFP by around 20 percent at the second-order approximation. Instead of taking first-order or second-order approximations, we impose a particular structure on how markups are determined at the firm-to-firm level, and compute the welfare benefits of reducing those markups. Although these numbers are not directly comparable, one reason we predict large aggregate effects is that the markups we back out are generally higher in firm-to-firm trade than in firms' sales to final demand. With our estimates of the CES parameters, our model indicates that while firms charge markups of 1.28 in their sales to final demand, firms on average charge markups of around 1.62 to other firms.[33] Instead of assuming firm-level markups that are common across destinations, we incorporate these differences and consider reductions in markups that are initially at higher levels.

Another reason relates to the greater effects of our baseline economy compared to the sectoral roundabout production economy. Considering the observed firm-to-firm network generates substantial heterogeneity in firm-level cost changes, and there are a few firms that experience extreme cost reductions. Due to non-linearities in the system of equilibrium changes (23), firms with large cost reductions obtain larger shares in both the final demand market and among their buyers' inputs, which

[32] As mentioned on page 26, this approach cannot accommodate extreme cases.

[33] The level of these accounting markups are generally higher than other markup estimates for Belgium obtained through production function estimation (see for example De Loecker, Fuss, and Van Biesebroeck, 2018).

leads to greater movements in the aggregate. As we saw in Figure 2, the sectoral roundabout production economy fails to capture the left tail of the distribution of firm-level cost changes. In Appendix D.4 we also consider the system of first-order approximated equilibrium changes and illustrate the non-linearities of the system by analyzing different magnitudes of shocks. We find that under first-order approximation, eliminating all firm-to-firm markups would lead to a 38 percent approximate increase in the aggregate welfare.

6 How do endogenous markups in firm-to-firm trade alter predictions of the transmission of shocks?

In the previous section, we backed out markups at the buyer-supplier level and took the reduction of these markups as the exogenous shock. The exercise informed us of the magnitude of distortions that are present due to double marginalization in the observed firm-to-firm network. Another point of interest is the treatment of these markups as endogenous variables and the investigation of how these endogenous markups in firm-to-firm trade alter predictions of the transmissions of shocks. In particular, we take the exogenous parameter of the model, the price of foreign goods, p_F, and use its changes as the shock.

Similar to the approach taken in the previous section, we take the observed firm-to-firm network as given and fixed. Potential endogeneities in the network may also alter counterfactual predictions. Dhyne, Kikkawa, Mogstad, and Tintelnot (2019) study how endogenous formation of the firm-to-firm network alters counterfactual predictions. In a model in which firms charge no markups in firm-to-firm trade, they find that endogenous formation of buyer-supplier relationships tends to attenuate the effects of large negative trade shocks (economy moving to autarky) and amplify the effects of large positive trade shocks (halving the foreign price). For smaller shocks (10 percent changes in the foreign price), assuming fixed linkages approximates well the aggregate movements. Taschereau-Dumouchel (2018) considers endogenous firm entry allowing for constant firm-level markups. He finds that reorganization of the network leads to smaller variations in aggregate output in response to idiosyncratic shocks. Because accounting also for the endogeneity in the firm-to-firm network while allowing for endogenous firm-to-firm markups would make the computation challenging, we focus on a fixed firm-to-firm network.

We consider the system of counterfactual changes presented below, taking as given the change in foreign price, $\hat{p}_F$:

$$
\begin{aligned}
\hat{c}_i^{1-\eta} =& s_{li}\hat{w}^{1-\eta} + s_{mi}\hat{p}_{mi}^{1-\eta} \\
\hat{p}_{mi}^{1-\rho} =& \sum_v s_{vi}^m (\hat{p}_{vi}^m)^{1-\rho} + s_{Fi}^m \hat{p}_F^{1-\rho} \\
(\hat{p}_{vi}^m)^{1-\sigma_v} =& \sum_{j\in Z_i, j\in\mathscr{V}} s_{ji}^{v(j)} \hat{\mu}_{ji}^{1-\sigma_v} \hat{c}_j^{1-\sigma_v} \\
\hat{\mu}_{ji} =& \hat{\varepsilon}_{ji} \frac{\varepsilon_{ji}-1}{\hat{\varepsilon}_{ji}\varepsilon_{ji}-1} \\
\hat{C}_i =& \frac{1}{C_i}\frac{V_{iH}}{\mu_{iH}}\hat{s}_{iH}\hat{E} + \frac{1}{C_i}\frac{V_{iF}}{\mu_{iH}}\hat{V}_{iF} + \frac{1}{C_i}\sum_j \frac{V_{ij}\hat{s}_{ij}}{\mu_{ij}\hat{\mu}_{ij}}\hat{C}_j \\
\hat{E} =& \frac{1}{1-\sum_i \frac{1}{E}\frac{\mu_{iH}-1}{\mu_{iH}}V_{iH}\hat{s}_{iH}} \left(\frac{wL}{E}\hat{w} + \sum_i \frac{\pi_i}{E}\left(\sum_k \frac{1}{\pi_i} V_{ik} \frac{\hat{\mu}_{ik}\mu_{ik}-1}{\hat{\mu}_{ik}\mu_{ik}} \hat{s}_{ik}\hat{C}_k + \frac{1}{\pi_i}\frac{\mu_{iH}-1}{\mu_{iH}} V_{iF}\hat{V}_{iF} \right)\right) \\
\hat{w} =& \frac{1}{wL}\sum_i s_{li}c_i q_i \hat{s}_{li}\hat{C}_i.
\end{aligned} \tag{24}
$$

Furthermore, $\varepsilon_{ji}\hat{\varepsilon}_{ji} = \sigma_{v(j)}\left(1 - s_{ji}^{v(j)}\hat{s}_{ji}^{v(j)}\right) + \rho s_{ji}^{v(j)}\hat{s}_{ji}^{v(j)}\left(1 - s_{v(j)i}^m \hat{s}_{v(j)i}^m\right) + \eta s_{ji}^{v(j)} s_{v(j)i}^m \hat{s}_{ji}^{v(j)} \hat{s}_{v(j)i}^m$, $\hat{s}_{ji}^{v(j)} = \hat{\mu}_{ji}^{1-\sigma_{v(j)}} \hat{c}_j^{1-\sigma_{v(j)}} \left(\hat{p}_{v(j)i}^m\right)^{\sigma_{v(j)}-1}$, $\hat{s}_{vi}^m = \left(\hat{p}_{vi}^m\right)^{1-\rho} \hat{p}_{mi}^{\rho-1}$, $\hat{s}_{mi} = \hat{p}_{mi}^{1-\eta}\hat{c}_i^{\eta-1}$, $\hat{s}_{li} = \hat{w}^{1-\eta}\hat{c}_i^{\eta-1}$, $\hat{P}^{1-\sigma} = \sum_i s_{iH}\hat{c}_i^{1-\sigma}$, $\hat{s}_{iH} = \hat{c}_i^{1-\sigma}\hat{P}^{\sigma-1}$, and $\hat{V}_{iF} = \hat{c}_i^{1-\sigma}$.[34] The above system is different from the system presented in (23) in that we now have the shock $\hat{p}_F$ in the second equation and that the changes in firm-to-firm markups, $\hat{\mu}_{ij}$, are additional endogenous variables to solve for. As in the previous section, we treat the error terms in equation (21), $\epsilon_i = \frac{\xi_i}{c_i q_i}$, and observed trade balance as constants.

We focus on a 20 percent reduction in the foreign price as the shock, $\hat{p}_F = 0.8$, and analyze its firm-level and aggregate consequences.[35] We compare these results with those from the alternative model of fixed markups laid out in Section 3.4. The only difference between the two economies are whether firm-to-firm markups endogenously respond to the foreign price shock or not. The system of counterfactual changes in the fixed markups economy is presented in Appendix B.6.

We plot the histogram of firm-level cost changes under the above system in Figure 3a. Because foreign inputs are heavily used directly or indirectly in production by Belgian firms, and also because foreign export demand is generally more elastic than Belgian demand for imports, nominal wage goes up by 3.22 percent to ensure fixed trade balance. The firm-level cost changes are bounded from above by this nominal wage change. We compare these firm-level cost changes to those obtained from a model with fixed markups. Since the nominal wage increases by 3.18 percent in the fixed markups economy, we work with cost changes normalized for the wage changes, $\hat{c}_i/\hat{w}$, to make comparisons. Figure 3b plots the differences in these normalized firm-level cost changes, relative to the normalized cost change in the fixed markups economy, $\frac{\hat{c}_i^{endog}/\hat{w}^{endog} - \hat{c}_i^{fixed}/\hat{w}^{fixed}}{1-\hat{c}_i^{fixed}/\hat{w}^{fixed}}$. For example, if a

[34] See Appendix B.5 for the full system of equilibrium changes.

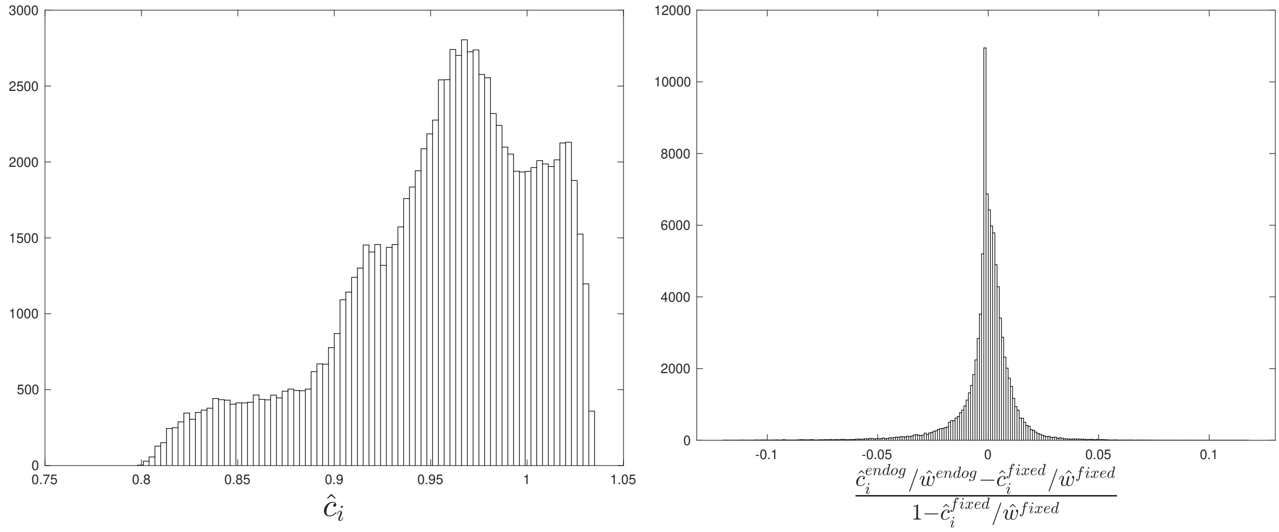
[35] We present results for the other magnitudes of foreign price reductions in Appendix E.3.

firm has $\frac{\hat{c}_i^{endog}/\hat{w}^{endog}-\hat{c}_i^{fixed}/\hat{w}^{fixed}}{1-\hat{c}_i^{fixed}/\hat{w}^{fixed}} = 0.05$, then the firm experiences smaller cost reduction relative to the nominal wage by 5 percent, compared to the cost reduction relative to the nominal wage under fixed markups. Incorporating endogenous markups has very different implications to cost changes across firms in the economy. Around 50 percent of firms experience smaller cost reductions in endogenous markups compared to fixed markups, while the rest experience larger cost reductions. In terms of magnitudes, 10 percent of firms experience cost reductions that are smaller than under fixed markups by 1 percent or more; 12 percent of firms experience cost reductions that are greater than under fixed markups by 1 percent or more.

Figure 3: Histograms of cost changes, $\hat{c}_i$, endogenous markups and fixed markups

(a) $\hat{c}_i$ under endogenous markups

(b) Differences in $\hat{c}_i/\hat{w}$, endogenous vs. fixed markups



Note: The left figure plots the distribution of firm-level cost changes using the baseline model under a 20 percent reduction in the foreign price. The right figure plots the distribution of the differences in normalized cost changes under the baseline economy and the fixed markups economy. The right figure is truncated from below, and the minimum value of $\frac{\hat{c}_i^{endog}/\hat{w}^{endog}-\hat{c}_i^{fixed}/\hat{w}^{fixed}}{1-\hat{c}_i^{fixed}/\hat{w}^{fixed}}$ is -0.45.

We then characterize these heterogeneous implications on firm-level costs. Which firms experience larger cost reductions and which firms experience smaller cost reductions when incorporating endogenous markups? For the sake of characterization, we focus on the first-order approximated system of equilibrium changes. Equation (25) shows the first-order approximated change of the cost of firm i, $\frac{\mathrm{d}c_i}{c_i}$. When one accounts for endogenous markups at the buyer-supplier level, the changes in markups charged by its suppliers, $\frac{\mathrm{d}\mu_{ji}}{\mu_{ji}}$, enter as additional variables that affect firm i's cost. The changes in firms' unit costs are affected by the changes in the unit costs of their suppliers, the changes in the markups these suppliers charge, change in the nominal wage, and change in the foreign price, each weighted by the firms' exposure to these inputs.

$$\frac{\mathrm{d}c_i}{c_i} = s_{li}\frac{\mathrm{d}w}{w} + \sum_{j\in Z_i} s_{ji}\left(\frac{\mathrm{d}\mu_{ji}}{\mu_{ji}} + \frac{\mathrm{d}c_j}{c_j}\right) + s_{Fi}\frac{\mathrm{d}p_F}{p_F}. \tag{25}$$

The changes in markups that i's suppliers charge, $\frac{\mathrm{d}\mu_{ji}}{\mu_{ji}}$, can be decomposed into two counteracting forces that push i's cost in opposite directions. Equation (26) shows the decomposition. The first term captures what we call the attenuation effect, as the reduction in supplier j's cost leads to an increase in the markup j charges i, μ_{ji}. On the other hand, the second term in equation (26) shows that the markup, μ_{ji}, is also affected by i's other suppliers besides j. If the prices of other suppliers and imported goods decline on average, then the supplier j reduces its markup to i in face of increased competition. We call this second effect the pro-competitive effect.[36]

$$\frac{\mathrm{d}\mu_{ji}}{\mu_{ji}} = \underbrace{-\Gamma_{ji}\frac{\mathrm{d}c_j}{c_j}}_{\text{attenuation effect}} + \underbrace{\Gamma_{ji}\frac{\mathrm{d}p_{\not{j}i}}{p_{\not{j}i}}}_{\text{pro-competitive effect}}. \tag{26}$$

The term Γ_{ji} represents the elasticity of the markup μ_{ji} with respect to the supplier's cost c_j:

$$\Gamma_{ji} = -\frac{\partial\mu_{ji}}{\partial c_j}\frac{c_j}{\mu_{ji}} = \frac{\Upsilon_{ji}}{1+\Upsilon_{ji}}, \tag{27}$$

and

$$\Upsilon_{ji} = \frac{\left(\varepsilon_{ji} - \sigma_{\nu(j)}\right)\left(1-\sigma_{\nu(j)}\right)\left(1-s_{ji}^{\nu(j)}\right) + s_{ji}^{\nu(j)}\left(\eta-\rho\right)\left(1-\rho\right)s_{ji}^{\nu(j)}\left(1-s_{\nu(j)i}^{m}\right)s_{\nu(j)i}^{m}}{\varepsilon_{ji}\left(\varepsilon_{ji}-1\right)}. \tag{28}$$

The term $\frac{\mathrm{d}p_{\not{j}i}}{p_{\not{j}i}}$ represents the average change in input prices of i excluding the price of j's goods sold to i.[37]

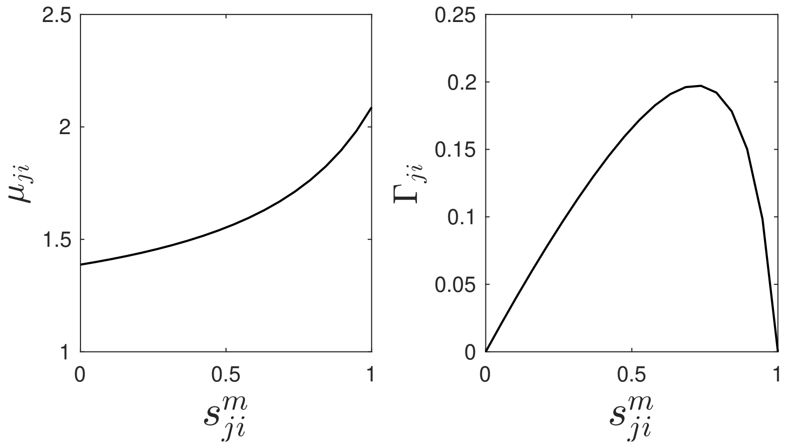
As one can see from equation (26), the magnitudes of both the attenuation and pro-competitive effects are governed by two components. The first is the elasticity term Γ_{ji}. At the first-order approximation, the supplier j's cost and other suppliers' prices affect markup, μ_{ji}, symmetrically with opposite signs. Hence the elasticity term, Γ_{ji}, enters symmetrically into the two effects. If the supplier firm j has infinitesimal share in buyer i's inputs, $s_{ji}^{\nu(j)} \to 0$, then the elasticity term converges to 0. The elasticity term also converges to 0 when the supplier firm j is the only supplier of buyer i, $s_{ji}^{\nu(j)}, s_{\nu(j)i}^{m} \to 1$. When the pair-specific input shares are in the intermediate range, both the attenuation and pro-competitive effects can have large magnitudes through large elasticity Γ_{ji}. This point can be conveyed visually when we collapse the model to a single-sector model. Once we assume $\sigma_u = \rho$,

[36]See Feenstra, Gagnon, and Knetter (1996), Atkeson and Burstein (2008), Amiti, Itskhoki, and Konings (2019) for similar strategic complementarities that operate at the firm-level within each sector.

[37]See Appendix B.5.2 for details.

then the relevant input share that determines the markup becomes $s^m_{ji} = s^{\nu(j)}_{ji} s^m_{\nu(j)i}$ from equation (14), and equation (28) collapses to $\Upsilon_{ji} = \frac{(\varepsilon_{ji}-\rho)(1-\rho)(1-s^m_{ji})}{\varepsilon_{ji}(\varepsilon_{ji}-1)}$. Figure 4 plots the markup, μ_{ji}, and the elasticity of markup, Γ_{ji}, with respect to the input share, s^m_{ji}. One can see that Γ_{ji} displays a hump shape with respect to the input share, s^m_{ji}, and when the input share is around 0.7, both attenuation and pro-competitive effects can have large magnitudes.

Figure 4: Markup μ_{ji} and elasticity Γ_{ji} with respect to input share s^m_{ji}, single-sector model



Note: The left figure plots the pairwise markup, μ_{ji}, as a function of s^m_{ji}. The right figure plots the elasticity of μ_{ji} with respect to c_j, Γ_{ji}, as a function of s^m_{ji}. For illustration we impose a single-sector structure, $\sigma_u = \rho$. We use the parameter values of $\rho = 2.16$ and $\eta = 1.92$.

In addition to the elasticity term, Γ_{ji}, the magnitudes of the attenuation and pro-competitive effects are each influenced by how much shock the supplier or other suppliers received, $\frac{dc_j}{c_j}$ and $\frac{dp_{\not{j}i}}{p_{\not{j}i}}$, respectively. For example, even if the input share for a specific pair is in the region where the elasticity Γ_{ji} is large, if the supplier's cost did not decrease at all, there will be no attenuation effect. The magnitudes of cost reductions by the suppliers govern the magnitudes of attenuation effects within the same values of input shares. Likewise, the average magnitudes of price changes by other suppliers determine the magnitudes of pro-competitive effects within the same value of input shares. Furthermore, the markup that the supplier j charges i would see net decrease if supplier j's cost reduction is greater than the average cost reductions of other suppliers. It would see net increase if other suppliers received greater cost reductions than what j received.

Having characterized the changes in markups at the buyer-supplier level, we move our attention to firm-level changes in average markups. As seen in equation (25), the additional force that affects firm i's costs by taking into account endogenous markups can be summarized by the average change in markups that suppliers charge to firm i, $\sum_{j\in Z_i} s_{ji}\frac{d\mu_{ji}}{\mu_{ji}}$. As discussed above, the changes in individual markups are governed by the input shares suppliers have and the relative magnitudes of the suppliers' cost changes to the other suppliers' cost changes. Suppose that firm i has multiple suppliers. Suppose also that its largest supplier, j, with input shares $s^{\nu(j)}_{ji}$ and $s^m_{\nu(j)i}$ which predict a large markup elasticity,

Γ_{ji}, receives the largest cost reduction among i's suppliers. Then the supplier j will increase its markup, and i will experience higher markups from its suppliers on average. If, on the other hand, j does not experience any cost reduction while other suppliers do, then j will reduce its markup and i will experience lower markups from its suppliers on average.

To approximate these firm-level changes in average markups, we consider a measure that captures firms' *indirect* exposure to foreign inputs, $s_{Fi}^{Indirect}$. We first construct the measure of "total import share," s_{Fi}^{Total}, that captures firm i's exposure to foreign inputs by summing its direct exposure, its suppliers' exposure, and so on:[38]

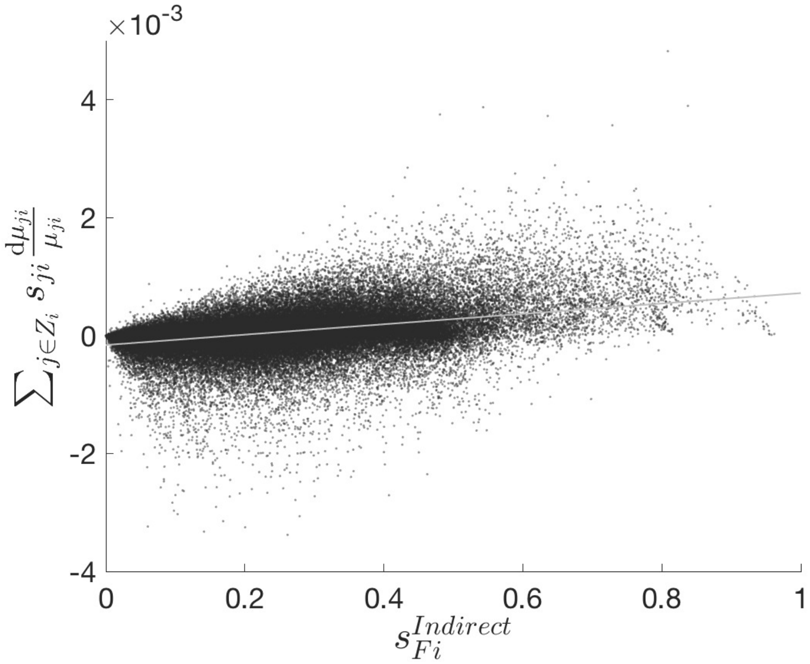
$$s_{Fi}^{Total} = s_{Fi} + \sum_{k \in Z_i} s_{ki} s_{Fk}^{Total}.$$

We then subtract firms' direct exposure to foreign inputs: $s_{Fi}^{Indirect} = s_{Fi}^{Total} - s_{Fi}$. Figure 5 plots these average changes in suppliers' markups, $\sum_{j \in Z_i} s_{ji} \frac{d\mu_{ji}}{\mu_{ji}}$, against firms' indirect exposure to foreign inputs, $s_{Fi}^{Indirect}$. There is a positive correlation between the two measures. Consider a firm with high value of $s_{Fi}^{Indirect}$, meaning that the supplier with a high input share is highly exposed to foreign imports. In this case the supplier with the high input share increases its markup and the firm will experience higher markups on average. This positive correlation informs us that the firm's position in its production network is an important determinant of whether the firm experiences greater or smaller cost changes than those implied from models with fixed markups.

To confirm this point, we present the correlations of firm-level cost changes and firm-level variables in Appendix E.1. The measure of the total foreign input share, s_{Fi}^{Total}, has the largest correlation with the cost changes under endogenous markups among other firm-level variables such as total sales, import share, and the number of suppliers. Even so, the measure of indirect foreign input share, $s_{Fi}^{Indirect}$, predicts best the differences in cost changes under endogenous markups and fixed markups, $\frac{\hat{c}_i^{endog}/\hat{w}^{endog} - \hat{c}_i^{fixed}/\hat{w}^{fixed}}{1 - \hat{c}_i^{fixed}/\hat{w}^{fixed}}$.

[38]We follow the definition of s_{Fi}^{Total} by Dhyne, Kikkawa, Mogstad, and Tintelnot (2019).

Figure 5: Average change in markups, $\sum_{j \in Z_i} s_{ji} \frac{d\mu_{ji}}{\mu_{ji}}$, and indirect exposure to foreign inputs, $s_{Fi}^{Indirect}$



Note: The figure plots the first-order approximated changes in average markups charged by suppliers, $\sum_{j \in Z_i} s_{ji} \frac{d\mu_{ji}}{\mu_{ji}}$, on a 20 percent reduction in the price of foreign goods, against firms' indirect exposure to foreign goods, $s_{Fi}^{Indirect}$. The least-squares line has a y-intercept of -0.0002 and slope coefficient of 0.0009. The R-squared is 0.15. The correlation between the two variables is 0.39.

In addition to the firms' position in the production network, the nature of the shock itself also affects how firms' cost changes behave differently from those under fixed markups. The shock we focus on here affects all importers (accounting for around 20 percent of all firms) directly, and many other firms indirectly at the same time. The median value of the total foreign input share, s_{Fi}^{Total}, is around 39 percent. As the shock affects many firms in the economy at the same time, many firms have multiple suppliers which experience roughly the same degree of cost reductions. In these cases, both the attenuation effects and the pro-competitive effects tend to cancel each other out.[39] To illustrate this point, in Appendix E.2 we study an alternative shock where we hit only one importer with the foreign price reduction.[40] We demonstrate that the positive correlation between the average changes in markups, $\sum_{j \in Z_i} s_{ji} \frac{d\mu_{ji}}{\mu_{ji}}$, and firms' exposure to the firm's goods is much stronger. Moreover, we show that the differences in firm-level cost changes between the baseline model and under fixed markups become greater. In this case, 71 percent of firms experience cost reductions that are smaller than under fixed markups by 1 percent or more, and 9 percent of firms experience cost reductions that are greater than under fixed markups by 1 percent or more.

Finally, we turn to the aggregate counterfactual changes. We report in Table 6 the counterfactual changes of aggregate welfare, real wage, expenditure, and profits across the two models. Because

[39] This point is also made by Amiti, Itskhoki, and Konings (2019) with a model of firm-level competition within sectors.
[40] We choose the importer with the largest number of domestic buyers as the firm receiving the shock.

the two economies are identical prior to the foreign price shock, and the only difference is whether firm-to-firm markups endogenously respond or not, unsurprisingly the baseline economy predicts quantitatively similar changes in the aggregate variables to those predicted by the economy with fixed markups. At the firm-level, allowing endogenous markups attenuated cost reductions for around half of the firms and amplified cost reductions for the rest. In the aggregate, these cost changes at the firm-level almost cancel out and produce a small net-amplification effect, resulting in a slightly larger increase in the real wage.[41] In Appendix E.2 we also present results on the change in aggregate welfare under a shock to one importer. In this case, the net effect of the two counteracting forces goes in the opposite direction in the aggregate. The aggregate effects are attenuated once incorporating endogenous markups, and the magnitude of the net effects becomes much larger than it would be considering uniform foreign price reduction.

Table 6: Aggregate effects of a 20 percent reduction in the foreign price

	Baseline	Fixed markups
$\hat{U} = \hat{E}/\hat{P}$	1.2726	1.2721
$\hat{w}/\hat{P}$	1.1421	1.1419
$\hat{E}$	1.1501	1.1493
$\hat{\Pi}$	1.3286	1.3285

[41] This result for the aggregate variables are also in line with the argument made by Amiti, Itskhoki, and Konings (2019).

7 Conclusion

In this paper we studied the implications of imperfect competition in firm-to-firm trade. We proposed a novel view on competition between firms. In addition to the market shares within sectors determining firms' market power, we suggest that the relative size of the firm in the total input sourcing of its buyers is also a relevant metric. The data on firm-to-firm transactions supports this view; firms charge higher markups if they have higher average input shares within their buyer firms, controlling for their sectoral market shares.

Using a model of oligopolistic competition in firm-to-firm trade where firms charge different markups to different buyers, we offered two counterfactual exercises. We first investigated the amount of distortion caused by variable markups in firm-to-firm trade. We backed out markups for each buyer-supplier pair in the data and found that the magnitudes of distortions coming from markups can be larger than previously suspected. Reducing all markups in firm-to-firm relationships by 20 percent could increase aggregate welfare by around 10 percent.

We also explored the effect of endogenous markups in firm-to-firm trade on the predictions of shock transmissions in both the aggregate and at the firm-level. Compared to a model featuring fixed markups in firm-to-firm trade, we found a large heterogeneity at the firm-level. In the counterfactual where we take a fall in import prices as the shock, we found that incorporating endogenous markups in firm-to-firm trade would amplify cost changes for some firms and attenuate cost changes for others. We characterized these differences and demonstrated that a measure of the firm's exposure to the indirect shock through its domestic suppliers is an important metric in explaining this firm-level heterogeneity.

While we focused on two specific counterfactual exercises, all results and intuitions offer insights into responses to other types of shocks, such as industry-level shocks or firm-level shocks. Moreover, our framework would be useful in analyzing the effects of various policies such as international trade policies and competition policies.

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A Data and additional empirical results

A.1 Aggregating VAT-IDs into firms

Our datasets are all at the VAT-ID level. Using the same procedure as in Dhyne, Kikkawa, Mogstad, and Tintelnot (2019), we aggregate the VAT-IDs into firms. As mentioned in the main text, we group all VAT-IDs into firms if they are linked with more than or equal to 50 percent of ownership, or if they share the same foreign parent firm that holds more than or equal to 50 percent of their shares. To determine if the two VAT-IDs share the same foreign parent firm, we use a "fuzzy string matching" method and compare the all possible pairs of the foreign parent firms' names. In order to correct for misreporting, we pair two separate VAT-IDs into one firm if the two were paired as one firm in the year before and the year after.

We then identify one VAT-ID as the "head VAT-ID" for each group of multiple VAT-IDs. This "head VAT-ID" will work as the identifier of the firm. We also make corrections on which VAT-ID becomes the "head VAT-ID" of the firm, so that the identifiers of the firms become consistent over time. For the procedure to choose the "head VAT-ID" and the corrections, see Appendix C.1 of Dhyne, Kikkawa, Mogstad, and Tintelnot (2019).

When converting the VAT-ID level variables into firm level variables, we simply sum up the variables if the variables are numeric. For variables such as total sales and inputs, we correct for double counting that arises from VAT-ID-to-VAT-ID trade that occur within firms. For other variables including the firm's age and sector, we take the values of the firm's "head VAT-ID".

A.2 Coverage and descriptive statistics

Table 7 reports the coverage of the full sample constructed in Dhyne, Magerman, and Rubinova (2015).

Table 7: Coverage of all Belgian firms

Year	All Belgian firms					Selected sample				
	Count	V.A.	Sales	Imports	Exports	Count	V.A.	Sales	Imports	Exports
2002	714,469	134	812	204	217	88,301	119	501	175	185
2007	782,006	176	1080	294	282	95,941	152	692	277	265
2012	860,373	195	1244	320	317	98,745	164	767	292	292

Note: All numbers except for Count are in billions of Euro in current prices. Data for Belgian aggregate statistics are from Eurostat. Firms' value added is from the reported values from the annual accounts. The sample for "All Belgian firms" cover all firms in the dataset constructed in Dhyne, Magerman, and Rubinova (2015). The "Selected sample" are the sample selected from the procedure described in Section 2.1.

Table 8 shows the sectoral composition of our selected sample.

Table 8: Sectoral composition of the selected sample in 2012

Sector	Count	V.A.	Sales	Imports	Exports
Agriculture and Mining	2,805	4.37	49.4	16.9	10.9
Manufacturing	16,577	54.9	272	146	193
Utility and Construction	20,421	25.4	77.0	27.8	17.5
Wholesale and Retail	31,117	30.7	241	84.1	53.4
Service	27,825	48.4	127	17.6	16.9
Toal	98,745	164	767	292	292

Note: This table shows the sectoral composition of firms selected from the procedure described in Section 2.1. All numbers except for Count are in billions of Euro in current prices. Firms' value added is from the reported values from the annual accounts. Agriculture and Mining corresponds to NACE 2-digit codes 01 to 09, Manufacturing corresponds to NACE 2-digit codes 10 to 33, Utility and Construction corresponds to NACE 2-digit codes 35 to 43, Whole- sale and Retail corresponds to NACE 2-digit codes 45 to 47, and Service corresponds to NACE 2-digit codes 49 to 63, 68 to 82, and 94 to 96.

Table 9 shows the distribution of the pairwise input shares, s_{ij}^m, in 2012, defined as the share of goods from firm i, among j's input purchases. We also report the distributions for the number of suppliers and buyers. Though the median firm has as many as 33 suppliers, the median value of the pairwise input share, s_{ij}^m, is very small. In addition, one can see that the distribution of the number of buyers is much more skewed than the number of suppliers.

Table 9: Descriptive statistics of the production network

	Mean	Percentiles				
		10%	25%	50%	75%	90%
$s_{ij}^m = \text{Sales}_{ij}/\text{InputPurchases}_j$	1.80%	0.00%	0.03%	0.19%	0.89%	3.56%
Num. suppliers	51	11	19	33	56	96
Num. buyers	51	0	2	9	35	100

Note: This table shows statistics of the firm-to-firm network, among the firms selected from the procedure described in Section 2.1.

Table 10 describes the shares of firms' inputs affected by the classification described on page 7. After the sample selection process, we classify input purchases to selected firms from non- selected firms as labor costs.

Table 10: Shares of re-classified labor costs

	Median	Mean	Weighted mean
Shares of labor cost, from non-selected firms	0.30	0.35	0.49

Note: The table reports the median, mean, and weighted mean fractions of firms' labor cost that were originally their purchases from non-selected firms. Firms' labor costs are used as weights.

Table 11 reports descriptive statistics of firms that are dropped when estimating the CES parameters. These firms are dropped because their total sales are less than their input costs.

Table 11: Firms dropped in estimation

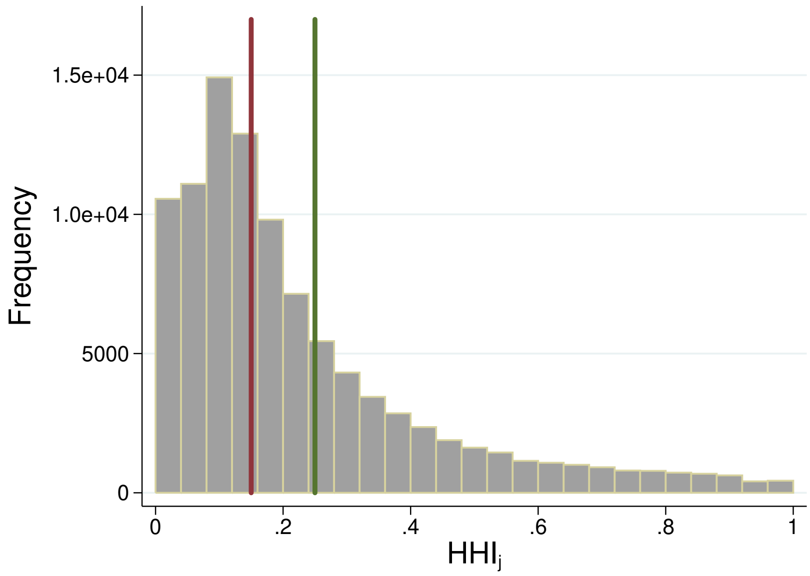
	Count	V.A.	Sales	Num. links
Full sample	98,745	164	874	5,026
Dropped sample	13,184	54	241	1,714
Fraction of dropped firms	0.13	0.33	0.28	0.34

Note: The table reports statistics of firms in 2012 which total sales are less than input costs. Value added and sales are in billions of Euro, and number of links are in thousands.

A.3 HHI of firms' input shares across suppliers

Here we compute the HHI of the pair-specific input shares, $s^m_{ij} = \frac{\text{Sales}_{ij}}{\text{InputPurchases}_j}$, for all buyer firms j, across suppliers i. Figure 6 displays the histogram of these firm-level HHI.

Figure 6: HHI of suppliers' input shares



Note: s^m_{ij} is defined as firm i's goods share among firm j's input purchases from other Belgian firms and abroad. The above histogram shows the HHI of s^m_{ij} for all buyer firms j in 2012 that have more than 10 suppliers. The median value is 0.15. The two vertical lines indicates HHI being 0.15 and 0.25.

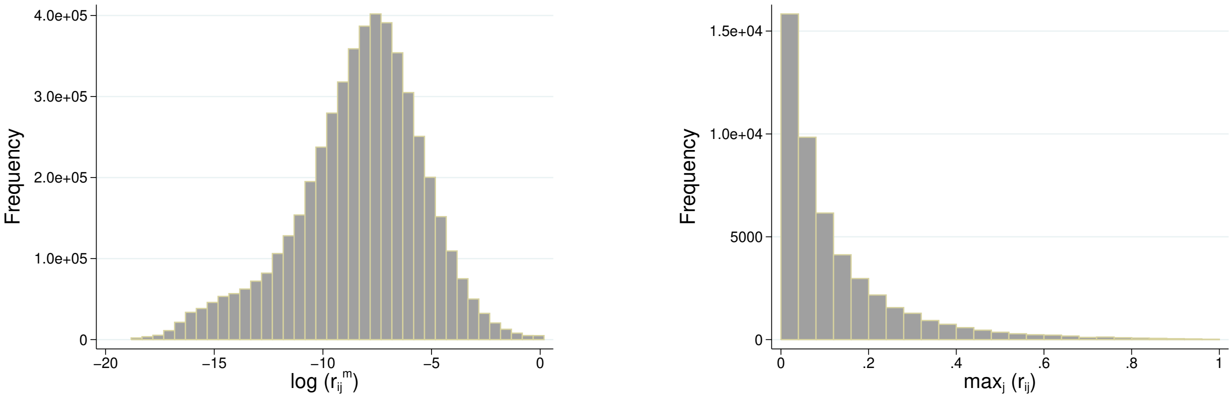
While there is no perfect reference for the HHI for suppliers' input shares for each buyer firm, the US Department of Justice and FTC consider markets in which the HHI is between 0.15 and 0.25 to be moderately concentrated. Markets in which the HHI is above 0.25 are considered highly concentrated (U.S. Department of Justice and Federal Trade Commission, 2010). We find here that 50 percent of firms have a HHI above 0.15. 26 percent of firms have a HHI above 0.25.

A.4 Distribution of firms' output shares across buyers

Figure 7 plots the distributions for the output shares. The output share, $r_{ij} = \frac{\text{Sales}_{ij}}{\text{Sales}_i}$, is defined as the sales share of firm i's output that were sold to firm j. Figure 7a plots the distribution of $\ln r_{ij}$ for all $i - j$ pairs in 2012, and Figure 7b plots the output shares of the largest buyers for all supplier firms in 2012 that have at least 10 buyers. The output share of the largest buyer for the median firm in this figure is 7 percent.

Figure 7: Distribution of output shares

(a) Histogram of $\ln r_{ij}$ (b) Output shares of the largest buyers



Note: r_{ij} is defined as the share of firm i's goods that were sold to firm j, out of firm i's total sales. The left histogram shows the distribution of $\ln r_{ij}$ for all firm-to-firm pairs in 2012. The right histogram shows the distribution of $\max_j (r_{ij})$, which is the maximum value of r_{ij} for each supplier firm i in 2012 that have more than 10 buyers. The median value is 0.07.

A.5 Disconnect between pairwise input shares and sectoral market shares

We showed in Section 2.2 that firms have skewed input shares across their suppliers. However, high skewness in input shares may simply be caused by firm-level components. For example, one may argue that the skewness of input shares across suppliers is coming from the skewness in the suppliers' productivity distribution. If that is indeed the case, one would expect that a firm with a high input share on a particular buyer would also be one with high total sales. Nevertheless, the results in Section 2.3 suggested otherwise. Firm-level markups, which have total sales on the numerator, were not perfectly collinear with firms' average input shares to their buyers. To investigate this further, we compute for each firm the rank correlation between its suppliers' input shares and their total sales.

Consider the firm on the left of Figure 8. This firm is purchasing goods worth 10, 5, and 1 Euro from its three suppliers, a, b, and c, respectively. The three suppliers' total sales are 100, 50, and 10 Euro. The ordering of the firm's suppliers according to the input shares aligns with the ordering of their total sales. Thus, the rank correlation for the firm is 1. One the other hand, consider the firm on the right of the figure. The transaction values are identical to the firm on the left, but the three suppliers' total sales are 10, 50, and 100 Euro, respectively. Here the ordering of the two are opposite, so the rank correlation for the firm is -1.

Figure 8: Example for computing rank correlations

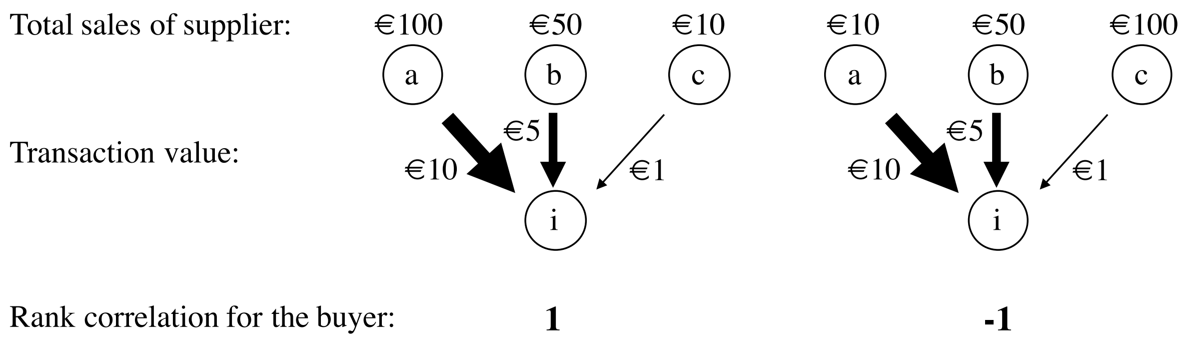
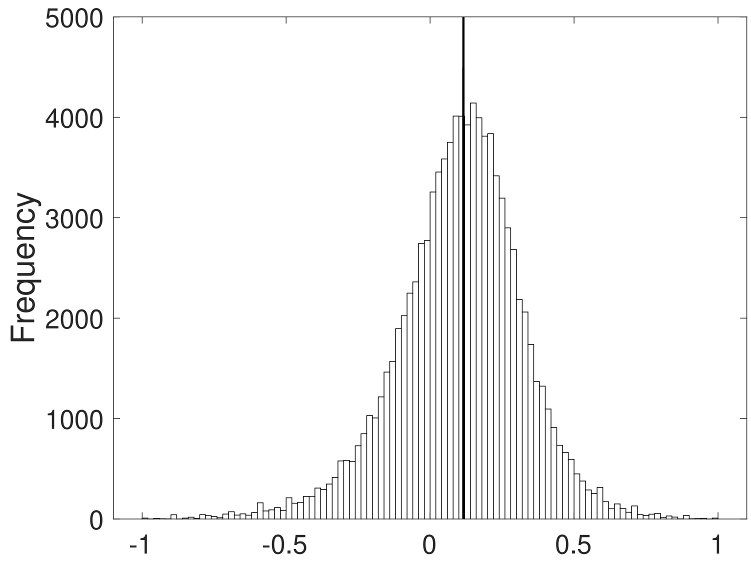


Figure 9 displays the histogram of the correlation coefficients. The median firm's coefficient is around 0.12. 30 percent of firms have correlation coefficients that are zero or negative. This result indicates that a firm with high input share on a particular buyer is not necessarily large.[42] It illustrates that pairwise match components play a large role in firm-to-firm trade in addition to firm-level components. Instead of computing the rank correlations, we find that the results when we compute the Pearson correlations also have a mass of firms around zero correlation, and even have a lower median coefficient value. Figure 10 shows the histogram of the Pearson correlation coefficients.

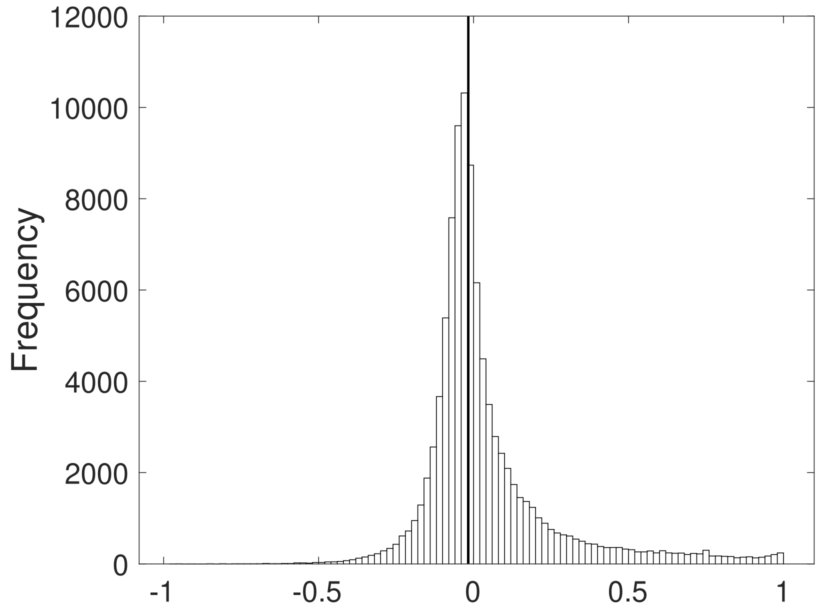
[42]This becomes the case if the distributions of firms' output shares to each buyer are skewed. See Appendix A.4 for a figure analogous to Figure 1b, but for output shares. The output shares are indeed skewed, where more than 20 percent of the output of a median firm goes to its largest buyer.

Figure 9: Histogram of rank correlation of suppliers' input shares and total sales



Note: This figure shows a histogram of Spearman's rank correlation coefficients between s^m_{ij} and Sales_i for suppliers of j for all j with 5 or more suppliers. The vertical line depicts the median correlation coefficient of 0.12.

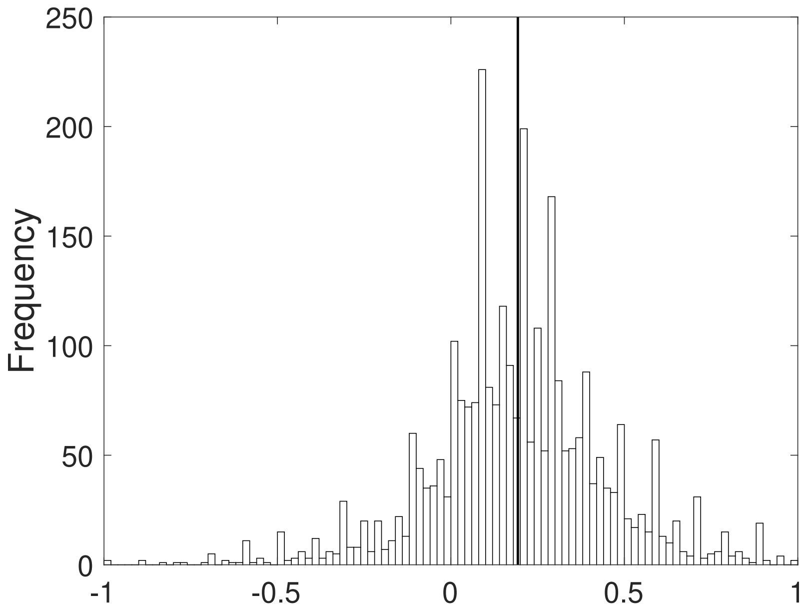
Figure 10: Histogram of Pearson correlation of suppliers' input shares and total sales



Note: This figure shows a histogram of Pearson correlation coefficients between s^m_{ij} and Sales_i, for suppliers of j for all j with 5 or more suppliers. The vertical line depicts the median correlation coefficient of -0.02.

Indeed, in Figures 9 and 10 we plot the unconditional correlations which do not take into account the difference in the goods produced by suppliers. The low correlations in the figure may come from the fact that a supplier's good is heavily used in firms from one sector, but not from firms in others. Therefore we then take into account this heterogeneity of input compositions across sector-to-sector relationships. We calculate the rank correlations for each firm, but now for each group of suppliers in each sector at the NACE 2-digit level. We compute the correlation coefficient for suppliers in a sector, if there are 5 or more suppliers in that sector supplying to the firm. We obtain distributions of those correlations, for each sector-to-sector pair. Figure 11 plots the histogram of the median rank correlations and Figure 12 shows the histogram of the median Pearson correlations coefficients for each sector-to-sector pair. The median values of these median correlations are larger than the unconditional median values from Figures 9 and 10. However, we still see a large role that pairwise match components play, even within the same sector-to-sector relationships.

Figure 11: Median rank correlations

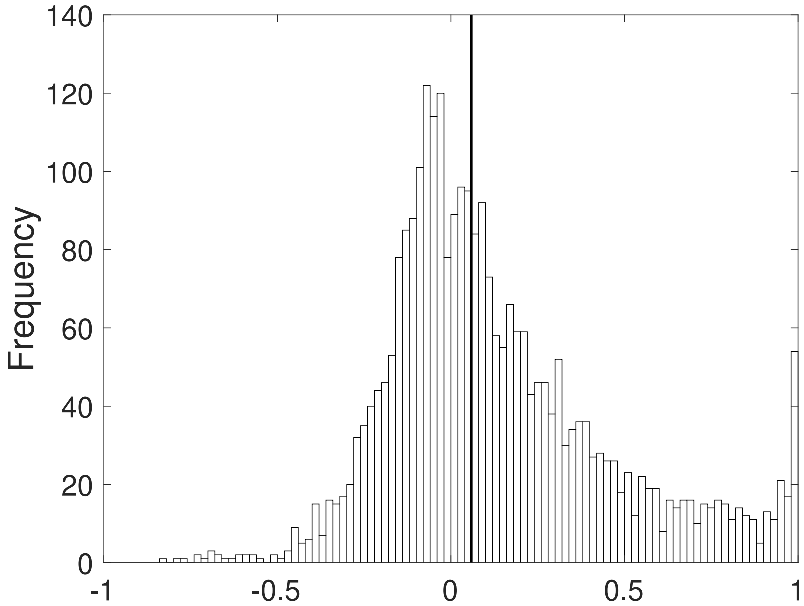


Note: For each buyer firm j, we compute the rank correlations of suppliers' input shares s_{ij}^{m} and Sales_i, for each sector in which 5 or more of j's suppliers are in. This figure shows a histogram of the median correlation coefficients, across each sector-to-sector pairs. The vertical line depicts the median value of 0.19.

A.6 Additional results on markups and input shares

First, we show that the firms' average input shares on buyers tend to have greater power in explaining the variation of firms' average markups, compared to firm-level market shares. In Table 12 we report the regression results when we add the two RHS variables one by one, for each of the three specifications in Table 3. The 4th, 8th and 12th columns are identical to the three columns in Table 3. For each specification reported in the main text, we add three additional specifications. One with neither average input shares nor firm-level market shares on the RHS, and ones with each variable without the other. In all three sets of specifications, the increase in R-squared by adding average input shares alone on the RHS is larger than or almost equal to the increase in R-squared by adding sectoral market shares alone.

Figure 12: Median Pearson correlations



Note: For each buyer firm j, we compute the Pearson correlations of suppliers' input shares s_{ij}^m and Sales_i, for each sector in which 5 or more of j's suppliers are in. This figure shows a histogram of the median correlation coefficients, across each sector-to-sector pairs. The vertical line depicts the median value of 0.06.

Table 12: Firm-level markups and input shares, R-squared across specifications

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
$\text{SctrMktShare}_{i,t}$ (4-digit)		0.0224		0.0219		0.0153		0.0154		0.0221		0.0221
		(0.00283)		(0.00280)		(0.00174)		(0.00174)		(0.00202)		(0.00201)
Average input share $\overline{s^m_{i\cdot,t}}$			0.0534	0.0524			0.0412	0.0412			0.0391	0.0391
			(0.00396)	(0.00395)			(0.00299)	(0.00300)			(0.00291)	(0.00290)
N	809722	809722	809722	809722	781627	781627	781627	781627	781627	781627	781627	781627
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector FE	4-digit	4-digit	4-digit	4-digit	No	No	No	No	No	No	No	No
Firm FE	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	Yes
R2	0.1033	0.1040	0.1043	0.1050	0.6375	0.6376	0.6377	0.6378	0.6385	0.6387	0.6387	0.6389

Note: Standard errors in parentheses. The coefficients are X-standardized. Standard errors are clustered at the NACE 2-digit-year level. The regression exclude outliers in the top and bottom 1 percent of the markup distribution. Controls include firms' number of suppliers, number of buyers, employment, total assets, and age.

We then show that the positive relationship between markups and firms' average input shares are robust in other specifications. Table 13 shows additional results when firm-level fixed effects are included, and Table 14 shows additional results when sector-level fixed effects are included. Table 15 shows results when we control for the denominator of $\overline{s^m_{i\cdot,t}}$: buyers' total input purchases, and Table 16 shows results when we additionally control for the average relationship age with its buyers. Since the data starts from 2002, we count the relationship age of a buyer-supplier pair as the number of years after its first observation from 2002. Then we take the mean of these relationship age across firms' buyers.

In our main specification, we drop firms that have no sales to other Belgian firms. Table 17 shows the results when we include such firms in the regression, by treating their average input shares to other firms as zero.

Furthermore, as an alternative measure of input shares we use the supplier's sales share among the buyer's inputs that are classified as the same goods as the supplier's, either at the 4-digit or 2-digit level. The results are reported in Tables 18 and 19.

Table 13: Firm-level markups and input shares, with firm fixed effects

	(1)	(2)	(3)	(4)	(5)	(6)
SctrMktShare$_{i,t}$ (4-digit)	0.0153	0.0154	0.0221			
	(0.00174)	(0.00174)	(0.00201)			
SctrMktShare$_{i,t}$ (2-digit)				0.0153	0.0153	0.0264
				(0.00256)	(0.00255)	(0.00380)
Average input share $\overline{s^m_{i\cdot,t}}$		0.0412	0.0391		0.0412	0.0390
		(0.00300)	(0.00290)		(0.00300)	(0.00290)
N	781627	781627	781627	781627	781627	781627
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls	No	No	Yes	No	No	Yes
R2	0.638	0.638	0.639	0.638	0.638	0.639

Note: Standard errors in parentheses. The coefficients are X-standardized. Standard errors are clustered at the NACE 2-digit-year level. The regression exclude outliers in the top and bottom 1 percent of the markup distribution. Controls include firms' number of suppliers, number of buyers, employment, total assets, and age.

Table 14: Firm-level markups and input shares, with sector fixed effects

	(1)	(2)	(3)	(4)
$\text{SctrMktShare}_{i,t}$ (4-digit)	0.0224	0.0219		
	(0.00283)	(0.00280)		
$\text{SctrMktShare}_{i,t}$ (2-digit)			0.0220	0.0215
			(0.00226)	(0.00223)
Average input share $\overline{s^m_{i\cdot,t}}$		0.0524		0.0540
		(0.00395)		(0.00422)
N	809722	809722	809727	809727
Year FE	Yes	Yes	Yes	Yes
Sector FE	4-digit	4-digit	2-digit	2-digit
Controls	Yes	Yes	Yes	Yes
R2	0.104	0.105	0.0719	0.0729

Note: Standard errors in parentheses. The coefficients are X-standardized. Standard errors are clustered at the NACE 2-digit-year level. The regression exclude outliers in the top and bottom 1 percent of the markup distribution. Controls include firms' number of suppliers, number of buyers, employment, total assets, and age.

Table 15: Firm-level markups and input shares, controlling for buyers' size

	(1)	(2)
$\text{SctrMktShare}_{i,t}$ (4-digit)	0.0235	0.0221
	(0.00264)	(0.00201)
Average input share $\overline{s^m_{i\cdot,t}}$	0.0417	0.0385
	(0.00358)	(0.00291)
N	809722	781627
Year FE	Yes	Yes
Sector FE	4-digit	No
Firm FE	No	Yes
Controls	Yes	Yes
R2	0.108	0.639

Note: Standard errors in parentheses. The coefficients are X-standardized. Standard errors are clustered at the NACE 2-digit-year level. The regression exclude outliers in the top and bottom 1 percent of the markup distribution. Controls include firms' number of suppliers, number of buyers, employment, total assets, age, and buyers' total input purchases.

Table 16: Firm-level markups and input shares, controlling for average relationship age

	(1)	(2)
$\text{SctrMktShare}_{i,t}$ (4-digit)	0.0220	0.0221
	(0.00279)	(0.00201)
Average input share $\overline{s^m_{i\cdot,t}}$	0.0566	0.0381
	(0.00398)	(0.00289)
N	809722	781627
Year FE	Yes	Yes
Sector FE	4-digit	No
Firm FE	No	Yes
Controls	Yes	Yes
R2	0.106	0.639

Note: Standard errors in parentheses. The coefficients are X-standardized. Standard errors are clustered at the NACE 2-digit-year level. The regression exclude outliers in the top and bottom 1 percent of the markup distribution. Controls include firms' number of suppliers, number of buyers, employment, total assets, age, and average relationship age.

Table 17: Firm-level markups and input shares, including firms without firm-to-firm sales

	(1)	(2)	(3)
$\text{SctrMktShare}_{i,t}$ (4-digit)	0.0231	0.0157	0.0228
	(0.00291)	(0.00166)	(0.00197)
Average input share $\overline{s^m_{i\cdot,t}}$	0.0383	0.0350	0.0333
	(0.00385)	(0.00272)	(0.00265)
N	921346	895043	892891
Year FE	Yes	Yes	Yes
Sector FE	4-digit	No	No
Firm FE	No	Yes	Yes
Controls	Yes	No	Yes
R2	0.112	0.648	0.642

Note: Standard errors in parentheses. The coefficients are X-standardized. Standard errors are clustered at the NACE 2-digit-year level. The regression exclude outliers in the top and bottom 1 percent of the markup distribution. Controls include firms' number of suppliers, number of buyers, employment, total assets, and age.

Table 18: Firm-level markups and input shares, input shares taking into account sectors (4-digit)

	(1)	(2)	(3)
SctrMktShare$_{i,t}$ (4-digit)	0.0205	0.0196	0.0266
	(0.00265)	(0.00182)	(0.00211)
Average sectoral input share $\overline{s^m_{i\cdot,t}}$ (4-digit)	0.0245	0.0156	0.0149
	(0.00194)	(0.00119)	(0.00118)
N	813681	786575	786575
Year FE	Yes	Yes	Yes
Sector FE	4-digit	No	No
Firm FE	No	Yes	Yes
Controls	Yes	No	Yes
R2	0.0830	0.612	0.613

Note: Standard errors in parentheses. The coefficients are X-standardized. Standard errors are clustered at the NACE 2-digit-year level. The regression exclude outliers in the top and bottom 1 percent of the markup distribution. Average sectoral input share, $\overline{s^m_{i\cdot,t}}$, is calculated as the supplier i's sales share among its buyers inputs that are classified as the same goods as i's, at the 4-digit level. Controls include firms' number of suppliers, number of buyers, employment, total assets, and age.

Table 19: Firm-level markups and input shares, input shares taking into account sectors (2-digit)

	(1)	(2)	(3)
SctrMktShare$_{i,t}$ (2-digit)	0.0205	0.0151	0.0254
	(0.00200)	(0.00228)	(0.00354)
Average sectoral input share $\overline{s^m_{i\cdot,t}}$ (2-digit)	0.0288	0.0203	0.0194
	(0.00208)	(0.00146)	(0.00143)
N	867568	840712	840712
Year FE	Yes	Yes	Yes
Sector FE	2-digit	No	No
Firm FE	No	Yes	Yes
Controls	Yes	No	Yes
R2	0.0820	0.608	0.609

Note: Standard errors in parentheses. The coefficients are X-standardized. Standard errors are clustered at the NACE 2-digit-year level. The regression exclude outliers in the top and bottom 1 percent of the markup distribution. Average sectoral input share, $\overline{s^m_{i\cdot,t}}$, is calculated as the supplier i's sales share among its buyers inputs that are classified as the same goods as i's, at the 2-digit level. Controls include firms' number of suppliers, number of buyers, employment, total assets, and age.

We then investigate whether input shares of firms' buyers in their buyers are correlated with the firms' markups. Similar to the definition of the weighted average input shares to its buyers, $\overline{s^m_{i\cdot,t}}$, we compute firm i's weighted average input shares of its buyers, $\overline{s^m_{i\cdot\cdot,t}}$, as

$$\overline{s^m_{i\cdot,t}} = \sum_{j\in W_{i,t}} \frac{\text{InputPurchases}_{j,t}}{\sum_{k\in W_{i,t}} \text{InputPurchases}_{k,t}} s^m_{ij,t}$$
$$\overline{s^m_{i\cdot\cdot,t}} = \sum_{j\in W_{i,t}} \frac{\text{InputPurchases}_{j,t}}{\sum_{k\in W_{i,t}} \text{InputPurchases}_{k,t}} \overline{s^m_{j\cdot,t}}.$$

Table 20 shows the results when we add this second-degree average input shares as another control variable. While the coefficients on both sectoral market shares and the average input shares are almost unchanged from those in Table 3, the coefficient on the second-degree average input shares are close to zero and not significant in the specifications with firm fixed effects.

Table 20: Firm-level markups and input shares, add second degree average input shares

	(1)	(2)	(3)
SctrMktShare$_{i,t}$ (4-digit)	0.0219	0.0154	0.0221
	(0.00279)	(0.00174)	(0.00201)
Average input share $\overline{s^m_{i\cdot,t}}$	0.0531	0.0413	0.0391
	(0.00396)	(0.00301)	(0.00291)
Second degree average input share $\overline{s^m_{i\cdot\cdot,t}}$	-0.00698	-0.000826	-0.000737
	(0.00119)	(0.000770)	(0.000767)
N	809722	781627	781627
Year FE	Yes	Yes	Yes
Sector FE	4-digit	No	No
Firm FE	No	Yes	Yes
Controls	Yes	No	Yes
R2	0.105	0.638	0.639

Note: Standard errors in parentheses. The coefficients are X-standardized. Standard errors are clustered at the NACE 2-digit-year level. The regression exclude outliers in the top and bottom 1 percent of the markup distribution. Controls include firms' number of suppliers, number of buyers, employment, total assets, and age.

Finally, we consider a specification in which we instrument the average input share, $\overline{s^m_{i\cdot,t}}$, with the sales from other suppliers, and report the results in Table 21. In equation (2), both firm-level average markups and the average input shares contain firms' sales value in their numerators. Here we focus only on the variations of a firm's average input share that come from the changes in the purchases the firm's buyers made from other suppliers. We consider an instrument that is the total input purchases of the firm's buyers, less of the firm's sales to these buyers, $\log\left(\sum_{j\in W_{i,t}} \text{InputPurchases}_{j,t} - \sum_{j\in W_{i,t}} \text{Sales}_{ijt}\right)$. The results in Table 21 indicate that the positive relationship between markups and average input shares are robust, even after only considering the variations in the average input shares coming from other suppliers' sales.

Table 21: Firm-level markups and input shares, input shares instrumented with sales from other suppliers

	(1)	(2)	(3)
SctrMktShare$_{i,t}$ (4-digit)	0.0185	0.0154	0.0163
	(0.00257)	(0.00173)	(0.00177)
Average input share $\overline{s^m_{i\cdot,t}}$	0.364	0.106	0.105
	(0.0200)	(0.00909)	(0.00903)
N	809722	781627	781627
Year FE	Yes	Yes	Yes
Sector FE	4-digit	No	No
Firm FE	No	Yes	Yes
Controls	Yes	No	Yes

Note: This table shows the second stage results in which average input share is instrumented with $\log\left(\sum_{j\in W_{i,t}} \text{InputPurchases}_{j,t} - \sum_{j\in W_{i,t}} \text{Sales}_{ijt}\right)$. Standard errors in parentheses. The coefficients are X-standardized. Standard errors are clustered at the NACE 2-digit-year level. The regression exclude outliers in the top and bottom 1 percent of the markup distribution. Controls include firms' number of suppliers, number of buyers, employment, total assets, and age.

A.7 Alternative markup estimates

In the main text, we recover firm-level average markups, μ_i, using the equation implied from the static model with CRS production function: $\mu_i = \frac{\text{Sales}_i}{\text{InputPurchases}_i+\text{LaborCosts}_i}$. To account for additional heterogeneity such as usage in capital inputs, we incorporate user cost of capital in the denominator of markups. We assume that the user cost of capital consists of capital depreciation rate and the interest rate. Following Dhyne, Petrin, Smeets, and Warzynski (2017), we set the yearly depreciation rate as 8 percent and set the interest rate as the long-term interest rate in Belgium. Table 22 reports the results when we add user cost of capital as one of the input costs of the firm.

Table 22: Firm-level markups and input shares, user cost of capital in markups

	(1)	(2)	(3)
SctrMktShare$_{i,t}$ (4-digit)	0.0414	0.0255	0.0288
	(0.00281)	(0.00188)	(0.00204)
Average input share $\overline{s^m_{i\cdot,t}}$	0.0214	0.0245	0.0235
	(0.00243)	(0.00197)	(0.00195)
N	890228	863458	863458
Year FE	Yes	Yes	Yes
Sector FE	4-digit	No	No
Firm FE	No	Yes	Yes
Controls	Yes	No	Yes
R2	0.115	0.730	0.731

Note: Standard errors in parentheses. The coefficients are X-standardized. Standard errors are clustered at the NACE 2-digit-year level. The regression exclude outliers in the top and bottom 1 percent of the markup distribution. Controls include firms' number of suppliers, number of buyers, employment, total assets, and age.

To further account for more general production functions that do not necessary exhibit CRS, or to accommodate firms' fixed costs, we also recover markups following De Loecker and Warzynski (2012). The method first estimates the production function allowing for firms' usage of capital and also for the heterogeneity in production technology across sectors. Then it recovers firm-level markups over marginal costs through the wedge between the output elasticity of a variable input and its expenditure share out of total revenue.

We briefly describe the estimation procedure. When a firm is engaging in cost minimization under the existence of at least one flexible input X, the markup of firm i at time t can be expressed as

$$\mu_{it} = \theta_{it}^{X} \frac{p_{it}q_{it}}{p_{it}^{X} X_{it}},$$

where θ_{it}^{X} is firm i's output elasticity with respect to X, and $p_{it}^{X} X_{it}$ is the input value of X. As the input value share of the flexible input X is directly observed, it remains for us to estimate the value of θ_{it}^{X} to recover firm-level markups. In order to estimate the output elasticity, we assume a translog production function. We also assume that the technology parameters do not vary within sectors, thus we estimate the production function of manufacturing sector firms at the NACE 2-digit level. We also allow for measurement errors in the output. Therefore, the production function to estimate becomes

$$\begin{aligned} y_{it} =& \alpha_l l_{it} + \alpha_k k_{it} + \alpha_m m_{it} + \alpha_{ll} l_{it}^2 + \alpha_{kk} k_{it}^2 + \alpha_{mm} m_{it}^2 \\ &+ \alpha_{lk} l_{it} k_{it} + \alpha_{km} k_{it} m_{it} + \alpha_{lm} l_{it} m_{it} + \omega_{it} + \varepsilon_{it}, \end{aligned}$$

where y_{it}, l_{it}, k_{it}, and m_{it} denote gross output, labor, capital, and material inputs, all in logs. The estimates from a least squares model would be biased as firm productivity ω_{it} is unobserved, and is potentially correlated with the inputs of the firm, which results in biased estimates of the technology parameters $\boldsymbol{\alpha}$. To overcome this issue, we follow Levinsohn and Petrin (2003) and use a "proxy" method. We assume that the innovation process of the firm-level productivities follow:

$$\omega_{it} = g_t\left(\omega_{it-1}\right) + \xi_{it}.$$

We identify $\boldsymbol{\alpha}$ via the following moment conditions:

$$E\left[\xi_{it}\left(\boldsymbol{\alpha}\right) \boldsymbol{z}_{it}\right] = \mathbf{0},$$

where z_{it} is a vector of lagged input variables:

$$\begin{aligned} z_{it} = [&l_{it-1}, k_{it}, m_{it-1}, \\ &l_{it-1}^2, k_{it}^2, m_{it-1}^2, \\ &l_{it-1}k_{it}, k_{it}m_{it-1}, l_{it-1}m_{it-1}] \,. \end{aligned}$$

The underlying assumption is that capital inputs are chosen a period ahead, and should be orthogonal to the future innovations of productivity. For other inputs, it is assumed that lagged variables are orthogonal to productivity innovations, as they are already chosen by the firm.

We estimate $\boldsymbol{\alpha}$ via GMM, and recover θ_{it}^X by assuming that material inputs are flexible. As purchases from other Belgian firms may include sunk costs or investments in capital, we use the material input costs reported in the annual accounts.

B Theoretical results

B.1 Derivation of equation (14)

Consider firm j selling its goods to i. Firm j chooses p_{ji} to maximize profits, taking into account the effect of p_{ji} on i's price indices for its intermediate goods, p_{mi} and $p_{\nu(j)i}^m$. It takes as given i's unit cost and production, c_i, and q_i, as well as i's sourcing sets, Z_i and I_{Fi}. The firm's problem is as follows:

$$\begin{aligned} &\max_{p_{ji}} \left(p_{ji} - c_j\right) q_{ji} \\ &s.t. q_{ji} = \alpha_{ji}^{\sigma_{\nu(j)}} \alpha_{\nu(j)}^{\rho} p_{ji}^{-\sigma_{\nu(j)}} \left(p_{\nu(j)i}^m\right)^{\sigma_{\nu(j)}-1} \left(p_{\nu(j)i}^m\right)^{1-\rho} p_{mi}^{\rho} m_i \\ &m_i = \omega_m^{\eta} p_{mi}^{-\eta} \phi_i^{\eta-1} c_i^{\eta} q_i. \end{aligned}$$

Solving the above problem while taking into account that $\frac{\partial p_{mi}}{\partial p_{ji}} \neq 0$ and $\frac{\partial p_{\nu(j)i}^m}{\partial p_{ji}} \neq 0$ yields

$$\begin{aligned} p_{ji} &= \frac{\varepsilon_{ji}}{\varepsilon_{ji} - 1} c_j \\ \varepsilon_{ji} &= \sigma_{\nu(j)} \left(1 - s_{ji}^{\nu(j)}\right) + \rho s_{ji}^{\nu(j)} \left(1 - s_{\nu(j)i}^m\right) + \eta s_{ji}^{\nu(j)} s_{\nu(j)i}^m. \end{aligned}$$

B.2 Alternative market structures

In our model we assume the following when firms participate in firm-to-firm trade. When selling to firm i, firm j sets price p_{ji} by internalizing the effect of p_{ji} on j's price indices for its intermediate goods, p_{mi} and $p_{\nu(j)i}^m$. However, it takes as given i's unit cost and total production, c_i and q_i. This yields our pricing equation of

$$p_{ji} = \frac{\varepsilon_{ji}}{\varepsilon_{ji} - 1} c_j$$
$$\varepsilon_{ji} = \sigma_{v(j)} \left(1 - s_{ji}^{v(j)}\right) + \rho s_{ji}^{v(j)} \left(1 - s_{v(j)i}^{m}\right) + \eta s_{ji}^{v(j)} s_{v(j)i}^{m}.$$

In this section we discuss alternative market structures in firm-to-firm trade.

B.2.1 Cournot competition

Instead of assuming Bertrand competition one can alternatively assume that firms engage in Cournot competition, where firms set quantity q_{ji} to maximize variable profits. In that case, the demand elasticity that firm j faces, ε_{ji}, becomes a weighted harmonic mean of the CES parameters $\sigma_{v(j)}$, ρ, and η:

$$p_{ji} = \frac{\varepsilon_{ji}}{\varepsilon_{ji} - 1} c_j$$
$$\varepsilon_{ji}^{-1} = \frac{1}{\sigma_{v(j)}} \left(1 - s_{ji}^{v(j)}\right) + \frac{1}{\rho} s_{ji}^{v(j)} \left(1 - s_{v(j)i}^{m}\right) + \frac{1}{\eta} s_{ji}^{v(j)} s_{v(j)i}^{m}.$$

B.2.2 Fixed demand shifters of buyers

Next we consider a case where firm j takes as given the two demand shifters that firm i faces - one from sales to other firms (D_{iB}) and another from sales to final demand (D_{iH}):

$$q_i = c_i^{-\sigma_{u(i)}} D_{iB} + c_i^{-\sigma} D_{iH}.$$

When one solves this problem the pricing equation becomes

$$p_{ji} = \frac{\varepsilon_{ji}}{\varepsilon_{ji} - 1} c_j$$
$$\varepsilon_{ji} = \sigma_{v(j)} \left(1 - s_{ji}^{v(j)}\right) + \rho s_{ji}^{v(j)} \left(1 - s_{v(j)i}^{m}\right) + s_{ji}^{v(j)} s_{v(j)i}^{m} \left(\left(1 - s_{mi}\right) \eta + s_{mi} \left(s_{iB}^{q} \sigma_{u(i)} + s_{iH}^{q} \sigma\right)\right).$$

The term s_{iB}^{q} is the quantity output share of firm i's goods that were shipped to other firms, and the term s_{iH}^{q} is the quantity output share of firm i's goods that were shipped to final demand:

$$s_{iB}^{q} = \frac{c_i^{-\sigma_{u(i)}} D_{iB}}{q_i}$$
$$s_{iH}^{q} = \frac{c_i^{-\sigma} D_{iH}}{q_i} = 1 - s_{iB}^{q}.$$

This implies that the firm needs to know the quantity output shares of its buyers.

B.2.3 Constant demand elasticity for buyers' goods

We also consider a case where firm j does not know the output compositions of its buyer i, but assumes that i is facing a common demand elasticity of θ. In this case q_i can be written as

$$q_i = c_i^{-\theta} D_i,$$

in which firm j takes as given the demand shifter, D_i. When one solves the problem of firm j under this setup, the pricing equation becomes

$$p_{ji} = \frac{\varepsilon_{ji}}{\varepsilon_{ji} - 1} c_j$$
$$\varepsilon_{ji} = \sigma_{v(j)} \left(1 - s_{ji}^{v(j)}\right) + \rho s_{ji}^{v(j)} \left(1 - s_{v(j)i}^{m}\right) + s_{ji}^{v(j)} s_{v(j)i}^{m} \left((1 - s_{mi}) \eta + s_{mi}\theta\right).$$

Notice that if we additionally assume that $\theta = \eta$, the above equation collapses to equation (14).

B.3 System of equilibrium changes upon changes in markups

B.3.1 System of exact changes

In this section we take the observed firm-to-firm trade network, and present the system of equations that pins down changes in the equilibrium variables upon exogenous changes in $\left\{\hat{\mu}_{ij}\right\}$.

The total variable inputs observed in the data is denoted by $c_i q_i = wl_i + \sum_k V_{ki} + V_{Fi}$. Also denote total input cost of firm i implied from the model as $C_i = \sum_j \frac{V_{ij}}{\mu_{ij}} + \frac{V_{iH}}{\mu_{iH}} + \frac{V_{iF}}{\mu_{iH}}$. The difference between the two is denoted as $\xi_i = c_i q_i - C_i$. We take the error term in equation (21), $\epsilon_i = \frac{\xi_i}{c_i q_i}$, as constants. With this assumption, the changes in the observed inputs, $\widehat{c_i q_i}$, are equal to the changes in the model implied inputs, $\hat{C}_i$, and also to the changes in the difference between the two, $\hat{\xi}_i$. We also denote trade balance as TB and treat them as fixed.

We now have the following system of equations defining the equilibrium:

$$\begin{aligned}
E &= wL + \sum_i \pi_i - \sum_i \xi_i - TB \\
\pi_i &= \sum_{k \in W_i} \frac{\mu_{ik} - 1}{\mu_{ik}} V_{ik} + \frac{\mu_{iH} - 1}{\mu_{iH}} \left(V_{iH} + V_{iF}\right) \\
V_{ik} &= s_{ik}^{u(i)} s_{u(i)k}^{m} s_{mk} c_k q_k \\
V_{iH} &= s_{iH} E \\
V_{iF} &= \mu_{iH}^{1-\sigma} c_i^{1-\sigma} D^* \\
\xi_i &= c_i q_i - C_i \\
&= c_i q_i - \left(\frac{V_{iH}}{\mu_{iH}} + \frac{V_{iF}}{\mu_{iH}} + \sum_j \frac{V_{ij}}{\mu_{ij}} \right).
\end{aligned}$$

From this system, we then proceed with the following steps and compute the hat-variables upon $\hat{\mu}_{ij}$.

1. Guess the change in nominal wage, $\hat{w}$.

2. Compute the changes in prices with

$$\begin{aligned}
\hat{c}_i^{1-\eta} &= s_{li} \hat{w}^{1-\eta} + s_{mi} \hat{p}_{mi}^{1-\eta} \\
\hat{p}_{mi}^{1-\rho} &= \sum_v s_{vi}^m \left(\hat{p}_{vi}^m\right)^{1-\rho} + s_{Fi}^m \\
\left(\hat{p}_{vi}^m\right)^{1-\sigma_v} &= \sum_{j \in Z_i, j \in \mathscr{V}} s_{ji}^{v(j)} \hat{\mu}_{ji}^{1-\sigma_v} \hat{c}_j^{1-\sigma_{v(j)}}.
\end{aligned}$$

3. Compute other variables' changes with

$$\begin{aligned}
\hat{s}_{ji}^{v(j)} &= \hat{\mu}_{ji}^{1-\sigma_{v(j)}} \hat{c}_j^{1-\sigma_{v(j)}} \left(\hat{p}_{v(j)i}^m\right)^{\sigma_{v(j)}-1} \\
\hat{s}_{vi}^m &= \left(\hat{p}_{vi}^m\right)^{1-\rho} \hat{p}_{mi}^{\rho-1} \\
\hat{s}_{mi} &= \hat{p}_{mi}^{1-\eta} \hat{c}_i^{\eta-1} \\
\hat{s}_{li} &= \hat{w}^{1-\eta} \hat{c}_i^{\eta-1} \\
\hat{s}_{ji} &= \hat{s}_{ji}^{v(j)} \hat{s}_{v(j)i}^m \hat{s}_{mi} \\
\hat{P} &= \left(\sum_i s_{iH} \hat{c}_i^{1-\sigma} \right)^{\frac{1}{1-\sigma}} \\
\hat{s}_{iH} &= \hat{c}_i^{1-\sigma} \hat{P}^{\sigma-1} \\
\hat{V}_{iF} &= \hat{c}_i^{1-\sigma}.
\end{aligned}$$

4. Compute $\hat{C}_i$ from

$$\begin{aligned}
\hat{C}_i =& \frac{1}{C_i}\frac{V_{iH}}{\mu_{iH}}\hat{s}_{iH}\hat{E} + \frac{1}{C_i}\frac{V_{iF}}{\mu_{iH}}\hat{V}_{iF} + \frac{1}{C_i}\sum_j \frac{V_{ij}\hat{s}_{ij}}{\mu_{ij}\hat{\mu}_{ij}}\hat{C}_j \\
\hat{E} =& \frac{1}{1-\sum_i \frac{1}{E}\frac{\mu_{iH}-1}{\mu_{iH}}V_{iH}\hat{s}_{iH}} \\
& \times \left\{ \frac{wL}{E}\hat{w} - \frac{TB}{E} - \frac{\sum_i \xi_i \hat{C}_i}{E} + \sum_i \frac{\pi_i}{E}\left(\sum_k \frac{1}{\pi_i} V_{ik} \frac{\hat{\mu}_{ik}\mu_{ik}-1}{\hat{\mu}_{ik}\mu_{ik}}\hat{s}_{ik}\hat{C}_k + \frac{1}{\pi_i}\frac{\mu_{iH}-1}{\mu_{iH}}V_{iF}\hat{V}_{iF} \right) \right\}.
\end{aligned}$$

5. Update $\hat{w}$ from

$$\hat{w} = \frac{1}{wL}\sum_i s_{li}c_i q_i \hat{s}_{li}\hat{C}_i,$$

and iterate from Step 1 until $\hat{w}$ converges.

B.3.2 System of first-order approximated changes

We take the system of equilibrium changes in the previous section and solve for the first-order approximated changes. Now we denote the shock with $\left\{\frac{\mathrm{d}\mu_{ij}}{\mu_{ij}}\right\}$.

1. Guess the change in nominal wage, $\frac{\mathrm{d}w}{w}$.

2. Compute the changes in prices with

$$\frac{\mathrm{d}c_i}{c_i} = s_{li}\frac{\mathrm{d}w}{w} + \sum_{j\in Z_i} s_{ji}\left(\frac{\mathrm{d}\mu_{ji}}{\mu_{ji}} + \frac{\mathrm{d}c_j}{c_j}\right).$$

3. Compute other variables' changes with

$$
\begin{aligned}
\frac{\mathrm{d}p^m_{vi}}{p^m_{vi}} &= \sum_{j\in Z_i, j\in\mathscr{V}} s^{v(j)}_{ji}\left(\frac{\mathrm{d}\mu_{ji}}{\mu_{ji}} + \frac{\mathrm{d}c_j}{c_j}\right)\\
\frac{\mathrm{d}p_{mi}}{p_{mi}} &= \sum_v s^m_{vi}\frac{\mathrm{d}p^m_{vi}}{p^m_{vi}}\\
\frac{\mathrm{d}s^{v(j)}_{ji}}{s^{v(j)}_{ji}} &= (1-\sigma_v)\left(\frac{\mathrm{d}\mu_{ji}}{\mu_{ji}} + \frac{\mathrm{d}c_j}{c_j} - \frac{\mathrm{d}p^m_{v(j)i}}{p^m_{v(j)i}}\right)\\
\frac{\mathrm{d}s^m_{vi}}{s^m_{vi}} &= (1-\rho)\left(\frac{\mathrm{d}p^m_{vi}}{p^m_{vi}} - \frac{\mathrm{d}p_{mi}}{p_{mi}}\right)\\
\frac{\mathrm{d}s_{mi}}{s_{mi}} &= (1-\eta)\left(\frac{\mathrm{d}p_{mi}}{p_{mi}} - \frac{\mathrm{d}c_i}{c_i}\right)\\
\frac{\mathrm{d}s_{li}}{s_{li}} &= (1-\eta)\left(\frac{\mathrm{d}w}{w} - \frac{\mathrm{d}c_i}{c_i}\right)\\
\frac{\mathrm{d}s_{ji}}{s_{ji}} &= \frac{\mathrm{d}s^{v(j)}_{ji}}{s^{v(j)}_{ji}} + \frac{\mathrm{d}s^m_{v(j)i}}{s^m_{v(j)i}} + \frac{\mathrm{d}s_{mi}}{s_{mi}}\\
\frac{\mathrm{d}P}{P} &= \sum_i s_{iH}\frac{\mathrm{d}c_i}{c_i}\\
\frac{\mathrm{d}s_{iH}}{s_{iH}} &= (1-\sigma)\left(\frac{\mathrm{d}c_i}{c_i} - \frac{\mathrm{d}P}{P}\right)\\
\frac{\mathrm{d}V_{iF}}{V_{iF}} &= (1-\sigma)\,\frac{\mathrm{d}c_i}{c_i}.
\end{aligned}
$$

4. Compute $\frac{\mathrm{d}C_i}{C_i}$ from

$$
\begin{aligned}
\frac{\mathrm{d}C_i}{C_i} =& \frac{1}{C_i}\frac{V_{iH}}{\mu_{iH}}\left(\frac{\mathrm{d}s_{iH}}{s_{iH}} + \frac{\mathrm{d}E}{E}\right) + \frac{1}{C_i}\frac{V_{iF}}{\mu_{iH}}\frac{\mathrm{d}V_{iF}}{V_{iF}} + \frac{1}{C_i}\sum_j \frac{V_{ij}}{\mu_{ij}}\left(\frac{\mathrm{d}s_{ij}}{s_{ij}} - \frac{\mathrm{d}\mu_{ij}}{\mu_{ij}} + \frac{\mathrm{d}C_j}{C_j}\right)\\
\frac{\mathrm{d}E}{E} =& \frac{1}{E}\frac{1}{1-\sum_k \frac{1}{E}\frac{\mu_{kH}-1}{\mu_{kH}}V_{kH}}\times\\
& \left\{\sum_i \frac{\mu_{iH}-1}{\mu_{iH}}V_{iH}\frac{\mathrm{d}s_{iH}}{s_{iH}} + wL\frac{\mathrm{d}w}{w} - \sum_i \xi_i\frac{\mathrm{d}C_i}{C_i}\right.\\
& \left. + \sum_i\left(\sum_k V_{ik}\frac{\mu_{ik}-1}{\mu_{ik}}\left(\frac{1}{\mu_{ik}-1}\frac{\mathrm{d}\mu_{ik}}{\mu_{ik}} + \frac{\mathrm{d}s_{ik}}{s_{ik}} + \frac{\mathrm{d}C_k}{C_k}\right) + \frac{\mu_{iH}-1}{\mu_{iH}}V_{iF}\frac{\mathrm{d}V_{iF}}{V_{iF}}\right)\right\}
\end{aligned}
$$

5. Update $\frac{\mathrm{d}w}{w}$ from

$$
\frac{\mathrm{d}w}{w} = \frac{1}{wL}\sum_i wl_i\left(\frac{\mathrm{d}s_{li}}{s_{li}} + \frac{\mathrm{d}C_i}{C_i}\right),
$$

and iterate from Step 1 until $\frac{\mathrm{d}w}{w}$ converges.

B.4 System of equilibrium changes upon changes in markups, sectoral roundabout production network

We also consider a sectoral roundabout production network that is consistent with the observed firm-level data, and present the system of equations that pins down changes in the equilibrium variables upon exogenous changes in markups. We consider a network where there two distinct composite goods, one of which is used as intermediate goods and another of which is used as a final consumption good. The cost function for firm i is expressed by equation (20). As in the previous section, the total variable inputs observed in the data is denoted by $c_i q_i = wl_i + \sum_k V_{ki} + V_{Fi}$, and the total input cost of firm i implied from the model is denoted as $C_i = \sum_j \frac{V_{ij}}{\mu_{iB}} + \frac{V_{iH}}{\mu_{iH}} + \frac{V_{iF}}{\mu_{iH}}$. The difference between the two is denoted as $\xi_i = c_i q_i - C_i$. We also assume that the error terms in the estimating equation (22), $\epsilon_i = \frac{\xi_i}{c_i q_i}$, are constants. Therefore we have $\hat{\xi}_i = \widehat{c_i q_i} = \hat{C}_i$.

We assume that firms charge constant markups $\mu_{iH_R} = \frac{\sigma}{\sigma-1}$ to the composite goods used for final consumption. In the intermediate goods market, firms now charge firm-level markups, μ_{iB_R}. We set these firm-level markups, μ_{iB_R}, to be consistent with the average markups firms charge on intermediate goods sales in our baseline model, $\mu_{iB_R} = \frac{\sum_j p_{ij} q_{ij}}{c_i q_i - \frac{p_{iH} q_{iH} + p_{iF} q_{iF}}{\mu_{iH_R}}}$. These assumptions make markups at the firm-level consistent with the baseline model with variable markups. We take the reduction in the markups that firms charge to the composite good used for intermediate inputs, $\hat{\mu}_{iB_R}$, as the shock.

Denote the share of sector v goods in the domestic intermediate input bundle for sector u as $s_{vu} = \frac{\sum_{i \in v} \sum_{j \in u} V_{ij}}{\sum_k \sum_{j \in u} V_{kj}}$. Also denote $s^B_{iu(i)}$ as firm i's share of sales to other firms, among other firms in the same sector.

1. Guess the change in nominal wage, $\hat{w}$.

2. Compute the changes in prices with

$$\begin{aligned}
\hat{c}_i^{1-\eta} &= s_{li} \hat{w}^{1-\eta} + s_{mi} \hat{p}_{mi}^{1-\eta} \\
\hat{p}_{mi}^{1-\rho} &= s^m_{Di} \sum_v s_{vu(i)} \hat{P}_{vB}^{1-\rho} + s^m_{Fi} \\
\hat{P}_{v(j)B}^{1-\sigma_{v(j)}} &= \sum_{j \in \mathcal{V}} s^B_{jv(j)} \hat{\mu}_{jB_R}^{1-\sigma_{v(j)}} \hat{c}_j^{1-\sigma_{v(j)}}.
\end{aligned}$$

3. Compute other variables' changes with

$$
\begin{aligned}
\hat{s}^m_{Di} &= \left(\sum_v s_{vu(i)} \hat{P}^{1-\rho}_{vB}\right) \hat{p}^{\rho-1}_{mi} \\
\hat{s}_{vu(i)} &= \hat{P}^{1-\rho}_{vB} \left(\sum_v s_{vu(i)} \hat{P}^{1-\rho}_{vB}\right)^{-1} \\
\hat{s}_{mi} &= \hat{p}^{1-\eta}_{mi} \hat{c}^{\eta-1}_i \\
\hat{s}_{li} &= \hat{w}^{1-\eta} \hat{c}^{\eta-1}_i \\
\hat{s}^B_{iu(i)} &= \hat{\mu}^{1-\sigma_{u(i)}}_{iB_R} \hat{c}^{1-\sigma_{u(i)}}_i \hat{P}^{\sigma_{u(i)}-1}_{u(i)B} \\
\hat{P} &= \left(\sum_i s_{iH} \hat{c}^{1-\sigma}_i\right)^{\frac{1}{1-\sigma}} \\
\hat{s}_{iH} &= \hat{c}^{1-\sigma}_i \hat{P}^{\sigma-1} \\
\hat{V}_{iF} &= \hat{c}^{1-\sigma}_i.
\end{aligned}
$$

4. Compute $\hat{C}_i$ from

$$
\begin{aligned}
\hat{C}_i =& \frac{1}{C_i} \frac{s_{iH} E}{\mu_{iH_R}} \hat{s}_{iH} \hat{E} + \frac{1}{C_i} \frac{s^B_{iu(i)} \hat{s}^B_{iu(i)}}{\mu_{iB_R} \hat{\mu}_{iB_R}} \left(\sum_v s_{u(i)v} \hat{s}_{u(i)v} \sum_{j \in v} V_{Dj} \hat{s}^m_{Dj} \hat{s}_{mj} \hat{C}_j\right) + \frac{1}{C_i} \frac{V_{iF}}{\mu_{iH_R}} \hat{V}_{iF} \\
\hat{E} =& \frac{1}{1 - \sum_i \frac{\mu_{iH_R}-1}{\mu_{iH_R}} s_{iH} \hat{s}_{iH}} \\
& \times \left\{ \frac{wL}{E} \hat{w} + \frac{1}{E} \sum_i \frac{\mu_{iB_R} \hat{\mu}_{iB_R} - 1}{\mu_{iB_R} \hat{\mu}_{iB_R}} s^B_{iu(i)} \hat{s}^B_{iu(i)} \left(\sum_v s_{u(i)v} \hat{s}_{u(i)v} \sum_{j \in v} V_{Dj} \hat{s}^m_{Dj} \hat{s}_{mj} \hat{C}_j\right) \right. \\
& \left. + \frac{1}{E} \sum_i \frac{\mu_{iH_R} - 1}{\mu_{iH_R}} V_{iF} \hat{V}_{iF} - \frac{TB}{E} - \frac{\sum_i \xi_i \hat{C}_i}{E} \right\}
\end{aligned}
$$

5. Update $\hat{w}$ from

$$
\hat{w} = \frac{1}{wL} \sum_i w l_i \hat{s}_{li} \hat{C}_i,
$$

and iterate from Step 1 until $\hat{w}$ converges.

B.5 System of equilibrium changes upon changes in the foreign price

Here we present the system of equations that pins down changes in the equilibrium variables upon an exogenous change in the price of foreign goods, $\hat{p}_F$.

B.5.1 System of exact changes

First we present the system under endogenous markups. Unlike the system in Appendix B.3, markups $\{\mu_{ij}\}$ are endogenous variables. In this section, we assume that the error terms in the estimating equation (22), $\epsilon_i = \frac{\xi_i}{c_i q_i}$, are constants. Therefore we have $\hat{\xi}_i = \widehat{c_i q_i} = \hat{C}_i$.

We first focus on the exact changes, and follow the steps below.

1. Guess the change in nominal wage, $\hat{w}$.

2. Compute the changes in prices and shares with

$$
\begin{aligned}
\hat{c}_i^{1-\eta} &= s_{li}\hat{w}^{1-\eta} + s_{mi}\hat{p}_{mi}^{1-\eta} \\
\hat{p}_{mi}^{1-\rho} &= \sum_v s_{vi}^m \left(\hat{p}_{vi}^m\right)^{1-\rho} + s_{Fi}^m \hat{p}_F^{1-\rho} \\
\left(\hat{p}_{vi}^m\right)^{1-\sigma_v} &= \sum_{j\in Z_i, j\in\mathscr{V}} s_{ji}^{v(j)} \hat{\mu}_{ji}^{1-\sigma_v} \hat{c}_j^{1-\sigma_v} \\
\hat{\mu}_{ji} &= \hat{\varepsilon}_{ji} \frac{\varepsilon_{ji} - 1}{\hat{\varepsilon}_{ji}\varepsilon_{ji} - 1} \\
\varepsilon_{ji} &= \sigma_{v(j)}\left(1 - s_{ji}^{v(j)}\right) + \rho s_{ji}^{v(j)}\left(1 - s_{v(j)i}^m\right) + \eta s_{ji}^{v(j)} s_{v(j)i}^m \\
\hat{\varepsilon}_{ji} &= \frac{1}{\varepsilon_{ji}}\left(\sigma_{v(j)}\left(1 - s_{ji}^{v(j)}\hat{s}_{ji}^{v(j)}\right) + \rho s_{ji}^{v(j)}\hat{s}_{ji}^{v(j)}\left(1 - s_{v(j)i}^m \hat{s}_{v(j)i}^m\right) + \eta s_{ji}^{v(j)} s_{v(j)i}^m \hat{s}_{ji}^{v(j)} \hat{s}_{v(j)i}^m\right) \\
\hat{s}_{ji}^{v(j)} &= \hat{\mu}_{ji}^{1-\sigma_{v(j)}} \hat{c}_j^{1-\sigma_{v(j)}} \left(\hat{p}_{v(j)i}^m\right)^{\sigma_{v(j)}-1} \\
\hat{s}_{vi}^m &= \left(\hat{p}_{vi}^m\right)^{1-\rho} \hat{p}_{mi}^{\rho-1}.
\end{aligned}
$$

3. Compute other changes in prices and shares with

$$
\begin{aligned}
\hat{s}_{mi} &= \hat{p}_{mi}^{1-\eta}\hat{c}_i^{\eta-1} \\
\hat{s}_{li} &= \hat{w}^{1-\eta}\hat{c}_i^{\eta-1} \\
\hat{s}_{ji} &= \hat{s}_{ji}^{v(j)} \hat{s}_{v(j)i}^m \hat{s}_{mi} \\
\hat{P} &= \left(\sum_i s_{iH}\hat{c}_i^{1-\sigma}\right)^{\frac{1}{1-\sigma}} \\
\hat{s}_{iH} &= \hat{c}_i^{1-\sigma}\hat{P}^{\sigma-1} \\
\hat{V}_{iF} &= \hat{c}_i^{1-\sigma}.
\end{aligned}
$$

4. Compute $\hat{C}_i$ from

$$\hat{C}_i = \frac{1}{C_i}\frac{V_{iH}}{\mu_{iH}}\hat{s}_{iH}\hat{E} + \frac{1}{C_i}\frac{V_{iF}}{\mu_{iH}}\hat{V}_{iF} + \frac{1}{C_i}\sum_j \frac{V_{ij}\hat{s}_{ij}}{\mu_{ij}\hat{\mu}_{ij}}\hat{C}_j$$

$$\hat{E} = \frac{1}{1 - \sum_i \frac{1}{E}\frac{\mu_{iH}-1}{\mu_{iH}} V_{iH}\hat{s}_{iH}} \times \left\{ \frac{wL}{E}\hat{w} - \sum_i \frac{\xi_i}{E}\hat{C}_i - \frac{TB}{E} + \sum_i \frac{\pi_i}{E}\left(\sum_k \frac{1}{\pi_i} V_{ik}\frac{\hat{\mu}_{ik}\mu_{ik}-1}{\hat{\mu}_{ik}\mu_{ik}}\hat{s}_{ik}\hat{C}_k + \frac{1}{\pi_i}\frac{\mu_{iH}-1}{\mu_{iH}} V_{iF}\hat{V}_{iF} \right) \right\}.$$

5. Update $\hat{w}$ from

$$\hat{w} = \frac{1}{wL}\sum_i s_{li}c_i q_i \hat{s}_{li}\hat{C}_i,$$

and iterate from Step 1 until $\hat{w}$ converges.

B.5.2 System of first-order approximated changes

We then turn to the system of first-order approximated changes. Taking first order approximations of the system presented in the previous section, we obtain the following steps.

1. Guess the change in nominal wage, $\frac{\mathrm{d}w}{w}$.

2. Compute the changes in prices and markups with

$$\frac{\mathrm{d}c_i}{c_i} = s_{li}\frac{\mathrm{d}w}{w} + \sum_{j\in Z_i} s_{ji}\left(\frac{\mathrm{d}\mu_{ji}}{\mu_{ji}} + \frac{\mathrm{d}c_j}{c_j}\right) + s_{Fi}\frac{\mathrm{d}p_F}{p_F}$$

$$\frac{\mathrm{d}\mu_{ji}}{\mu_{ji}} = -\Gamma_{ji}\frac{\mathrm{d}c_j}{c_j} + \Gamma_{ji}\frac{\mathrm{d}p_{\not{j}i}}{p_{\not{j}i}},$$

where Γ_{ji} equals the elasticity of markup μ_{ji} with respect to the supplier's cost c_j:

$$\Gamma_{ji} = -\frac{\partial \mu_{ji}}{\partial c_j}\frac{c_j}{\mu_{ji}} = \frac{\Upsilon_{ji}}{1+\Upsilon_{ji}}$$

$$\Upsilon_{ji} = \frac{\left(\varepsilon_{ji} - \sigma_{v(j)}\right)\left(1-\sigma_{v(j)}\right)\left(1 - s_{ji}^{v(j)}\right) + s_{ji}^{v(j)}(\eta-\rho)(1-\rho)\, s_{ji}^{v(j)}\left(1 - s_{v(j)i}^{m}\right) s_{v(j)i}^{m}}{\varepsilon_{ji}\left(\varepsilon_{ji}-1\right)}.$$

The term $\frac{\mathrm{d}p_{\not{j}i}}{p_{\not{j}i}}$ is expressed as:

$$\frac{\mathrm{d}p_{\not{j}i}}{p_{\not{j}i}} = \frac{\Upsilon_{\cdot i}^{\cdot\in\mathscr{V}(j)}}{\Upsilon_{ji}}\sum_{k\in\mathscr{V}(j),k\neq j} s_{ki}^{v(j)}\left(\frac{\mathrm{d}\mu_{ki}}{\mu_{ki}} + \frac{\mathrm{d}c_k}{c_k}\right) + \frac{\Upsilon_{\cdot i}^{\mathscr{U}(\cdot)\neq v(j)}}{\Upsilon_{ji}}\left(\sum_{k\in\mathscr{U},u\neq v(j)} s_{ki}^{m}\left(\frac{\mathrm{d}\mu_{ki}}{\mu_{ki}} + \frac{\mathrm{d}c_k}{c_k}\right) + s_{Fi}^{m}\frac{\mathrm{d}p_F}{p_F}\right)$$

where

$$\Upsilon_{\cdot i}^{\cdot\in\mathscr{V}(j)} = \frac{\left(\varepsilon_{ji} - \sigma_{v(j)}\right)\left(1 - \sigma_{v(j)}\right) - (\eta - \rho)(1 - \rho)\, s_{ji}^{v(j)} \left(1 - s_{v(j)i}^{m}\right) s_{v(j)i}^{m}}{\varepsilon_{ji}\left(\varepsilon_{ji} - 1\right)}$$

$$\Upsilon_{\cdot i}^{\mathscr{U}(\cdot)\neq v(j)} = \frac{s_{ji}^{v(j)} (\eta - \rho)(1 - \rho)\, s_{v(j)i}^{m}}{\varepsilon_{ji}\left(\varepsilon_{ji} - 1\right)}.$$

$\frac{\mathrm{d}p_{\not{j}i}}{p_{\not{j}i}}$ is the weighted average of the price changes of i's suppliers other than j, with suppliers in the same sector as j's sector ($k \in \mathscr{V}(j), k \neq j$) and suppliers in different sectors as j's sector ($k \in \mathscr{U}, u \neq v(j)$) having different elasticity weights.[43]

3. Compute other changes in prices and shares with

$$\frac{\mathrm{d}p_{vi}^{m}}{p_{vi}^{m}} = \sum_{j\in Z_i, j\in\mathscr{V}} s_{ji}^{v(j)} \left(\frac{\mathrm{d}\mu_{ji}}{\mu_{ji}} + \frac{\mathrm{d}c_j}{c_j}\right)$$

$$\frac{\mathrm{d}p_{mi}}{p_{mi}} = \sum_{v} s_{vi}^{m} \frac{\mathrm{d}p_{vi}^{m}}{p_{vi}^{m}} + s_{Fi}^{m} \frac{\mathrm{d}p_F}{p_F}$$

$$\frac{\mathrm{d}s_{ji}^{v(j)}}{s_{ji}^{v(j)}} = (1 - \sigma_v)\left(\frac{\mathrm{d}\mu_{ji}}{\mu_{ji}} + \frac{\mathrm{d}c_j}{c_j} - \frac{\mathrm{d}p_{vi}^{m}}{p_{vi}^{m}}\right)$$

$$\frac{\mathrm{d}s_{vi}^{m}}{s_{vi}^{m}} = (1 - \rho)\left(\frac{\mathrm{d}p_{vi}^{m}}{p_{vi}^{m}} - \frac{\mathrm{d}p_{mi}}{p_{mi}}\right)$$

$$\frac{\mathrm{d}s_{mi}}{s_{mi}} = (1 - \eta)\left(\frac{\mathrm{d}p_{mi}}{p_{mi}} - \frac{\mathrm{d}c_i}{c_i}\right)$$

$$\frac{\mathrm{d}s_{li}}{s_{li}} = (1 - \eta)\left(\frac{\mathrm{d}w}{w} - \frac{\mathrm{d}c_i}{c_i}\right)$$

$$\frac{\mathrm{d}s_{ji}}{s_{ji}} = \frac{\mathrm{d}s_{ji}^{v(j)}}{s_{ji}^{v(j)}} + \frac{\mathrm{d}s_{v(j)i}^{m}}{s_{v(j)i}^{m}} + \frac{\mathrm{d}s_{mi}}{s_{mi}}$$

$$\frac{\mathrm{d}P}{P} = \sum_{i} s_{iH} \frac{\mathrm{d}c_i}{c_i}$$

$$\frac{\mathrm{d}s_{iH}}{s_{iH}} = (1 - \sigma)\left(\frac{\mathrm{d}c_i}{c_i} - \frac{\mathrm{d}P}{P}\right)$$

$$\frac{\mathrm{d}V_{iF}}{V_{iF}} = (1 - \sigma)\frac{\mathrm{d}c_i}{c_i}.$$

[43]For illustration, consider a single-sector model where we impose $\sigma_u = \rho$. Then we obtain $\Upsilon_{ji} = \frac{(\varepsilon_{ji}-\rho)(1-\rho)\left(1-s_{ji}^{m}\right)}{\varepsilon_{ji}\left(\varepsilon_{ji}-1\right)}$ and $\frac{\mathrm{d}p_{\not{j}i}}{p_{\not{j}i}} = \frac{1}{1-s_{ji}^{m}}\left(\sum_{k\neq j} s_{ki}^{m}\left(\frac{\mathrm{d}\mu_{ki}}{\mu_{ki}} + \frac{\mathrm{d}c_k}{c_k}\right) + s_{Fi}^{m}\frac{\mathrm{d}p_F}{p_F}\right)$.

4. Compute $\frac{\mathrm{d}C_i}{C_i}$ from

$$
\begin{aligned}
\frac{\mathrm{d}C_i}{C_i} =& \frac{1}{C_i}\frac{V_{iH}}{\mu_{iH}}\left(\frac{\mathrm{d}s_{iH}}{s_{iH}} + \frac{\mathrm{d}E}{E}\right) + \frac{1}{C_i}\frac{V_{iF}}{\mu_{iH}}\frac{\mathrm{d}V_{iF}}{V_{iF}} + \frac{1}{C_i}\sum_j \frac{V_{ij}}{\mu_{ij}}\left(\frac{\mathrm{d}s_{ij}}{s_{ij}} - \frac{\mathrm{d}\mu_{ij}}{\mu_{ij}} + \frac{\mathrm{d}C_j}{C_j}\right) \\
\frac{\mathrm{d}E}{E} =& \frac{1}{E}\frac{1}{1-\sum_k \frac{1}{E}\frac{\mu_{kH}-1}{\mu_{kH}}V_{kH}} \times \\
& \left\{\sum_i \frac{\mu_{iH}-1}{\mu_{iH}}V_{iH}\frac{\mathrm{d}s_{iH}}{s_{iH}} + wL\frac{\mathrm{d}w}{w} - \sum_i \xi_i \frac{\mathrm{d}C_i}{C_i}\right. \\
& \left. + \sum_i \left(\sum_k V_{ik}\frac{\mu_{ik}-1}{\mu_{ik}}\left(\frac{1}{\mu_{ik}-1}\frac{\mathrm{d}\mu_{ik}}{\mu_{ik}} + \frac{\mathrm{d}s_{ik}}{s_{ik}} + \frac{\mathrm{d}C_k}{C_k}\right) + \frac{\mu_{iH}-1}{\mu_{iH}}V_{iF}\frac{\mathrm{d}V_{iF}}{V_{iF}}\right)\right\}
\end{aligned}
$$

5. Update $\frac{\mathrm{d}w}{w}$ from
$$
\frac{\mathrm{d}w}{w} = \frac{1}{wL}\sum_i wl_i\left(\frac{\mathrm{d}s_{li}}{s_{li}} + \frac{\mathrm{d}C_i}{C_i}\right).
$$

B.6 System of equilibrium changes upon changes in the foreign price, fixed markups

Now we consider the system under fixed markups, where firms charge heterogeneous markups of μ_{ij} and μ_{iH} as in the baseline economy. We back-out these markups as we do for the baseline economy, but treat them as fixed in the counterfactual exercise. As in the previous section, we assume that the error terms in the estimating equation (22), $\epsilon_i = \frac{\xi_i}{c_i q_i}$, are constants.

1. Guess the change in nominal wage, $\hat{w}$.

2. Compute the changes in prices and shares with

$$
\begin{aligned}
\hat{c}_i^{1-\eta} &= s_{li}\hat{w}^{1-\eta} + s_{mi}\hat{p}_{mi}^{1-\eta} \\
\hat{p}_{mi}^{1-\rho} &= \sum_v s_{vi}^m (\hat{p}_{vi}^m)^{1-\rho} + s_{Fi}^m \hat{p}_F^{1-\rho} \\
(\hat{p}_{vi}^m)^{1-\sigma_v} &= \sum_{j\in Z_i, j\in\mathscr{V}} s_{ji}^{v(j)}\hat{c}_j^{1-\sigma_v}.
\end{aligned}
$$

3. Compute other changes in prices and shares with

$$\begin{aligned}
\hat{s}_{ji}^{v(j)} &= \hat{c}_j^{1-\sigma_{v(j)}} \left(\hat{p}_{v(j)i}^m\right)^{\sigma_{v(j)}-1} \\
\hat{s}_{vi}^m &= \left(\hat{p}_{vi}^m\right)^{1-\rho} \hat{p}_{mi}^{\rho-1}. \\
\hat{s}_{mi} &= \hat{p}_{mi}^{1-\eta} \hat{c}_i^{\eta-1} \\
\hat{s}_{li} &= \hat{w}^{1-\eta} \hat{c}_i^{\eta-1} \\
\hat{s}_{ji} &= \hat{s}_{ji}^{v(j)} \hat{s}_{v(j)i}^m \hat{s}_{mi} \\
\hat{P} &= \left(\sum_i s_{iH} \hat{c}_i^{1-\sigma}\right)^{\frac{1}{1-\sigma}} \\
\hat{s}_{iH} &= \hat{c}_i^{1-\sigma} \hat{P}^{\sigma-1} \\
\hat{V}_{iF} &= \hat{c}_i^{1-\sigma}.
\end{aligned}$$

4. Compute $\hat{C}_i$ from

$$\begin{aligned}
\hat{C}_i =& \frac{1}{C_i} \frac{V_{iH}}{\mu_{iH}} \hat{s}_{iH} \hat{E} + \frac{1}{C_i} \frac{V_{iF}}{\mu_{iH}} \hat{V}_{iF} + \frac{1}{C_i} \sum_j \frac{V_{ij}}{\mu_{ij}} \hat{s}_{ij} \hat{C}_j \\
\hat{E} =& \frac{1}{1 - \sum_i \frac{1}{E} \frac{\mu_{iH}-1}{\mu_{iH}} V_{iH} \hat{s}_{iH}} \\
& \times \left\{ \frac{wL}{E} \hat{w} - \sum_i \frac{\xi_i}{E} \hat{C}_i - \frac{TB}{E} + \sum_i \frac{\pi_i}{E} \left(\sum_k \frac{1}{\pi_i} \frac{\mu_{ik}-1}{\mu_{ik}} V_{ik} \hat{s}_{ik} \hat{C}_k + \frac{1}{\pi_i} \frac{\mu_{iH}-1}{\mu_{iH}} V_{iF} \hat{V}_{iF} \right) \right\}.
\end{aligned}$$

5. Update $\hat{w}$ from

$$\hat{w} = \frac{1}{wL} \sum_i s_{li} c_i q_i \hat{s}_{li} \hat{C}_i,$$

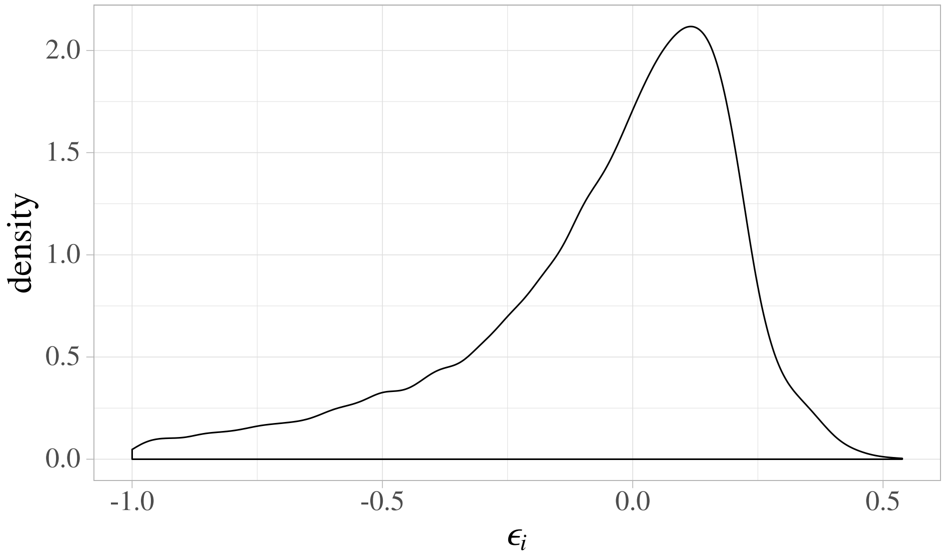
and iterate from Step 1 until $\hat{w}$ converges.

C Additional estimation results

C.1 Distribution of errors

Figure 13 plots distribution of firm-level errors, ϵ_i, from equation (21) under the estimated CES parameters. The density plot is truncated at $\epsilon_i = -1$. Under the estimated parameters, firms in the positive region of ϵ_i are purchasing more inputs than they need in order to produce their observed outputs, and firms in the negative region of ϵ_i are selling more outputs than what is implied from their observed inputs.

Figure 13: Distribution of ϵ_i



Note: The figure displays the distribution of firm-level errors, ϵ_i, from equation (21).

C.2 Assuming Cournot competition

When assuming Cournot competition in firm-to-firm trade instead, equation (14) becomes

$$p_{ji} = \frac{\varepsilon_{ji}}{\varepsilon_{ji} - 1} c_j$$
$$\varepsilon_{ji} = \left(\frac{1}{\sigma_{v(j)}} \left(1 - s_{ji}^{v(j)}\right) + \frac{1}{\rho} s_{ji}^{v(j)} \left(1 - s_{v(j)i}^{m}\right) + \frac{1}{\eta} s_{ji}^{v(j)} s_{v(j)i}^{m} \right)^{-1}.$$

We follow the same procedure described in Section 4 and obtain the estimates shown in Table 23.

Table 23: Estimated CES parameters under Cournot competition

(a) η, ρ, and σ

	$\frac{1}{\eta}$	$\frac{1}{\rho}$	$\frac{\sigma}{\sigma-1}$
Estimate	0.47	0.45	1.28
s.e.	0.11	0.10	0.05
	η (Labor and goods)	ρ (Sectoral goods and imports in production)	σ (Firms' goods in consumption)
Implied value	2.12	2.22	4.55

(b) Sectoral estimates of σ_u

Description of sector	Estimate	s.e.
Agriculture, forestry, and fishing	2.44	0.29
Mining and quarrying	2.33	0.30
Manufacture of food products, beverages, and tobacco products	3.41	0.48
Manufacture of textiles, apparel, leather, and related products	2.22	0.27
Manufacture of wood and paper products, and printing	3.05	0.41
Manufacture of coke, refined petroleum products, chemicals, and chemical products	2.69	0.35
Manufacture of pharmaceuticals, medicinal chemical, and botanical products	4.25	0.70
Manufacture of rubber and plastics products, and other non-metallic mineral products	3.48	0.50
Manufacture of basic metals and fabricated metal products, except machinery and equipment	2.97	0.39
Manufacture of computer, electronic, and optical products	2.31	0.28
Manufacture of electrical equipment	3.53	0.52
Manufacture of machinery and equipment n.e.c.	2.92	0.39
Manufacture of transport equipment	2.36	0.33
Other manufacturing, and repair and installation of machinery and equipment	2.36	0.27
Electricity, gas, steam and air-conditioning supply	2.08	0.47
Water supply, sewerage, waste management, and remediation	2.26	0.26
Construction	3.65	0.52
Wholesale and retail trade, repair of motor vehicles and motorcycles	2.27	0.25
Transportation and storage	2.98	0.39
Accommodation and food service activities	3.67	0.53
Publishing, audiovisual and broadcasting activities	2.48	0.30
Telecommunications	2.04	0.22
IT and other information services	2.21	0.24
Real estate activities	1.69	0.15
Legal, accounting, management, architecture, engineering, technical testing, and analysis activities	1.68	0.14
Scientific research and development	4.90	0.83
Other professional, scientific and technical activities	2.54	0.31
Administrative and support service activities	2.38	0.28
Other services	2.53	0.32

Note: Standard errors are based on 25 bootstrap samples drawn with replacements. The samples are drawn at the firm-level for each sector.

C.3 Accounting for capital inputs

In the model, total input $c_i q_i$ is an aggregate of labor costs and goods purchases. Here we account for capital inputs by interpreting labor as the composite input of labor and capital. As we do not directly observe capital rental costs for each firm, we take two alternate approaches.

First, we assume that firms have common labor shares, and uniformly scale up labor cost. We use the aggregate labor share of $2/3$ that we compute as the total labor cost divided by the total value added. Second, we assume that the user cost of capital consists of capital depreciation rate and the interest rate. Following Dhyne, Petrin, Smeets, and Warzynski (2017), we set the yearly depreciation rate as 8 percent and set the interest rate as the long-term interest rate in Belgium. We compute the capital rental costs using fixed tangible assets reported in the annual accounts. We report the estimation results in Table 24.

Table 24: Estimated CES parameters accounting for capital

(a) η, ρ, and σ

	η (Labor and goods)	ρ (Sectoral goods and imports in production)	σ (Firms' goods in consumption)
Common labor share	2.05	3.03	5.29
Annual accounts	1.63	2.55	4.79

(b) Sectoral estimates of σ_u

Description of sector	Common labor share	Annual accounts
Agriculture, forestry, and fishing	3.07	3.57
Mining and quarrying	2.66	2.59
Manufacture of food products, beverages, and tobacco products	4.97	3.73
Manufacture of textiles, apparel, leather, and related products	3.23	2.27
Manufacture of wood and paper products, and printing	4.79	3.48
Manufacture of coke, refined petroleum products, chemicals, and chemical products	3.51	2.90
Manufacture of pharmaceuticals, medicinal chemical, and botanical products	10.26	5.73
Manufacture of rubber and plastics products, and other non-metallic mineral products	5.33	4.23
Manufacture of basic metals and fabricated metal products, except machinery and equipment	4.69	3.36
Manufacture of computer, electronic, and optical products	3.16	2.73
Manufacture of electrical equipment	5.40	3.27
Manufacture of machinery and equipment n.e.c.	3.86	3.09
Manufacture of transport equipment	3.41	4.42
Other manufacturing, and repair and installation of machinery and equipment	3.03	2.38
Electricity, gas, steam and air-conditioning supply	2.13	2.16
Water supply, sewerage, waste management, and remediation	2.52	2.34
Construction	6.43	3.83
Wholesale and retail trade, repair of motor vehicles and motorcycles	2.94	2.39
Transportation and storage	4.48	3.22
Accommodation and food service activities	7.87	4.47
Publishing, audiovisual and broadcasting activities	3.18	2.48
Telecommunications	2.96	2.51
IT and other information services	3.54	2.30
Real estate activities	2.03	2.28
Legal, accounting, management, architecture, engineering, technical testing, and analysis activities	2.38	1.79
Scientific research and development	11.52	3.99
Other professional, scientific and technical activities	3.77	2.62
Administrative and support service activities	3.50	2.39
Other services	8.07	2.80

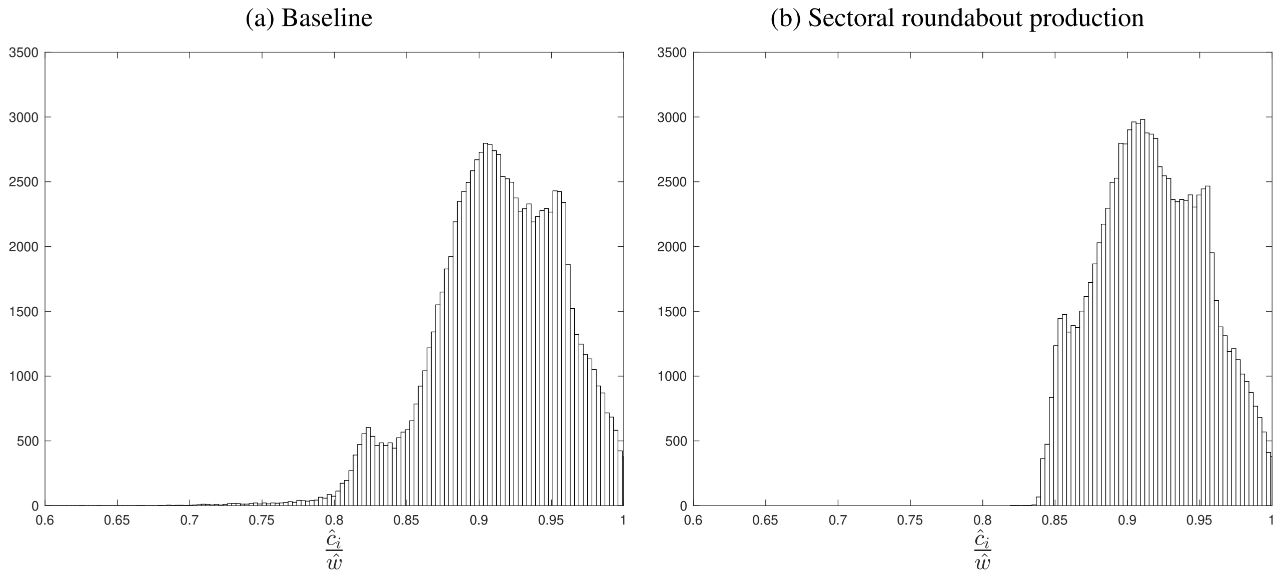
In the two cases above, the estimates of most parameters are larger than those without taking account capital inputs. Inflating firms' labor costs by adding capital usage costs lead to smaller firm-level markups, and these lower accounting markups are accommodated by the larger CES parameters.

D Additional results from Section 5

D.1 Cost changes under reduction of all firm-to-firm markups

Figure 2 in the main text shows results where markups of firms with sales less than input costs are held fixed. Here we show an analogous figure in which we remove this condition and consider reductions of all firm-to-firm markups. The pattern in which the distribution of cost changes under the baseline economy is more dispersed is more prominent in Figure 14.

Figure 14: Histograms of cost changes relative to wage change, $\hat{c}_i/\hat{w}$, under 20 percent reduction in markups (upon reduction of all firm-to-firm markups)



D.2 Correlation between $\hat{c}_i$ and downstreamness measures

We present the correlations between firm-level cost changes, $\hat{c}_i$, and several measures that capture how downstream firms are in the production network. We consider log-total sales, $\log(V_i)$, log-sales to domestic final demand, $\log(V_{iH})$, and revenue share of sales to domestic final demand, $r_{iH} = \frac{V_{iH}}{V_i}$. In addition, we also consider the total revenue share of sales to domestic final demand. This measure takes into account not only the firm's own sales to domestic final demand but also its buyers' sales and their buyers' sales and so on: $r_{iH}^{Total} = r_{iH} + \sum_j r_{ij} r_{jH}^{Total}$, where r_{ij} is the share of sales to firm j, out of firm i's total sales. Finally, we also consider the upstreamness measure, $Upstreamness_i$, defined by Antràs, Chor, Fally, and Hillberry (2012). Table 25 reports the results.

Table 25: Correlation between $\hat{c}_i$ and firm-level measures

	$\log(V_i)$	$\log(V_{iH})$	r_{iH}	r_{iH}^{Total}	$Upstreamness_i$
Correlation with $\hat{c}_i$	-0.10	-0.15	-0.13	-0.09	0.08

Note: This table shows the correlations between firm-level cost changes, $\hat{c}_i$, upon a 20 percent reduction in firm-to-firm markups in the baseline economy. $Upstreamness_i$ is a firm-level upstreamness measure defined by Antràs, Chor, Fally, and Hillberry (2012).

D.3 Taking out the effects of the changes in $\sum_i \xi_i$

We first present results where we consider the change in aggregate expenditure without considering the changes in $\sum_i \xi_i$. We define the aggregate expenditure without taking into account $\sum_i \xi_i$, $\tilde{E}$, as $wL + \Pi - TB$ and consider $\hat{\tilde{E}}$ as $\frac{wL}{\tilde{E}}\hat{w} + \frac{\Pi}{\tilde{E}}\hat{\Pi} - \frac{TB}{\tilde{E}}$. We report the results on $\hat{\tilde{E}}$ and the analogous change in aggregate welfare, $\hat{\tilde{U}}$, in Table 26.

Table 26: Aggregate effects when taking out the changes in $\sum_i \xi_i$

	Baseline	Sectoral roundabout
$\hat{\tilde{U}} = \hat{\tilde{E}}/\hat{P}$	1.100	1.073
$\hat{w}/\hat{P}$	1.070	1.060
$\hat{\tilde{E}}$	1.068	1.048
$\hat{\Pi}$	1.124	1.0712

Note: $\tilde{E}$ is defined as $wL + \Pi - TB$, and the variables in the table are computed using the equilibrium changes from the system described in Appendix B.4.

Another way to not take into account the changes in $\sum_i \xi_i$ is to consider the system of counterfactual changes by fixing the values of ξ_i. As noted on page 26, this approach does not allow us to consider extreme cases, but the aggregate welfare is only affected by the change in the nominal wage and aggregate profits. We solve the system of equilibrium changes in Appendix B.4, but now solving for both $\widehat{c_i q_i}$ and $\hat{C}_i$ separately, using the relationship $\widehat{c_i q_i} = \frac{C_i}{c_i q_i}\hat{C}_i + \frac{\xi_i}{c_i q_i}$. Table 27 presents the results.

Table 27: Aggregate effects when treating ξ_i as fixed

	Baseline	Sectoral roundabout
$\hat{U} = \hat{E}/\hat{P}$	1.096	1.066
$\hat{w}/\hat{P}$	1.070	1.060
$\hat{E}$	1.065	1.041
$\hat{\Pi}$	1.149	1.075

Note: The table reports the results when we solve for the equilibrium changes in the system described in Appendix B.4, but now solving for both $\widehat{c_i q_i}$ and $\hat{C}_i$ separately using the relationship $\widehat{c_i q_i} = \frac{C_i}{c_i q_i}\hat{C}_i + \frac{\xi_i}{c_i q_i}$.

Finally, we follow the approach by Ossa (2014) and first eliminate the differences between the observed and model implied input values, ξ_i. We first solve for the counterfactual changes by forcing the observed differences, ξ_i, to zero. The resulting economy becomes fully consistent with the model, with which we can solve for the counterfactual changes under $\hat{\mu}_{ij}$. Table 28 presents the results.

Table 28: Aggregate effects by first eliminating ξ_i

	Baseline	Sectoral roundabout
$\hat{U} = \hat{E}/\hat{P}$	1.111	1.086
$\hat{w}/\hat{P}$	1.066	1.062
$\hat{E}$	1.082	1.051
$\hat{\Pi}$	1.148	1.088

Note: The table reports the results when we solve for the equilibrium changes in the system described in Appendix B.4, but first solving the system taking $\hat{\xi}_i = 0$ as the shock.

D.4 First-order approximated changes and different magnitudes of shocks

Here we report numbers analogous to those of Table 5, with first-order approximation of the baseline model and under different magnitudes of shocks. See the system of first-order approximated equilibrium changes in Appendix B.3.2.

Table 29: Welfare effects of reduction in firm-to-firm markups

	10 percent reduction		
	Baseline, $\hat{x}$	FOA, $\frac{dx}{x}$	Sectoral roundabout, $\hat{x}$
Welfare	1.044	0.038	1.028
Real wage	1.030	0.028	1.027
Agg. expenditure	1.031	0.027	1.017
Agg. profits	1.055	0.049	1.036
	20 percent reduction		
	Baseline, $\hat{x}$	FOA, $\frac{dx}{x}$	Sectoral roundabout, $\hat{x}$
Welfare	1.102	0.076	1.060
Real wage	1.069	0.054	1.059
Agg. expenditure	1.070	0.053	1.035
Agg. profits	1.124	0.0897	1.072
	30 percent reduction		
	Baseline, $\hat{x}$	FOA, $\frac{dx}{x}$	Sectoral roundabout, $\hat{x}$
Welfare	1.194	0.115	1.094
Real wage	1.120	0.082	1.099
Agg. expenditure	1.131	0.080	1.054
Agg. profits	1.218	0.146	1.107

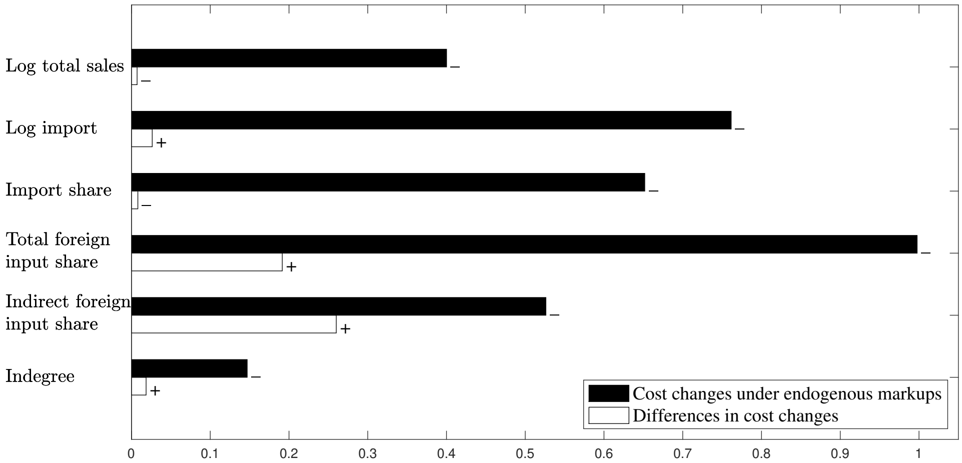
Note: This table shows the results from the baseline model and the sectoral roundabout model where we feed different magnitudes of reduction in markups in firm-to-firm trade. The results are denoted in terms of equilibrium changes, $\hat{x}$, and the first-order approximated results of the baseline model are denoted in log-changes, $\frac{dx}{x}$.

E Additional results from Section 6

E.1 Correlations between cost changes and firm-level variables

Figure 15 plots the correlations between firm-level cost changes under endogenous markups, $\hat{c}_i^{endog}$, and firm-level variables. It also plots the correlations between the difference between firm-level cost changes under endogenous and fixed markups, $\frac{\hat{c}_i^{endog}/\hat{w}^{endog}-\hat{c}_i^{fixed}/\hat{w}^{fixed}}{1-\hat{c}_i^{fixed}/\hat{w}^{fixed}}$, and firm-level variables.

Figure 15: Correlations between cost changes and firm-level variables

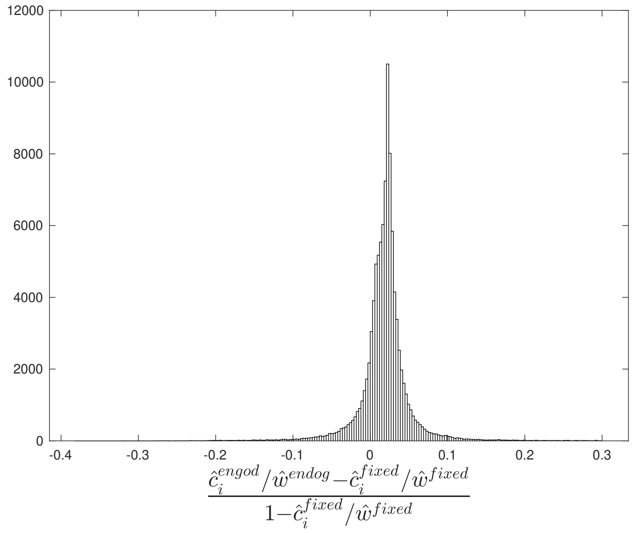


Note: The black bars depict the univariate correlations between firms' cost changes under endogenous markups, $\hat{c}_i^{endog}$, and firm-level variables. The white bars depict the correlations between the differences in firm-level cost changes under endogenous markups and fixed markups, $\frac{\hat{c}_i^{endog}/\hat{w}^{endog}-\hat{c}_i^{fixed}/\hat{w}^{fixed}}{1-\hat{c}_i^{fixed}/\hat{w}^{fixed}}$, and firm-level variables.

E.2 Shock to one importer

Here we consider a shock of foreign price reduction that hits a single importer, firm I. In this exercise we pick the importer with the largest number of domestic buyer as firm I. Analogous to Figure 3b, we first plot the differences in firm-level cost changes normalized for changes in nominal wages, across two economies: the baseline economy and the economy with fixed markups. We plot the histogram of these differences in Figure 16. Compared to Figure 3b in which we consider a uniform foreign price change that affected all importers, Figure 16 shows larger differences between cost changes under endogenous markups and cost changes under fixed markups. In this case, 71 percent of firms experience cost reductions that are smaller than under fixed markups by 1 percent or more, and 9 percent of firms experience cost reductions that are greater than under fixed markups by 1 percent or more.

Figure 16: Differences in $\hat{c}_i$, endogenous vs. fixed markups



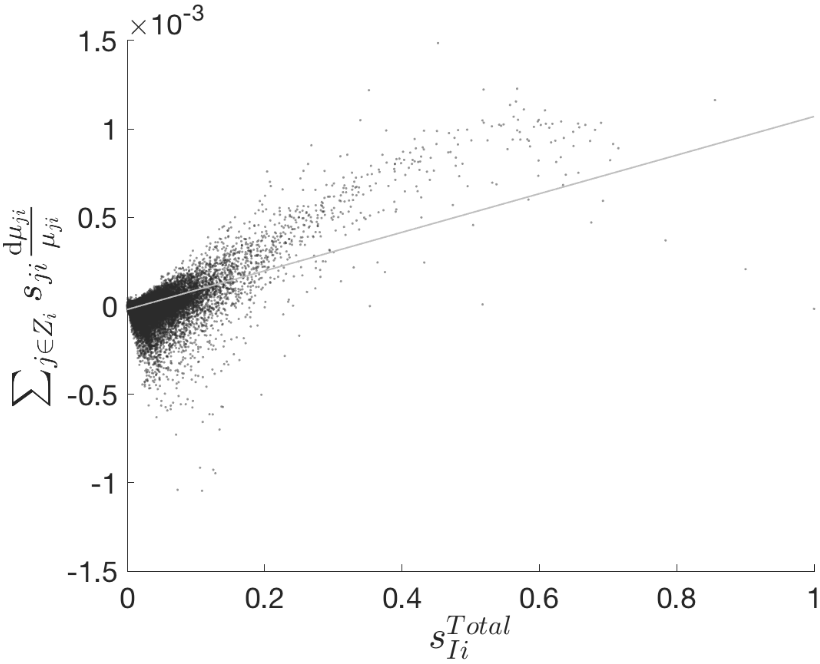
Note: The figure plots the distribution of the differences in normalized cost changes under the baseline economy and the fixed markups economy. The right figure is truncated from below, and the minimum value of $\frac{\hat{c}_i^{endog}/\hat{w}^{endog} - \hat{c}_i^{fixed}/\hat{w}^{fixed}}{1-\hat{c}_i^{fixed}/\hat{w}^{fixed}}$ is -0.47.

We then plot in Figure 17 the firms' average change in markups, $\sum_{j \in Z_i} s_{ji} \frac{\mathrm{d}\mu_{ji}}{\mu_{ji}}$, against the measure capturing how close first are to the shock. We construct a measure s_{Ii}^{Total} that captures firms' exposure to firm I's goods:

$$
\begin{aligned}
s_{Ii}^{Total} &= \sum_{k \in Z_i} s_{ki} s_{Ik}^{Total} \quad && \text{if } i \neq I \\
s_{Ii}^{Total} &= 1 && \text{if } i = I.
\end{aligned}
$$

As in Figure 5, one can also see a positive correlation between the two measures. In this case the correlation between the two measures is 0.59, larger than that under the uniform foreign price change.

Figure 17: Average change in markups, $\sum_{j\in Z_i} s_{ji}\frac{\mathrm{d}\mu_{ji}}{\mu_{ji}}$, and exposure to firm I, s_{Ii}^{Total}



Note: The figure plots the first-order approximated changes in average markups charged from suppliers, $\sum_{j\in Z_i} s_{ji}\frac{\mathrm{d}\mu_{ji}}{\mu_{ji}}$, upon a 20 percent reduction in the price of foreign goods that firm I imports, against firms' exposure to firm I's goods, s_{Ii}^{Total}. The least-squares line has a y-intercept of -0.00002 and slope coefficient of 0.0011. The R-squared is 0.35. The correlation between the two variables is 0.59.

Finally in Table 30, we report the differences in the aggregate predictions under the baseline economy and under fixed markups, across the two shocks. We show the differences in the counterfactual changes of aggregate welfare, normalized by the aggregate changes predicted under fixed markups. While endogenous markups amplify the increase in aggregate welfare by around 0.2 percent when considering the uniform price change as the shock, once we consider the price change hitting a single firm, then incorporating endogenous markups attenuate the increase in aggregate welfare by around 3 percent.

Table 30: Differences in aggregate predictions under baseline and fixed markups

	Shock to all importers	Shock to firm I
$(\hat{U}_{endog}-\hat{U}_{fixed})/(\hat{U}_{fixed}-1)$	0.0019	-0.0303

Note: The table shows the differences in aggregate predictions under the two models, normalized by the aggregate changes predicted under fixed markups. We consider 20 percent reduction in the price of foreign goods.

E.3 Different magnitudes of shocks

Table 31 reports the aggregate predictions under different magnitudes of foreign price change, from the baseline model together with the fixed-markup model outlined in Section 3.4.

Table 31: Aggregate effects of reductions in the foreign price

	$\hat{p}_F = 1.3$		$\hat{p}_F = 1.2$	
	Baseline	Fixed markups	Baseline	Fixed markups
$\hat{U} = \hat{E}/\hat{P}$	0.826	0.827	0.868	0.869
$\hat{w}/\hat{P}$	0.897	0.897	0.923	0.923
$\hat{E}$	0.912	0.913	0.932	0.932
$\hat{\Pi}$	0.796	0.796	0.844	0.844

	$\hat{p}_F = 0.8$		$\hat{p}_F = 0.7$	
	Baseline	Fixed markups	Baseline	Fixed markups
$\hat{U} = \hat{E}/\hat{P}$	1.273	1.272	1.536	1.535
$\hat{w}/\hat{P}$	1.141	1.141	1.266	1.264
$\hat{E}$	1.150	1.149	1.294	1.293
$\hat{\Pi}$	1.329	1.329	1.646	1.646