Price updating in production networks

Working Paper Research

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October 2018 No 352

NationalBank
OF BELGIUM
Eurosystem

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First draft: October, 2018

Abstract

This paper evaluates how firms change their prices in response to cost shocks and other price changes in their environment. We first document three new facts on the heterogeneity of firm-level producer prices and their relationship to buyers and suppliers in a production network. We then develop a non-parametric framework of how producers update their prices, taking into account this production network. The framework is very general, and accounts for the heterogeneity in price changes and the production network from the stylized facts. Moreover, the framework is consistent with various price setting mechanisms, and does not impose a particular market structure or demand functional form. Exploiting rich data on producer prices and the network structure of production in Belgium, we estimate the model to evaluate the importance of both channels in the data. We find that, on average, input price pass-through is incomplete and very much below one, while firms also strongly react to other prices in their environment. This implies that firms can adjust their markups in response to both cost shocks and prices of other firms. Furthermore, firms react differently to common shocks than to idiosyncratic shocks, on average completely passing through common shocks, but much less idiosyncratic shocks.

Keywords: Pricing, production networks, pass-through, variable markups.
JEL codes: D21, L14, L16.

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[*] This research has been performed in the context of the 2018 Colloquium of the National Bank of Belgium on "Understanding inflation dynamics: the role of costs, mark-ups and expectations". We would like to thank Emmanuel Dhyne and Catherine Fuss from the National Bank of Belgium, Joep Konings, Mathieu Parenti and Thomas De Muynck for various comments, and Danny Delcambre at Eurostat for help with the RAMON product classification files.

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1 Introduction

How do firms adjust their prices? What is the impact of cost shocks on prices, and the response of firms to changes in other prices in their environment? How much of cost shocks are ultimately passed on in the aggregate, and how much is absorbed by the markups of firms? The nature of price setting has important implications for a wide range of issues in both macroeconomics, including the welfare consequences of business cycles, the behavior of real exchange rates and optimal monetary policy, and in microeconomics, such as efficiency, reallocation, productivity, competition and firms' decisions to trade. The topic has also attracted considerable attention in industrial organization, particularly because pass-through can elucidate the welfare implications from various types of imperfect competition or price discrimination. Incomplete pass-through can reveal important characteristics about supply, demand, or market power. Moreover, repeated empirical evidence has been presented on incomplete pass-through in various settings.

Changes in output prices have been rationalized along two main lines: (i) changes in the costs of the firm, and (ii) firms' responses to other prices in their environment. Unfortunately, while both the micro and macro responses to cost shocks depend on the exact nature of these cost shocks (e.g. brownian motion versus lumpy shocks as in Alvarez et al. (2016)), firm-level information on cost changes is generally missing. At best, one observes changes in output prices, but not changes in particular input prices. Any prediction on changes in output prices then depends on assumptions on the nature of these cost shocks. Furthermore, even if cost information is available at the firm level, this information is generally incomplete, and studies focus on one aspect that is identifiable such as exchange rates, or detailed information on costs in particular sectors. Additionally, while many papers only observe retail price information (e.g. Eichenbaum et al. (2011)), there is evidence that a significant fraction of aggregate incomplete pass-through occurs at the firm level along the value chain (Alvarez et al. (2016)). Any update in prices of consumption goods is thus confounded with price updating along the value chain, which is not observed with consumption data only.

This paper studies how firms change their output prices in the presence of production networks, and makes four main contributions. First, we document three new stylized facts about the distribution of changes in producer prices and the distribution of input expenditures across suppliers. These facts exploit unique information on prices for goods producers in Belgium and input expenditures of these producers across all their suppliers, both domestic and international. Second, we develop a general, non-parametric model of how producers update output prices, taking into account input prices from suppliers in the production network and price changes in their output environment. Third, the model provides a structural estimation of cost pass-through and other price effects, exploiting the Belgian production network data, which is consistent with a large class of pricing models and functional forms. Importantly, there is no need to estimate either marginal costs or markups in our framework. Finally, we propose a new and detailed procedure to concord product-level production data and international trade data over time, as well as across statistical classifications.

We start by documenting three facts on price changes and supplier-buyer connections for goods producers in Belgium. The empirical analysis in this paper exploits very detailed data on output prices at the firm-product level for all firms in the Prodcom survey, combined with information on expenditures for all suppliers of these producers and corresponding input prices from these suppliers. First, the distribution of producer price changes exhibits both large increases and decreases from one year to another. Moreover, the median price change is zero. This is very different from consumer prices, which predominantly go up in nominal terms. Second, there is a striking difference in patterns of co-movement of producer prices. A fraction of prices tend to co-move within narrowly defined product categories, but at the same time, large idiosyncrasies exist: many output price changes are not correlated with the changes of other producers in the same product category. Third, across all producers, one supplier tends to dominate in terms of input expenditures, which is not vanishing in the number of suppliers. However, there is no correlation between the importance of the input share and size of an input price shock.

Next, we develop a general model of how producers change output prices in the presence of production networks. Firms produce output according to a non-parametric cost function, combining inelastic factors with inputs from other firms. The framework allows for variable markups at the firm level with minimal restrictions on costs, possible price setting mechanisms and product-market competition. In particular, firms are cost minimizing and the cost function exhibits constant returns to scale with respect to variable inputs. Under these conditions, the resulting pricing equation is consistent with a large class of mechanisms, including but not limited to profit maximization, cost-plus pricing and revenue maximization. Moreover, markups charged by the firm are not necessarily an equilibrium outcome such as a strategic best response function across oligopolistic competitors, but are also consistent with models in which the firm is a price follower in its sector or in the aggregate.

The model allows to recover underlying elasticities that are consistent with a broad class of price setting models and functional forms. These elasticities represent how firms change their output prices in response to a combination of cost shocks and adjustment of prices by other firms in the same product market, the latter which is captured by a general index of other firms' prices. We then exploit the rich data on pricing and the production network in Belgium to structurally estimate these elasticities. Importantly, we can estimate a cost pass-through parameter without the need to estimate marginal costs or markups. Instead, we directly obtain a change in the input price index from the data on input prices and input expenditures.

Estimating the pricing equation however, implies dealing with endogeneity issues: both input price changes and other firms' price changes can be simultaneously determined with changes in output prices. Hence, we employ an instrumental variable approach, and use average import prices and productivity shocks to construct three instruments from the different micro datasets. As the estimation equation requires information on productivity shocks, we follow a large literature when estimating productivity (TFP) (e.g. De Loecker & Warzynski (2012); Ackerberg et al. (2015)). However, standard estimates of TFP rely on revenue-based or value-added production function estimations, generating additional simultaneity in prices. Therefore, we estimate a quantity based measure of productivity (*TFPq*), which purges the TFP measure from prices. Moreover, we do not have to rely on sector-level price deflators for materials. Instead, we construct the change the input price index from the micro data, generating a firm-level measure of input price expenditures and changes therein, rather than firms in the same sector facing the same input price deflators, avoiding another possible source of simultaneity.

The results are telling: on average across all firms, the cost pass-through of input price shocks to output prices is incomplete and well below one, with an estimated coefficient of 0.44: a 1% increase in input prices leads to a 0.44% increase in output prices. The environment's price elasticity is also highly significant and positive at 0.28. This implies that empirically, models of price setting behavior with constant markups, such as perfect competition or monopolistic competition with CES preferences are refuted, at least at the average. These average results possibly conceal heterogeneity in price responses. We re-estimate the pricing equation on common shocks and idiosyncratic shocks separately, and find that firms on average fully pass through common shocks (with an estimated coefficient of one), while the pass-through rates for idiosyncratic shocks are much lower, around 0.4.

Finally, in order to combine both international trade data and domestic production data, we have developed a detailed concordance procedure that takes into account changes in the statistical classifications of the Combined Nomenclature (CN) and Prodcom (PC). These classifications tend to change regularly over time, and for various reasons, which makes tracing products over time hard. Our procedure takes into account these changes, including not only one-to-one correspondences, but also non-singular correspondences (i.e. many-to-one, one-to-many and many-to-many) from one year to another. Our procedure differs from other concordance methods, most importantly in the sense that we do not need to group products into "family trees" (Pierce & Schott (2012)) over time. Instead, we identify price changes for products between any two years, and do not impose a panel structure over time. This procedure is applied to both the CN and PC datasets over time, as well as a contemporaneous correspondence between CN and PC .

This paper connects to different strands of literature. First, the paper is related to the theoretical literature on incomplete pass-through and variable markups (e.g. Atkeson & Burstein (2008); Melitz & Ottaviano (2008); Weyl & Fabinger (2013); Atkin & Donaldson (2015); Edmond et al. (2015); Amiti et al. (2016); Parenti et al. (2017); Arkolakis & Morlacco (2018)). We provide a very general and non-parametric framework of price setting that is consistent with a broad class of models of competition and demand. Importantly, variable markups in our set-up can arise from strategic interaction between firms, but also from non-strategic responses of firms to their environments, such as aggregate price indices or even simply following the market price evolution.

Second, this paper relates to the empirical literature on variable markups and the estimation of incomplete pass-through. For instance, many contributions from the international macro literature have focused on how international shocks such as exchange rate movements, affect domestic prices through importers (for an overview, see Burstein & Gopinath (2014)). Conversely, many papers have estimated incomplete pass-through and variable markups in specific industries, such as coffee (Nakamura & Zerom (2010)), beer (Goldberg & Hellerstein (2013)), cars (Goldberg & Verboven (2001)), or electricity (Fabra & Reguant (2014)). Exploiting the rare features of the various datasets, we structurally estimate pass-through rates and adjustment of firms' prices to their environment's price index across all manufacturing sectors.

Third, this paper speaks to a growing literature on production networks, pricing and propagation (e.g. Magerman et al. (2016); Baqaee (ming); Baqaee & Farhi (2018)). However, most models impose perfect pass-through, even under double marginalization, and any shock ultimately ends up unattenuated at the final consumer. This has important aggregation implications, as changes in both producer and consumer surplus are accrued over the whole network of production. Some notable exceptions with incomplete pass-through include Kikkawa et al. (2018); Grassi (2018); Heise (2018).

The remainder of this paper is organized as follows. Section 2 describes the data and stylized facts. Section 3 describes the non-parametric model of pricing. Section 4 discusses identification and estimation. Section 5 presents the main results, while Section 6 presents additional results. Section 7 concludes.

2 Data and stylized facts

2.1 Data sources and construction

The empirical analysis in this paper exploits several comprehensive data sources on the firm-to-firm production network and micro prices in Belgium. The three main datasets are (i) the Belgian Prodcom Survey, (ii) the NBB B2B Transactions Dataset, and (iii) the International Trade data at the National Bank of Belgium (NBB). All data sources are panel data, and cover the period 2002-2014. A brief description of the data structure follows below, while Appendix A discusses the data sources and construction in detail.

First, input cost shares are obtained by combining information from the NBB B2B Transactions dataset for domestic firm-to-firm relationships (Dyhne et al. (2015)) with information on imports from the International Trade data at the NBB. In particular, the input share in cost expenditures accounted for by supplier i in input consumption of firm j is defined as $\omega_{ijt} \equiv \frac{m_{ijt}}{\sum_i m_{ijt}}$, where m_{ijt} is the value of sales by supplier i to producer j in period t. The NBB B2B Transactions dataset contains information on the yearly value of sales m_{ijt}, from any firm i to any firm j across all economic sectors (including goods and services) within Belgium. From the International Trade data at the NBB, goods import values m_{ijt} are obtained as the value of product-country i to firm j in Belgium at time t. Imported products are defined at the 8-digit Combined Nomenclature level (CN8). Both datasets combined provide complete information on firm j's expenditures across all sourced inputs i at time t, domestically and imported. We perform two corrections to ensure measured inputs are used in production and reflect variable inputs: to account for re-exports that are imported but not used in production, exports are subtracted from imports at the firm-product level.[1] To account for expenditures that are not used as variable inputs in production, capital goods are excluded from both domestic and imported inputs.

Second, yearly changes in output prices at the firm-product level are obtained from the Belgian Prodcom survey. This survey contains information on values and quantities at the 8-digit product level (PC8), sold for firms in Belgium, active in *Mining and Quarrying* or *Manufacturing* (NACE Rev.2 Sections 8-33). Price changes by producer j from year $t-1$ to t are defined as log-differences in unit values. In the Prodcom database, sales to both domestic and foreign markets are not recorded separately. However, we will use output price changes from Prodcom producers as input price changes for other firms, and thus we need to correct for exports to obtain domestic price changes. Changes in domestic output prices are obtained by subtracting exported values and quantities using the detailed international trade data.[2]

Third, changes in input prices i to j, are obtained from combining both the NBB B2B Transactions dataset and the International Trade data. For imports, changes in input prices are obtained from values and quantities reported at the firm-country-product level. For domestic inputs, input price changes are obtained as the change in output price of supplier i.

Fourth, we have developed a detailed concordance method, taking into account possible changes in the statistical classifications of domestic products (PC8) over time, including both one-to-one correspondences and non-singular correspondences (i.e. many-to-one, one-to-many and many-to-many) from one year to another, while also ensuring the unit of measurement of the product is identical when going from $t-1$ to t. Similarly, this concordance method is also applied to concord the international trade data (CN8) over time. Moreover, the developed method also generates a detailed contemporaneous correspondence between PC8 and CN8, used to combine the domestic and international flows in this paper.[3]

2.2 Stylized facts

This section provides three stylized facts about the distribution of changes in producer prices and the distribution of input expenditures across suppliers.

Fact 1: *The distribution of producer price changes is symmetric, centered around zero and highly dispersed.*

We start by documenting producer output price changes in the Belgian production network. Table 1 shows summary statistics on the distribution of yearly price changes across all firm-products over the sample period. The last row of the Table shows price changes across 84,059 distinct firm-products, pooled over the years 2003-2014. The median price change is essentially zero. Moreover, the distribution is strikingly symmetric: 50% of nominal prices increase, while 50% of observations exhibit decreasing prices from one year to another. This implies that nominal producer

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[1] Amiti et al. (2014) show that large importers are on average also large exporters in Belgium.

[2] In order to account for re-exports not used in production, we subtract net export values (exports minus imports) from the values and quantities in Prodcom.

[3] The most important difference with other concordance methods such as Pierce & Schott (2012), is that we do not impose aggregation of non-singular correspondences (product changes) into a panel, so called "family trees". Identification in this paper relies on product-specific year-on-year price changes, without the need to trace the same product (tree) over the whole sample period. The method will be made publicly available at a later stage.

Table 1: Distribution of producer output price changes (2003-2014).

						percentiles						
Year	N	mean	sd	p1	p5	p10	p25	p50	p75	p90	p95	p99
2003	9,214	.004	0.23	-0.75	-0.37	-0.20	-0.05	0.00	0.06	0.22	0.39	0.77
2004	9,127	.017	0.22	-0.72	-0.33	-0.17	-0.04	0.00	0.07	0.23	0.40	0.76
2005	8,565	.012	0.22	-0.73	-0.33	-0.18	-0.04	0.00	0.08	0.21	0.36	0.73
2006	8,397	.018	0.21	-0.74	-0.32	-0.16	-0.03	0.00	0.08	0.22	0.35	0.73
2007	8,535	.033	0.22	-0.74	-0.30	-0.15	-0.02	0.02	0.10	0.24	0.39	0.77
2008	6,271	.038	0.26	-0.80	-0.38	-0.21	-0.03	0.03	0.12	0.32	0.49	0.86
2009	6,524	-.010	0.22	-0.71	-0.39	-0.24	-0.08	0.00	0.06	0.19	0.34	0.75
2010	6,062	.000	0.22	-0.80	-0.37	-0.22	-0.06	0.00	0.06	0.21	0.35	0.74
2011	5,774	.042	0.21	-0.75	-0.26	-0.13	-0.02	0.02	0.11	0.26	0.37	0.73
2012	5,305	.023	0.22	-0.76	-0.35	-0.17	-0.03	0.01	0.08	0.22	0.39	0.76
2013	5,201	.002	0.22	-0.75	-0.35	-0.19	-0.05	0.00	0.06	0.18	0.33	0.72
2014	5,084	-.002	0.21	-0.71	-0.33	-0.18	-0.06	0.00	0.05	0.18	0.32	0.75
All	84,059	.015	.22	-.74	-.34	-.18	-.04	.00	.08	.22	.38	.76

Note: Table reports yearly firm-product price changes across all firms in NACE Rev.2 8-33. Price changes are expressed in log changes, and are trimmed at ±1.

prices are not only moving up (e.g. through positive inflation). This is different from typical movements in consumer prices in Belgium, which also exhibit both increasing and decreasing prices across and within product categories, but the median consumer price change is positive with a share of price increases between 50 and 100% of products within product categories (e.g. Aucremanne & Dhyne (2004)). At the same time, the distribution exhibits substantial dispersion: firm-product prices drop with .18 log points at the 10th percentile, while they increase with .22 log points at the 90th percentile. In the tails, fluctuations are even more significant: at the 1st and 99th percentiles, prices respectively decrease and increase with roughly .75 log points. While the dispersion of price changes is the largest during the financial crisis in 2008, there is little variation over time.[4] Figure 1 also shows the distribution of price changes pooled over the sample period, graphically confirming the symmetry, center and dispersion of the distribution.

These patterns are robust across many cuts of the data. Table 10 in Appendix B documents price changes across 2-digit NACE sectors for the year 2014. Across all sectors, the median price change is virtually zero. When considering only the main product of the firm (Table 11), or alternatively using a revenue-weighted average of price changes at the firm level (Table 12), the distribution is very similar with identical means and medians, while exhibiting slightly lower variances. This suggests that within firms, core products are slightly less volatile than peripheral products.

Fact 2: *Within narrowly defined product categories, the distribution of price changes exhibit both co-movement and idiosyncrasies.*

Next, we document whether and how output prices tend to co-move within narrowly defined product categories. Firm-product price changes are first demeaned across firms at the 8-digit product level, weighted by the yearly sales share they represent within that product category. Figure 2 then plots the output price changes against their demeaned values using a local polynomial regression. If product prices perfectly co-move across firms within the same product category, the resulting regression line would be flat; conversely, if price changes are perfectly idiosyncratic within

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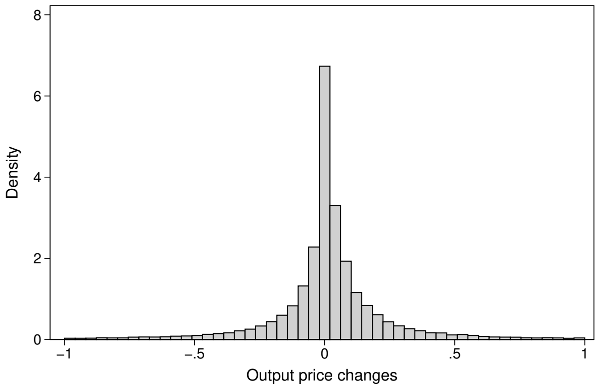
[4] The decline in the number of firm-products over time is due to the declining number of products that are recorded in the Prodcom survey. The number of firms in NACE Rev.2 sectors 8-33 remains fairly stable over time.

Figure 1: Producer output price changes (2003-2014).



Note: Distribution of domestic price changes at the 8-digit Prodcom level, pooled over the sample period 2003-2014. Price changes are trimmed at ±1.

product categories, the regression line would be on the 45 degree line. There are two distinguished regimes in the graph: for relatively moderate price changes between approximately -.20 and +.20 log points, prices tend to co-move to a large extent across firms within product categories. For larger price changes, prices are more idiosyncratic. This pattern also persists on the input side: when aggregating input prices across suppliers of j, and demeaning these changes at the product level again, an identical picture emerges. It is important to note that one cannot disentangle these idiosyncrasies from co-movement using aggregate data such as output price deflators, which are mostly specified at the 2-digit NACE level.

This pattern is extremely robust across different specifications. The same pattern remains when comparing products within 4-digit product categories, within NACE 4-digit and 2-digit sectors, year by year, or using unweighted means.

Fact 3: *The distribution of input shares is skewed towards a dominant supplier. However, there is no correlation between the importance of the input share and the average size of an input price shock.*

Finally, panel (a) in Figure 3 plots the distribution of the main input share across all firms over the sample period. The average input share for the largest supplier across all firms is 25%.[5] This skewness remains as the number of suppliers of j grows, as shown in Table 2: while at the first decile of the distribution of the number of suppliers, the main supplier accounts for 38% of total input expenditures on average, at the last decile, the main supplier still accounts for 19% on average. This suggests that the most important supplier has a non-vanishing input share as the number of suppliers increases for any firm.

Panel (b) in Figure 3 shows the result of a local polynomial regression to visualize the correlation between the size of the input share from i and the size of the input price change for that supplier i. The 95% confidence bands widen as the input share ω_{ijt} increases naturally, as most input shares are small and the regression is much more tightly estimated for these small input shares. However, as the input share increases, there is no apparent correlation with the size of input price changes. Again, this result is robust across different specifications, including considering only the

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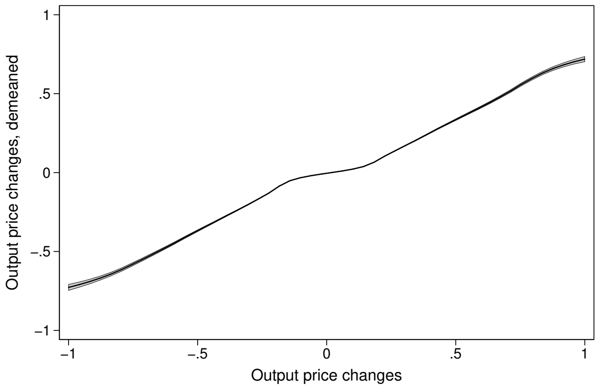
[5] The distribution of the main input share is also documented in the context of shock propagation in Magerman et al. (2016) and Kikkawa et al. (2018).

Figure 2: Within-product category co-movement of price changes.



Note: The correlation between price changes and their demeaned values are shown using a local polynomial regression. 95% confidence bands are shown around the local point estimates. Prices are demeaned at the 8-digit product level, weighted by their market share in the respective product category, and pooled over all years in the sample.

main input instead of all inputs, demeaning at the product level, or within firms.

These stylized facts highlight the importance of substantial firm-level heterogeneity in both input sourcing and output pricing patterns. We will exploit this heterogeneity in identifying the sources of firms' output price changes from cost shocks and responses to other prices within and across product categories.

3 A general framework of price updating

In this section, we present a general framework of how producers change output prices in the presence of production networks. The framework allows for variable markups at the firm level with minimal restrictions on price setting mechanisms and product-market competition. The framework also allows to recover elasticities on costs, prices and markups that are consistent with a broad class of widely used functional forms.

3.1 The network structure of production

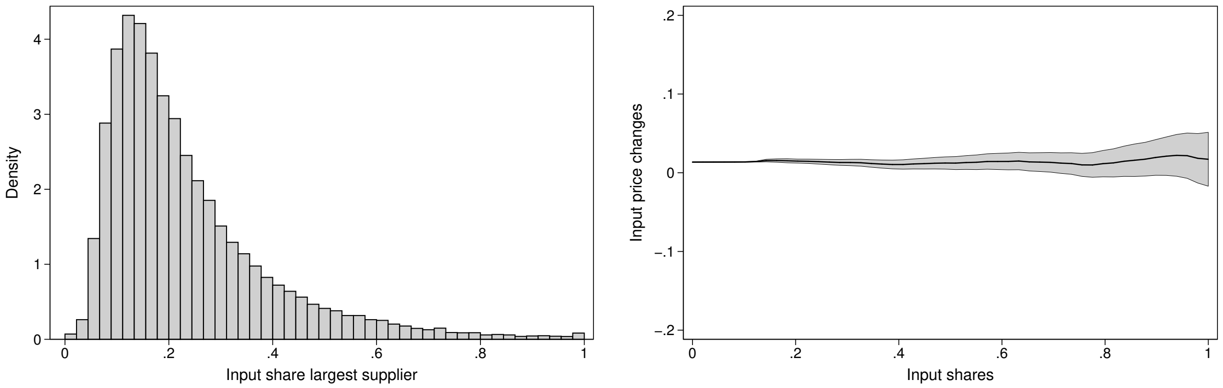
There are N producers indexed by j, who produce output combining fixed inputs with variable inputs from other producers, and sell their output to other producers and final demand. Producer j produces at time t, according to the following cost function

$$y_{jt}c_{jt}\left(\left(1+\tau_{1j}\right)p_{1t},...,\left(1+\tau_{nj}\right)p_{nt},z_{jt}\right)+F_{jt}$$

where y_{jt} is the output level, τ_{ij} is a pair-specific friction on input i used by j, p_{it} is the price of input i and z_{jt} is producer j's efficiency in transforming inputs into outputs. F_{jt} is a fixed cost to be paid by j in every period t.

Some notes. First, c_{jt} is a non-parametric function accommodating any production function as long as production exhibits constant returns to scale with respect to variable inputs. Second, this specification embeds the network structure of production: producers i's output is used as an input by producer j, whose output can be used again as an input by other producers. Third, bilateral frictions can drive a wedge between the output price of supplier i and the input

Figure 3: Input shares and price changes.



(a) Distribution of main input shares.

(b) Correlation input shares and input price changes.

Note: Panel (a): Histogram of the distribution of the input share of main supplier i in terms of expenditure shares for every firm j. Observations are pooled over all years in the sample. Panel (b): The correlation between input shares and input price changes are shown using a local polynomial regression. 95% confidence bands are shown around the local point estimates. Observations are pooled over all years in the sample.

Table 2: Distribution of main input shares by deciles.

Decile	mean	p50	# suppl.
1	.38	.31	68
2	.31	.28	94
3	.28	.24	117
4	.26	.22	139
5	.24	.20	164
6	.22	.18	195
7	.22	.17	236
8	.21	.17	301
9	.20	.16	435
10	.19	.15	8,888

Note: Decile refers to the position of j in the distribution of the number of suppliers across firms. # suppl. denotes the cutoff number of suppliers at the particular decile.

price faced by buyer j. These frictions are very general conditional on being fixed at the pair level, and can include bilateral taxes, tariffs, transport costs etc. Fourth, this specification does not impose a particular form of technological change z_{jt}, and is consistent with for instance Hicks- and Harrod-neutral productivity, but also allows for non-neutral technological change. Finally, for ease of exposition, in the main text we consider single-product firms. Appendix C derives a multi-product version of the model and identifies the additional identification assumptions.

3.2 Pricing and markups

Next, consider the following pricing equation of producers j at time t, which holds under cost minimization:

$$\ln p_{jt} = \ln c_{jt}\left(\left(1+\tau_{1j}\right)p_{1t},...,\left(1+\tau_{nj}\right)p_{nt}, z_{jt}\right) + \ln \mu_{jt}\left(p_{jt}, \mathscr{P}_{-jt}\right) \tag{1}$$

where p_{jt} is the output price of producer j, and μ_{jt} represents the markup of j, which is a function of j's own price p_{jt} and an index of other prices $\mathscr{P}_{-jt}$.

It is important to note that this pricing equation is consistent with a large class of price setting mechanisms. First, eq(1) does not impose profit maximization, but is still consistent with other pricing schemes such as cost-plus pricing or revenue maximization. Second, the pricing equation does not impose any particular market structure, and allows for either no markups, constant markups, or variable markups. Moreover, $\ln \mu_{jt}\left(p_{jt}, \mathscr{P}_{-jt}\right)$ does not have to be an equilibrium outcome such as a strategic best response function across oligopolistic competitors. Third, the index of other prices $\mathscr{P}_{-jt}$ is very general, and the exact construction of $\mathscr{P}_{-jt}$ depends on the underlying model of price setting behavior. This can include the price of direct competitors, but also geographically close firms, sector-level or aggregate price indices etc. Hence, eq(1) can also be seen as a reduced form pricing equation, in which the nature of price setting is not specified.

3.3 Price updating in production networks

Next, totally differentiating eq(1) leads to the following decomposition of the pricing equation:

$$d\ln p_{jt} = \underbrace{\sum_{i\in\mathscr{S}_{jt}} \frac{\partial \ln c_{jt}}{\partial \ln p_{it}} d\ln p_{it}}_{\text{total input price shock}} + \underbrace{\frac{\partial \ln c_{jt}}{\partial \ln z_{jt}} d\ln z_{jt}}_{\text{productivity shock}} + \underbrace{\frac{\partial \ln \mu_{jt}}{\partial \ln p_{jt}} d\ln p_{jt}}_{\text{own price markup effect}} + \underbrace{\frac{\partial \ln \mu_{jt}}{\partial \ln \mathscr{P}_{-jt}} d\ln \mathscr{P}_{-jt}}_{\text{environment price index effect}} \tag{2}$$

where $\mathscr{S}_{jt}$ is the set of suppliers to j. A change in j's output price is a combination of (i) a total change in input prices p_{it}, (ii) a productivity shock to the j's technology z_{jt}, and (iii) a change in markups $\mu_{jt}(p_{jt}, \mathscr{P}_{-jt})$.

Eq(2) merits some explanation. First, the total input price shock evaluates how changes in input prices affect the cost function. It is a linear combination of shocks to all input prices p_{it} to j, and reflects how j's cost function responds to all these input price shocks combined. This implies that shocks to all input prices can be linearly aggregated, independent of the exact functional form of the cost function. Moreover, the cost response to an input price shock can be written as

$$\frac{\partial \ln c_{jt}}{\partial \ln p_{it}} = \frac{(1+\tau_{ij})p_{it}x_{ijt}}{\sum_{i\in\mathscr{S}_{jt}}(1+\tau_{ij})p_{it}x_{ijt}} \equiv \omega_{ijt} \tag{3}$$

where $\sum_{i\in\mathscr{S}_{jt}}(1+\tau_{ij})p_{it}x_{ijt}$ is j's total variable cost, and ω_{ijt} is the elasticity of the marginal cost with respect to a change in one input price p_{it}. The second equality uses Shephard's lemma to equate the input elasticity to the share of expenditures on input i. Next, it is straightforward to aggregate individual input price shocks to a change in the input price index for producer j:

$$d \ln P_{jt} \equiv \sum_{i \in \mathscr{S}_{jt}} \omega_{ijt} d \ln p_{it} \tag{4}$$

The total change in j's input price index, $d\ln P_{jt}$, is a weighted average of price shocks to inputs i bought by j, weighted by their share in total variable costs ω_{ijt}. It is important to stress that eq(4) is not restricted to a Cobb-Douglas input price index, but is consistent with several functional forms: individual price shocks can be aggregated linearly to a total input price shock, independent of the underlying functional form of the cost function or the input price index.

Second, eq(2) separates the impact of input price shocks from that of productivity shocks within the cost function. Again from an envelope theorem argument, at the cost minimizing input tuple $(x^*_{1jt}, \ldots, x^*_{njt})$, any potential input reallocation effects through $d\ln x_{ijt}$ have no effect on marginal costs, and therefore also not on output prices. Hence, the total impact of a productivity shock on marginal cost is given by $\frac{\partial \ln c_{jt}}{\partial \ln z_{jt}} d\ln z_{jt} = \frac{\partial \ln y_{jt}(x_{1jt},\ldots,x_{njt},z_{jt})}{\partial \ln z_{jt}} d\ln z_{jt}$.

Third, the markup adjustment is a combination of change in j's own price p_{jt}, and that of j's environment price index $\mathscr{P}_{-jt}$. The first markup effect isolates the own price effect on j's markup. This elasticity determines the amount of cost pass-through, as discussed below. The environment's price index effect evaluates how j adjusts its markup in response to its output environment.

3.4 Cost pass-through

Finally, rearranging eq(2) and eq(3) generates an estimation equation that can be taken to the data.

$$d \ln p_{jt} = \beta_{jt} \sum_{i \in \mathscr{S}_{jt}} \omega_{ijt} d \ln p_{it} + \gamma_{jt} d \ln z_{jt} + \delta_{jt} d \ln \mathscr{P}_{-jt} \tag{5}$$

where the coefficients have a clear structural interpretation:

$$\begin{cases} \beta_{jt} = \frac{1}{1 - \frac{\partial \ln \mu_{jt}}{\partial \ln p_{jt}}} \\ \gamma_{jt} = \frac{1}{1 - \frac{\partial \ln \mu_{jt}}{\partial \ln p_{jt}}} \frac{\partial \ln y_{jt}}{\partial \ln z_{jt}} \\ \delta_{jt} = \frac{1}{1 - \frac{\partial \ln \mu_{jt}}{\partial \ln p_{jt}}} \frac{\partial \ln \mu_{jt}}{\partial \ln \mathscr{P}_{-jt}} \end{cases} \tag{6}$$

First, β_{jt} can be interpreted as a cost pass-through parameter. It captures how much a change in input prices p_{it} relates to a change in output price p_{jt}, and nests several pricing mechanisms. Under either no or constant markups, $\frac{\partial \ln \mu_{jt}}{\partial \ln p_{jt}} = 0$ and $\beta_{jt} = 1$. In this case, cost pass-through is complete. Under variable markup regimes however, $\frac{\partial \ln \mu_{jt}}{\partial \ln p_{jt}} \neq 0$, and thus $\beta_{jt} \neq 1$. Whether $\frac{\partial \ln \mu_{jt}}{\partial \ln p_{jt}} \lesseqgtr 0$ depends on the specification of $\mu_{jt}(p_{jt}, \mathscr{P}_{-jt})$, but most standard price setting models with variable markups will generate $\frac{\partial \ln \mu_{jt}}{\partial \ln p_{jt}} < 0$, such that $\beta_{jt} < 1$ and incomplete pass-through occurs.

4 Identification and estimation

In order to estimate eq(5), we exploit the rich structure of the different datasets described above.

4.1 Variables

In addition to price changes $d\ln p_{jt}$ and $d\ln p_{it}$, and input shares ω_{ijt}, estimating eq(5) requires information on efficiency shocks $d\ln z_{jt}$ and changes in other prices $d\ln \mathscr{P}_{-jt}$. First, we use lagged input shares, ω_{ijt-1} when estimating the pricing equation. The use of lagged input expenditure shares avoids measurement issues with weights being influenced by contemporaneous changes in prices.[6]

Second, input price shocks $d\ln p_{ijt}$ are obtained from changes in input prices p_{it} sold to j. These include domestic inputs and imported inputs from the different datasets described in Section 2. Capital inputs and labor are considered to be part of fixed costs.[7]

Next, $\ln z_{jt}$ is estimated as the residual of a production function. Our procedure is similar to the productivity literature (e.g. De Loecker & Warzynski (2012), Ackerberg et al. (2015)), but with some marked differences exploiting the rich structure of the different datasets. These datasets allow us to overcome several typical measurement problems, which in turn improve identification of the resulting TFP estimates. First, exploiting the Prodcom data, the production function is estimated in quantities, generating a measure of $TFPq$, rather than the more commonly estimated revenue- or value added-based measures. This is crucial, as (i) the TFP measure is then purged from prices, avoiding potential simultaneity issues when estimating eq(5), and (ii) output quantities are not derived from firm revenues and sector-level output price deflators. Second, estimation does not rely on input price deflators. Instead, $d\ln P_{jt}$ is constructed directly from information on supplier prices and their input shares as described above. This implies that producers face firm-specific input prices for their input bundles, which take into account heterogeneity in sourcing patterns and prices paid for those bundles, rather than sector-level prices resulting from deflators. Note that, while the pricing schemes in this paper are very general, a few more assumptions are needed on the underlying production function to estimate productivity using the machinery of the productivity literature. These include some restrictions on the admissible functional forms and timing assumptions on how firms choose variable and fixed inputs.[8] We want to stress that these assumptions are only imposed to estimate $\ln z_{jt}$ and the resulting control variable $d\ln z_{jt}$, and do not affect the generality of the pricing equation.

Finally, for exposition, we follow Amiti et al. (2016), and changes in the price index of other producers $d\ln \mathscr{P}_{-jt}$ are calculated as the market share weighted average of price changes of other producers in the same product category. In particular,

$$d\ln \mathscr{P}_{-jt} = \frac{\sum_{l\in\{\mathscr{D}_{jt}\cup\mathscr{I}_{jt}\}} S_{lt-1} d\ln p_{lt}}{\sum_{l\in\{\mathscr{D}_{jt}\cup\mathscr{I}_{jt}\}} S_{lt-1}} \tag{7}$$

where $\mathscr{D}_{jt}$ is the set of domestic producers, producing the same output as j at time t,[9] $\mathscr{I}_{jt}$ is the set of imported products corresponding to output j in Belgium at time t, and S_{lt-1} is the sales value by producer l in year $t-1$. Alternatively, one can construct a price index based on assumptions of the underlying model of competition, including geographic competition, or responses of j with respect to aggregate price indices.

4.2 Instruments

Estimating eq(5) using OLS might lead to biased coefficients due to potential endogeneity arising from simultaneity and measurement error.

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[6] While using lagged input shares implies only price changes for continuing products from $t-1$ to t are identified, this is a mild constraint in the data: across all producers, the average input expenditure share of continuing products is over 90%. Taking into account changes on the extensive margin of the input product mix would imply estimating shadow prices for unobserved products, forcing us to take a stance on price setting behavior and functional forms. Alternatively, one could use the average share between $t-1$ and t, but then weights are again contaminated by changes in prices.

[7] Particularly in Belgium, hiring and firing is not flexible, and many wages are subject to indexation schemes that are linked to inflation. Therefore, as a baseline, we consider labor to be part of fixed costs, to be paid by j at the start of every period t. Note that hired labor through temporary employment agencies (NACE 7820) is recorded as intermediary inputs in our data, and is part of variable costs. Hence labor can be split up into a fixed and variable part.

[8] Lagged materials are used as a regressor in this setup, so the estimation sample starts from 2004 instead of 2003.

[9] Producer j is excluded from the set, as this would otherwise generate a mechanical correlation between j and the resulting weighted average.

First, simultaneity arises if changes in output prices $d\ln p_{jt}$ also affect changes in input prices $d\ln p_{it}$. For example, this might be due to cyclicality of the network structure of production, in which a producer j is (in-)directly supplying its supplier i. Alternatively, prices might co-move across the board, inducing simultaneity in both input and output prices. As prices tend to be positively correlated, OLS estimates of β will be biased downwards.

Second, while we exploit the rare features of the data in constructing $\sum_{i\in\mathscr{S}_{jt}}\omega_{ijt}d\ln p_{it}$, using unprecedented detail on micro prices and input shares, there is still potential measurement error. In particular, changes in input prices $d\ln p_{it}$ are obtained from unit values, which are arguably a noisy measure of true but unobserved prices.

Third, changes in other prices $d\ln\mathscr{P}_{-jt}$ are also potentially simultaneously determined with $d\ln p_{jt}$. For example, if they reflect competitors prices, these can be jointly determined in a strategic price setting scheme.

To account for these different endogeneity issues and to obtain consistent estimates, an instrumental variable approach is implemented. In particular, we generate three instruments, which are used to instrument changes in input prices $d\ln p_{it}$ and changes in other producers' prices $d\ln\mathscr{P}_{-jt}$.

As a first instrument, changes in input prices $d\ln p_{it}$ are instrumented using a market share-weighted average change in import prices of the same product $d\ln\bar{p}_{-it}$. More formally

$$d\ln\bar{p}_{-it}=\frac{\sum_{m\in\mathscr{I}_{it}}S_{mt-1}d\ln p_{mt}}{\sum_{m\in\mathscr{I}_{it}}S_{mt-1}}$$

where $\mathscr{I}_{it}$ is the set of imported products corresponding to input i in Belgium at time t, and S_{mt-1} is the value of imports. For imported inputs, $d\ln\bar{p}_{-it}$ is constructed excluding input i. For domestic inputs, we use the concordance procedure from CN8 to PC8 to obtain a weighted average price change for these inputs.

The rationale for instrumenting input price changes using average import price shocks is that the average import price change only affects a change in output prices $d\ln p_{jt}$ through the input prices $d\ln p_{it}$, theoretically satisfying the exclusion restriction. For domestic inputs, producers j could have sourced the input internationally instead of domestically. Then, all instrumented input price shocks are aggregated across inputs of producer j, so that[10]

$$d\ln P_{jt}^{IV1}=\sum_{i\in\mathscr{S}_{jt}}\omega_{ijt-1}d\ln\bar{p}_{-it}$$

The average change in prices of other producers, $d\ln\mathscr{P}_{-jt}$, also suffers from the same endogeneity issues. As a second instrument, average changes in import prices are used again, but now to instrument price changes other firms in the same product space, instead of those of suppliers. In particular, the instrument is constructed as

$$d\ln\mathscr{P}_{-jt}^{IV2}=\frac{\sum_{l\in\mathscr{I}_{jt}}S_{lt-1}d\ln p_{lt}}{\sum_{l\in\mathscr{I}_{jt}}S_{lt-1}}$$

Finally, as a third instrument, changes in components of $d\ln\mathscr{P}_{-jt}$ are instrumented with productivity shocks $d\ln z_{lt}$ to producers l. In order to satisfy the exclusion restriction, a productivity shock to a firm l has no direct impact on the change in output price of j, but is only correlated with a change in output price of j through the change in l's price $d\ln p_{lt}$. Productivity shocks across all producers l for producer j are then aggregated using product market share weights as

$$d\ln\mathscr{P}_{-jt}^{IV3}=\frac{\sum_{l\in\mathscr{D}_{jt}}S_{lt-1}d\ln z_{lt}}{\sum_{l\in\mathscr{D}_{jt}}S_{lt-1}}$$

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[10] Whenever a domestic supplier i is a multi-product firm, we calculate the instrument by averaging across its output products, using revenue shares as weight.

4.3 Estimation specifications

The model in Section 3 presents a general framework on how single-product producers update prices in the presence of production networks. In Appendix C, an extension is presented for multi-product firms, along with additional assumptions required for identification. When presenting the empirical results below, Section 5 reports regression results for the main product of producer j, trivially including single-product firms. Alternative specifications, including pass-through regressions for an output price index $d\ln\tilde{P}_{jt}$ at the firm level are discussed in the robustness section.

Additionally, in order to obtain an estimate for cost pass-through, eq(5) is estimated using $d\ln P_{jt} = \sum_{i\in\mathscr{S}_{jt}} \omega_{ijt-1} d\ln p_{it}$ as the total impact of all suppliers' shocks to j. From eq(2), it is possible to evaluate individual shocks to any supplier i on output prices of j. The robustness section discusses in more detail how to disentangle common versus idiosyncratic shocks on the input bundle.

Finally, estimating the cost pass-through regression does not impose using any type of fixed effects (including a regression constant). Under an alternative specification, markups can be a function of demand shifters to producer j ,ξ_{jt}, so that $\ln\mu_{jt}\left(p_{jt}, \mathscr{P}_{-jt}; \xi_{jt}\right)$. One might be tempted to use product or sector fixed effects to account for these possible demand shocks. However, these fixed effects will not only capture demand shocks but also the common part of supply shocks. Therefore, the baseline specifications do not impose fixed effects, but their addition is discussed in the results section. It is important to stress however, that under these fixed effects specifications, the estimated parameters are not their theoretical counterparts in eq(2), but instead deviations from their product or industry means.

5 Results on price updating

5.1 Baseline results

Table 3 reports our baseline results from estimating equation eq(5). Columns (i)-(iii) report the coefficients by estimation of eq(5) using OLS. Column (i) shows results without fixed effects, while columns (ii) and (iii) add in year and sector fixed effects sequentially. All estimated coefficients are significant at the 1% level, with robust standard errors clustered at the 4-digit NACE level.

The estimated cost pass-through coefficient is .23, indicating that a 1% shock to input prices by suppliers of j, $d\ln P_{jt}$, correlates with a .23% increase in the output price of j on average, all else equal. The coefficient on the productivity shock $d\ln z_{jt}$ is -.09, implying that an increase in productivity correlates with a downward adjustment of output prices. Finally, price changes of other firms, $d\ln\mathscr{P}_{-jt}$, are important: on average, and conditional on cost shocks, a 1% increase in the price of producers in the same the 8-digit product (PC8) level, relates to a .33% increase in j's own price on average, entirely accruing to an increase in its markup. When accounting for year and sector fixed effects in columns (ii) and (iii), both the cost pass-through and effect of other firms' prices slightly decline, with the effect of the productivity shock on the output price remaining stable.

However, these estimates are likely to suffer from endogeneity bias due to simultaneity and measurement error, as discussed above. To deal with these endogeneity issues and to obtain consistent estimates, we implement an instrumental variable approach. In particular, changes in input prices $d\ln P_{jt}$ and changes in prices of other producers $d\ln\mathscr{P}_{-jt}$ are instrumented using three instruments: changes in input prices are instrumented using average import price shocks to suppliers of j, aggregated to a weighted average using input expenditure shares, $d\ln P_{jt}^{IV1}$. Changes in prices of other producers are instrumented using both average import prices and productivity shocks to these producers, aggregated to a weighted average using market shares in the product space k, respectively $d\ln\mathscr{P}_{-jt}^{IV2}$ and $d\ln\mathscr{P}_{-jt}^{IV3}$.

For these instruments to be valid, they have to be correlated with the endogenous variables (relevance) and only affect the dependent variable through these endogenous variables (exclusion). Table 4 reports the results of the first

Table 3: Price updating regressions.

	OLS			IV		
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
Dep. var.	$d\ln p_{jt}$	$d\ln p_{jt}$	$d\ln p_{jt}$	$d\ln p_{jt}$	$d\ln p_{jt}$	$d\ln p_{jt}$
$d\ln P_{jt}$	0.229***	0.199***	0.192***	0.440***	0.388***	0.379***
	(0.032)	(0.029)	(0.029)	(0.056)	(0.058)	(0.047)
$d\ln z_{jt}$	-0.091***	-0.094***	-0.095***	-0.089***	-0.092***	-0.092***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
$d\ln \mathscr{P}_{-jt}$	0.334***	0.314***	0.308***	0.277***	0.253***	0.267***
	(0.029)	(0.029)	(0.028)	(0.039)	(0.041)	(0.033)
FE(year)	no	yes	yes	no	yes	yes
FE(sector)	no	no	yes	no	no	yes
N	23,590	23,590	23,590	20,722	20,722	20,722
Over-identification J-test				4.61	1.29	0.00
χ^2 and [p-value]				[.03]	[.26]	[1.00]

Note: Columns (i)-(iii) report OLS estimates, columns (iv)-(vi) reports the second stage of IV estimates employing GMM. All regressions are pooled over the years 2004-2014. For the IV specifications, Hansen's over-identification J-test statistic cannot reject the null hypothesis that the over-identifying restrictions are valid at the 1% level. Robust standard errors between brackets, all clustered at the 4-digit NACE sector level. Significance: * < 5%, ** < 1%, *** <0.1%.

stage regressions for the three different specifications of the IV estimation, using GMM. Each IV estimation involves two first stage regressions, one for each endogenous variable. In all cases, the first stage F-test is high (larger than 40 in each specification) with a corresponding p-value of .00, strongly supporting the relevance of the instruments used. Conditional on $d\ln z_{jt}$, there is a strong correlation between the endogenous variables and their proposed instruments, both in terms of significance and size.[11]

Next, columns (iv)-(vi) in Table 3 report the IV regression results. A Hansen over-identification J-test strongly supports the exclusion restriction at the 1% level in all specifications. The estimated IV coefficients confirm the anticipated downward bias in the cost pass-through coefficient from using OLS, and the estimated coefficient in our preferred specification has now increased to .44. From eq(6), the implied elasticity of a change in output price to markups is $\frac{\partial \ln \mu_{jt}}{\partial \ln p_{jt}} = 1 - 1/\beta = -1.27$; i.e. on average, producers j face elastic changes in markups: a 1% increase in output price relates to a 1.27% decrease in markups. The coefficients on productivity shocks and other firms' price changes remain largely unchanged. Again, from eq(6), the structural interpretation of the productivity shock elasticity on output is $\frac{\partial \ln y_{jt}}{\partial \ln z_{jt}} = \frac{\gamma}{\beta} = .20$. Similarly, the response in j's markup from changes in other prices is structurally recovered from $\frac{\partial \ln \mu_{jt}}{\partial \ln \mathscr{P}_{-jt}} = \frac{\delta}{\beta} = .63$. Finally, when accounting for year and sector fixed effects in columns (v) and (vi), all estimated coefficients are largely unaffected, with a slight decline in the pass-through coefficient. This suggests that business cycles or sector-level characteristics do not fundamentally explain j's average cost pass-through, nor its average response to price changes in its environment.

These results are telling. They show that manufacturing firms in Belgium do not completely pass through cost shocks, and that there is room for significant reaction to prices of other firms in the same product space, conditional on cost shocks. On average across all firms, the pass-through elasticity is .44, very much below 1, while the environments'

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[11] A Cragg and Donald test strongly rejects the null of weak instruments at any plausible level of significance. An additional endogeneity test using Hayashi's C statistic strongly reject the null hypothesis that the endogenous variables can be treated as exogenous.

Table 4: First stage results, instrumental variables estimation.

	No fixed effects		Year fixed effects		Year and sector fixed effects	
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
Dep. var.	$d\ln P_{jt}$	$d\ln \mathscr{P}_{-jt}$	$d\ln P_{jt}$	$d\ln \mathscr{P}_{-jt}$	$d\ln P_{jt}$	$d\ln \mathscr{P}_{-jt}$
$d\ln z_{jt}$	-.005**	.009**	-.005**	.009**	-.005***	.008***
	(.002)	(.003)	(.002)	(.003)	(.001)	(.002)
$d\ln P_{jt}^{IV1}$	.792***	.239***	.769***	.196***	.770***	.188***
	(.000)	(.039)	(.027)	(.033)	(.018)	(.018)
$d\ln \mathscr{P}_{-jt}^{IV2}$	-.007	.438***	-.008	.431***	-.006	.437***
	(.007)	(.041)	(.007)	(.041)	(.005)	(.011)
$d\ln \mathscr{P}_{-jt}^{IV3}$	.001	.038***	-.004	.028***	-.005	.029***
	(.004)	(.010)	(.004)	(.008)	(.004)	(.006)
First stage F-test	240.08	62.07	102.27	53.10	78.30	42.81
[p-value]	[.00]	[.00]	[.00]	[.00]	[.00]	[.00]

Note: Regression results for the first stages of the IV estimation. For each specification, there are two first stages, one for each endogenous and instrumented variable. Columns (i)-(ii) refer to the first stages of column (iv) in Table 3, etc. Significance: * < 5%, ** < 1%, *** <0.1%.

price elasticity is 0.28. This implies that empirically, models of price setting behavior with constant markups, such as perfect competition or monopolistic competition with CES preferences are refuted, at least at the average.

5.2 Common vs. idiosyncratic shocks

The results in the baseline specifications potentially obfuscate sizable heterogeneity in price responses to cost pass-through rates, productivity shocks and other price changes. Stylized fact 2 in Section 2 documents that output and input price changes exhibit both idiosyncrasies and co-movement within narrowly defined product categories. Here, we analyze the heterogeneous response in pass-through rates to these different types of input shocks.

The procedure is as follows. First, changes in the input price bundle $d\ln P_{jt}$, are demeaned at the sector-year level. The demeaned values are then classified into three terciles. An observation in the first tercile refers to a large negative price shock on the input bundle, relative to other producers j in the same 4-digit NACE sector. (i.e. a relatively large cost reduction for j). Similarly, observations in the second tercile exhibit close to average input price shocks. Finally, producers in the third tercile represent firms that have experienced relatively bad input price shocks, as their change in input price index increased more, relative to the average in that industry.

Next, eq(5) is estimated by input price shock quantile. The results are in Table 5. The first three columns report the OLS coefficients by tercile, while the last three columns report these for the IV. Robust standard errors are clustered at the 4-digit NACE level. The results are striking: on average across all producers, firms tend to completely pass through input price shocks that are common to firms in the same sector. In the IV regressions, the cost pass-through coefficient is not significantly different from one for the second tercile. Conversely, relatively large, idiosyncratic shocks, are passed through at a much lower rate, at .51 and .34 for terciles one and three respectively. At the same time, the coefficients on other firms' prices and productivity shocks remain largely the same over the whole distribution.

Figure 4 plots the pass-through coefficients across the specified terciles. Panels (a) and (b) depict the estimated

Table 5: Common vs. idiosyncratic input shocks.

	OLS			IV		
	q1	q2	q3	q1	q2	q3
Dep. var.	$d\ln p_{jt}$	$d\ln p_{jt}$	$d\ln p_{jt}$	$d\ln p_{jt}$	$d\ln p_{jt}$	$d\ln p_{jt}$
$d\ln P_{jt}$	0.114**	0.802***	0.269***	0.509***	1.175***	0.342***
	(0.041)	(0.131)	(0.037)	(0.080)	(0.221)	(0.062)
$d\ln z_{jt}$	-0.079***	-0.111***	-0.089***	-0.073***	-0.116***	-0.087***
	(0.011)	(0.015)	(0.012)	(0.012)	(0.015)	(0.012)
$d\ln \mathscr{P}_{-jt}$	0.346***	0.300***	0.320***	0.332***	0.249***	0.257***
	(0.031)	(0.048)	(0.041)	(0.050)	(0.063)	(0.068)
N	7,934	7,719	7,852	6,878	6,882	6,891

Note: Columns (i)-(iii) report OLS estimates, columns (iv)-(vi) reports the second stage of IV estimates employing GMM. q1 refers to the first tercile etc. All regressions are pooled over the years 2004-2014. Significance: * < 5%, ** < 1%, *** <0.1%.

coefficients from OLS and IV, respectively. The circles represent the point estimates, with 95% confidence intervals. First, complete pass-through of sector-specific common shocks cannot be rejected at the 95% confidence level. Second, the pass-through rates for idiosyncratic shocks are statistically different from these for the common shocks, and well below one. It is important to stress that these results are not a by-product of large changes in input prices that represent only a small input share: the results remain unchanged when excluding price changes to inputs that account for less than 1% of input expenditures.

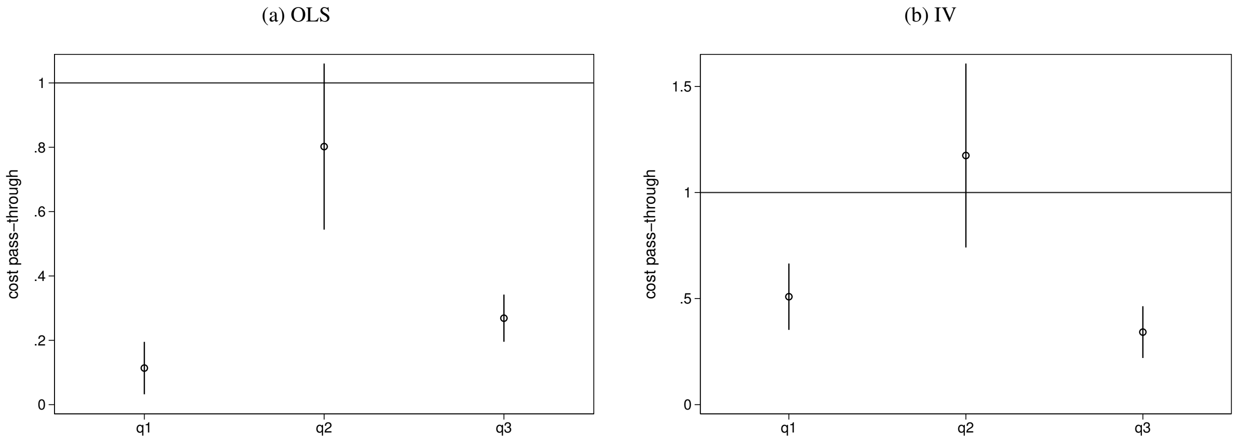
Why do firms pass through cost shocks differently, based on common or idiosyncratic input price shocks? One possible explanation is the use of commodities in production: many commodities are priced publicly in international markets. Producers know other firms face also the same cost shock, creating room for each firm to pass through these shocks on output prices. More generally, price updating in response to idiosyncratic or common shocks is related to expectations. If a producer suspects its input price shock is common to other firms in the same industry, that producer expects other firms to also increase their prices, again leaving room to increase its own price.

6 Robustness

This section discusses alternative specifications and additional results to the main results in Section 5.

First, the estimates in Section 5 represent average elasticities across all firms and over time, in which each observation is weighted equally. Here, we re-estimate eq(5), using lagged firm-level sales as a weighting scheme. The purpose is two-fold. First, a sales-weighted average provides a representation of the average pass-through coefficient in the aggregate. Second, comparing weighted versus unweighted schemes allows to evaluate the heterogeneity of pass-through rates across small and large firms. Table Table 6 reports these results. The average pass-through in the aggregate is around .53 in our main specification (column (iv)). Compared to the baseline results in Table 3, the weighted average pass-through rate is higher across all specifications. The same holds for the reaction to other prices. However, the change in output price in response to a productivity shock is lower than in the unweighted regressions. Taken together, these results suggest that, on average, (i) larger firms have higher cost pass-through rates, (ii) they pass through less of their productivity shocks, and (iii) they tend to adjust output prices more in response to the environment's price index

Figure 4: Cost pass-through coefficient, common vs. idiosyncratic.



(a) OLS

(b) IV

changes.

Second, we re-estimate eq(5) for by sector and report results in Table 7. Sectors are defined as NACE aggregates in the National Accounts system (A64). Both OLS and IV estimates are reported, with robust standard errors clustered at the NACE 4-digit level. While the statistical power of the hypothesis tests decreases due to the limited number of observations per sector over the panel, there is a large amount of heterogeneity across sectors. First, cost pass-through rates vary substantially across sectors. While the coefficient was .44 in the baseline setting using IV, pass-through rates are highest in Manufacture of chemicals and chemical products (.63) and Manufacture of furniture and other manufacturing (.54). Conversely, firms update prices in response to their environment most in Repair and installation of machinery and equipment (1.19) and Manufacture of basic metals (.70).

Third, the baseline results report on the output price changes for single-product firms and the main product of multi-product firms. Appendix C derives further conditions and identification assumptions, under which the model can be extended to multi-product firms, such that the estimated coefficients can still be interpreted as input price cost shocks and markup adjustments in our general pricing model. Table 8 shows the estimation results when aggregating firm-product output price changes to the firm level, as $d\ln\tilde{P}_{jt} \equiv \sum_k \varphi_{jkt} d\ln p_{jkt}$, where φ_{jkt} is the revenue share of product k in firm j. Compared to the baseline results, the coefficients are largely unaffected. Since multi-product producers are also larger on average, we additionally estimate eq(5) using the sales weighting scheme presented above, and present the results in Table 9. These pass-through estimates are slightly higher than in the unweighted case, and confirm the earlier results: larger firms have higher pass-through rates.

7 Conclusion

Firms can change their prices as a function of both changes in their cost structure (either through input prices or productivity shocks) and changes in other prices in their environment. The non-parametric pricing model is very general, and can be applied to various settings of market structure and demand. The particularities of each parameterization will impose further restrictions on the sign and size of the elasticities that can be taken to the data.

Importantly, full pass-through of cost shocks and constant markups are empirically refuted, at least on average.

Table 6: Price updating regressions, weighted.

	WLS			IV (weighted)		
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
Dep. var.	$d\ln p_{jkt}$	$d\ln p_{jkt}$	$d\ln p_{jkt}$	$d\ln p_{jkt}$	$d\ln p_{jkt}$	$d\ln p_{jkt}$
$d\ln P_{jkt}$	0.312***	0.280***	0.259***	0.529***	0.499***	0.462***
	(0.070)	(0.067)	(0.065)	(0.093)	(0.083)	(0.105)
$d\ln z_{jkt}$	-0.049*	-0.051*	-0.049*	-0.070***	-0.072***	-0.064*
	(0.023)	(0.021)	(0.021)	(0.018)	(0.018)	(0.025)
$d\ln \mathscr{P}_{-jkt}$	0.407***	0.386***	0.418***	0.405***	0.402***	0.418***
	(0.057)	(0.056)	(0.052)	(0.097)	(0.097)	(0.061)
FE(year)	no	yes	yes	no	yes	yes
FE(sector)	no	no	yes	no	no	yes
N	23,590	23,590	23,590	20,722	20,722	20,722

Note: Columns (i)-(iii) report WLS estimates, columns (iv)-(vi) reports the second stage of weighted IV estimates employing GMM. All regressions are pooled over the years 2004-2014. Robust standard errors between brackets, all clustered at the 4-digit sector level. Significance: * < 5%, ** < 1%, *** <0.1%.

This includes the rejection of various models, such as the canonical model of international trade with monopolistic competition with CES preferences, thereby shutting down important welfare mechanisms that operate through these channels.

Credibly estimating pass-through rates is only a first step in understanding the aggregate implications of variable markups. This paper proposes a very detailed but general input-output representation of an economy in which individual entries represent firm-product elasticities with respect to prices and markups. The next step in this research is to characterize the impact of incomplete and heterogeneous pass-through along the production network, and formalize how price shocks, sticky prices and heterogeneity in the network structure of production aggregate up to the economy level.

Table 7: Price updating, by sector.

	OLS				IV			
NACE Rev.2 sectors	N	β	γ	δ	N	β	γ	δ
8-9 – Mining and quarrying	435	.363	-.75*	.001	398	.933*	-.050	.387
		(.269)	(.033)	(.100)		(.367)	(.038)	(.242)
10-12 – Manufacture of food products and beverages	6242	.360***	-.055***	.362***	6,023	.340***	-.059***	.512***
		(.072)	(.012)	(.095)		(.080)	(.012)	(.054)
13-15 – Manufacture of textiles and apparel	1,184	.306***	-.114**	.219***	1,363	.229	-.122***	.232**
		(.081)	(.035)	(.057)		(.162)	(.028)	(.080)
16 – Manufacture of wood[...]	1,294	.031	-.107***	.347***	1,281	.077	-.100***	.192**
		(.022)	(.029)	(.071)		(.146)	(.024)	(.059)
17-18 – Manufacture of paper products and media	1,238	.047	-.141***	.567**	1,121	.334**	-.119***	.239*
		(.074)	(.018)	(.090)		(.134)	(.027)	(.119)
20 – Manufacture of chemicals and chemical products	1,630	.336**	-.050*	.310***	1,479	.628***	-.061*	.274**
		(.116)	(.023)	(.067)		(.173)	(.026)	(.097)
22 – Manufacture of rubber and plastic products	1,240	.177***	-.105***	.251	1,159	.344	-.112**	-.067
		(.034)	(.015)	(.162)		(.197)	(.034)	(.139)
23 – Manufacture of other non-metallic mineral[...]	2,300	.06	-.108***	.373***	2,179	.459**	-.103***	.218
		(.058)	(.017)	(.055)		(.147)	(.021)	(.237)
24 – Manufacture of basic metals	685	.579***	-.034	.424***	468	.486**	-.042	.695***
		(.123)	(.028)	(.057)		(.185)	(.037)	(.178)
25 – Manufacture of fabricated metal products[...]	3,574	.215*	-.096***	.376***	2,841	.391**	-.095***	.374***
		(.088)	(.021)	(.061)		(.142)	(.017)	(.093)
26-27 – Manufacture of computer, electronic and[...]	798	.108	-.176	.284**	580	.583	-.162***	.035
		(.119)	(.041)	(.101)		(.294)	(.041)	(.167)
28-29 – Manufacture of machinery, motor vehicles[...]	818	-.002	-.073	.302**	254	-1.86	-.058	1.148
		(.111)	(.040)	(.082)		(3.112)	(.068)	(1.300)
31-32 – Manufacture of furniture and other manufacturing	1,489	.182***	-.122***	.251***	1,342	.541***	-.139***	-.016
		(.046)	(.027)	(.061)		(.160)	(.020)	(.199)
33 – Repair and installation of machinery and equipment	131	-.705	-.086	.305***	63	.381	-.007	1.187**
		(.155)	(.095)	(.059)		(1.082)	(.117)	(.435)

Table 8: Price updating regressions, multi-product firm aggregation.

	OLS			IV		
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
Dep. var.	$d\ln\tilde{P}_{jt}$	$d\ln\tilde{P}_{jt}$	$d\ln\tilde{P}_{jt}$	$d\ln\tilde{P}_{jt}$	$d\ln\tilde{P}_{jt}$	$d\ln\tilde{P}_{jt}$
$d\ln P_{jkt}$	0.236***	0.202***	0.197***	0.436***	0.374***	0.368***
	(0.032)	(0.030)	(0.029)	(0.055)	(0.056)	(.045)
$d\ln z_{jt}$	-0.087***	-0.090***	-0.092***	-0.086***	-0.089***	-0.088***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.007)
$d\ln\mathscr{P}_{-jkt}$	0.295***	0.272***	0.267***	0.260***	0.234***	0.250***
	(0.026)	(0.026)	(0.025)	(0.040)	(0.040)	(0.030)
FE(year)	no	yes	yes	no	yes	yes
FE(sector)	no	no	yes	no	no	yes
N	23,733	23,733	23,733	20,844	20,844	20,844

Note: Columns (i)-(iii) report OLS estimates, columns (iv)-(vi) reports the second stage of IV estimates employing GMM. All regressions are pooled over the years 2003-2014. Robust standard errors between brackets, all clustered at the 4-digit sector level. Significance: * < 5%, ** < 1%, *** <0.1%.

Table 9: Price updating regressions, multi-product firms, weighted.

	OLS			IV		
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
Dep. var.	$d\ln\tilde{P}_{jt}$	$d\ln\tilde{P}_{jt}$	$d\ln\tilde{P}_{jt}$	$d\ln\tilde{P}_{jt}$	$d\ln\tilde{P}_{jt}$	$d\ln\tilde{P}_{jt}$
$d\ln P_{jkt}$	0.407***	0.366***	0.338***	0.616***	0.591***	0.584***
	(0.067)	(0.066)	(0.058)	(0.066)	(0.073)	(0.072)
$d\ln z_{jt}$	-0.051*	-0.053*	-0.051*	-0.077***	-0.078***	-0.071***
	(0.023)	(0.022)	(0.021)	(0.021)	(0.020)	(0.021)
$d\ln\mathscr{P}_{-jkt}$	0.331***	0.306***	0.346***	0.317***	0.293***	0.302***
	(0.057)	(0.054)	(0.044)	(0.076)	(0.077)	(0.046)
FE(year)	no	yes	yes	no	yes	yes
FE(sector)	no	no	yes	no	no	yes
N	23,733	23,733	23,733	20,844	20,844	20,844

Note: Columns (i)-(iii) report OLS estimates, columns (iv)-(vi) reports the second stage of IV estimates employing GMM. All regressions are pooled over the years 2003-2014. Robust standard errors between brackets, all clustered at the 4-digit sector level. Significance: * < 5%, ** < 1%, *** <0.1%.

Appendices

A Data sources and construction

The empirical analysis in this paper mainly draws from three data sources at the National Bank of Belgium (NBB). These include (i) information on production values and quantities from the Prodcom Survey, (ii) domestic supplier-buyer relationship values from the NBB B2B Transactions Dataset, and (iii) international trade data at the firm-product-country level from Intrastat and Extrastat. Firms are identified by a unique corporate registration number from the Crossroads Bank for Enterprises, which allows for unambiguous merging across all datasets.

Additional data comes from the Crossroads Bank for Enterprises, from which we extract the main NACE sector at the 4-digit industry of each firm. Finally, product classification tables and correspondence files for international trade (CN) and Prodcom (PC) are obtained from Eurostat to construct our concordance method.

Prodcom Survey

The Prodcom Classification (PC) provides statistics on the production of manufactured goods and industrial services across Mining and Quarrying (NACE Rev.2 Section B) and Manufacturing (Section C) in the EU. Depending on the year, the classification describes roughly 4,000 industrial products at the disaggregated 8-digit (PC8) level.[12] For example, in 2014, within the 6-digit grouping of "*Polymers of ethylene, in primary forms*", code 20.16.10.35 refers to "*Linear polyethylene having a specific gravity < 0,94, in primary forms*", code 20.16.10.39 is *"Polyethylene having a specific gravity < 0,94, in primary forms (excluding linear)*", code 20.16.10.50 refers to *"Polyethylene having a specific gravity of* $\geq$ *0,94, in primary forms*", etc.

All firms that produce goods covered by the Prodcom Classification, and that have at least 20 persons employed or a turnover of at least 3,928,137 euro in the previous reference year, have to submit a monthly report to Statistics Belgium.[13] Reporting thresholds are defined at the consolidated level, such that daughters of surveyed firms also report their production and sales, independent of their size. The database reports, for each product in the prodcom list, values and quantities for total production and sold production in Belgium during the reference period. Some products only have to report values, not quantities, such as some industrial manipulations (e.g. bleaching of leather, dying of textile). Values are reported in current euro. Quantities are reported in one of several possible units (over two thirds of observation are in kilograms; other units include liters, meters, square meters, kilowatt, kg of active substance etc.), and we keep track of these units when we compare and harmonize international trade data and Prodcom data later on.[14] The survey is collected in an electronic format, which includes automatic checks when filing the data and additional checks and cross-references with both micro and macro data by the national statistical office, to ensure a pristine quality of reporting.

We extract information from the monthly Prodcom Survey for all firms with their main activity in Mining, Quarrying and Manufacturing for the period 2002-2014. For some monthly observations at the firm-product level, either values or quantities are missing. We impute these by first calculating the average monthly unit value for that firm-product, and then back out values or quantities for these months. We aggregate values and quantities from monthly to yearly observations. We obtain firm-product prices as values over quantities. We subtract net exports from total

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[12] In the Prodcom survey for Belgium, the following sectors are covered: NACE Rev.2 Divisions 08-33, except 09, 19, 1011 and the slaughterhouse part of 1051. These represent roughly 2,500 PC8 codes in a given year, produced in Belgium.

[13] See here for more info.

[14] For example, we correct the Prodcom sales data for net exports to obtain domestic unit values. To do so, we need to concord the trade data with the Prodcom data, identify products that can be corresponded from CN to PC, and when subtracting quantities, we need to ensure that both products are reported in the same unit of measurement.

Prodcom sales by the firm, as we need to obtain a measure of domestic output prices to be used as input prices for other firms (see the procedure below).

Next, we calculate the change in logs of domestic output prices for every continuing firm-product-year observation. We have constructed a custom concordance method that takes into account changes in the PC classification over time, and that makes sure the product is reported in the same units in both years.[15] In short, as the classification changes over time, some product codes are merged to one single PC code in from one year to another, or one PC code can be split up into different codes from one year to the next. We identify these changes and deal with merges and splits year by year. We do not impose a harmonization over time, as we only need to identify continuing products from $t-1$ to t. Whenever 1:m matches occur over time, so that one PC8 product in $t-1$ splits into multiple products in t, we allocate prices proportionally to the new products in t, with firm-level weights given by the revenue shares of these products in t. Whenever m:1 matches occur, we generate a weighted average of prices in $t-1$ to calculate price changes. We also identify the units of measurement each year, so that we do not erroneously calculate price changes based on unit values in kilograms and square meters from one year to another for instance. We trim log-differenced unit values at ± 1.

Firm-to-firm relationships

The confidential NBB B2B Transactions Dataset contains the values of yearly sales relationships among all VAT-liable Belgian enterprises for the years 2002 to 2014, and is based on the VAT listings collected by the tax authorities. At the end of every calendar year, all VAT-liable enterprises have to file a complete listing of their Belgian VAT-liable customers over that year.[16] An observation in this dataset refers to the sales value in euro of enterprise i selling to enterprise j within Belgium, excluding the VAT amount due on these sales. The reported value is the sum of invoices from i to j in a given calendar year. Whenever this aggregated value is 250 euros or greater, the relationship has to be reported. Fines are imposed for late and/or erroneous reporting. Each observation m_{ij} is directed, as firm i can be selling to j, but not necessarily the other way around, i.e. $m_{ij} \neq m_{ji}$. A detailed description of the collection and cleaning of this dataset is given in Dhyne et al. (2015). We keep producers j that are sellers in the Prodcom data, and extract all input suppliers i to these firms. We drop suppliers to j that mainly produce capital goods (NACE Rev.2 codes 28 and 41-43), as these goods are not part of the marginal cost bundle of their customers.

International trade data

We obtain information on imports and exports from the Intrastat (intra-EU) and Extrastat (extra-EU) declarations for Belgium. Observations in this dataset are at the firm-product-country-year level. Products are defined at the 8-digit Combined Nomenclature (CN8) level. We exploit information on values and quantities to generate import and export prices, and we additionally retain information on the units of measurement for quantities reported. At the CN8 level, most products' export and import quantities are recorded in weight (kilograms). Depending on the particular product, some products' quantities are also recorded in a secondary unit (which is the same as the PC8 unit if there exists a concordance between the CN8 and PC8 products).

Data cleaning proceeds as follows. First, we calculate the average export price at the firm-product-year level as total export value over total export quantities, summed across all export destinations. We need this to correct for export prices in the Prodcom data to obtain domestic unit values. Second, we use imports as inputs in production. For that, we (i) subtract goods that are re-exported without manipulation by the firm, and (ii) ignore imported capital goods as

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[15] The method is slightly different from e.g. Pierce & Schott (2012), as we do not harmonize products over the whole sample period. Harmonizing would imply creating "family trees", in which m:1, 1:m and m:m matches over time are collapsed to single products. The longer the time horizon of the data, the more granularity the dataset would lose. With our method, we can track all changes of 1:1, 1:m, m:1 and m:m from $t-1$ to t and identify price changes for these products.

[16] Sample VAT listings forms can be found at here (French) and here (Dutch).

inputs, as both types of goods are not part of the marginal cost of the firm in our setup. We identify capital goods from the concordance tables between CN and BEC (Broad Economic Classification), and drop imports that are marked as capital goods in the BEC classification (codes 410 and 521). Re-exports can be a particular issue in Belgium, which is considered as a transit country (see e.g. Duprez (2014)). To clean imports from re-exports, we subtract the value of exported products at the CN8 level that are also imported by the firm in the same year. We proportionally redistribute exports over all import countries for the same firm-product observation. Next, we obtain prices for imports at the firm-product-country-year level as net imported values over net imported quantities.

The next step is to obtain the change in prices for continuing imports at the product-country level. We use the same methodology for changes in CN8 from year to year, and for m:1, 1:m and m:m correspondences as the procedure above for yearly changes in PC8. Finally, log-differenced unit values are trimmed at ±1.

B Additional descriptive statistics

This section provides additional statistics on the stylized facts presented in the main text. Table 10 shows the distribution of output price changes at the firm-product level by 2-digit NACE sector for the year 2014. Sectors with at least 10 observations are reported. Table 11 shows the distribution of output price changes by year, using the main output for each firm instead of all products in the main text. Similarly, Table 12 shows the distribution using a sales-weighted average of product price changes at the firm level.

C Model with multi-product firms

This section develops an extended version of the model, in which firms now produce multiple outputs instead of being single-product firms as in the main text. Two variants of the model are presented, in which the unit of observation is either the firm-product or the firm as a whole. This distinction has implications for the identification assumptions when taken to the data.

C.1 Model at the firm-product level

The cost function of output k by firm j is now

$$y_{jkt} c_{jkt} \left((1+\tau_{1j})\, p_{1t}, \ldots, (1+\tau_{nj})\, p_{nt}, z_{jt} \right) + F_{jkt}$$

For our purpose of identifying the sources of output price changes, allowing for multi-product firms requires the following additional assumptions:

Assumption 1. *No physical synergies across products within producers.*

This implies that the cost function of one product is independent of the production of the other products within the firm.

Table 10: Distribution of producer price changes, by sector (2014).

						percentiles						
NACE Rev.2 Division	N	mean	st. dev.	p1	p5	p10	p25	p50	p75	p90	p95	p99
8 – Other mining and quarrying	69	-.023	.18	-.70	-.29	-.15	-.07	.00	.03	.11	.21	.73
9 – Mining support service activities	15	-.054	.18	-.53	-.53	-.25	-.12	-.01	.04	.19	.21	.21
10 – Manufacture of food products	1,704	-.014	.19	-.69	-.29	-.18	-.07	.00	.04	.13	.25	.68
11 – Manufacture of Beverages	89	-.001	.21	-.91	-.31	-.19	-.06	.00	.05	.24	.37	.72
13 – Manufacture of textiles	192	.006	.24	-.83	-.45	-.21	-.06	.00	.08	.25	.36	.76
14 – Manufacture of wearing apparel	38	-.008	.18	-.71	-.41	-.13	-.07	.00	.05	.17	.27	.39
16 – Manufacture of wood [...]	199	.001	.19	-.81	-.31	-.13	-.02	.00	.07	.13	.21	.50
17 – Manufacture of paper and paper products	151	-.016	.23	-.88	-.52	-.21	-.05	.00	.05	.14	.27	.82
18 – Printing and reproduction of recorded media	48	-.02	.23	-.75	-.58	-.14	-.03	.00	.03	.09	.25	.64
19 – Manufacture of coke and refined petroleum products	28	-.041	.21	-.78	-.69	-.16	-.03	.00	.02	.14	.17	.21
20 – Manufacture of chemicals and chemical products	622	-.001	.22	-.78	-.33	-.20	-.07	.00	.07	.22	.34	.80
21 – Manufacture of basic pharmaceutical products[...]	31	-.023	.22	-.56	-.48	-.20	-.12	.00	.09	.18	.30	.59
22 – Manufacture of rubber and plastic products	247	.009	.23	-.65	-.35	-.22	-.05	.00	.05	.22	.35	.92
23 – Manufacture of other non-metallic mineral[...]	330	.016	.16	-.46	-.15	-.09	-.02	.00	.03	.14	.23	.74
24 – Manufacture of basic metals	134	-.008	.23	-.80	-.38	-.17	-.08	-.01	.04	.21	.43	.70
25 – Manufacture of fabricated metal products[...]	463	.006	.22	-.68	-.35	-.17	-.06	.00	.04	.18	.45	.77
26 – Manufacture of computer, electronic and optical products	83	-.005	.28	-.99	-.46	-.40	-.13	.00	.10	.23	.41	.96
27 – Manufacture of electrical equipment	91	.053	.22	-.73	-.17	-.14	-.04	.00	.09	.31	.52	1
28 – Manufacture of machinery etc.	190	.041	.27	-.69	-.48	-.25	-.07	.01	.15	.37	.51	.92
29 – Manufacture of motor vehicles, trailers and semi-trailers	39	-.026	.22	-.72	-.53	-.32	-.07	-.01	.05	.19	.29	.56
31 – Manufacture of furniture	253	0	.18	-.69	-.30	-.19	-.03	.00	.05	.16	.27	.49
32 – Other manufacturing	24	.009	.31	-.81	-.33	-.27	-.13	.01	.10	.20	.48	.97
33 – Repair and installation of machinery and equipment	11	.096	.22	-.05	-.05	-.02	.00	.02	.09	.18	.72	.72

Table 11: Distribution of producer price changes, main output (2003-2014).

						percentiles						
Year	N	mean	st. dev.	p1	p5	p10	p25	p50	p75	p90	p95	p99
2003	4,186	.005	.21	-.72	-.33	-.17	-.04	.00	.05	.20	.36	.71
2004	4,123	.009	.20	-.67	-.30	-.16	-.03	.00	.06	.18	.32	.64
2005	3,835	.011	.20	-.65	-.29	-.16	-.04	.00	.07	.18	.30	.69
2006	3,719	.014	.19	-.70	-.28	-.13	-.03	.00	.07	.18	.30	.64
2007	3,827	.028	.19	-.65	-.25	-.12	-.02	.01	.09	.21	.32	.67
2008	2,756	.035	.24	-.76	-.33	-.20	-.03	.02	.10	.28	.44	.82
2009	2,878	-.013	.20	-.71	-.34	-.21	-.07	.00	.04	.17	.28	.66
2010	2,694	-.001	.21	-.78	-.33	-.21	-.05	.00	.06	.18	.30	.63
2011	2,529	.031	.19	-.70	-.24	-.11	-.02	.01	.09	.22	.34	.65
2012	2,369	.011	.20	-.71	-.33	-.15	-.03	.01	.07	.19	.30	.66
2013	2,301	-.004	.20	-.77	-.32	-.18	-.05	.00	.05	.16	.28	.67
2014	2,238	-.001	.20	-.68	-.31	-.16	-.06	.00	.05	.17	.31	.72
All	5,800	.011	.20	-.70	-.31	-.16	-.04	.00	.07	.19	.32	.68

Table 12: Distribution of producer price changes, firm-level weighted average (2003-2014).

						percentiles						
Year	N	mean	st. dev.	p1	p5	p10	p25	p50	p75	p90	p95	p99
2003	4,186	.006	.20	-.66	-.30	-.16	-.04	.00	.05	.19	.34	.68
2004	4,123	.01	.19	-.64	-.27	-.15	-.03	.00	.06	.17	.30	.62
2005	3,835	.011	.18	-.61	-.28	-.15	-.04	.00	.07	.18	.29	.65
2006	3,719	.014	.18	-.67	-.25	-.12	-.03	.00	.06	.17	.29	.60
2007	3,827	.029	.18	-.58	-.23	-.12	-.02	.02	.09	.20	.29	.62
2008	2,756	.032	.23	-.76	-.32	-.19	-.03	.02	.10	.26	.41	.79
2009	2,878	-.012	.19	-.66	-.32	-.20	-.07	.00	.04	.16	.27	.61
2010	2,694	-.002	.19	-.76	-.30	-.20	-.05	.00	.06	.18	.28	.62
2011	2,529	.032	.18	-.63	-.22	-.10	-.01	.01	.08	.21	.31	.60
2012	2,369	.011	.19	-.69	-.31	-.14	-.03	.01	.06	.17	.30	.65
2013	2,301	-.002	.19	-.74	-.31	-.17	-.04	.00	.05	.16	.25	.63
2014	2,238	-.001	.18	-.59	-.28	-.16	-.06	.00	.04	.15	.28	.63
All	5,800	.011	.19	-.66	-.28	-.15	-.04	.00	.06	.18	.31	.64

Assumption 2. *Proportionality of inputs to outputs.*

The share of input i allocated to product k by producer j, $\varphi_{ijkt} = \frac{S_{jkt}}{\sum_k S_{jkt}}$ is constant across all inputs i, whereS_{jkt} is the revenue share of k in revenue of j. This assumption implies that all inputs are proportionally allocated to outputs, with their shares corresponding to the respective revenue shares in production. In the data, there is no information on how firms allocate their inputs to producing multiple outputs, and an assumption on this allocation has to be made. This issue is omni-present in firm-level datasets with multi-product firms, and is not specific to our setup. Note that in our setup we have to allocate any domestic PC8 and foreign CN8 inputs to specific output, not only factors of production as in De Loecker et al. (2016).

Under these assumptions, the pricing equation eq(1) can be written at the firm-product level as

$$\ln p_{jkt} = \ln c_{jkt}\left(\left(1+\tau_{1j}\right)p_{1t},\ldots,\left(1+\tau_{nj}\right)p_{nt}, z_{jt}\right) + \ln \mu_{jkt}\left(p_{jkt}, \mathscr{P}_{-jkt}\right)$$

The fact that productivity is firm-specific (and not firm-product specific) is not necessarily required in our setting, but it follows the large literature on estimating productivity in multi-product firms (see e.g. Bernard et al. (2011); De Loecker et al. (2016)).

Log-differentiating the price equation, we have that the log change in price of output k by producer j can be approximated as

Hence,

$$d\ln p_{jkt} = \sum_{i\in\mathscr{S}_{jt}} \frac{\partial \ln c_{jkt}}{\partial \ln p_{it}} d\ln p_{it} + \frac{\partial \ln c_{jkt}}{\partial \ln z_{jt}} d\ln z_{jt} + \frac{\partial \ln \mu_{jkt}}{\partial \ln p_{jkt}} d\ln p_{jkt} + \frac{\partial \ln \mu_{jkt}}{\partial \ln \mathscr{P}_{-jkt}} d\ln \mathscr{P}_{-jkt}$$

Then,

$$d\ln p_{jkt} = \frac{1}{1-\frac{\partial \ln \mu_{jkt}}{\partial \ln p_{jkt}}} \left(\sum_{i\in\mathscr{S}_{jt}} \omega_{ijt} d\ln p_{it} + \frac{\partial \ln c_{jkt}}{\partial \ln z_{jt}} d\ln z_{jt} + \frac{\partial \ln \mu_{jkt}}{\partial \ln \mathscr{P}_{-jkt}} d\ln \mathscr{P}_{-jkt} \right) \tag{8}$$

where we have exploited the proportionality assumption, $\varphi_{ijkt} = \varphi_{jkt}$ for all i, so that

$$\omega_{ijkt} \equiv \frac{\varphi_{ijkt} x_{ijt} p_{it}\left(1+\tau_{ij}\right)}{\sum_{i\in\mathscr{S}_{jt}} \varphi_{ijkt} x_{ijt} p_{it}\left(1+\tau_{ij}\right)} = \frac{x_{ijt} p_{it}\left(1+\tau_{ij}\right)}{\sum_{i\in\mathscr{S}_{jt}} x_{ijt} p_{it}\left(1+\tau_{ij}\right)} \equiv \omega_{ijt}$$

Under the above conditions, eq(8) specifies a pass-through regression for multi-product firms, where the change in output price for a particular product k of producer j is evaluated against a combination of input price shocks, productivity shocks and the price index $\mathscr{P}_{-jkt}$.

C.2 Model at the firm level

It is possible to aggregate firm-product price shocks again to the firm level, with one additional assumption.

Assumption 3. *Markup shocks are the same across products within firms,* $\frac{\partial \ln \mu_{jkt}}{\partial \ln p_{jkt}} = \psi_{jt}$ *for all* k.

In this case, changes in output prices are aggregated to a firm-level output price index $d\ln \tilde{P}_{jt}$, with weights given by the revenue share of each product k, φ_{jkt}, so that $d\ln \tilde{P}_{jt} \equiv \sum_k \varphi_{jkt} d\ln p_{jkt}$.

Eq(2) then becomes

$$d\ln\tilde{P}_{jt}=\sum_k\varphi_{jkt}\left(\sum_{i\in\mathscr{S}_{jt}}\frac{\partial\ln c_{jkt}}{\partial\ln p_{it}}d\ln p_{it}+\frac{\partial\ln c_{jkt}}{\partial\ln z_{jt}}d\ln z_{jt}+\frac{\partial\ln\mu_{jkt}}{\partial\ln p_{jkt}}d\ln p_{jkt}+\frac{\partial\ln\mu_{jkt}}{\partial\ln\mathscr{P}_{-jkt}}d\ln\mathscr{P}_{-jkt}\right)$$

Rearranging:

$$d\ln\tilde{P}_{jt}\left(1-\psi_{jt}\right)=\sum_k\varphi_{jkt}\left(\sum_{i\in\mathscr{S}_{jt}}\frac{\partial\ln c_{jkt}}{\partial\ln p_{it}}d\ln p_{it}+\frac{\partial\ln c_{jkt}}{\partial\ln z_{jt}}d\ln z_{jt}+\frac{\partial\ln\mu_{jkt}}{\partial\ln\mathscr{P}_{-jkt}}d\ln\mathscr{P}_{-jkt}\right)$$

Finally, the pass-through regression becomes

$$d\ln\tilde{P}_{jt}=\beta_{jt}\sum_{i=1}^{n}\omega_{ijt}d\ln p_{it}+\gamma_{jt}\sum_k\varphi_{jkt}\frac{\partial\ln c_{jkt}}{\partial\ln z_{jt}}d\ln z_{jt}+\delta_{jt}\sum_k\varphi_{jkt}\frac{\partial\ln\mu_{jkt}}{\partial\ln\mathscr{P}_{-jkt}}d\ln\mathscr{P}_{-jkt}$$

where

$$\begin{cases}\beta_{jt}=\frac{1}{1-\psi_{jt}}\\ \gamma_{jt}=\frac{1}{1-\psi_{jt}}\frac{\partial\ln c_{jkt}}{\partial\ln z_{jt}}\\ \delta_{jt}=\frac{1}{1-\psi_{jt}}\frac{\partial\ln\mu_{jkt}}{\partial\ln\mathscr{P}_{-jt}}\end{cases}$$

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RLP Brussels – Company's number : 0203.201.340
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Editor

Jan Smets
Governor of the National Bank of Belgium

Layout : Analysis and Research Group
Cover : NBB AG – Prepress & Image

Published in October 2018