International Shocks, Variable Markups and Domestic Prices*

Mary Amiti
Mary.Amiti@NY.FRB.ORG

Oleg Itskhoki
Itskhoki@Princeton.EDU

Jozef Konings
Joep.Konings@KULeuven.BE

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Abstract

How strong are *strategic complementarities* in price setting across firms? In this paper, we provide a direct empirical estimate of firm price responses to changes in prices of their competitors. We develop a general framework and an empirical identification strategy, taking advantage of a new micro-level dataset for the Belgian manufacturing sector. We find strong evidence of strategic complementarities, with a typical firm adjusting its price with an elasticity of 0.4 in response to the price changes of its competitors and with an elasticity of 0.6 in response to its own cost shocks. Furthermore, we find evidence of substantial heterogeneity in these elasticities across firms. Small firms exhibit no strategic complementarities in price setting and a 100% cost pass-through. In contrast, large firms exhibit strong strategic complementarities, responding to both competitor price changes and their own cost shocks with roughly equal elasticities of around 0.5. We show that this pattern of heterogeneity in markup variability across firms is important for explaining the aggregate markup adjustment in response to international shocks and, in particular, the observed low exchange rate pass-through into domestic prices.

*Previous drafts circulated as "International Shocks and Domestic Prices: How Large are Strategic Complementarities?" Amiti: Federal Reserve Bank of New York, 33 Liberty Street, New York, NY 10045 (email: Mary.Amiti@ny.frb.org); Itskhoki: Princeton University, Department of Economics, Princeton, NJ 08544 (email: itskhoki@princeton.edu); Konings: Katholieke Universiteit Leuven, Department of Economics, Naamsestraat 69, 3000 Leuven, Belgium, National Bank of Belgium (email: joep.konings@kuleuven.be). Access to confidential data was possible while Jozef Konings was affiliated to the National Bank of Belgium. Most of this research was carried out during that period. We thank Ilke Van Beveren for all her help with the concordances of the product codes; and Emmanuel Dhyne and Catherine Fuss of the National Bank of Belgium for data clarifications and suggestions. We thank Costas Arkolakis, David Atkin, Andy Bernard, Ariel Burstein, Arnaud Costinot, Jan de Loecker, Dave Donaldson, Gilles Duranton, Linda Goldberg, Gita Gopinath, Gene Grossman, Anna Kovner, Ben Mandel, Dmitry Mukhin, Peter Neary, Ezra Oberfield, Gianmarco Ottaviano, Jacques Thisse, Felix Tintelnot, David Weinstein, and seminar and conference participants at multiple venues for insightful comments. Tyler Bodine-Smith, Sungki Hong, Preston Mui and Rafael Parente provided excellent research assistance. The views expressed in this paper are those of the authors and do not necessarily represent those of the Federal Reserve Bank of New York or the Federal Reserve System or the National Bank of Belgium.

1 Introduction

How strong are *strategic complementarities* in price setting across firms? Do firms mostly respond to their own costs, or do they put a significant weight on the prices set by their competitors? The answers to these questions are central for understanding the transmission of shocks through the price mechanism, and in particular the transmission of international shocks such as exchange rate movements across borders.[1] A long-standing classical question in international macroeconomics, dating back at least to Dornbusch (1987) and Krugman (1987), is how international shocks affect domestic prices. Although these questions are at the heart of international economics, and much progress has been made in the literature, the answers have nonetheless remained unclear due to the complexity of empirically separating the movements in the marginal costs and markups of firms.

In this paper, we construct a new micro-level dataset for Belgium containing the necessary information on firms' domestic prices, their marginal costs, and competitors' prices, to directly estimate the strength of strategic complementarities across a broad range of manufacturing industries. We develop a general theoretical framework, which allows us to empirically decompose the price change of the firm into a response to the movement in its own marginal cost (the *own cost pass-through*) and a response to the price changes of its competitors (the *strategic complementarity* elasticity). An important feature of our theoretical framework is that it does *not* require us to commit to a specific model of demand, market structure, price setting, or production to obtain our estimates.

Within our framework, we develop an identification strategy to deal with three major empirical challenges: (i) the endogeneity of the competitor prices, which are determined simultaneously with the price of the firm in the equilibrium of the price-setting game; (ii) the measurement error in the marginal cost of the firm; and (iii) correlated demand and cost shocks. We exploit the rare features of our dataset to construct instrumental variables to address these issues. In particular, our data provide information on the domestic market prices set by the firm and all its competitors (both domestic and foreign), as well as the prices of all of the firm's imported intermediate inputs. Matched domestic prices with firm-level imported input prices are usually absent from most datasets. We use these highly disaggregated unit values of imported inputs to construct instruments for the firm's cost shocks and the prices of the competitors.

Our results provide strong evidence of strategic complementarities. We estimate that, on average, a domestic firm changes its price in response to competitors' price changes with an elasticity of about 0.4. In other words, when the firm's competitors raise their prices by 10%, the firm increases its own price by 4% in the absence of any movement in its marginal cost, and thus entirely translating into an increase in its markup. At the same time, the elasticity of the firm's price to its own marginal cost, holding constant the prices of its competitors, is on average about 0.6, corresponding to a 60% pass-through. These estimates stand in sharp contrast with the implications of the workhorse model in international economics, which features CES demand and monopolistic competition and implies constant markups, a complete (100%) cost pass-through and no strategic complementarities in price setting. However,

[1] In macroeconomics, the presence of strategic complementarities in price setting creates additional persistence in response to monetary shocks in models of staggered price adjustment (see e.g. Kimball 1995, and the literature that followed).

models that relax either of those assumptions (i.e., the assumption of monopolistic competition *or* of CES demand) are consistent with our findings, predicting both a positive response to competitor prices and incomplete pass-through. In our estimation, we cannot reject that the two elasticities sum to one, providing important information for distinguishing among models of variable markups.

We further show that the average estimates for all manufacturing firms conceal the heterogeneity in the elasticities across firms. We find that small firms exhibit no strategic complementarities in price setting, and pass through fully the shocks to their marginal costs into their domestic prices. The behavior of these small firms is approximated well by constant-markup pricing, in line with the standard model of monopolistic competition under CES demand. In contrast, large firms exhibit strong strategic complementarities and incomplete pass-through of own marginal cost shocks. Specifically, we estimate their own cost pass-through elasticity to be slightly below 0.5, and the elasticity of their prices with respect to the prices of their competitors to be slightly above 0.5. These large firms, though few in number, account for the majority of sales, and therefore shape the average elasticities in the data.[2]

We use these estimated markup elasticities to study the transmission of an international shock, namely an exchange rate depreciation, to aggregate sectoral level domestic prices. We find that the presence of strategic complementarities and markup variability at the micro level does *not* necessarily translate into aggregate markup adjustment. In particular, markup adjustments at the micro level wash out in the aggregate when there is no heterogeneity in the markup elasticities across firms, independently of the heterogeneity in the firm exposure to shocks. In this case, the markup reduction by some firms (e.g., foreign and some domestic firms that are negatively affected by a depreciation) are exactly offset by the markup increases of the other (domestic) firms. Thus, it is the *interaction* between strategic complementarities and firm heterogeneity that is necessary for aggregate markup adjustment.

We find that heterogeneity in markup adjustment plays an important role in helping to explain the low exchange rate pass-through into domestic prices, emphasized in the empirical literature. It is specifically the type of heterogeneity in markup elasticities that we document in the data — with larger firms exhibiting both greater variability of markups and greater exposure to foreign inputs — that results in aggregate markup adjustment in response to international shocks. In particular, large domestic firms reduce their markups in response to an exchange rate depreciation, and thereby mute the exchange rate pass-through into domestic prices. We further show the quantitative relevance of this mechanism using a calibrated industry equilibrium model disciplined with our empirical estimates.[3] The structural model also enables us to explore the response in counterfactual industries that may be more typical in other countries. Interestingly, we find that the channel through which foreign value added reaches the home market is important for the aggregate exchange rate pass-through in the industry. In particular, aggregate markups fall by a larger amount in industries with less direct foreign competition in the output market and more import intensive large domestic firms.

[2] According to our baseline definition, a large firm employs at least 100 workers (FTE), which roughly corresponds to firms with at least a 2% market share (or also in the top 20% of the sales distribution) within their industries. Such firms account for over 60% of total manufacturing sales. The effects we estimate are robust to different cutoffs used to define large firms.

[3] For this exercise, we adopt the Atkeson and Burstein (2008) model of variable markups, which we show accurately captures the extent of strategic complementarities for both small and large firms that we find in the data. We further ensure that the model matches the market share and import intensity distributions across firms in Belgian manufacturing.

Our paper is the first to provide direct evidence on the extent of strategic complementarities in price setting across a broad range of industries. It builds on the literature that has estimated pass-through and markup variability in specific industries such as cars (Feenstra, Gagnon, and Knetter 1996), coffee (Nakamura and Zerom 2010), and beer (Goldberg and Hellerstein 2013). By looking across a broad range of industries, we explore the importance of strategic complementarities at the macro level for the pass-through of exchange rates into aggregate producer prices. The industry studies typically rely on structural estimation by adopting a specific model of demand and market structure, which is tailored to the industry in question.[4] In contrast, for our estimation we adopt a general theoretical framework, with an identification that relies on instrumental variables estimation, providing direct evidence on the importance of strategic complementarities within a broad class of price setting models.

The few studies that have focused on the pass-through of exchange rate shocks into domestic consumer and producer prices have mostly relied on aggregate industry level data (see, e.g. Goldberg and Campa 2010). The more disaggregated empirical studies that use product-level prices (Auer and Schoenle 2013, Cao, Dong, and Tomlin 2012, Pennings 2012) have typically not been able to match the product-level price data with firm characteristics, prices of local competitors, nor measures of firm marginal costs, which play a central role in our identification. Without data on firm marginal costs, one cannot distinguish between the correlated cost shocks and strategic complementarities in price setting, as discussed in Gopinath and Itskhoki (2011).[5]

Berman, Martin, and Mayer (2012) emphasize that large firms exhibit lower exchange rate pass-through into export prices relative to small firms. Amiti, Itskhoki, and Konings (2014) demonstrate the importance of imported intermediate inputs, in addition to variable markups, in explaining the lower exchange rate pass-through into export prices for large firms. While these elasticities are informative, the pass-through into export prices is only one component of the overall pass-through into domestic prices of the destination countries. The other component, namely domestic prices of the domestic producers, are also affected by the exchange rate both directly through the cost of their imported inputs and indirectly due to strategic complementarities with the competing foreign firms. These overall effects are the focus of our current paper. Further, both of the papers on export prices estimate reduced-form equilibrium relationships between export price pass-through and firm size in the cross-section of firms, which are not suitable for counterfactual analysis.[6] In contrast, this paper adopts an instrumental variable strategy to estimate structural markup elasticities, as well as the extent of strategic

[4]A survey by De Loecker and Goldberg (2014) contrasts these studies with an alternative approach for recovering markups based on production function estimation, which was originally proposed by Hall (1986) and recently developed by De Loecker and Warzynski (2012) and De Loecker, Goldberg, Khandelwal, and Pavcnik (2012; henceforth, DLGKP). Our identification strategy, which relies on the direct measurement (of a portion) of the marginal cost and does not involve a production function estimation, constitutes a third alternative for recovering information about the markups of the firms. If we observed the full marginal cost, we could calculate markups directly by subtracting it from prices. Since we have an accurate measure of only a portion of the marginal cost, we identify only certain properties of the firm's markup, such as its elasticities. Nonetheless, with enough observations, one can use our method to reconstruct the entire markup function for the firms.

[5]Gopinath and Itskhoki (2011) and Burstein and Gopinath (2012) survey a broader *pricing-to-market* (PTM) literature, which documents that firms charge different markups and prices in different destinations, and actively use markups to smooth the effects of exchange rate shocks across markets (in particular, Fitzgerald and Haller 2014 offer a direct empirical test).

[6]The unavailability of comprehensive measures of competitor prices and market shares in the domestic market prevented these studies from providing direct estimates of strategic complementarities. For example, Amiti, Itskhoki, and Konings (2014) use industry-destination-time fixed effects to absorb the competitor prices.

complementarities in price setting in the domestic market.

Our framework applies more broadly beyond the study of counterfactual exchange rate shocks because our elasticity estimates do not rely on projections of firm prices on exchange rates, as is conventionally done in the pass-through literature. Our structural estimates of markup elasticities can also be used to explore other international shocks such as trade reforms and commodity price movements.[7] The literature on the effects of tariff liberalizations on domestic prices has mostly focused on developing countries, where big changes in tariffs have occurred in the recent past. For example, DLGKP analyze the Indian trade liberalization and Edmond, Midrigan, and Xu (2015; henceforth EMX) study a counterfactual trade liberalization in Taiwan, both finding evidence of procompetitive effects of a reduction in output tariffs. These studies take advantage of detailed firm-product level data, but neither has matched import data, which constitutes the key input in our analysis, enabling us to directly measure the component of the firm marginal cost that is most directly affected by the international shocks.

Lastly, our theoretical results on aggregate markup adjustment, and the lack thereof, are related to the recent papers by Arkolakis, Costinot, Donaldson, and Rodríguez-Clare (2017; henceforth ACDR) and Feenstra (2018). In contrast with these papers, however, our focus is on the medium-run industry equilibrium (without entry and exit), yet we do not impose any restrictions on the class of the demand models or the productivity distribution across firms, and also allow for arbitrary patterns in the use of imported inputs across firms.

The rest of the paper is organized as follows. In section 2, we set out the theoretical framework to guide our empirical analysis. Section 3 describes the data and presents the empirical results. Section 4 applies the general framework with our empirical estimates of markup elasticities to analyze the effect of an exchange rate depreciation on aggregate domestic prices. Section 5 concludes.

2 Theoretical Framework

This section lays out the theoretical framework for the empirical estimation in Section 3 and the quantitative analysis in Section 4. We estimate the strength of strategic complementarities in price setting using the following empirical specification:

$$\Delta p_{it} = \alpha \Delta mc_{it} + \gamma \Delta p_{-it} + \varepsilon_{it}, \tag{1}$$

where Δp_{it} is the log price change of firm i, Δmc_{it} is the log change in its marginal cost and Δp_{-it} is the index of log price changes of its competitors. Thus, coefficient γ measures the strategic complementarity elasticity, while α measures the own cost pass-through elasticity. In section 2.1, we extend the accounting framework of Gopinath, Itskhoki, and Rigobon (2010) and Burstein and Gopinath (2012), to

[7] The strategic complementarity elasticity also plays an important role in the New Keynesian literature, as it directly affects the slope of the New Keynesian Phillips curve (e.g., see Gopinath and Itskhoki 2011). Our estimates can be used as a direct input in these studies. In addition, in a recent paper Rodnyansky (2018) provides macroeconomic evidence for the importance of the mechanism we study here for the transmission of the Japanese quantitative easing policy in 2012-14, while Itskhoki and Mukhin (2017) and Mukhin (2017) study the implications of this mechanism for the *disconnect* behavior of the exchange rates and for the emergence of the dollar as a vehicle currency in general equilibrium.

show that equation (1) emerges in a broad class of models, including oligopolistic competition models under general demand and cost structures, and the coefficients α and γ are shaped by the structural elasticities of the firm's optimal markup function. We also show that the index of competitor price changes Δp_{-it} is well-defined in general and can be directly measured in the data under some further testable assumptions. In Section 2.2, we discuss our instrumental variable identification strategy for estimating equation (1) in the data.

2.1 General framework

We start with an accounting identity for the log price of firm i in period t, which equals the sum of the firm's log marginal cost mc_{it} and log markup μ_{it}:

$$p_{it} \equiv mc_{it} + \mu_{it}, \tag{2}$$

where our convention is to use small letters for logs and capital letters for the levels of the corresponding variables. This identity can also be viewed as the definition of a firm's realized log markup, whether or not it is chosen optimally by the firm and independently of the details of the equilibrium environment. Since datasets with precisely measured firm marginal costs are usually unavailable, equation (2) cannot be directly implemented empirically to recover firm markups. Instead, in what follows we impose the minimum structure on the equilibrium environment that is necessary to convert the price identity (2) into a decomposition of price changes, which can be estimated in the data to recover important properties of the firm's markup.[8]

We focus on a given industry s with N competing firms, denoted with $i \in \{1, .., N\}$, where N may be finite or infinite. We omit the industry identifier when it causes no confusion. Our analysis is at the level of the firm-product, and for now we abstract from the issue of multi-product firms, which we address in Section 3.3. We denote with $\boldsymbol{p}_t \equiv (p_{1t}, .., p_{Nt})$ the vector of prices of all N firms in the industry, and with $\boldsymbol{p}_{-it} \equiv \{p_{jt}\}_{j \neq i}$ the vector of prices of all $(N-1)$ firm-i's competitors, and we make use of the notational convention $\boldsymbol{p}_t \equiv (p_{it}, \boldsymbol{p}_{-it})$. We consider an *invertible* demand system $q_{it} = q_i(\boldsymbol{p}_t; \boldsymbol{\xi}_t)$ for $i \in \{1, .., N\}$, which constitutes a one-to-one mapping between any vector of prices $\boldsymbol{p}_t$ and a corresponding vector of quantities demanded $\boldsymbol{q}_t \equiv (q_{1t}, .., q_{Nt})$, given the vector of demand shifters $\boldsymbol{\xi}_t = (\xi_{1t}, \ldots, \xi_{Nt})$. The demand shifters summarize all variables that move the quantity demanded for a given price vector.

We now reproduce a familiar expression for the profit-maximizing log markup of the firm:

$$\mu_{it} = \log \frac{\sigma_{it}}{\sigma_{it} - 1}, \tag{3}$$

which expresses the markup as a function of the curvature of demand, namely the demand elasticity σ_{it}. In fact, the characterization (3) of the optimal markup generalizes beyond the case of monopolistic competition, and also applies in models with oligopolistic competition, whether in prices (Bertrand)

[8] An alternative approach in the Industrial Organization literature imposes specific demand and market structure in a given industry to back out the implied optimal markups of the firms, and then uses identity (2) to calculate the marginal costs.

or in quantities (Cournot). More precisely, for any demand and competition structure, there exists a *perceived demand elasticity* function of firm i, $\sigma_{it} \equiv \sigma_i(\boldsymbol{p}_t;\boldsymbol{\xi}_t)$, such that the firm's static optimal markup satisfies (3). Outside the monopolistic competition case, σ_{it} depends both on the curvature of demand and the conjectured equilibrium behavior of the competitors.[9] We summarize this logic in:

Proposition 1 *For any given* invertible *demand system and any given competition structure, there exists a markup function $\mu_{it} = \mathcal{M}_i(p_{it}, \boldsymbol{p}_{-it};\boldsymbol{\xi}_t)$, such that the firm's* static profit-maximizing price $\tilde{p}_{it}$ *is the solution to the following fixed point equation, for any given price vector of the competitors $\boldsymbol{p}_{-it}$:*

$$\tilde{p}_{it} = mc_{it} + \mathcal{M}_i\big(\tilde{p}_{it}, \boldsymbol{p}_{-it};\boldsymbol{\xi}_t\big). \tag{4}$$

We provide a formal proof of this result in Appendix C, and here offer a brief commentary and a discussion of the assumptions. The *markup function* characterizes the firm's optimal markup, $\mu_{it} = \mathcal{M}_i(\boldsymbol{p}_t;\boldsymbol{\xi}_t)$, which depends in particular on the firm's own price, as it affects the elasticity of the firm's effective demand σ_{it}. As a result, the firm's optimal price $\tilde{p}_{it}$ is a solution to the *fixed point* equation (4). Note that Proposition 1 does *not* require that competitor prices are equilibrium outcomes, as equation (4) holds for any possible vector $\boldsymbol{p}_{-it}$, and corresponds to the firm's first order optimality condition. Therefore, equation (4) characterizes both the on- and off-equilibrium behavior of the firm given its competitors' prices, and thus with a slight abuse of terminology we refer to it as the firm's *best response schedule* (or *reaction function*).[10] The full industry equilibrium is achieved when equations corresponding to (4) hold for every firm $i \in \{1,..,N\}$ in the industry, that is all firms are on their best response schedules.

Proposition 1 relies on two assumptions. One, the demand system is invertible. This is a mild technical requirement, which allows us to fully characterize the market outcome in terms of a vector of prices, with a unique corresponding vector of quantities recovered via the demand system. The invertibility assumption rules out the case of perfect substitutes, where multiple allocations of quantities across firms are consistent with the same common price, as long as the overall quantity $\sum_{i=1}^N q_{it}$ is unchanged. At the same time, our analysis allows for arbitrarily large but finite elasticity of substitution between varieties, which approximates well the case of perfect substitutes (see Kucheryavyy 2012). Note that this assumption does not rule out most popular demand systems, including CES (as in Atkeson and Burstein 2008), linear (as in Melitz and Ottaviano 2008), Kimball (as in Gopinath and Itskhoki 2010), translog (as in Feenstra and Weinstein 2010), discrete-choice logit (as in Goldberg 1995), and many others. Our analysis also applies under the general non-homothetic demand system considered by ACDR, which in turn nests, as they show, a large number of commonly used models of demand.

[9]The perceived elasticity is defined as $\sigma_{it} \equiv -\frac{\mathrm{d}q_{it}}{\mathrm{d}p_{it}} = -\Big[\frac{\partial q_i(\boldsymbol{p}_t;\boldsymbol{\xi}_t)}{\partial p_{it}} + \sum_{j\neq i}\frac{\partial q_i(\boldsymbol{p}_t;\boldsymbol{\xi}_t)}{\partial p_{jt}}\frac{\mathrm{d}p_{jt}}{\mathrm{d}p_{it}}\Big]$, where $\mathrm{d}p_{jt}/\mathrm{d}p_{it}$ is the conjectured response of the competitors. Under monopolistic competition, $\mathrm{d}p_{jt}/\mathrm{d}p_{it} \equiv 0$, and the perceived elasticity is determined by the curvature of demand alone. The same is true under oligopolistic price (Bertrand) competition. Under oligopolistic quantity (Cournot) competition, the assumption is that $\mathrm{d}q_{jt}/\mathrm{d}q_{it} \equiv 0$ for all $j \neq i$, which results in a system of equations determining $\{\mathrm{d}p_{jt}/\mathrm{d}p_{it}\}_{j\neq i}$ as a function of $(\boldsymbol{p}_t;\boldsymbol{\xi}_t)$, as we describe in Appendix C.

[10]In fact, when the competition is oligopolistic in prices, (4) is formally the reaction function. When competition is monopolistic, there is no strategic motive in price-setting, but the competitor prices nonetheless can affect the curvature of a firm's demand and hence its optimal price, as captured by equation (4). This characterization also applies in models of oligopolistic competition in quantities, where the best response is formally defined in the quantity space, in which case (4) is the mapping of the best response schedule from quantity space into price space.

The second assumption is that firms are *static profit maximizers* under full information. This assumption excludes dynamic price-setting considerations such as menu costs (as e.g. in Gopinath and Itskhoki 2010) or inventory management (as e.g. in Alessandria, Kaboski, and Midrigan 2010). It is possible to generalize our framework to allow for dynamic price-setting, however in that case the estimating equation is sensitive to the specific dynamic structure.[11] Instead, in Section 3.3, we address this assumption empirically, which confirms that the likely induced bias in our estimates from this static assumption is small.

Importantly, Proposition 1 imposes no restriction on the nature of market competition, allowing for both monopolistic competition (as N becomes unboundedly large or as firms do not internalize their effect on aggregate prices) and oligopolistic competition (for any finite N).[12] Note that the markup function $\mathcal{M}_i(\cdot)$ is endogenous to the demand and competition structure, that is, its specific functional form changes from one structural model to the other. What Proposition 1 emphasizes is that for any such model, there exists a corresponding markup function, which describes the price-setting behavior of firms. In particular, the implication of Proposition 1 is that competitor prices $\boldsymbol{p}_{-it}$ form a sufficient statistic for firm i's pricing decision, i.e. conditional on $\boldsymbol{p}_{-it}$ the firm's behavior does *not* depend on the competitors' marginal costs $\boldsymbol{mc}_{-it} \equiv \{mc_{jt}\}_{j\neq i}$. We test this property in Section 3.3.

Estimating equation Our next step in deriving the estimating equation (1) is to totally differentiate the best response condition (4) around some admissible point $(\tilde{p}_{it}, \boldsymbol{p}_{-it}; \boldsymbol{\xi}_t)$, i.e. any equilibrium point $(\boldsymbol{p}_{it}; \boldsymbol{\xi}_t)$. We obtain the following decomposition for the firm's log price differential:

$$\mathrm{d}p_{it} = \mathrm{d}mc_{it} + \frac{\partial \mathcal{M}_i(\boldsymbol{p}_t; \boldsymbol{\xi}_t)}{\partial p_{it}} \mathrm{d}p_{it} + \sum_{j\neq i} \frac{\partial \mathcal{M}_i(\boldsymbol{p}_t; \boldsymbol{\xi}_t)}{\partial p_{jt}} \mathrm{d}p_{jt} + \sum_{j=1}^{N} \frac{\partial \mathcal{M}_i(\boldsymbol{p}_t; \boldsymbol{\xi}_t)}{\partial \xi_{jt}} \mathrm{d}\xi_{jt}. \tag{5}$$

Note that the markup function $\mathcal{M}_i(\cdot)$ is not an equilibrium object as it can be evaluated for an arbitrary price vector $\boldsymbol{p}_t = (p_{it}, \boldsymbol{p}_{-it})$, and therefore (5) characterizes all possible perturbations to the firm's price, both on and off equilibrium, in response to shocks to its marginal cost $\mathrm{d}mc_{it}$, the prices of its competitors $\{\mathrm{d}p_{jt}\}_{j\neq i}$, and the demand shifters $\{\mathrm{d}\xi_{jt}\}_{j=1}^{N}$. In other words, equation (5) does not require that the competitor price changes are chosen optimally or correspond to some equilibrium behavior, as it is a differential of the best response schedule (4), and thus it holds for arbitrary perturbations to competitor prices.[13] Importantly, note that the perturbation to the optimal price of the firm does not depend on the shocks to competitor marginal costs, as competitor prices provide a sufficient statistic for the optimal price of the firm (according to Proposition 1).

[11] The adopted structural interpretation of our estimates is specific to the flexible-price model, where μ_{it} is the static profit-maximizing oligopolistic markup. Nonetheless, our statistical estimates are still informative even when price setting is dynamic. In this case, the realized markup μ_{it} is not necessarily statically optimal for the firm, yet its estimated elasticity is still a well-defined object, which can be analyzed using a calibrated model of dynamic price setting (e.g., a Calvo staggered price setting model or a menu cost model, as in Gopinath and Itskhoki 2010). We choose not to pursue this alternative approach due to the nature of our data, as we discuss in Section 3.

[12] Beyond oligopolistic competition, Proposition 1 also applies to some sequential-move price-setting games, such as Stackelberg competition, yet for simplicity we limit our focus here to the static simultaneous-move games.

[13] Combining equations (5) for all firms $i = 1..N$, we can solve for the *equilibrium* perturbation of all prices $\mathrm{d}\boldsymbol{p}_t$ as a function of the exogenous cost and demand shocks $(\mathrm{d}\boldsymbol{mc}_t, \mathrm{d}\boldsymbol{\xi}_t)$, corresponding to the *reduced form* of the model (see Section 2.2).

By combining the terms in competitor price changes and solving for the fixed point in (5) for $\mathrm{d}p_{it}$, we rewrite the resulting equation as:

$$\mathrm{d}p_{it} = \frac{1}{1+\Gamma_{it}}\mathrm{d}mc_{it} + \frac{\Gamma_{-it}}{1+\Gamma_{it}}\mathrm{d}p_{-it} + \varepsilon_{it}, \tag{6}$$

where the residual $\varepsilon_{it} \equiv \frac{1}{1+\Gamma_{it}}\sum_{j=1}^{N}\frac{\partial\mathcal{M}_i(\boldsymbol{p}_t;\boldsymbol{\xi}_t)}{\partial\xi_{jt}}\mathrm{d}\xi_{jt}$ is firm i's effective demand shock. In (6), we introduce the following new notation:

$$\Gamma_{it} \equiv -\frac{\partial\mathcal{M}_i(\boldsymbol{p}_t;\boldsymbol{\xi}_t)}{\partial p_{it}} \qquad \text{and} \qquad \Gamma_{-it} \equiv \sum\nolimits_{j\neq i}\frac{\partial\mathcal{M}_i(\boldsymbol{p}_t;\boldsymbol{\xi}_t)}{\partial p_{jt}} \tag{7}$$

for the *own* and (cumulative) *competitor markup elasticities*, respectively, measuring the slope of the optimal markup function $\mathcal{M}_i(\cdot)$. Finally, we denote with

$$\mathrm{d}p_{-it} \equiv \sum\nolimits_{j\neq i}\omega_{ijt}\mathrm{d}p_{jt}, \qquad \text{where} \qquad \omega_{ijt} \equiv \frac{\partial\mathcal{M}_i(\boldsymbol{p}_t;\boldsymbol{\xi}_t)/\partial p_{jt}}{\sum_{k\neq i}\partial\mathcal{M}_i(\boldsymbol{p}_t;\boldsymbol{\xi}_t)/\partial p_{kt}}, \tag{8}$$

the (scalar) *index of competitor price changes.* This implies that, independently of the demand and competition structure, there exists a theoretically well-defined index of competitor price changes, even when the model of the demand does not admit a well-defined ideal price index (e.g., under non-homothetic demand). The index of competitor price changes $\mathrm{d}p_{-it}$ aggregates the individual price changes across all firm's competitors, $\mathrm{d}p_{jt}$ for $j \neq i$, using endogenous (firm-state-specific) weights ω_{ijt}, which are defined to sum to one. These weights depend on the relative markup elasticity: the larger is the firm i markup elasticity with respect to price change of firm j, the greater is the weight of firm j in the competitor price index.

The own markup elasticity Γ_{it} is defined in (7) with a negative sign, as many models imply that a firm's markup function is non-increasing in firm's own price, $\partial\mathcal{M}_i(\boldsymbol{p}_t;\boldsymbol{\xi}_t)/\partial p_{it} \leq 0$. Intuitively, a higher price of the firm may shift the firm towards a more elastic portion of demand (e.g., as under Kimball demand) and/or reduce the market share of the firm (in oligopolistic competition models), both of which result in a lower optimal markup (see Appendix D). In contrast, the markup elasticity with respect to competitor prices is typically non-negative and, when positive, reflects the presence of strategic complementarities in price setting. Nevertheless, we do *not* impose any sign restrictions on Γ_{it} and Γ_{-it} in our empirical analysis in Section 3.

Equation (6) is the theoretical counterpart to our estimating equation (1), which is the focus of our empirical analysis in Section 3. It decomposes the price change of the firm $\mathrm{d}p_{it}$ into responses to its own cost shock $\mathrm{d}mc_{it}$, the competitor price changes $\mathrm{d}p_{-it}$, and the demand shifters captured by the residual ε_{it}. The two coefficients of interest are:

$$\alpha_{it} \equiv \frac{1}{1+\Gamma_{it}} \qquad \text{and} \qquad \gamma_{it} \equiv \frac{\Gamma_{-it}}{1+\Gamma_{it}}, \tag{9}$$

characterizing the *slopes* of the firm's best response schedule, defined implicitly by (4). The coefficient α_{it} measures the *own* (or idiosyncratic) *cost pass-through* of the firm, i.e. the elasticity of the firm's price with respect to its marginal cost, holding the prices of its competitors constant. The coefficient γ_{it} measures the strength of *strategic complementarities* in price setting, as it is the elasticity of the firm's price with respect to the prices of its competitors.[14] The coefficients α_{it} and γ_{it} are shaped by the markup elasticities Γ_{it} and Γ_{-it}: a higher own markup elasticity reduces the own cost pass-through, as markups are more accommodative of shocks, while a higher competitor markup elasticity increases the strategic complementarities elasticity.

In order to empirically estimate the coefficients in the theoretical price decomposition (6), we need to measure the competitor price index (8). We now provide conditions under which the weights in (8) can be easily measured in the data, as well as a way to test these conditions empirically. Let z_t denote the *log* industry expenditure function, defined in a standard way.[15] We then have (see Appendix C):

Proposition 2 (i) *If the log expenditure function z_t is a sufficient statistic for competitor prices, i.e. if the demand can be written as $q_{it} = q_i(p_{it}, z_t; \boldsymbol{\xi}_t)$, then the weights in the competitor price index* (8) *are proportional to the competitor revenue market shares S_{jt}, for $j \neq i$, and given by $\omega_{ijt} \equiv S_{jt}/(1 - S_{it})$. Therefore, the index of competitor price changes simplifies to:*

$$\mathrm{d}p_{-it} \equiv \sum\nolimits_{j\neq i} \frac{S_{jt}}{1 - S_{it}} \mathrm{d}p_{jt}. \tag{10}$$

(ii) *If, furthermore, the perceived demand elasticity is a function of the price of the firm relative to the industry expenditure function, i.e. $\sigma_{it} = \sigma_i(p_{it} - z_t; \boldsymbol{\xi}_t)$, the two markup elasticities in* (7) *are equal:*

$$\Gamma_{-it} \equiv \Gamma_{it}. \tag{11}$$

The key property of the expenditure function for the purposes of this proposition is the Shephard's lemma: the elasticity of the expenditure function with respect to firm-j's price equals firm-j's market share, $\partial z_t/\partial p_{jt} = S_{jt}$. This clarifies why the relevant weights in the competitor price index (10) are proportional to the market shares. Indeed, under the assumption of part (i) of the proposition, the markup function can be written as $\mathcal{M}_i(p_{it}, z_t; \boldsymbol{\xi}_t)$, so that $\partial \mathcal{M}_{it}/\partial p_{jt} = \partial \mathcal{M}_{it}/\partial z_t \cdot S_{jt}$ by Shephard's lemma. The result then follows from the definitions in (8). The condition in part (ii) of the proposition implies the condition in part (i), and further implies that the markup function is $\mathcal{M}_i(p_{it} - z_t; \boldsymbol{\xi}_t)$, so that $\partial \mathcal{M}_{it}/\partial p_{it} = -\partial \mathcal{M}_{it}/\partial z_t$, and hence (11) follows from the definitions in (7).

The main assumption of Proposition 2 is that the demand function depends only on (p_{it}, z_t) rather than on $(p_{it}, \boldsymbol{p}_{-it})$, that is, the log expenditure function z_t summarizes all necessary information contained in competitor prices $\boldsymbol{p}_{-it}$. While this assumption is not innocuous, and in particular imposes

[14] This abuses the terminology somewhat since γ_{it} can be non-zero even under monopolistic competition when firm's behavior is non-strategic, yet the complementarities in pricing still exist via the curvature of demand. In this case, the term *demand complementarity* may be more appropriate. Furthermore, γ_{it} could, in principle, be negative, in which case the prices of the firms are strategic substitutes. Also note that in models of oligopolistic competition, constant competitor prices do not in general constitute an equilibrium response to an idiosyncratic cost shock for a given firm. This is because price adjustment by the firm induces its competitors to change their prices as well because of strategic complementarities. Nonetheless, α_{it} is a well-defined counterfactual elasticity, characterizing a firm's best response off equilibrium.

[15] Formally, $z_t = \log \min_{\{Q_{it}\}} \big\{ \sum_{i=1}^{N} P_{it} Q_{it} \big| U\big(\{Q_{it}\}; Q_t\big) = 1 \big\}$, where $U(\cdot)$ is the preference aggregator, which defines the aggregate industry consumption Q_t.

symmetry in preferences,[16] it is satisfied for a broad class of demand models considered in ACDR and Parenti, Thisse, and Ushchev (2014), including all separable preference aggregators $Q_t = \sum_{i=1}^N u_i(Q_{it})$, as in Krugman (1979). In addition, Proposition 2 offers a way to empirically test the implication of its assumptions. Indeed, condition (11) on markup elasticities implies that the two coefficients in the price decomposition (6) sum to one. In other words, using the notation in (9), it can be summarized as the following parameter restriction:

$$\alpha_{it} + \gamma_{it} = 1. \tag{12}$$

We do *not* impose condition (11) and the resulting restriction (12) in our estimation, but instead test it empirically. This also tests the validity of the weaker property (10) in Proposition 2, which we adopt for our measurement of the competitor price changes, and then relax it non-parametrically in Section 3.3.

Structural elasticities Specific models of demand and competition structure link our two elasticities of interest, α_{it} and γ_{it}, to model primitives, and impose restrictions on the values of these elasticities. For example, the most commonly used model in the international economics literature follows Dixit and Stiglitz (1977) and combines constant elasticity of substitution (CES) demand with monopolistic competition, with a constant $\sigma_{it} \equiv \sigma$. This model hence implies constant-markup pricing, and consequently complete pass-through of the cost shocks and no strategic complementarities in price setting. In other words, in the terminology introduced above, all firms have $\Gamma_{it} = \Gamma_{-it} \equiv 0$, and therefore $\alpha_{it} \equiv 1$ and $\gamma_{it} \equiv 0$. These implications are in gross violation of the stylized facts about the price setting in actual markets, a point recurrently emphasized in the *pricing-to-market* literature.

In the following Section 3 we provide direct empirical evidence on the magnitudes of α_{it} and γ_{it}, both of which we find to lie strictly between zero and one. In order to capture these empirical patterns in a model, one needs to depart from either the CES or the monopolistic competition assumption. We illustrate, following Krugman (1987) and Atkeson and Burstein (2008), with a model of variable markups based on oligopolistic competition and nested CES demand. Under Cournot competition, the perceived elasticity σ_{it} in equation (3) is a function of the firm's market share, averaging the between- and within-industry elasticities of substitution (given, respectively, by $\eta \geq 1$ and $\rho > \eta$):[17]

$$\sigma_{it} = \left[\frac{1}{\eta} S_{it} + \frac{1}{\rho}(1 - S_{it})\right]^{-1}. \tag{13}$$

Furthermore, the market share is a decreasing function of the firms relative price, $S_{it} = \xi_{it}\big(P_{it}/P_{st}\big)^{1-\rho}$, where $P_{st} = \left[\sum_{j=1}^N \xi_{jt} P_{jt}^{1-\rho}\right]^{1/(1-\rho)}$ is the industry price index, which is also the expenditure function. Note that this model satisfies the conditions of both Propositions 1 and 2.

Using the above expressions, we can write out the markup function $\mathcal{M}_i(\boldsymbol{p}_t; \boldsymbol{\xi}_t) = \log \frac{\sigma_{it}}{\sigma_{it}-1}$ for this

[16] Namely, the significance of any firm for all other firms is fully summarized by the firm's market share. Proposition 2, formally, rules out cases in which a sufficient statistic for competitor prices exists, but is different from the expenditure function, as is the case for the Kimball demand. We show, nonetheless, that Proposition 2 still provides a first order approximation in that case (see Appendix D).

[17] The only difference under Bertrand competition is that $\sigma_{it} = \eta S_{it} + \rho(1 - S_{it})$; both cases are derived in Appendix C.

model, and calculate its respective elasticities according to (7), to yield:

$$\Gamma_{it} = \Gamma_{-it} = \frac{(\rho-1)S_{it}}{1+\frac{\rho(\eta-1)}{(\rho-\eta)(1-S_{it})}}, \tag{14}$$

which simplifies to $\Gamma_{it} = \Gamma_{-it} = (\rho-1)S_{it}$ in the Cobb-Douglas case with $\eta = 1$. The main additional insight from this example is that Γ_{it} is an increasing function of the firm's market share S_{it}.[18] This observation is not exclusive to the nested-CES model, and applies more generally in many models of oligopolistic and monopolistic price setting, as we show in Appendix D. For a broad class of models, the markup elasticity is increasing in a firm's market share, although the specific functional form underlying the markup elasticities does depend on the model details. What is more special to the nested-CES model is the property that $\Gamma_{it} \approx 0$ for the very small firms with $S_{it} \approx 0$. Indeed, such small firms behave nearly as constant-markup monopolistic competitors, with a complete own cost pass-through ($\alpha_{it} \approx 1$) and no strategic complementarities ($\gamma_{it} \approx 0$). In contrast, firms with positive market shares have $\Gamma_{it} > 0$, and hence exhibit incomplete pass-through and positive strategic complementarities, $\alpha_{it} < 1$ and $\gamma_{it} > 0$. Intuitively, small firms charge low markups and have only a limited capacity to adjust them in response to shocks, while large firms set high markups and actively adjust them to maintain their market shares. This offers sharp testable hypotheses.

2.2 Identification

We have established that the price change decomposition in (6) holds across a broad class of models. We are interested in estimating the magnitudes of elasticities α_{it} and γ_{it} in this decomposition, as they have a *sufficient statistic* property for the response of firm prices to shocks, independently of the industry demand and competition structure. In order to estimate these elasticities, α_{it} and γ_{it}, we rewrite (6) in changes over time:

$$\Delta p_{it} = \alpha_{it}\Delta mc_{it} + \gamma_{it}\Delta p_{-it} + \varepsilon_{it}, \tag{15}$$

where $\Delta p_{it} \equiv p_{i,t+1} - p_{it}$. Therefore, the estimating equation (15) is a first-order Taylor expansion for the firm's price in period $t+1$ around its equilibrium price in period t, generalizing equation (1) by allowing for heterogeneity in coefficients α_{it} and γ_{it}. Estimation of equation (15) is associated with a number of identification challenges, as we now discuss.

Measurement Estimation of (15) requires measures of firm's full marginal cost Δmc_{it} and full competitor price index Δp_{-it}, to avoid omitted variable bias. Good measures of firm marginal costs are notoriously hard to come by. We address this challenge in two steps. First, we adopt a rather general production structure, where we assume that upon paying a fixed cost the firm has access to a technology with a firm-specific returns-to-scale parameter $\frac{1}{1+\nu_i} \leq 1$. As a result, the marginal cost of the firm can be written as:

$$MC_{it} = C_{it}Y_{it}^{\nu_i}, \tag{16}$$

[18]Strictly speaking, for $\eta > 1$, Γ_{it} is non-monotonic in S_{it}, however the point of non-monotonicity is outside of the empirically-relevant range, for $S_{it} \approx 1$

where Y_{it} is output and C_{it} is the unit cost of the firm assumed independent from the scale of production. This cost structure immediately implies that the log change in the marginal cost is equal to the log change in the average variable cost:

$$\Delta mc_{it} = \Delta avc_{it}, \tag{17}$$

where $avc_{it} \equiv \log\big(TVC_{it}/Y_{it}\big)$ and TVC_{it} denotes the total variable cost of production.[19] Therefore, we measure the log changes in the marginal costs using the log changes in the average variable costs, which we obtain from the firm accounting data. Importantly for our structural inference, this reflects not just the exogenous cost shock, to which the firm may adjust in various ways, but the full resulting change in the costs of the firm.

Accounting measures of average costs are known to be very noisy, and to address this problem, the second step in our approach is to use the rare feature of our dataset which enables us to measure with great precision one component of the marginal cost. In particular, we assume that the unit cost of the firm C_{it} depends on the firm productivity A_{it}, as well as the prices of its inputs, including labor and intermediates. We denote with W_{it} and V_{it} the firm-i-specific cost indexes for domestic and imported inputs, respectively. The first-order expansion for the marginal cost is then given by:

$$\mathrm{d}mc_{it} = \phi_{it}\mathrm{d}v_{it} + (1-\phi_{it})\mathrm{d}w_{it} - \mathrm{d}a_{it} + \nu_i \mathrm{d}y_{it}, \tag{18}$$

where the small letters denote the logs of the corresponding variables and ϕ_{it} is the *import intensity* of the firm, i.e. the expenditure share on imported inputs in total variable costs. In our data, we can measure with a high level of precision the cost changes of the imported intermediate inputs:

$$\Delta mc^*_{it} \equiv \phi_{it}\Delta v_{it}, \tag{19}$$

which we use as an instrument for the marginal cost Δmc_{it}.

An essential, and rare, feature of our dataset is that we are able to measure price changes for *all* domestic and foreign competitors of the firm in the home market. We follow Proposition 2 in constructing the full competitor price index Δp_{-it}. Section 3.3 relaxes the underlying assumptions non-parametrically by splitting the competitors into more homogenous subgroups and estimating separate strategic complementarity elasticities for each subgroup. Further details of the measurement and specification tests are provided in Section 3.

Endogeneity Our identification strategy relies on the presence of sufficient variation in the firm's marginal cost shocks that is independent from the firm's competitior prices to identify the two elasticities in equation (15). In the data, this correlation is extremely low at 0.09. But of course, all prices

[19] Note that (16) implies that the average variable cost is $AVC_{it} = \frac{1}{1+\nu_i} MC_{it}$, and the i-specific multiplicative factor in front of MC_{it} cancels out when log changes are taken, given the time-invariant return-to-scale parameter. In the fully general case, which allows for a varying degree of returns to scale ν_{it}, our estimation is still valid, yet the structural interpretation of Γ_{it} needs to be adjusted to reflect curvature arising from both the demand and the cost sides (i.e., non-constant σ_{it} and ν_{it}). Also note that the *macroeconomic complementarities* operating through the marginal cost, such as roundabout production (Basu 1995) and local input markets (Woodford 2003), do not confound our estimates of the *microeconomic* complementarities.

are set simultaneously, so we need to instrument for the the competitor prices, which we do with the marginal costs of the competitors.[20] The correlation between the firm's own marginal costs and the domestic competitor's marginal cost is positive, but still low at 0.27. Even so, there may still be concern that there are correlated demand shocks across input and output industries and endogenous feedback mechanisms between demand shocks and input prices at the level of the firm. We provide a full discussion of the threats to our identification strategy and corresponding robustness checks in Section 3.

Heterogeneity of coefficients Finally, the estimating equation (15) features heterogeneity in the coefficients of interest α_{it} and γ_{it}, potentially both across firms within industries and across industries. In our baseline, we pool the observations to estimate common coefficients α and γ for all firms and time periods, which we interpret as average elasticities across all manufacturing firms. The two potential concerns here are that the IV estimation can complicate the interpretation of the estimates as the averages, and the possibility of unobserved heterogeneity may result in biased estimates. We address these issues non-parametrically, by splitting our observations into subgroups of firm-products that we expect to have more homogenous elasticities. In particular, guided by the insights from Section 2.1, the elasticities α_{it} and γ_{it} are functions of the market share of the firm within industry. Accordingly, we split our firms into small and large bins, and estimate elasticities separately for each subgroup. We discuss additional slices of the sample in Section 3.3.

Alternative estimating equation We close this section with a brief discussion of our choice of estimating equation (15). We use equilibrium variation in marginal costs and prices to estimate the firm's best response function (6). Instead, one could estimate the *reduced form* of the model:

$$\Delta p_{it} = a_{it}\Delta mc_{it} + b_{it}\Delta mc_{-it} + \tilde{\varepsilon}_{it}, \tag{20}$$

which is an equilibrium relation between the firm's price change and all exogenous shocks of the model.[21] Appendix C provides an explicit solution for the reduced-form coefficients a_{it} and b_{it}, as well as for the theoretically-grounded notion of the competitor marginal cost index Δmc_{-it}, which differs from a simple sales-weighted average even when Proposition 2 holds.

There are a number of reasons why we choose to estimate the reaction function (15) as opposed to the reduced form (20). The first reason is due to data limitations. Equation (20) requires measures of the full marginal cost for all firms in order to construct Δmc_{-it}, whereas we only have comprehensive measures of marginal costs available for the domestic competitors. While this would constitute an omitted variable bias in (20), it is not a problem for estimating (15), which only requires an instrument for the full index of competitor price changes Δp_{-it}, which we can construct in the data. Second, the coefficients of the reaction function α_{it} and γ_{it} have a clear structural interpretation, and a direct

[20]Even though the theoretical underpinning of the estimating equation (15) is the best response schedule, rather than an equilibrium relationship, the variation in competitor prices observed in the data is an equilibrium outcome, where all prices are set simultaneously as a result of an oligopolistic competition game.

[21]Equation (20) corresponds to the theoretical fixed-point solution for equilibrium price changes of all firms in the industry, which requires that conditions (6) hold simultaneously for all firms.

relationship with the firm's markup elasticities Γ_{it} and Γ_{-it}. These coefficients have an appealing sufficient statistic property for describing the micro-level and aggregate responses to various shocks, such as an exchange rate shock, a theme we return to in Section 4. In contrast, the reduced-form coefficients compound the industry equilibrium effects, and are thus much less tractable for structural interpretation. Nonetheless, we report the reduced form results in the online appendix Table O1.[22]

3 Empirical Analysis

3.1 Data Description

To empirically implement the theoretical framework of Section 2, we need to be able to measure each variable in equation (15). We do this by combining three different datasets for Belgium manufacturing firms for the period 1995 to 2007 at the annual frequency. The first dataset is firm-product level production data (PRODCOM), collected by Statistics Belgium. A rare feature of these data is that it reports highly disaggregated information on both values and quantities of sales, which enables us to construct domestic unit values at the firm-product level. It is the same type of data that is more commonly available for firm-product exports. Firms in the Belgian manufacturing sector report production values and quantities for all their products, defined at the PC 8-digit (over 1,500 products). The survey includes all Belgian firms with a minimum of 10 employees, which covers over 90% of production value in each NACE 4-digit industry (which corresponds to the first 4 digits of the PC 8-digit code).[23] Firms are required to report total values and quantities but are not required to report the breakdown between domestic sales and exports. Therefore, to get a measure of domestic values and quantities we merge on the export data from customs and subtract total export values and quantities from total production values and quantities sold.

The second dataset, on imports and exports, is collected by Customs. These data are reported at the firm level by destination and source country for each product classified at the 8-digit combined nomenclature (CN) in values and quantities, with around 10,000 distinct products. The first 6-digits of the CN codes correspond to the World Harmonized System (HS). These data are easily merged with the PRODCOM data using a unique firm identifier; however, the product matching between the two datasets is more complicated, as we describe in Appendix B.

The third dataset, on firm characteristics, draws from annual income statements of all incorporated firms in Belgium. These data are used to construct measures of total variable costs. They are available on an annual frequency at the firm level. Each firm reports its main economic activity within a 5-digit NACE industry, but there is no individual firm-product level data available from this dataset. We combine these three datasets to construct the key variables for our analysis.[24]

Domestic Prices The main variable of interest is the price of the domestically sold goods, which we proxy using the log change in the domestic unit value, denoted Δp_{it}, where i corresponds to a firm-

[22]The online appendix is available at: http://www.princeton.edu/~itskhoki/papers/DomesticPricesOA.pdf
[23]We only keep firms that report their main activity to be in the manufacturing sector, defined as NACE 2-digit codes 15–36.
[24]Jozef Konings had access to these confidential data during his affiliation with the National Bank of Belgium.

product at the PC-8-digit level. The domestic unit values are calculated as the ratio of production value sold domestically to production quantity sold domestically:[25]

$$\Delta p_{it} = \Delta \log \frac{\text{Domestic Value}_{it}}{\text{Domestic Quantity}_{it}} \tag{21}$$

We clean the data by dropping the observations with abnormally large price jumps, namely with year-to-year price ratios above 3 or below 1/3. Summary statistics for all variables are provided in the Appendix Table A1.

Marginal Cost Changes in a firm's marginal cost can arise from changes in the price of imported and domestic inputs, as well as from changes in productivity. We have detailed information on a firm's imported inputs, however the datasets only include total expenditure on domestic inputs without any information on individual domestic input prices or quantities. Given this limitation, we need to infer the firm's overall marginal cost. We follow (17), and construct the change in the log marginal cost of firm i as follows:

$$\Delta mc_{it} = \Delta \log \frac{\text{Total Variable Cost}_{it}}{Y_{it}}, \tag{22}$$

where total variable cost is the sum of the total material cost and the total wage bill, and Y_{it} is the production quantity of the firm.[26] Note that mc_{it} is calculated at the firm level and it acts as a proxy for the marginal cost of all products produced by the firm. We address the possible induced measurement error for multi-product firms with a robustness check in Section 3.3.

Our marginal cost variable Δmc_{it} is likely to be a noisy measure more generally, as we rely on firm accounting data to measure economic marginal costs. Therefore, we construct the foreign-input component of a firm's marginal cost, a counterpart to (19), which we measure as follows:

$$\Delta mc^*_{it} = \phi_{it} \sum\nolimits_m \omega^c_{imt} \Delta v_{imt}, \tag{23}$$

where ϕ_{it} is the firm's overall import intensity (the share of expenditure on imported intermediates in total variable costs), m indexes the firm's imported inputs at the country of origin and CN-8-digit product level, and Δv_{imt} are the changes in the log unit values of the firm's imported intermediate inputs (in euros). The weights ω^c_{imt} are the average of t and $t-1$ firm import shares of input m. We drop abnormally large jumps in import unit values, and we take into account that not all imports are intermediate inputs. In our baseline case, we define an import to be a final good for a firm if it also reports positive production of that good (at PC-8 digit level). To illustrate, suppose a firm imports cocoa and chocolate, and it also produces chocolate. In that case we would classify the imported cocoa as an

[25] In order to get at the domestic portion of total production, we need to net out firm exports. One complication in constructing domestic sales is the issue of carry-along-trade (see Bernard, Blanchard, Van Beveren, and Vandenbussche 2012), arising when firms export products that they do not themselves produce. To address this issue we drop all observations for which exports of a firm in period t are greater than 95% of production sold (dropping 11% of the observations and 15% of revenues, which amounts to a much lower share of domestic value sold since most of these revenues come from exports).

[26] More precisely, we calculate the change in the log production quantity as the difference between $\Delta \log \text{Revenues}$ and $\Delta \log \text{Price index}$ of the firm, and subtract the resulting $\Delta \log Y_{it}$ from $\Delta \log \text{Total Variable Cost}_{it}$ to obtain Δmc_{it} in (22).

intermediate input and the imported chocolate as a final good, and hence only the imported cocoa would enter in the calculation of the marginal cost variable. There is large idiosyncratic variation in Δmc^*_{it}, as firms within the same industry source different inputs from different countries.

Competition Variables When selling goods in the Belgian market, Belgian firms in the PRODCOM sample face competition from other Belgian firms that produce and sell their goods in Belgium (also in the PRODCOM sample), as well as from the firms not in the PRODCOM sample that import goods to sell in the Belgian market. We refer to the former set of firms as the *domestic firms* and the latter as the *foreign firms*. We follow Proposition 2 and equation (10), and calculate the full index of competitor price changes as:

$$\Delta p_{-it} = \sum\nolimits_{j\in D_i} \frac{S_{jt}}{1-S_{it}} \Delta p_{jt} + \sum\nolimits_{j\in F_i} \frac{S_{jt}}{1-S_{it}} \Delta p_{jt}, \tag{24}$$

where D_i and F_i denote respectively the sets of domestic and foreign firm-product competitors of firm i. The changes in individual prices Δp_{jt} are constructed at the most disaggregated level that is possible in the data − for domestic competitors this is at the firm×PC8-digit level, and for foreign competitors it is at the level of the (importing firm)×(source country)×CN8. The market shares S_{jt} are at the corresponding levels, defined as the ratio of the firm-product sales in Belgium relative to the total sales in industry s.[27]

We define an industry at the NACE 4-digit level and include all industries for which there are a sufficient number of domestic firms in the sample (around 160 industries). We chose this level of aggregation in order to avoid huge market shares arising solely due to narrowly defined industries, and we show the robustness of our results to more disaggregated industry definitions in Section 3.3.

Instruments The instrument to address the measurement error in firms' marginal cost Δmc_{it} is the foreign component of the marginal cost Δmc^*_{it}, defined above in (23). Here, we describe the construction of the three additional instruments we use in our baseline specifications to address the endogeneity of competitor prices in Δp_{-it}, each proxying for the marginal costs of the different types of competitors. For the domestic competitors, we use a weighted average (in parallel with the first term in (24)) of each domestic competitor's foreign component of marginal cost:

$$\Delta mc^*_{-it} = \sum\nolimits_{j\in D_i} \frac{S_{jt}}{1-S_{it}} \Delta mc^*_{jt},$$

which is an aggregator of Δmc^*_{jt} for domestic competitors of i ($j \neq i$) using their market shares as weights. In the robustness Section 3.3, we replace the marginal cost instruments Δmc^*_{it} and Δmc^*_{-it} with the corresponding firm-level exchange rates, weighted by firm import intensities from specific source countries, which we denote with Δe_{it} and Δe_{-it} respectively.[28]

[27] In (24), S_{it} is the cumulative market share of firm i in industry s (identified by the given product i of the firm), which constitutes a slight abuse of notation to avoid numerous additional subscripts. Note that $\sum_{j\in D_i} S_{jt}$ and $\sum_{j\in F_i} S_{jt}$ are the cumulative market shares of all domestic and all foreign competitors of firm i in the industry, and therefore the weights sum to one (as $\sum_{j\in D_i} S_{jt} + \sum_{j\in F_i} S_{jt} = 1 - S_{it}$). In practice, we measure S_{jt} as the average of t and $t-1$ market shares of firm-product j.

[28] Formally, in parallel with (23), $\Delta e_{it} = \phi_{it} \sum_m \omega^c_{imt} \Delta e_{mt}$, that is we replaced the input price changes Δv_{imt} with the corresponding bilateral exchange rate changes Δe_{mt}, where m denotes the source country for each imported input of firm i;

For foreign competitors, direct measures of marginal costs at the firm level are unavailable in our data, and thus we need to rely on product level data to construct instruments for their price movements. For the non-euro foreign competitors of firm i (i.e., $j \in X_i$), we proxy for their marginal costs using bilateral exchange rates. Specifically, we construct:

$$\Delta e^X_{-it} = \sum\nolimits_{j \in X_i} \frac{S_{jt}}{1 - S_{it}} \Delta e_{k(j)t},$$

where Δe_{kt} is the euro exchange rate with country k, $k(j)$ is the country origin of the non-EZ competitor $j \in X_i$.

Finally, for the euro foreign competitors of firm i (i.e., $j \in E_i$), we construct a proxy for their marginal costs using their export prices to all destination other than Belgium.[29] We construct this instrument in two steps. In the first step, we take all of Belgium's euro trading partners except Luxembourg (that is, Austria, Germany, Spain, Finland, France, Greece, Ireland, Italy, Netherlands and Portugal) and calculate weighted averages of the change in their log export prices to all destination countries, except Belgium and Luxembourg. Then for each product at the CN 8-digit level we have the log change in the export price index for each of the 10 euro countries (denoted k). In the second step, we aggregate these up to the 4-digit NACE industry level (denoted s), using the value of imports of each product-country pair into Belgium as import weights, and denote with Δp^m_{kst} the resulting proxy for the Belgian import price index from country k in sector s. This allows us to construct our next instrument as:

$$\Delta p^E_{-it} = \sum\nolimits_{j \in E_i} \frac{S_{jt}}{1 - S_{it}} \Delta p^m_{k(j)s(i)t},$$

where $k(j)$ denotes the country of origin of competitor $j \in E_i$ and $s(i)$ is the industry of the Belgian firm-product i. The idea is that movements in the price indexes Δp^m_{kst} should correlate with movements in european competitors' marginal costs without being affected by the demand conditions in Belgium.

In the robustness Section 3.3, we experiment with a variety of other instruments.

3.2 Empirical Results

We now turn to estimating the strength of strategic complementarities in price setting across Belgian manufacturing industries. We do this by regressing the annual change in the log firm-product price on the changes in the firm's log marginal cost and its competitors' price index, as in equation (1). This results in two estimated average elasticities, the own cost pass-through elasticity α and the strategic complementarities elasticity γ. Under the conditions of Proposition 2, these two elasticities sum to one, resulting in parameter restriction $\alpha + \gamma = 1$, which we test empirically without imposing it in estimation. Section 2.1 further suggests that these two elasticities are non-constant and vary systematically with the market share of the firm. We allow for this heterogeneity in elasticities in the second part of the section by estimating the main specification separately for small and large firms.

Δe_{-it} is constructed from $\{\Delta e_{jt}\}_{j \in D_i}$ in parallel with Δmc^*_{-it}. Note that if firm i does not import outside the eurozone, $\Delta e_{it} \equiv 0$. The bilateral exchange rates are average annual rates from the IMF, reported for each country relative to the US dollar and converted to be relative to the euro.

[29] These data are from the Comext trade database of Eurostat (http://ec.europa.eu/eurostat/web/international-trade/data/database).

Baseline estimates Table 1 reports the results from the baseline estimation. All of the equations are weighted using one-period lagged domestic sales, and the standard errors are clustered at the 4-digit industry level. The first two columns of Table 1 estimate equation (1) using OLS, with year fixed effects in column 1 and with both year and industry fixed effects in column 2.[30] The coefficients on both the firm's marginal cost and on the competitors' price index are positive, of similar magnitudes and significant, yet the two coefficients only sum to 0.7, violating the parameter restriction of Proposition 2. These estimates, however, are likely to suffer from endogeneity bias due to the simultaneity of price setting by the firm and its competitors Δp_{-it}, as well as from downward bias due to measurement error in our marginal cost variable Δmc_{it}. Indeed, while our proxy for marginal cost, as described in equation (22), has the benefit of encompassing all of the components of marginal costs, it has the disadvantage of being measured with a lot of noise.

To address these concerns, we reestimate equation (1) using instrumental variables. For the firm's marginal cost, we instrument with the foreign component of its marginal cost Δmc^*_{it}, as defined in equation (23).[31] For the competitor price index, we instrument with the three proxy measures of competitors' marginal costs, as defined in section 3.1. We present the results using all of these instruments combined in columns 3 and 4 of Table 1, with the lower panel reporting the corresponding first-stage regressions. The coefficients in the first-stage regressions have the expected signs and are strongly statistically significant.[32] In order to be valid, the instruments need to be orthogonal to the residual ε_{it}, which reflects shocks to demand and perceived quality of the product (see Section 2.1). Table 1 reports that our instruments pass the Hansen overidentification J-tests and the weak identification tests with the F-stat over 100, well above the critical value of around 12. We provide a detailed discussion of possible threats to our identification strategy and the validity of the instruments in Section 3.3.

We now turn to a discussion of our baseline IV estimates of the pass-through and strategic complementarity elasticities in columns 3 and 4 of Table 1. We see that both coefficient estimates increase relative to the OLS results in columns 1–2, with the coefficient on the firm's marginal cost almost doubling in size. Moreover, the sum of the two coefficients is now slightly above one, yet we cannot reject the null that it equals one at the 5% significance level. When we estimate the constrained version of equation (1) in column 5, imposing $\alpha+\gamma=1$, the estimate of the coefficient on the firm's marginal cost is unaffected, equal to 0.6. This implies that the data are consistent with the class of models identified in Proposition 2, and our approach to measuring the competitor price index according to (10) is not at odds with the data. Nonetheless, Section 3.3 offers additional robustness tests, which relax the structure imposed on the competitor price index.

[30]Robustness tables without weights, with current sales weights, and standard errors clustered at the firm level are presented in the online appendix Table O2.

[31]One of our identifying assumptions is that Δavc_{it} provides an unbiased, yet possibly noisy measure of the true overall marginal cost Δmc_{it}, for which we instrument using one of its components, namely the imported input costs Δmc^*_{it}. If this were true, the projection of Δavc_{it} on true Δmc_{it} must yield a coefficient of 1 (reflecting the unbiasedness of the proxy Δavc_{it}), while the reverse projection of Δmc_{it} on Δavc_{it} should give a coefficient biased towards zero (reflecting the noise in the proxy Δavc_{it}). We check this by projecting Δavc_{it} on our instrument for the marginal cost Δmc^*_{it}, which results in a large and highly significant coefficient of 0.97, while the reverse projection yields a much smaller coefficient.

[32]Importantly for identification, we have sufficient independent variation in the firm's own marginal cost and the competitor marginal costs: while the correlation between the two is positive, it is moderate in size equal to 0.27.

Table 1: Strategic complementarities: Baseline estimates

	OLS		IV		
Dep. var.: Δp_{it}	(1)	(2)	(3)	(4)	(5)
Δmc_{it}	0.348^{***}	0.348^{***}	0.588^{***}	0.650^{***}	0.616^{***}
	(0.040)	(0.041)	(0.094)	(0.112)	(0.103)
Δp_{-it}	0.400^{***}	0.321^{***}	0.549^{***}	0.484^{***}	
	(0.079)	(0.095)	(0.097)	(0.118)	
# obs.	64,823	64,823	64,823	64,823	64,823
Industry F.E.	no	yes	no	yes	yes
H_0: $\psi + \gamma = 1$	0.747	0.669	1.137	1.133	yes
[p-value]	[0.00]	[0.00]	[0.05]	[0.16]	
Overid J-test χ^2			2.41	0.74	1.44
[p-value]			[0.30]	[0.69]	[0.70]
Weak IV F-test			199.1	154.6	156.3

Table 1b: First stage regressions

	For column 3		For column 4	
Dep. var.:	Δmc_{it}	Δp_{-it}	Δmc_{it}	Δp_{-it}
Δmc^*_{it}	0.681^{***}	0.167^{***}	0.647^{***}	0.180^{***}
	(0.117)	(0.034)	(0.120)	(0.033)
Δmc^*_{-it}	0.851^{***}	1.355^{***}	0.832^{***}	1.344^{***}
	(0.363)	(0.217)	(0.372)	(0.238)
Δe^X_{-it}	-0.407	0.637^{***}	-0.353	0.695^{***}
	(0.363)	(0.217)	(0.372)	(0.238)
Δp^E_{-it}	0.089	0.481^{***}	0.194	0.438^{***}
	(0.226)	(0.149)	(0.281)	(0.113)
# obs.	64,823	64,823	64,823	64,823
Industry F.E.	no	no	yes	yes
First stage F-test	48.5	79.7	28.9	73.0
[p-value]	[0.00]	[0.00]	[0.00]	[0.00]

Notes: All regressions are weighted by lagged domestic firm sales and include year fixed effects, with robust standard errors clustered at the 4-digit industry level reported in parentheses. The lower panel presents the first stage regressions corresponding to column 3 and 4 respectively. See the text for the definition of the instruments. The IV regressions pass the weak instrument test with F-stats well above critical values and pass all over-identification tests. The null of Proposition 2 (parameter restriction (12) that $\psi + \gamma = 1$) cannot be rejected in both IV specifications, while it is rejected in OLS specifications; column 5 reports the results of the IV estimation under the restriction $\psi + \gamma = 1$.

The results in Table 1 show that firms exhibit incomplete pass-through of their cost shocks, holding constant the competitor prices, with an average elasticity α of around 0.6. At the same time, firms exhibit substantial strategic complementarities, adjusting their prices with an average elasticity γ around 0.5 in response to the price changes of their competitors, in the absence of any own cost shocks. In other words, in response to a 10% increase in competitor prices, the firm raises its own price by almost 5%, accounted for entirely by an increase in the firm's markup. These estimates are very stable across various specifications and subsamples, as we report in Section 3.3. The estimates of γ and α offer a direct quantification of the strength of strategic complementarities in price setting across Belgian manufacturing firms. Using (9), we can convert these estimates to recover the average markup elasticity Γ in the range of 0.6–1 (recall that we cannot reject $\Gamma_{-it} = \Gamma_{it}$).[33]

Heterogeneity The results in Table 1 provide us with average pass-through and strategic complementarity elasticities across Belgian manufacturing. In Table 2, we explore whether there is heterogeneity in firms' responses, by allowing the coefficients on the marginal cost and competitor price index to vary with firm size, as is typical in a broad class of models illustrated in Section 2.1. We begin by defining a large firm as one with 100 or more employees on average over the sample period. Columns 1 and 2 report the results from IV estimation of equation (1) for the sub-samples of small and large firms separately. In comparison to the average baseline results, we find that small firms have a larger coefficient on their own marginal cost, equal to 0.97, insignificantly different from 1, and a small and insignificant coefficient of -0.05 on the competitor price index. In contrast, large firms have a smaller coefficient on marginal cost, 0.48, and a larger coefficient on the competitor price index, 0.65, both statistically significant. An alternative way to identify differential effects between small and large firms is to pool all firms in one equation and interact both right-hand-side variables with a Large_i dummy, as in column 3. We find the same pattern of results, albeit with more noisy estimates: the two elasticities for the small firms are estimated at 1.01 and 0.02, while these elasticities for the large firms are 0.49 ($=1.01-0.52$) and 0.62 ($=0.02+0.60$). Interestingly, despite these differences between the large and small firms, we cannot reject that the sum of the elasticities within each group still equals one, consistent with Proposition 2.

The next two columns of Table 2 additionally include industry$\times$year fixed effects to address a number of potential identification concerns. In particular, in column 4, we show that the results are robust to including very fine 4-digit industry$\times$year fixed effects, replacing the competitor price index Δp_{-it}. This specification addresses the potential concern about the effects of correlated industry-level marginal costs shocks, as well as the measurement of an appropriate competitor price index.[34] In column 5, we

[33] These estimates are largely in line with the values suggested by Gopinath and Itskhoki (2011) based on the analysis of various indirect pieces of evidence. Gopinath and Itskhoki (2011) further discuss the relationship of these estimates with the calibrations of the strategic complementarities in popular monetary macro models. In order to obtain substantial amplification of monetary non-neutrality in the New Keynesian literature, some studies have adopted rather extreme calibrations with $\Gamma > 5$, an order of magnitude above our estimates (see also Klenow and Willis 2006). Our results, however, do not imply that strategic complementarities in price setting are unimportant for monetary business cycles, yet this mechanism alone cannot account for the full extent of monetary non-neutralities and it needs to be reinforced by other mechanisms (such as roundabout production as in Basu 1995 or local input markets as in Woodford 2003).

[34] Since the variation in Δp_{-it} is predominantly at the industry-year level (accounting for more than 90% of the variation), the strategic complementarity elasticity is identified largely from the panel data variation, and thus Δp_{-it} has to be excluded when the 4-digit industry$\times$year fixed effects are included into the regression. The own pass-through elasticity, however, can

Table 2: Strategic complementarities: Heterogeneity

Large$_i$ definition:	Employment $\geq$ 100					Top 20%	S_{it} >2%
Sample:	Small	Large	All	All	All	All	All
Dep. var.: Δp_{it}	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Δmc_{it}	0.972***		1.006***	0.937***	1.012***	0.802***	0.800***
	(0.160)		(0.211)	(0.128)	(0.195)	(0.221)	(0.123)
$\Delta mc_{it} \times$ Large$_i$		0.478**	−0.515	−0.297*	−0.549	−0.235	−0.315
		(0.203)	(0.344)	(0.178)	(0.432)	(0.364)	(0.201)
Δp_{-it}	−0.047		0.019		0.134	0.208	0.100
	(0.194)		(0.237)		(0.229)	(0.205)	(0.102)
$\Delta p_{-it} \times$ Large$_i$		0.645***	0.604*		0.668*	0.396	0.604***
		(0.175)	(0.320)		(0.403)	(0.335)	(0.187)
# obs.	49,469	15,354	64,823	64,823	64,822	64,823	64,823
Ind.&Year F.E.	yes	yes	yes	—	—	yes	yes
Ind.×Year F.E.	no	no	no	4-digit	2-digit	no	no
Overid. J-test χ^2	2.26	0.49	5.62	—	4.96	5.42	4.98
[p-value]	[0.32]	[0.78]	[0.23]		[0.29]	[0.25]	[0.29]
Weak IV F-test	87.4	40.3	67.2	211.7	69.3	77.7	77.9

Notes: The definition of Large$_i$ in columns 1–5 is based on employment size and in columns 6–7 is based on firm's sectoral market share, as described in the text. All specifications include variable Large$_i$ in levels, and observations are weighted with lagged domestic firm sales. Regressions in columns 1–3 and 6–7 include 4-digit industry *and* year fixed effects, with robust standard errors clustered at the industry level, and the instrument set is as in Table 1. Column 4 includes 4-digit industry×year fixed effects and drops the competitor price variables, with standard errors clustered at the firm level; this specification is exactly identified with two endogenous variables and two instruments Δmc^*_{it} and $\Delta mc^*_{it} \times$ Large$_i$ (hence no overid J-test). Column 5 is the same as in column 3, but with 2-digit industry×year fixed effects. Appendix Table A3 reports the first stages.

re-estimate column 3 adding in broader 2-digit industry×year fixed effects, to both control for sectoral demand shocks and directly identify the strategic complementarity coefficient on the competitor price changes. We find the results are almost identical to the baseline column 3. In the last two columns we re-estimate the specification in column 3 using alternative definitions of large firms based on a firm's market share within its respective 4-digit industry: in column 6, we define large firms to be those in the top 20% of their 4-digit industry by domestic sales; and in column 7 those with average market shares exceeding 2% within their industry. Both cases yield similar results.[35]

Our results suggest substantial heterogeneity in firms' pass-through elasticities and strategic complementarities in price setting. Namely, the small firms exhibit nearly complete pass-through of cost shocks ($\alpha \approx 1$) and almost no strategic complementarities in price setting ($\gamma \approx 0$), consistent with the

be identified from the within-industry-year variation in Δmc_{it}. Under the assumptions of Proposition 2, strategic complementarities can be recovered from these estimates using the parameter restriction (12), which implies an insignificant strategic complementarity elasticity of 0.06 for small firms and a significantly larger elasticity of 0.36 for large firms.

[35] Appendix Table A2 provides evidence that these heterogeneity results are not driven by spurious correlations in the data. In particular, we check that the large-firm results are not driven by exporters or multinationals and the small-firm results are not driven by non-importers. In addition, Appendix Table A3 reports the first-stage regressions corresponding to columns 1–3 of Table 2, showing consistent patterns for both small and large firms.

constant-markup behavior of monopolistic competitors under CES demand. Indeed, this corresponds to the predicted behavior of firms with nearly zero market shares in the oligopolistic competition model of Section 2.1. At the same time, the large firms behave very differently, exhibiting both incomplete pass-through of cost shocks (around 0.5) and strong strategic complementarities in price setting (around 0.6). Since these largest firms account for the majority of market sales, their behavior drives the average patterns across all of manufacturing described in Table 1.[36] In Section 4, we use a calibrated model to explore the implications of these estimates of strategic complementarity and heterogeneity across firms for the transmission of international shocks into aggregate domestic prices and markups.

3.3 Robustness

In this section, we address a number of potential concerns regarding the baseline results in the previous section by showing the robustness of our findings to alternative instrument sets, controls for quality upgrading, multiproduct firms, and alternative measures of the competitor price index.

Alternative sets of instruments We first consider the possible threats for our IV identification strategy, in particularly, the concerns of endogeneity and failure of the exclusion restriction. Identification requires that the residual term ε_{it} in estimating equation (1) is orthogonal to our instruments. The general theoretical framework of Section 2.1 implies that the residual term ε_{it} is a transformation of the firm-specific demand shocks. Therefore, the main identification concern is the presence of correlated demand shocks between Belgian and international products. Such shocks can simultaneously raise Δp_{it} and Δmc^*_{it}, since our marginal cost instrument is constructed using firm-product-country level changes in the prices of imported inputs. This concern could be relevant in the context of Europe because Belgian firms tend to source their imported inputs disproportionately from within the eurozone, and there could be correlated demand shocks across these integrated economies. A similar concern could be raised regarding the exclusion restriction for the instrument Δp^E_{-it} that is constructed using the change in the export prices of eurozone countries (to destinations other than Belgium) as a proxy for the prices paid by Belgian firms for their foreign inputs.

Table 3 addresses these identification concerns by considering alternative instrument sets, which rely on different sources of variation with the aim of excluding the potential sources of endogeneity in the instrumental variables. Recall from the earlier subsection that our baseline instrument set includes different sources of variation and jointly passes the overidentification J-test. One may still be concerned with the validity of each of the instruments, which may be challenged on different grounds. To this end, Table 3 shows that our findings are not sensitive to dropping any one instrument used in the

[36] Estimating pass-through and strategic complementarities by finer bins of firms (beyond a simple two-bin split) is difficult because there are so few large firms. Indeed, our small bin of firms contains over 75% of observations (yet accounts for less than 25% of total domestic sales), and strategic complementarities for these firms are not statistically distinguishable from zero. In contrast, extra-large firms with more than 1000 employees account for over 33% of sales, yet under 4% of observations, making separate estimation for this bin infeasible. We describe additional splits of the data in Appendix Figure A1, where we re-estimate column 1 of Table 2 for eight different employment-size cutoffs, starting with fewer than 100 employees and gradually adding large firms to the sample, which results in a gradually decreasing own cost pass-through elasticity and a gradually increasing strategic complementarity elasticity.

Table 3: Robustness: alternative sets of instruments

Robustness to:	Δp^E_{-it}		Δe^X_{-it}	Δmc^*_{-it}	Δmc^*_{it} and Δmc^*_{-it}			
Dep. var.: Δp_{it}	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Δmc_{it}	0.649***	0.702***	0.653***	0.557***	0.761	0.522*	0.504*	0.431*
	(0.099)	(0.154)	(0.150)	(0.123)	(0.525)	(0.315)	(0.293)	(0.240)
Δp_{-it}	0.473***	0.402**	0.480***	0.665***	0.541	0.627**	0.617**	0.683**
	(0.114)	(0.174)	(0.147)	(0.239)	(0.401)	(0.283)	(0.314)	(0.267)

Notes: All regressions are counterpart to column 4 of Table 1, with baseline instrument set ($\Delta mc^*_{it}, \Delta mc^*_{-it}, \Delta e^X_{-it}, \Delta p^E_{-it}$). Each column drops one or two of these instruments in turn, sometimes replacing them with alternative more conservative instruments. Column 1 replaces Δp^E_{-it} with one that only uses export prices to non-eurozone destination, and column 2 drops Δp^E_{-it} altogether. Column 3 drops Δe^X_{-it}, and hence excludes exchange rate variation from the instrument set. Column 4 drops Δmc^*_{-it}. Columns 5–8 drop both Δmc^*_{it} and Δmc^*_{-it}. Column 5 adds instead exchange-rate-based alternatives Δe_{it} and Δe^*_{-it} described in the text. Column 6 (7) additionally adds two new instruments analogous to Δmc^*_{it} and Δmc^*_{-it}, which replace firm import prices with proxies based on source-country export prices to countries other than Belgium (to outside the eurozone). Column 8 is like column 7, but with time-invariant firm-level weights used to construct the instruments. In all cases, the regressions pass the weak instrument F-test and the overidentification J-test, and the null that the coefficients sum to one cannot be rejected; the number of observations is 64,823, as in the baseline regression.

baseline estimation (Table 1), as well as to replacing them with alternative more conservative instruments. Since the potential source of endogeneity for different subsets of instruments is not the same, the robustness of our results across different sets of instruments gives confidence as to the validity of our identification strategy (this argument is developed further, in a different context, in Duranton and Turner 2012).

Columns 1 and 2 of Table 3 consider the robustness of an instrument constructed using the export prices to non-Belgian destinations as an instrument for Belgian import prices. In particular, column 1 replaces Δp^E_{-it} with a similar instrument that only uses export prices to destinations outside the eurozone to mitigate the possibility of correlated demand shocks across Belgium and other eurozone countries. We see that there is no change in the point estimates compared to the baseline specification in column 4 of Table 1. Column 2 drops the Δp^E_{-it} instrument altogether, and again the point estimates hardly change, even though standard errors increase by about 50%. In column 3, we instead drop the exchange rate instrument Δe^X_{-it} proxying for the prices of the non-eurozone competitors of the firm, which also leaves the point estimates unchanged, but with larger standard errors. Note that in this case we leave our instrument set free of any exchange rate variables. Our results, therefore, are not dependent on the use of the exchange rate or export prices to other european destinations as instruments.

In the remaining columns 4–8, we explore robustness to the use of our main instruments Δmc^*_{it} and Δmc^*_{-it}, which are constructed using changes in the individual import prices of Belgian firms. There is potential concern that including the firm's import prices may be endogenous with the demand shocks of the firm, due to either firm quality upgrading (affecting both its output and inputs) or upward sloping firm-level supply curves for inputs. In particular, column 4 simply drops the competitor imported marginal cost index Δmc^*_{-it} from the instrument set, also yielding little change in results.

In column 5, we replace both imported marginal cost instruments Δmc^*_{it} and Δmc^*_{-it} with analogous instruments Δe_{it} and Δe_{-it}, constructed using exchange rate changes, as described in footnote 28. In this specification, we find that both coefficients of interest become insignificant, even though the point estimates remain of similar magnitude to the baseline. What is important to note is that column 5 does not contain any instruments that proxy for prices of inputs that are imported from the eurozone, which lacks exchange rate variation with Belgium, and which proves problematic given the disproportionately large share of such imported inputs. To address this, we construct new instruments for imports from the eurozone that do *not* use the actual prices paid by Belgian firms. In columns 6–8, we add in two new instruments to the set in column 5, with columns 6 and 7 using country-specific export price changes outside Belgium and outside the eurozone, respectively, aggregated using Belgian firm-specific import weights. This restores the significance levels of the two coefficients of interest with little change in their magnitudes. In the final column 8, we re-estimate the specification in column 7, but now with time-invariant firm weights in the instruments, thus excluding all Belgian firm-time variation from the instrument set. The similarity in the estimation results across these different specifications helps alleviate the concerns about the validity of the instruments.

Quality and productivity Recall that in columns 4 and 5 of Table 2, we included industry-year fixed effects at the 4-digit and 2-digit industry levels to our baseline specification, which absorb all correlated industry-level demand shocks across Belgium and trading partners, and found that our baseline point estimates and their statistical significance were robust. However, there may still be correlation between the residual term and the firm's imported input prices, for example, if a firm were to endogenously adjust quality and/or productivity in response to changes in their own input costs or in their competitors' prices, and violate the orthogonality of instruments and ε_{it}.[37] We address these concerns in Table 4

To check if quality upgrading might be biasing our results, we follow Fan, Li, and Yeaple (2018) by including a robustness test where we check if the coefficients in differentiated industries, according to Rauch classifications, differ with homogeneous industries. It is expected that the scope for quality upgrading would be higher in differentiated industries. If endogenous quality upgrading were to bias our results, we would expect this to be more likely in industries where the scope for quality upgrading is high. To test for this, column 1 of Table 4 interacts the differentiated industry dummy with the firm's marginal cost and competitor price variables. We find no statistical differential effects for differentiated versus homogenous industries.

Another way of identifying industries with possibly elastic quality adjustment is to use measures of R&D intensity, as was done in Fan, Li, and Yeaple (2018) and Verhoogen (2008) at the industry level. We extend this approach using firm-level R&D data, and compare R&D-intensive firms with the non-R&D-intensive firms. Again, if quality upgrading were biasing our results, we would expect to find evidence of that bias for firms that were engaging in quality upgrading. To identify these firms, we create a firm-level indicator equal to 1 if the firm ever had positive expenditures on R&D during our

[37] Note that the change in productivity and in the input mix are not part of our instrument set, and therefore are not a direct concern on its own, if demand shifter (quality) shocks and imported input price changes are not correlated.

Table 4: Robustness: Quality and productivity upgrading

Dep. var.: Δp_{it}	Rauch index (1)	Firm R&D (2)	Large firm R&D (3)	TFP (4)	VA/worker (5)
Δmc_{it}	0.654***	0.721***	0.489*	0.672***	0.670***
	(0.175)	(0.151)	(0.258)	(0.116)	(0.118)
$\Delta mc_{it} \times R_i$	-0.182	-0.295	-0.141		
	(0.215)	(0.213)	(0.283)		
Δp_{-it}	0.523***	0.405***	0.659*	0.448***	0.450***
	(0.191)	(0.207)	(0.346)	(0.122)	(0.124)
$\Delta p_{-it} \times R_i$	0.088	0.207	0.033		
	(0.270)	(0.247)	(0.360)		
$\Delta \log TFP_{it}$				0.074***	
				(0.018)	
$\Delta \log(VA_{it}/L_{it})$					0.076***
					(0.018)
# obs.	64,823	64,823	15,354	64,247	64,405

Notes: All regressions are counterpart to column 4 of Table 1. In column 1, R_i is a dummy for whether firm-product i is in a differentiated sector according to the Rauch classification. In columns 2 and 3, R_i is a dummy for whether firm i records any positive R&D expenditure during the sample; column 3 limits the sample to the large firms only (as in column 2 of Table 2). Columns 4 and 5 add controls for firm-level log changes in measured TFP and value added per worker, respectively.

sample period.[38] We interact this dummy with the firm's marginal cost and competitor price variables in column 2. Both interaction terms are insignificant but the point estimates suggest effects for R&D-intensive firms similar to large firms, which is not surprising given that large firms are the more R&D intensive firms. So in column 3, we re-estimate column 2 for the subset of large firms, defined as those with average employment above 100. Note that half of the observations in this large sample have an R&D dummy equal to 1. The interactive coefficients are again insignificant and now much closer to zero in magnitude, suggesting that quality upgrading is unlikely biasing our results.

An additional way to check if quality upgrading might be biasing our results is to control for the change in firm's log TFP, with the premise that productivity changes and quality upgrading are correlated. In column 4, we find a positive significant coefficient on the productivity variable, but its inclusion leaves the coefficients on marginal costs and competitor prices unchanged. Therefore, firms with a measured increase in TFP start charging higher prices, possibly because of higher quality, but this doesn't affect the elasticities α and γ we estimate, consistent with the assumption of the validity of our instruments. Similarly, including a measure of labor productivity instead of TFP in column 5 leads to the same conclusion.[39]

[38] These data come from ECOOM (https://www.ecoom.be/en/services/rd). Because there was a change in the way these data were collected in 2002, we cannot use the time variation so we assume that firms that engaged in R&D in any year are R&D-intensive over the whole sample period.

[39] We also check whether currency movements, which were used as instruments in some specifications, are associated with systematic change in the set of imported inputs, which could in turn affect the quality of output, measured marginal costs and prices. We find no evidence of such extensive margin adjustment at the annual frequency that we focus on. Similarly, we show that the firm's import intensity ϕ_{it} is not sensitive to exchange rate movements at the annual frequency, as 90% of the variation in ϕ_{it} is explained by firm fixed effects. We report these results in the online appendix Tables O4 and O5.

Table 5: Robustness: alternative samples and variables

	Main product		IO-table input allocation		Finer industries		Two-period differences
					5-digit	6-digit	
Dep. var.: Δp_{it}	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Δmc_{it}	0.555***	0.631***	0.744***	0.620***	0.731***	0.609***	0.663***
	(0.145)	(0.126)	(0.162)	(0.128)	(0.145)	(0.145)	(0.161)
Δp_{-it}	0.498***	0.538***	0.387***	0.443***	0.438**	0.549***	0.385*
	(0.192)	(0.177)	(0.135)	(0.131)	(0.174)	(0.143)	(0.210)
# obs.	27,031	48,284	64,823	64,823	64,350	62,713	51,322

Notes: All regressions are counterpart to column 4 of Table 1. Columns 1 and 2 include only observations for the firm's largest product in terms of domestic sales: column 1 at the 8-digit product category level and column 2 at the 4-digit industry level. Columns 3 and 4 construct a firm-product level measure of Δmc_{it} by apportioning inputs to products using IO tables (weighted and simple averages of firm inputs in column 3 and 4, respectively). Columns 5 and 6 define all competition variables relative to 5- and 6-digit industries, respectively. Column 7 is in 2-period (year) differences.

Multiproduct firms An important potential concern is that the marginal cost variable is constructed at the firm level, whereas our unit of observation is at the firm-product level, resulting in measurement error. It is generally difficult to assign costs across products within firms. To check that this multi-product issue is not biasing our results (in particular, biasing downwards the coefficient on the own marginal cost), we conduct a number of robustness tests in Table 5. First, in columns 1 and 2, we restrict the sample to the firm's largest product in terms of domestic sales, defined at the PC 8-digit in column 3 and at the NACE 4-digit in column 4.[40] If present, the measurement error from assigning the inputs proportionally to all products of the firm should be considerably smaller in these specifications. We find no change in the results relative to our baseline, suggesting at most a limited role for a potential measurement error bias. Nonetheless, we provide further robustness checks in columns 3 and 4, where we construct a firm-product level measure of Δmc_{it} by apportioning inputs to products using the IO tables, as in Manova and Yu (2017). Since the IO tables are far more aggregated than the import data, we aggregate firm inputs up to the IO level using firm-expenditure weighted averages in column 1 and simple input count averages in column 2. The competitor marginal cost is also reconstructed using these new firm-product level measures. We again find no material change in our baseline results.

Additional robustness tests Table 5 provides two additional robustness checks. First, in columns 5 and 6, we experiment with alternative definitions of an industry. In our baseline, we define an industry at the 4-digit NACE level, which divides the 1,500 8-digit products in our sample into about 160 industries. In columns 5 and 6, we redefine the competition variables at the more narrow 5- and 6-digit industries, splitting products into roughly 270 and 320 industries, respectively. We find the results to be qualitatively robust under these alternative definitions.

Second, column 7 re-estimates the baseline specification with all variables constructed using two-year differences instead of the baseline annual differences, to address the concern of price stickiness

[40]We prefer this approach over limiting the sample to single-product firms only, as single-product firms constitute a very selected sample of small firms. We report the results from the sample of single-product firms in the online appendix Table O3.

and other types of dynamic considerations in price setting. Our theoretical framework of Section 2 relies on the assumption of static flexible price setting. If, instead, prices were set dynamically, as for example in sticky price models, the markups of firms could mechanically move with shocks, resulting in incomplete pass-through of marginal cost shocks. More generally, with sticky prices we would expect the price changes to be on average smaller for any given set of shocks, as some firms fail to adjust prices. Consequently, we would expect downward biased estimates for both of our elasticities, with less biased estimates over longer time horizons, as more firms have a chance to fully adjust their prices. We find that the coefficients in the specification with bi-annual differences are very similar to the baseline, albeit somewhat less precisely estimated, as the sample size shrinks. In particular, the sum of the two elasticities is still close to one. This suggests that the sticky price, and other dynamic considerations in price setting, do not bias our results in a major way.

Placebo tests and competitor prices We provide further support for our identification strategy with evidence from placebo regressions. We construct fictitious industries by randomly assigning each firm-product-year to one of 8-digit products, and then calculate a counterfactual industry-year competitor price index and associated instruments using this random set of firms within a particular NACE 4-digit industry. In column 1 of Table 6, we replace the actual competitor price index and associated instruments with corresponding fictitious ones. We find that the coefficient on such competitor price index (which we denote $\Delta\tilde{p}_{-it}$) in this placebo specification is estimated to be 0.04 with a standard error of 0.11. When we additionally control for the actual competitor price index (Δp_{-it}), in column 2, the coefficient on the counterfactual competitor price index drops to 0.004 with a standard error of 0.094, that is a very precisely estimated zero. We also note, from comparing columns 1 and 2, that when the true competitor price index is omitted, the regression erroneously recovers a nearly complete pass-through of 0.95 on own marginal costs shocks of the firms.

The next two columns of Table 6 address the potential concern about the measurement of the competitor price index Δp_{-it}. In our baseline, we relied on Proposition 2, and aggregated the competitor price changes weighting by their market shares. Instead, firms may put a higher or lower weight on prices on certain competitors. Therefore, we now allow for the possibility that the firms follow in particular the largest firm in the industry, and are less sensitive to the prices of other competitors, as in an industry-leader model. In column 3, we test the null of Proposition 2 by splitting the competitor price index Δp_{-it} into the largest competitor Δp^L_{-it} and all other competitors Δp^{-L}_{-it}, and premultiply them by their respective market shares, to test whether the firm is equally sensitive to the two resulting variables.[41] Both estimated coefficients are significant, close to 0.5, and nearly indistinguishable quantitatively. In column 4, we redefine Δp^L_{-it} to correspond to all firms within industry with at least 2% market share. In this case, we find that the coefficient on the large firms is somewhat smaller (equal to 0.4) than that on the other firms (equal to 0.6), although the difference is not statistically significant. These results imply that there is no extraordinary role for the largest firms in the industry, beyond their effect on the industry price index proportional to their market share, consistent with the construction

[41] Formally, the decomposition of the full competitor price index is as follows: $\Delta p_{-it} = S^L_{-it}\Delta p^L_{-it} + (1 - S^L_{-it})\Delta p^{-L}_{-it}$, where $S^L_{-it} = \max_{j\neq i} S_{jt}/(1 - S_{it})$, where js are firms in the 4-digit industry of firm i.

Table 6: Robustness: alternative measures of competitor prices

Dep. var.: Δp_{it}	Placebo with random industry assignment (1)	(2)	Largest competitor(s) (3)	(4)	Placebo with Δmc_{-it} (5)
Δmc_{it}	0.949***	0.647***	0.652***	0.628***	0.685***
	(0.101)	(0.139)	(0.114)	(0.100)	(0.155)
Δp_{-it}		0.487***			0.675*
		(0.159)			(0.408)
$S^L_{-it} \cdot \Delta p^L_{-it}$			0.470**	0.394*	
			(0.238)	(0.223)	
$(1 - S^L_{-it}) \cdot \Delta p^{-L}_{-it}$			0.477***	0.639***	
			(0.161)	(0.245)	
$\Delta \tilde{p}_{-it}$	0.036	0.004			
	(0.114)	(0.094)			
Δmc_{-it}					−0.220
					(0.424)
# obs.	64,823	64,823	64,823	64,823	64,780

Notes: All regressions build on the baseline specification in column 4 of Table 1. Columns 1 and 2 add a randomly constructed price index $\Delta\tilde{p}_{-it}$ for fictitious competitors randomly assigned to the industry. Column 3 (4) splits the competitor price index into the price changes for the largest competitor(s) Δp^L_{-it} and the other competitors Δp^{-L}_{-it}, as described in the text and footnote 41. Column 5 includes *domestic* competitor marginal costs Δmc_{-it}.

of our baseline competitor price index Δp_{-it}. Lastly, column 5 includes the marginal cost index for the firm's competitors Δmc_{-it}, which according to Proposition 1 should have no effect on firm pricing once we control for competitor prices Δp_{-it}. This theoretical prediction is again borne out by the data.

In sum, we find strong robust evidence of positive strategic complementarities, with substantial heterogeneity across small and large firms.

4 Exchange Rate Depreciation and Domestic Price Inflation

We now apply the general framework of the earlier section, with our elasticity estimates, to study the effects of an exchange rate depreciation on aggregate domestic prices and markups.[42] We use this framework to study the underlying transmission mechanism from firm-level shocks to sector-level price and markup adjustment. In particular, we show that the transmission of shocks into aggregate prices depends not just on the presence of strategic complementarities, but more importantly on the heterogeneity in markup variability across firms of the sort we document in Section 3. We study under what circumstances aggregate markups fall in response to an exchange rate depreciation and act to mute the response of domestic price inflation, thereby shedding light on the low exchange rate pass-through observed in the data (see e.g. Goldberg and Campa 2010).

[42] Our framework is suitable for the analysis of any shock that affects marginal costs differentially across firms, for example, import tariffs or the "rise of China" (i.e., the productivity growth in a major trade partner).

4.1 From micro to macro

We start with the firm-level price setting behavior and show how import intensity of individual firms and foreign competition in the product market aggregate up and shape the price and markup responses at the *aggregate* (sectoral) level. Towards this goal, we specialize the price change decomposition in equation (6) to the case of an exchange rate shock $\mathrm{d}e_t > 0$, corresponding to a domestic currency depreciation. The projection of equation (6) onto the exchange rate shock can be written as:

$$\overbrace{\mathbb{E}\left\{\frac{\mathrm{d}p_{it}}{\mathrm{d}e_t}\right\}}^{\equiv\psi_{it}} = \frac{1}{1+\Gamma_{it}} \cdot \overbrace{\mathbb{E}\left\{\frac{\mathrm{d}mc_{it}}{\mathrm{d}e_t}\right\}}^{\equiv\varphi_{it}} + \frac{\Gamma_{-it}}{1+\Gamma_{it}} \cdot \overbrace{\mathbb{E}\left\{\frac{\mathrm{d}p_{-it}}{\mathrm{d}e_t}\right\}}^{\equiv\Psi_{-it}}, \tag{25}$$

where expectations are taken over possible realizations of the firm idiosyncratic shocks. We assume that idiosyncratic demand shifters are not systematically correlated with the exchange rate shock, i.e. $\mathbb{E}\{\mathrm{d}\varepsilon_{it}/\mathrm{d}e_t\} = 0$, which is a realistic assumption in the context of individual products in differentiated industries.

In (25), ψ_{it} is firm i's exchange rate pass-through (ERPT), Ψ_{-it} is ERPT into its competitor prices, and φ_{it} is its marginal cost sensitivity (or *exposure*) to the exchange rate. We assume that the conditions of Proposition 2 apply, and thus we have $\Psi_{-it} = \sum_{j\neq i}\frac{S_{jt}}{1-S_{it}}\psi_{jt}$ and $\Gamma_{it} = \Gamma_{-it}$, consistent with our empirical estimates. These restrictions prove useful for tractable aggregation. To further simplify the analysis, we make a strong assumption that φ_{it} can be proxied by the import intensity of the firm ϕ_{it}, which we observe in the data. That is, we assume that a firm's exposure to the exchange rate φ_{it} reflects its share of foreign value added in total variable costs.[43] While we view this as a natural assumption for our baseline quantification, the theoretical results below apply more generally for an arbitrary structure of cost shocks φ_{it}, which may differ from the observable expenditure shares ϕ_{it}.

We are interested in characterizing the aggregate ERPT:

$$\Psi_t \equiv \mathbb{E}\left\{\frac{\mathrm{d}p_t}{\mathrm{d}e_t}\right\} = \sum\nolimits_{i=1}^{N} S_{it}\psi_{it}, \tag{26}$$

where $\mathrm{d}p_t = \sum_{i=1}^{N} S_{it}\mathrm{d}p_{it}$ is the *sectoral price inflation* and N is the total number of firms in the sector, including both domestic and foreign firms. The aggregate cost sensitivity to the exchange rate is a similar weighted average across firms:

$$\bar{\varphi}_t \equiv \mathbb{E}\left\{\frac{\mathrm{d}mc_t}{\mathrm{d}e_t}\right\} = \sum_{i=1}^{N} S_{it}\varphi_{it}. \tag{27}$$

[43] There are a number of caveats to this assumption. First, the pass-through into foreign input prices may be incomplete; there may be correlated adjustment in the prices of domestically-produced inputs; or some of the foreign inputs may reach non-importing home firms via domestic wholesalers. While these factors could raise or lower the level of aggregate ERPT, our qualitative conclusions about the aggregate markup adjustment still hold provided the ranking of φ_{it} across firms remains unchanged. Second, exchange rate movements may trigger firms to adjust their cost structure, including sources of intermediate inputs, or to invest in quality and productivity-upgrading. While such changes are likely to occur over longer horizons and in response to larger exchange rate devaluations, they are less prevalent for typical exchange rate movements at the annual frequency, which is our focus here. Still, our main results apply more generally, provided φ_{it} is reinterpreted to capture both the intensive and extensive margin responses over longer horizons.

Under our assumptions regarding φ_{it}, we interpret $\bar{\varphi}_t$ as the *foreign value added* content of the aggregate sectoral output, embodied partly in output supplied by the foreign firms and partly in foreign intermediate inputs used by the domestic firms. In a competitive model with marginal cost pricing, $\bar{\varphi}_t$ is a sufficient statistic for ERPT, as it does not matter whether foreign value added reaches the domestic market in the form of output or intermediate inputs. As we will shortly see, this distinction, and in particular the distribution of $\{\varphi_{it}\}$ across firms, matter a lot in a world of imperfect competition with strategic complementarities in pricing.

The difference between Ψ_t and $\bar{\varphi}_t$ captures the *aggregate markup response* to the shock. This can be seen by taking the difference between (26) and (27) to obtain $\Psi_t - \bar{\varphi}_t = \sum_{i=1}^N S_{it}(\psi_{it} - \varphi_{it})$, and further observing that $\psi_{it} - \varphi_{it} = \mathbb{E}\{\mathrm{d}\mu_{it}/\mathrm{d}e_t\}$ is the individual markup response, since $\mu_{it} = p_{it} - mc_{it}$. Manipulating (25) using the definitions of Ψ_{-it} and Ψ_t, we express the firm-level markup adjustment as follows:

$$\psi_{it} - \varphi_{it} = -\kappa_{it}(\varphi_{it} - \Psi_t), \qquad \text{where} \qquad \kappa_{it} \equiv \frac{\Gamma_{it}}{1 - S_{it} + \Gamma_{it}}. \tag{28}$$

Note that $\kappa_{it} \in [0,1)$ increases in the markup elasticity Γ_{it}, and it captures the elasticity of the firm's price with respect to the sectoral price index, while $1 - \kappa_{it}$ is the firm's own cost pass-through elasticity holding the sectoral price index constant.[44] It follows from (28) that a firm reduces its markup if $\varphi_{it} > \Psi_t$, that is if its costs are affected more by the shock than the average price in the industry. We next explore the conditions under which this holds in the aggregate, that is $\Psi_t < \bar{\varphi}_t$ and the industry markups decline on average in response to an exchange rate depreciation, muting the aggregate ERPT.

We prove the following main result:

Proposition 3 *The equilibrium exchange rate pass-through into the sectoral price level is given by:*

$$\Psi_t = \frac{1}{1-\bar{\kappa}_t}\sum_{i=1}^N S_{it}(1-\kappa_{it})\varphi_{it} = \bar{\varphi}_t - \frac{\mathrm{cov}\big(\kappa_{it}, \varphi_{it}\big)}{1-\bar{\kappa}_t}, \tag{29}$$

where $\bar{\kappa}_t = \sum_{j=1}^N S_{it}\kappa_{it}$ *and* $\mathrm{cov}\big(\kappa_{it}, \varphi_{it}\big) = \sum_{i=1}^N S_{it}(\kappa_{it} - \bar{\kappa}_t)\varphi_{it}$ *is a sales-weighted covariance.*

Proposition 3 shows that, in general, in the presence of strategic complementarities ($\Gamma_{it} \neq 0$), the aggregate pass-through into prices Ψ_t differs from that into costs $\bar{\varphi}_t$. This, however, requires *heterogeneity* in both the cost shocks φ_{it} and markup elasticities Γ_{it}, as well as a *correlation* between them, as we highlight in the following two corollaries.

Corollary 1 *If* $\frac{\Gamma_{it}}{1-S_{it}} = const$ *for all* i*, then* $\Psi_t = \bar{\varphi}_t$*, and aggregate markup is constant, even if all* $\Gamma_{it} > 0$ *and individual markups adjust to the shock.*

The main case of interest, which fits Corollary 1, is that of monopolistic competition (with $N \to \infty$ and $S_{it} \to 0$ for all i) and a common markup elasticity $\Gamma_{it} = \Gamma$ for all i. This nests the conventional

[44] Elasticities κ_{it} and $(1 - \kappa_{it})$ differ from those we estimate in Section 3 when firms are large, i.e. $S_{it} > 0$, while under monopolistic competition (with $S_{it} \to 0$ for all i) they are the same. Formally, $1 - \kappa_{it}$ and $1/(1 + \Gamma_{it})$ both capture $\mathrm{d}p_{it}/\mathrm{d}mc_{it}$, where the former holds the full price index constant ($\mathrm{d}p_t = 0$), while the latter holds the competitor price index constant ($\mathrm{d}p_{-it} = 0$).

CES case, but it is considerably more general, as it does not require $\Gamma = 0$. Indeed, with $\Gamma > 0$, Corollary 1 allows for arbitrary strong strategic complementarities and incomplete pass-through at the firm level. Therefore, Corollary 1 is a powerful, and perhaps surprising, implication of Proposition 3, as it suggests that the effects of strategic complementarities may well wash out in the aggregate, resulting in exactly zero adjustment to the aggregate markup, despite the arbitrary heterogeneity in the cost shocks across firms.[45] The intuition is that, under conditions of Corollary 1, a reduction in markups by some firms (e.g., foreign firms strongly exposed to the exchange rate shock) is *exactly* offset by an increase in markups by the other firms (e.g., home firms less exposed to the exchange rate).

Corollary 1 points to the importance of heterogeneity in markup elasticities Γ_{it} for the aggregate markup to respond to shocks, that is for strategic complementarities to manifest themselves at the aggregate level. Furthermore, this heterogeneity must be systematic and correlated with the exposure to the shock, as we emphasize in:

Corollary 2 *If Γ_{it} and φ_{it} are increasing with firm size S_{it}, then $\Psi_t < \bar{\varphi}_t$, and the aggregate markup in the home market declines in response to an exchange rate devaluation, muting the exchange rate pass-through into the domestic price inflation.*

Under the condition of Corollary 2, $\operatorname{cov}(\kappa_{it}, \varphi_{it}) > 0$ and hence $\Psi_t < \bar{\varphi}_t$ by Proposition 3. The evidence in Section 3 shows that the case of Corollary 2 is indeed empirically relevant. In the data, we find that large firms have both large markup elasticities and high import intensity. Corollary 2 suggests that it is specifically this type of interaction between strategic complementarities and firm heterogeneity that causes a muted response of domestic prices to exchange rate fluctuations in the aggregate.

These results have important implications for the international transmission of shocks into the relative price levels across countries. The pricing-to-market literature emphasizes markup adjustment at the level of the firm, resulting in a violation of the law of one price across markets.[46] Our results here suggest that in the absence of heterogeneity in markup elasticities across firms, pricing to market at the level of individual firms does not translate into changes in aggregate markups across markets, and hence has no effect on the relative price levels and *cannot* explain the volatility of the real exchange rate. Heterogeneity in markup variability across firms, in particular of the sort we document in the data, is necessary for the pricing-to-market mechanism to manifest itself at the aggregate level and contribute to the volatility of the real exchange rate.

Aggregate pass-through of domestic firms The conventional view is that a currency depreciation gives a competitive edge to the domestic firms, which allows them to raise markups in the domestic market in response to higher prices of foreign competitors. We now ask whether this is always the case or if there are circumstances when home firms reduce markups in response to a depreciation. To

[45]The result in Corollary 1 has been noted in the exchange rate pass-through literature (see Burstein and Gopinath 2012, Itskhoki and Mukhin 2017). It also resonates with the "elusive pro-competitive effects of trade" result in ACDR, yet their result of zero aggregate markup adjustment is obtained under very different conditions. The ACDR result relies on Pareto-distributed firm productivities and a demand system with a choke-off price, binding for some firms, neither of which are required in Corollary 1.

[46]While the large firms reduce markups in the home market in response to a home currency depreciation, as we study below, these same firms increase markups considerably in the foreign destinations, as we show in Amiti, Itskhoki, and Konings (2014).

distinguish the subset of domestic firms D, we define $\bar{\varphi}_t^D = \sum_{i\in D} S_{it}^D \varphi_{it}$ and $\Psi_t^D = \sum_{i\in D} S_{it}^D \psi_{it}$, where $S_{it}^D = S_{it}/\sum_{j\in D} S_{jt}$. Under the conditions of Corollary 1, the conventional logic holds, and in particular:

$$\bar{\varphi}_t^D < \Psi_t^D < \Psi_t < \bar{\varphi}_t^F,$$

provided that foreign firms rely, on average, more on foreign inputs in production than domestic firms (i.e., $\bar{\varphi}_t^F > \bar{\varphi}_t^D$). This means that home firms would necessarily increase their markups on average, $\Psi_t^D - \bar{\varphi}_t^D > 0$, independently of the distribution of $\{\varphi_{it}\}_{i\in D}$. Intuitively, because domestic firms are less exposed to exchange rate shocks than foreign firms, they will typically raise their markups in response to a currency depreciation.

Nonetheless, this is not the case in general. If heterogeneity among home firms is sufficiently vast, and the largest home firms both are strongly exposed to foreign inputs and exhibit strong strategic complementarities in price setting, the average markup of home firms may go down, $\Psi_t^D - \bar{\varphi}_t^D < 0$. Formally, aggregating (28) across home firms yields:

$$\Psi_t^D - \bar{\varphi}_t^D = -\sum_{i\in D} S_{it}^D \kappa_{it}(\varphi_{it} - \Psi_t), \tag{30}$$

Expression (30) makes it clear that a necessary condition for $\Psi_t^D < \bar{\varphi}_t^D$ is an existence of some $i \in D$ such that $\varphi_{it} > \Psi_t$, that is some domestic firm(s) with an exposure to the foreign inputs in excess of the average pass-through into prices in the domestic market. Empirically, this condition is easily met, as some of the largest domestic firms indeed rely heavily on foreign-sourced intermediate inputs. If such firms have a substantial cumulative market share and exhibit strong strategic complementarities, then $\Psi_t^D < \bar{\varphi}_t^D$ is indeed a possible outcome, as we explore quantitatively in what follows.

4.2 A stylized example

To provide intuition for these results, we present a simple stylized example with three types of firms, which captures the essence of a more sophisticated quantitative model in the following subsection. In particular, we study an industry with small and large home firms, as well as large foreign firms exporting into the home market. We index the three types of firms with S, L and F, respectively. All firms are small relative to the market, so that $N \to \infty$ and $S_{it} \to 0$ for all i. The cumulative market share of the small and large home firms is λ_S and λ_L, respectively, and the rest of the market is served by the foreign firms with $\lambda_F = 1 - \lambda_S - \lambda_L$.

To capture in a stylized way the salient features of heterogeneity observed in the Belgian data, we make the following assumptions. The small and large home firms differ in import intensity and markup elasticity, with $\varphi_S = \Gamma_S = 0$, reflecting that small firms do not rely on imported inputs and exhibit constant-markup behavior. In contrast, the large home firms have $\varphi_L = \varphi > 0$ and $\Gamma_L = \Gamma > 0$. Lastly, the foreign firms have $\varphi_F = \varphi^* > \varphi$, and $\Gamma_F = \Gamma$, capturing the Melitz (2003) selection effect of the largest firms into exporting. The results below also hold for any $\Gamma_F \geq \Gamma$.

For our baseline case, we set the foreign share $\lambda_F = 0.2$, and $\lambda_S = \lambda_L = 0.4$, so that the small and large home firms split equally the remaining home market. This approximates a typical Belgian manufacturing industry in our sample. We further set $\varphi = 0.4$ and $\Gamma = 1.5$ for the large home firms. This implies an own-cost pass-through, $\frac{1}{1+\Gamma}$, of 70% on average for home firms, with a 100% pass-through for small firms and a 40% pass-through for large firms, capturing in a stylized way our empirical findings in Section 3. For the foreign firms, we set $\varphi^* = 0.7$, implying that 30% of foreign exporters' production expenditure is on intermediates purchased from the eurozone. Altogether, the share of foreign value added in aggregate output is given by $\bar{\varphi} = \lambda_L\varphi + \lambda_F\varphi^* = 0.3$, where a portion $\lambda_F\varphi^* = 0.14$ comes in the form of foreign output and a portion $\lambda_L\varphi = 0.16$ comes in the form of foreign intermediates used by the large home firms, broadly in line with the Belgian patterns documented by Tintelnot, Kikkawa, Mogstad, and Dhyne (2017).

Using the general result in Proposition 3, we can characterize the aggregate ERPT and study its variation as a function of parameters in our stylized example:

$$\Psi = \frac{\bar{\varphi}}{1 + \lambda_S\Gamma}, \tag{31}$$

and therefore $\Psi < \bar{\varphi}$ if $\lambda_S\Gamma > 0$.[47] This illustrates how the presence of small firms that differ from large firms in terms of both exchange rate exposure φ and strategic complementarities Γ is essential for the aggregate markup adjustment. The larger is the share of the small firms λ_S, the bigger is the gap between $\bar{\varphi}$ and Ψ. This is because the prices of the small firms are not sensitive to the exchange rate, and this acts to limit the price adjustment by the large firms who exhibit strategic complementarities. In our baseline, the average exchange rate pass-through into costs is $\bar{\varphi} = 0.3$, while the average pass-through into prices is $\Psi = 0.19 < \bar{\varphi}$. In other words, markup adjustment at the industry level offsets almost 40% of the direct effect of the shock to the marginal cost. This also means that in response to a 10% depreciation of the home currency, the average industry markup declines by more than one percentage point.

Next, we evaluate the markup adjustment by the subset of the *domestic* firms. Since $\psi_S = \varphi_S = 0$, we have:

$$\Psi_D - \bar{\varphi}_D = \frac{\lambda_L}{\lambda_S + \lambda_L}(\psi_L - \varphi_L) = \frac{\lambda_L}{\lambda_S + \lambda_L}\frac{\Gamma}{1+\Gamma}\left[\frac{\bar{\varphi}}{1 + \lambda_S\Gamma} - \varphi\right].$$

Therefore, a necessary and sufficient condition for the markup of the home firms to decline on average is $\varphi > \bar{\varphi}/(1 + \lambda_S\Gamma)$. Evidently, this is more likely to be the case when strategic complementarities are strong, large home firms rely intensively on foreign inputs, and also face relatively more small domestic competitors than foreign competitors (which reduces $\bar{\varphi}$). In our baseline, $\bar{\varphi}_D = 0.2$ and $\Psi_D = 0.14 < \bar{\varphi}_D$, suggesting a considerable reduction in home firms' average markups in response to an exchange rate depreciation. This contrasts with the conventional narrative whereby domestic firms increase markups in response to a depreciation. In our example, small domestic firms are not exposed to the exchange rate directly and do not adjust their markups, as they exhibit no strategic complementarities in price setting. The large home firms are, in contrast, strongly exposed to the

[47] Indeed, in this simple example, $\lambda_S\Gamma > 0$ ensures that the conditions of Corollary 2 are satisfied, while whenever $\lambda_S = 0$ or $\Gamma = 0$, the conditions of Corollary 1 are satisfied instead. We discuss the more general case in Appendix C.

exchange rate directly, as they import a considerable portion of their inputs. And, since these large home firms compete most intensely against the small home firms (as the cumulative share of foreign firm is only 20% of the market), strategic complementarities compel the large home firms to reduce their markups.

Our conclusion that depreciations lead to lower average markups of the home firms, while contradicting the conventional logic, is rather robust under a variety of alternative scenarios. There are two essential requirements for this to happen. First, a considerable portion of foreign value added in the sector must come not just in the form of output, but also in the form of intermediate inputs, used primarily by the largest home producers. Second, as emphasized in Corollary 2, firms must exhibit differential degrees of strategic complementarity in price setting, which is correlated with the exposure to foreign value added. This *heterogeneity* requirement is, however, not implausibly stringent. In this three-type economy, $\Psi_D < \bar{\varphi}_D$ still holds true even if we reduce considerably the extent of heterogeneity between small and large home firms, relative to our highly stylized example with $\varphi_S = \Gamma_S = 0$.[48] Therefore, we conclude that our finding that domestic firms may reduce their markups on average in the home market in response to a home currency depreciation is not merely a curiosity, but indeed a likely empirical outcome.

4.3 Quantitative model

We now confirm the insights from the stylized example of the previous section using a fully-specified industry equilibrium model, disciplined quantitatively using Belgian manufacturing data. This richer modeling approach can be used to analyze counterfactual industries to determine the direction of aggregate markup adjustment in response to international shocks. We adopt the Atkeson and Burstein (2008) model of oligopolistic competition under nested-CES demand and explore robustness in a model of monopolistic competition with non-CES (Kimball) demand in Appendix D. In the model, firm-level markup elasticities Γ_{it} emerge endogenously as an outcome of an industry price-setting game given the structure of demand and competition. We relegate the full setup and calibration of the models to Appendix D, and provide here only a brief summary of our findings.

We consider an industry with N firms with marginal costs given by

$$MC_{it} = \frac{W_t^{1-\phi_i} \left(V_t^* \mathcal{E}_t\right)^{\phi_i}}{A_{it}}, \tag{32}$$

where W_t is the price index of domestic inputs, V_t^* is the foreign-currency price index of foreign inputs, and $\mathcal{E}_t$ is the nominal exchange rate with an increase in $\mathcal{E}_t$ indicating a depreciation of the home currency. The firm specific parameter ϕ_i captures the exposure of the firm to foreign inputs, and we assume it to be constant over the medium-run (annual) horizon that we focus on. Finally, A_{it} is the idiosyncratic firm productivity, which we assume is drawn from a Pareto distribution. The home and foreign firms differ in their exposure to foreign inputs, in particular, we assume that all foreign firms

[48] For example, holding constant $\bar{\varphi}_D$ at 0.2 and the average of $1/(1+\Gamma)$ at 0.7, the average markup of home firms still falls when we reduce heterogeneity in exchange rate exposure to $\varphi_S = 0.16$ and $\varphi_L = 0.24$, or in markup elasticity to $\Gamma_S = 0.32$ and $\Gamma_L = 0.56$.

Table 7: Strategic complementarities in the quantitative model

Dep. var.: Δp_{it}	All	Small	Large	Interaction
Δmc_{it}	0.532	0.899	—	0.900
$\Delta mc_{it} \times \text{Large}_{it}$	—	—	0.424	-0.393
Δp_{-it}	0.417	0.060	—	0.066
$\Delta p_{-it} \times \text{Large}_{it}$	—	—	0.529	0.335

Note: The regressions parallel those in column 4 of Table 1.A and columns 1, 2 and 4 of Table 2. As in the data, the observations include only home firms, while Δp_{-it} includes both home and foreign competitors of the firm. Large_{it} is a dummy for whether the firm belongs to the top 20% of home firms by home-market sales within each industry. Observations are weighted by firm sales. Regressions include industry and year fixed effects, and are IV regressions using $\phi_i \Delta e_t$ and $\phi_{-i}\Delta e_t$ as instruments. The reported coefficients are averaged over 20 simulations, each with 50 industries and 11 years of observations, to eliminate small sample variation.

have $\phi_i \equiv \phi^*$, while for the home firms $\phi_i < \phi^*$ and is positively correlated with the firm size, as in the data. Lastly, only a subset of the most productive foreign firms can enter the home market, in line with the empirical evidence on firm selection into exporting.

We focus on partial industry equilibrium with exogenous idiosyncratic productivity and exchange rate shocks. We assume that the log of the exchange rate follows a random walk and the log of firm-level productivities follow a random walk with drift and idiosyncratic shocks, which maintains the stability of the cross-sectional productivity distribution (as in Gabaix 2009). Consistent with the evidence on exchange rate disconnect, we assume that the prices of local inputs W_t and V_t^* are not correlated with the exchange rate shock, and we normalize them to $W_t = V_t^* = 1$.[49] Under these assumptions, the exchange rate exposure of firms' marginal costs equals their foreign input shares, $\varphi_i = \phi_i$.

Given the demand and marginal costs, firms play a Cournot price setting game, resulting in the optimal markup pricing, as characterized in Section 2.1. We calibrate the parameters of the model to be broadly in line with the features of the typical Belgian manufacturing industries. In particular, we set the elasticity of demand to match the pass-through estimates in Section 3 and the Pareto shape parameter of the productivity distribution to ensure that 20% of the largest home firms account for 60% of the total home-firm sales. We set $\{\phi_i\}$, so that the average home-firm exposure to foreign inputs is $\bar{\phi}_D = 0.2$, and the correlation between ϕ_i and S_i across home firms within industries is 0.3, like in our data. This results in the average import intensity of 0.25 for the largest 20% of firms and 0.125 for the remaining small firms. Finally, we choose the number of foreign firms so that they account for 20% of the domestic market sales and set $\phi^* \equiv 0.7$, as in our stylized example, to match the ERPT of foreign firms into export prices of about 50%.

Table 7 shows how the calibrated model with CES demand and Cournot competition matches accurately our empirical estimates from Section 3. Indeed, the model captures nearly complete cost pass-through and zero strategic complementarities typical of the small firms, and strong strategic comple-

[49]See Itskhoki and Mukhin (2017) for a fully-specified model of exchange rate disconnect, driven by shocks to the exchange rate in the financial markets, which exhibits similar properties in general equilibrium. One can adopt alternative assumptions about ERPT into local input prices W_t and V_t^*, however, since this does not change the heterogeneity profile of $\{\varphi_{it}\}$ across firms, it is inconsequential for the pattern of markup adjustment, which is our focus here.

Table 8: Exchange rate pass-through in the quantitative model

ERPT into:		Sets of firms				
		All	Home	Large	Small	Foreign
Costs	$\bar{\varphi}_J$	0.300	0.200	0.245	0.121	0.700
Prices	Ψ_J	0.238	0.185	0.217	0.131	0.475
Markups	$\Psi_J - \bar{\varphi}_J$	-0.062	-0.015	-0.028	0.010	-0.225

Note: a counterfactual response to a 10% home currency depreciation, averaged across 10,000 industries; $\bar{\varphi}_J$ and Ψ_J are sales-weighted averages of φ_i and ψ_i, respectively, for $i \in J$, where Js are the different subsets of firms. Large corresponds to the top 20% of home firms by sales within each industry.

mentarities and incomplete own cost pass-through exhibited by the large firms. As a result, the model is capable of reproducing the empirical patterns of markup elasticities across firms $\{\Gamma_i\}$, and it is calibrated to match the variation in market shares and import intensities $\{S_i, \phi_i\}$, providing the necessary ingredients for a counterfactual analysis of exchange rate depreciations.

The results in Table 8 underscore the findings that emerged using our stylized example. We find that a 10% currency depreciation leads to a fall in the aggregate industry markup, with the average pass-through into home prices $\Psi = 0.24$ below the pass-through into cost $\bar{\varphi} = 0.3$. That is, markup adjustment attenuates the aggregate pass-through into domestic prices by about 20%. This supports the quantitative relevance of Proposition 3 and Corollary 2. Furthermore, the calibrated model features sufficient heterogeneity so that home firm markups decline on average, with the increase in the small firm markups more than offset by the fall in the large firm markups. We further illustrate this heterogeneity in the markup adjustment across domestic firms of different size in the Appendix Figure A2.

We reach similar conclusions in an alternative quantitative model with Kimball demand and monopolistic competition (see Appendix D). Using these quantitative models, we can vary the characteristics of counterfactual industries to determine the direction and degree of aggregate markup response to an exchange rate depreciation, as well as other international shocks. In general, relative to the baseline case, aggregate markups fall by a larger amount in industries with less direct foreign competition in the output market and more import intensive large domestic firms.[50] Moreover, the results critically depend on the degree of heterogeneity. If an industry features little heterogeneity in strategic complementarities across firms, the markup adjustments washes out in the aggregate, with the fall in foreign firm markups offset by the increase in domestic firm markups.

5 Conclusion

In this paper, we provide a direct estimate of strategic complementarities in price setting. We find that a firm increases its price by an average of 4% in response to a 10% increase in the prices of its competitors, holding its own marginal cost constant, and thus due entirely to the markup adjustment.

[50] The opposite case, where the presence of strategic complementarities leads to an increase in the aggregate markup, would occur if the small firms were relatively more exposed to the international shock than large firms. However, the selection of the large firms into importing makes this alternative case unlikely in practice.

Furthermore, there is considerable heterogeneity in the strength of strategic complementarities across firms. Small firms show no strategic complementarities and a complete pass-through of their cost shocks into prices, in line with constant-markup pricing behavior, as is characteristic of monopolistic competitors under CES demand. In contrast, large firms exhibit strong strategic complementarities and incomplete pass-through. We estimate these elasticities within a general theoretical framework, using a new rich micro dataset with detailed information on firm marginal costs and competitor prices. We develop an instrumental variable identification strategy to estimate the properties of firm markups without imposing strong structural assumption on demand, competition or production.

These results have important implications for the aggregate markup response to international shocks. Interestingly, the presence of strategic complementarities *per se* at the micro-level is not sufficient to generate movements in aggregate markups. If the strategic complementarity elasticity is the same across all firms, an international shock results in zero aggregate markup adjustments irrespective of the strength of strategic complementarities. In particular, the fall in foreign firms' markups is exactly offset by the rise in domestic markups, or vice versa. A novel finding from our analysis is that heterogeneity in markup elasticities across firms is necessary for any aggregate markup adjustment. We show that an exchange rate depreciation in a typical Belgian manufacturing industry, where large firms import a substantial share of their intermediate inputs, results in a fall in aggregate markups. In this case, the large domestic firms, in fact, decrease their markups, thereby attenuating the aggregate exchange rate pass-through into domestic prices.

A Additional Empirical and Quantitative Results

Table A1: Summary Statistics

	Variable	5 pctl	Mean	Median	95 pctl	St.dev.
Firm-product variables	Δp_{it}	-0.363	0.013	0.003	0.400	0.235
	Δp_{-it}	-0.061	0.012	0.008	0.093	0.054
	S_{it}	0.000	0.010	0.001	0.044	0.039
Firm-level variables	L_{it}	9.9	168.9	36.1	666.8	515.1
	Δmc_{it}	-0.262	0.022	0.015	0.330	0.212
	Δmc^*_{it}	-0.030	0.002	0.000	0.041	0.029
	ϕ_{it}	0.000	0.148	0.109	0.452	0.156
	ϕ^X_{it}	0.000	0.032	0.003	0.168	0.071
Industry-level variables (NACE 4-digit)	$\max_{i\in D} S_{it}$	0.013	0.098	0.063	0.313	0.110
	$\sum_{i\in D} S_{it}$	0.111	0.565	0.588	0.901	0.238
	$\sum_{i\in F} S_{it}$	0.080	0.369	0.315	0.864	0.236
	$\sum_{i\in X} S_{it}$	0.003	0.092	0.066	0.273	0.090
	# of firms	6	65	40	310	80

	Fraction of firms with >0			Average across firms		
	All	Large	Small	All	Large	Small
ϕ_{it}	0.701	0.984	0.638	0.150	0.221	0.134
ϕ^X_{it}	0.576	0.958	0.491	0.032	0.059	0.026

Notes: The table reports percentiles, means and standard deviations of the main variables used in the analysis, as defined in the text. Additionally: L_{it} denotes firm employment; ϕ_{it} and ϕ^X_{it} are the firm expenditure shares (in total variable costs) on foreign intermediate inputs from outside Belgium and from outside the eurozone, respectively; D, F and X correspond to the sets of domestic, all foreign and foreign non-eurozone firms, respectively. The statistics characterize our sample distributions across observations, which are at the firm-product-year level, except the '# of firms', which is at the industry-year level. The lower panel reports averages across firm-year observations; Large (Small) firms are based on the average employment cutoff of 100 employees, as in columns 1 and 2 of Table 2.

Table A2: Robustness: large and small firms

Sample	Large firms		Small firms	
	Export share < 0.1	FDI share < 0.005	$\phi_i > 0$	$\phi^X_i > 0$
	(1)	(2)	(3)	(4)
Δmc_{it}	0.648***	0.518**	0.976***	1.028***
	(0.227)	(0.220)	(0.158)	(0.166)
Δp_{-it}	0.441**	0.550***	0.036	0.012
	(0.187)	(0.188)	(0.202)	(0.211)
# obs.	7,941	14,389	32,984	25,900

Notes: Large and small sample based on employment$\gtrless$100 threshold, as in columns 1 and 2 of Table 2. Column 1 only includes large firms with the share of export in total sales less than 10%. Column 2 only includes large firms with related-party foreign sales or purchases less than 0.005% of their total sales. Column 3 and 4 only include firms with positive imports of intermediates from outside Belgium and outside eurozone, respectively. See online appendix Table O7 for additional checks.

Table A3: First-stage Results

	Column (1)		Column (2)		Column (3)			
	Δmc_{it}	Δp_{-it}	Δmc_{it}	Δp_{-it}	Δmc_{it}	Δmc_{it} $\times$Large$_i$	Δp_{-it}	Δp_{-it} $\times$Large$_i$
Δmc^*_{it}	0.54***	0.12***			0.54***	−0.02	0.12***	0.00
	(0.09)	(0.03)			(0.09)	(0.01)	(0.03)	(0.01)
$\Delta mc^*_{it} \times$ Large$_i$			0.59***	0.18***	0.09***	0.64***	0.07***	0.19***
			(0.15)	(0.04)	(0.17)	(0.15)	(0.05)	(0.04)
Δe^X_{-it}	−0.24	0.45***	−0.25	0.34**	−0.31	−0.15	−0.46***	−0.08
	(0.20)	(0.15)	(0.34)	(0.17)	(0.27)	(0.24)	(0.14)	(0.09)
$\Delta e^X_{-it} \times$ Large$_i$					0.18	0.03	−0.13	0.23*
					(0.30)	(0.28)	(0.13)	(0.12)
Δmc^*_{-it}	0.71***	0.68***			0.53***	−0.20***	0.73***	−0.05*
	(0.20)	(0.14)			(0.21)	(0.07)	(0.17)	(0.57)
$\Delta mc^*_{-it} \times$ Large$_i$			0.30**	0.52***	−0.19	−0.54***	−0.21	−0.57***
			(0.14)	(0.10)	(0.24)	(0.15)	(0.16)	(0.10)
Δp^E_{-it}	0.16***	0.15***			0.20***	0.02	0.17***	−0.01
	(0.06)	(0.05)			(0.07)	(0.02)	(0.05)	(0.01)
$\Delta p^E_{-it} \times$ Large$_i$			0.23***	0.32***	0.02	0.21***	0.15***	0.33***
			(0.06)	(0.05)	(0.08)	(0.06)	(0.05)	(0.05)

Notes: The table reports the first stage results for the IV regressions in columns 1–3 of Table 2. See note to Tables 1 and 2.

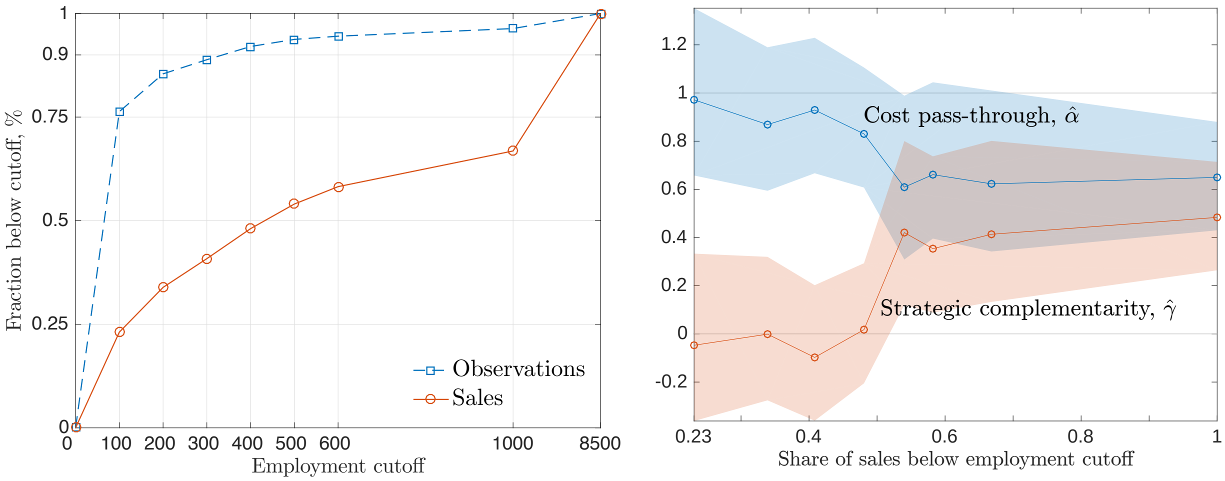

Figure A1: Cost pass-through and strategic complementarity elasticities for different employment-size cutoffs

Note: The figure reports the results for firms with average employment below the following 8 cutoffs: 100, 200, 300, 400, 500, 600, 1,000, and 8,500 (corresponding to the full sample). The left panel reports the fraction of observations and domestic sales accounted for by the firms below each of the employment cutoffs, illustrating the very skewed firm-size distribution in the data. The right panel re-estimates the specification in column 1 of Table 2 under different employment cutoffs, and plots the estimated elasticities $\hat{\psi}$ and $\hat{\gamma}$ (and the respective 95% confidence intervals) against the shares of sales accounted for by the firms in each subsample (corresponds to the red solid line in the left figure). Note that the very first (left) points correspond to the estimates in column 1 of Table 2, while the very last (right) points to those in column 4 of Table 1.

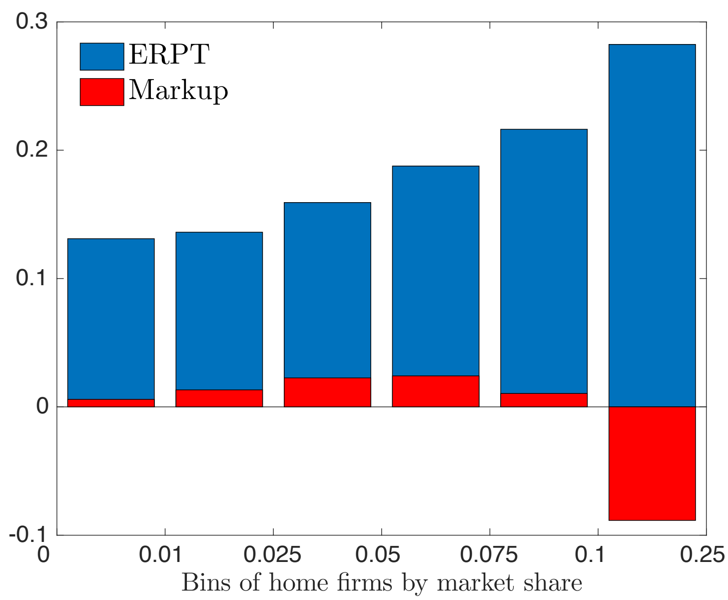

Figure A2: ERPT and markup adjustment, by size bins of home firms

Note: Simulated currency depreciation counterfactual, as in Table 8. The figure plots average ERPT (Ψ_J, blue bars) by bins of home firms based on within-industry market shares, as well as the markup adjustment ($\Psi_J - \bar{\varphi}_J$, red bars), and the difference between the two is the direct cost shock ($\bar{\varphi}_J$). As in the Belgian data, firms with less than 1% market shares within their industries account for almost 60% of the count of firms, but less than 20% of domestic-firm home market sales; the bin of the largest firms with more than 10% market shares account for 2% of firm count and almost 20% of home market sales.

B Data Appendix

Data Sources The production data (PRODCOM) report production values and quantities at the firm-product level in the manufacturing sector, where the product is defined at the PC 8-digit. It is a survey of all firms with a minimum of 10 employees, covering at least 90% of production in each NACE 4-digit (that is, the first 4 digits of the PC 8-digit code), which includes around 1,700 manufacturing product codes in any one year. We only keep PC codes that are classified as manufactured goods - these are products for which the first 4-digits of the PC8 codes are in the range of 1500 to 3699. We drop all PC8 codes in petroleum (NACE 2-digit code 23) and industrial services. Firms are required to report total values and quantities but are not required to report the breakdown between domestic and exports. Therefore, to get a measure of domestic values and quantities we merge on the export data from customs and subtract total export values and quantities from total production values and quantities sold.

The international data comprise transactions on intra-EU trade data collected by the Intrastat Inquiry and the extra-EU transactions data by Customs. These data are reported at the firm level by destination and source country for each product classified at the 8-digit combined nomenclature (CN) in values and quantities, with around 10,000 distinct products. The first 6-digits of the CN codes correspond to the World Harmonized System (HS). All transactions that involve a change of "ownership with compensation" (codes 1 and 11) are in our sample. These data include all extra-EU transactions of firms with trade greater than 1,000 euros or whose weights are more than 1,000 kilograms - these thresholds were reduced in 2006; and intra-EU trade with a higher threshold of 250,000 euros, with both these thresholds raised somewhat in 2006.

The firm characteristics data are available on an annual frequency at the firm level, with each firm reporting their main economic activity within a 5-digit NACE industry. However, there is no product level data within firms available from this source.

Merging the trade and production data The production and trade data are easily merged using a unique firm identifier. But the merging of the firm's products in the production and customs data is a bit more complicated.

First, we had to aggregate the monthly PRODCOM data to the annual frequency. To avoid large jumps in annual values due to nonreporting for some months by some firms, we only keep a firm's observation in year t if there was positive production reported for at least one product in each month. In some cases the firm reported positive values but the quantities were missing. For these cases, in order to construct domestic unit values we impute the quantity sold from the average value to quantity ratio in the months where both values and quantities were reported - this only affected 3% of the observations, accounting for 1% of the production value. With this adjustment, we aggregated the data to the annual level.

Second, there is the task of converting the highly disaggregated trade data that is at the CN 8-digit level with the more aggregated PC 8-digit PC codes. To match these two datasets, we use the concordance provided by Eurostat - these mappings may be one-to-one, many-to-one, one-to-many, or many-to-many. We use the files developed by Van Beveren, Bernard, and Vandenbussche (2012) to identify these mappings. While CN-to-PC conversion is straightforward for one-to-one and many-to-one mappings, conversion for one-to-many and many-to-many mappings required grouping of some PC codes. There were 77 such groupings, which account for approximately 4% of the observations and production value.

Third, in order to construct the domestic unit values, where we net out exports from total production values and quantities, we need to ensure that the quantities in the two datasets are comparable. So we drop observations where the units that match in the two datasets are less than 95% of the total export value and the firm's export share is greater than 5% within a firm-PC-year observation. The rationale for doing this is that if the export share (exports as a ratio of production) is really small then the domestic unit value won't be affected very much if we don't subtract all of the firm's exports.

Fourth, some PC codes change over time. Here, we only make an adjustment if the code is a one-to-one change between two years. We do not take into account changes in PC codes that involve splitting into multiple codes or multiple PC codes combining into one code. Effectively, these changes in the PC codes are treated as though they are new products.

C Derivations and Proofs

Proof of Proposition 1 Consider the profit maximization problem of the firm written in the conjectural variation form:

$$\max_{p_i, \boldsymbol{p}_{-i}} \Big\{ \exp\left\{p_i + q_i(p_i, \boldsymbol{p}_{-i}; \boldsymbol{\xi})\right\} - TC_i\Big(\exp\left\{q_i(p_i, \boldsymbol{p}_{-i}; \boldsymbol{\xi})\right\}\Big)\Big| \text{ s.t } h_{-i}(p_i, \boldsymbol{p}_{-i}; \boldsymbol{\xi}) = 0\Big\}, \tag{A1}$$

where p_i and q_i are log price and log quantity demanded of the firm, $TC_i(\cdot)$ is the total cost function (in levels), and $h_{-i}(\cdot)$ is the conjectural variation vector function with elements given by $h_{ij}(\cdot)$ for $j \neq i$; we omit t subscript for brevity. Note that this formulation nests monopolistic competition, oligopolistic Bertrand competition, and oligopolistic Cournot competition, as long as the demand system is invertible. In particular, to capture firm behavior under monopolistic and oligopolistic Bertrand competition, we choose the conjectural variation function:

$$h_{-i}(p_i, \boldsymbol{p}_{-i}; \boldsymbol{\xi}) = \boldsymbol{p}_{-i} - \boldsymbol{p}^*_{-i}. \tag{A2}$$

Indeed, this corresponds to the assumption of the firm that its price choice p_i leads to no adjustment in the prices of its competitors which are set at $\boldsymbol{p}_{-i} = \boldsymbol{p}^*_{-i}$. The case of Cournot competition requires choosing $h_{-i}(\cdot)$ such that it implies $\boldsymbol{q}_{-i} \equiv \boldsymbol{q}^*_{-i}$ for some given $\boldsymbol{q}^*_{-i}$ vector. Provided an invertible demand system, this can be simply ensured by choosing:

$$h_{-i}(p_i, \boldsymbol{p}_{-i}; \boldsymbol{\xi}) = -\big(\boldsymbol{q}_{-i}\big(p_i, \boldsymbol{p}_{-i}; \boldsymbol{\xi}\big) - \boldsymbol{q}^*_{-i}\big). \tag{A3}$$

Therefore, we can capture the firm behavior under competition in both prices and quantities with a conditional profit maximization with respect to prices (A1).

We introduce the following notation:

1. $e^{p_i + q_i}\lambda_{ij}$ for $j \neq i$ is the set of Lagrange multipliers for the constraints in (A1);

2. $\zeta_{ijk}(\boldsymbol{p}; \boldsymbol{\xi}) \equiv \partial h_{ij}(\boldsymbol{p}; \boldsymbol{\xi})/\partial p_k$ is the elasticity of the conjectural variation function, with $\zeta_{ijj}(\cdot) > 0$ as a normalization and the matrix $\{\zeta_{ijk}(\cdot)\}_{j,k\neq i}$ having full rank, which is trivially the case for (A2) and is satisfied for (A3) due to the assumption of demand invertibility;

3. $\epsilon_i(\boldsymbol{p}; \boldsymbol{\xi}) \equiv -\partial q_i(\boldsymbol{p}; \boldsymbol{\xi})/p_i > 0$ and $\delta_{ij}(\boldsymbol{p}; \boldsymbol{\xi}) \equiv \partial q_i(\boldsymbol{p}; \boldsymbol{\xi})/p_j$ for $j \neq i$ are the own and cross price elasticities of demand.

We can then write the first-order conditions for (A1), after simplification, as:

$$\begin{aligned} &\big(1 - \epsilon_i + \epsilon_i e^{-\mu_i}\big) + \textstyle\sum_{k\neq i} \lambda_{ik}\zeta_{iki} = 0, \\ \forall j \neq i \qquad &\big(-\delta_{ij} + \delta_{ij} e^{-\mu_i}\big) + \textstyle\sum_{k\neq i} \lambda_{ik}\zeta_{ikj} = 0, \end{aligned}$$

where $\mu_i \equiv p_i - mc_i$ is the log markup and $mc_i \equiv \log(\partial TC_i/\partial Q_i)$ is the log marginal cost. Using these conditions to solve out the Lagrange multipliers, we obtain the expression for the optimal markup of the firm:

$$\mu_i = \log \frac{\sigma_i}{\sigma_i - 1}, \tag{A4}$$

where σ_i is the perceived elasticity of demand given by (using vector notation):

$$\sigma_i \equiv \epsilon_i - \boldsymbol{\zeta}_i' \boldsymbol{Z}_i^{-1} \boldsymbol{\delta}_i, \tag{A5}$$

where $\boldsymbol{\zeta}_i \equiv \{\zeta_{iji}\}_{j\neq i}$ and $\boldsymbol{\delta}_i \equiv \{\delta_{ij}\}_{j\neq i}$ are $(N-1)\times 1$ vectors and $\boldsymbol{Z}_i \equiv \{\zeta_{ijk}\}_{j\neq i, k\neq i}$ is $(N-1)\times(N-1)$ matrix of cross-price elasticities, which has full rank (under the market competition structures we consider) due to the demand invertibility assumption.

Recall that ζ_{ijk}, ϵ_i and δ_{ij} are all functions of $(\boldsymbol{p};\boldsymbol{\xi})$, and therefore $\sigma_i \equiv \sigma_i(\boldsymbol{p};\boldsymbol{\xi})$. Consequently, (A4) defines the log markup function:

$$\mathcal{M}_i(\boldsymbol{p};\boldsymbol{\xi}) \equiv \log \frac{\sigma_i(\boldsymbol{p};\boldsymbol{\xi})}{\sigma_i(\boldsymbol{p};\boldsymbol{\xi}) - 1},$$

and the optimal price of the firm solves the following fixed point equation:

$$\tilde{p}_i = \mathcal{M}_i(\tilde{p}_i, \boldsymbol{p}_{-i};\boldsymbol{\xi}) + mc_i$$

completing the proof of Proposition 1. ■

We can now discuss a number of special cases. First, in the case of monopolistic competition and oligopolistic price (Bertrand) competition, for which the conjecture function satisfies (A2), and therefore $\zeta_{ijj} \equiv 1$, $\zeta_{iji} = 0$ for $j \neq i$ and $\zeta_{ijk} \equiv 0$ for $k \neq j, i$. This implies that $\boldsymbol{Z}_i$ is an identity matrix and $\boldsymbol{\zeta}_i \equiv \boldsymbol{0}$, substituting which into (A5) results in:

$$\sigma_i = \epsilon_i(\boldsymbol{p};\boldsymbol{\xi}) = -\frac{\partial q_i(\boldsymbol{p};\boldsymbol{\xi})}{\partial p_i}. \tag{A6}$$

In words, the perceived elasticity of demand in this case simply equals the partial price elasticity of the residual demand of the firm.

In the case of oligopolistic quantity (Cournot) competition, we have $\zeta_{ijk} = \epsilon_j$ for $k = j$ and $\zeta_{ijk} = -\delta_{jk}$ for $j \neq k$. Therefore, in this case we can rewrite (A5) as in footnote 9:

$$\sigma_i = \epsilon_i(\boldsymbol{p};\boldsymbol{\xi}) - \sum\nolimits_{j\neq i} \delta_{ij}(\boldsymbol{p};\boldsymbol{\xi})\kappa_{ij}(\boldsymbol{p};\boldsymbol{\xi}), \tag{A7}$$

where $\boldsymbol{\kappa}_i = \{\kappa_{ij}\}_{j\neq i}$ solves

$$\boldsymbol{\kappa}_i = \boldsymbol{\zeta}_i' \boldsymbol{Z}_i^{-1} = \left\{ \frac{\mathrm{d}p_j}{\mathrm{d}p_i}\bigg|_{\mathrm{d}q_j(\boldsymbol{p};\boldsymbol{\xi})=0, j\neq i} \right\}_{j\neq i}.$$

This is easy to verify by writing the system $\mathrm{d}q_j(\boldsymbol{p};\boldsymbol{\xi}) = \sum_{k\neq j} \frac{\partial q_j(\boldsymbol{p};\boldsymbol{\xi})}{\partial p_k}\mathrm{d}p_k = 0$ for all $j \neq i$ in matrix form and solving it for $\kappa_{ij} = \mathrm{d}p_j/\mathrm{d}p_i$, which results in $\boldsymbol{\kappa}_i = \boldsymbol{\zeta}_i' \boldsymbol{Z}_i^{-1}$.

Proof of Proposition 2 If $q_i = q_i(p_i, z; \boldsymbol{\xi})$, then following the same steps as above, we can show that there exists a markup function:

$$\mu_i = \mathcal{M}_i(p_i, z; \boldsymbol{\xi}) \equiv \log \frac{\sigma_i(p_i, z; \boldsymbol{\xi})}{\sigma_i(p_i, z; \boldsymbol{\xi}) - 1},$$

such that the profit-maximizing price of the firm solves $\tilde{p}_i = mc_i + \mathcal{M}_i(\tilde{p}_i, z; \boldsymbol{\xi})$. Using the definition of the competitor price change index (8) and the properties of the log expenditure function $z = z(\boldsymbol{p}; \boldsymbol{\xi})$, we have:

$$\omega_{ij} = \frac{\partial \mathcal{M}_i(p_i, z; \boldsymbol{\xi})/\partial p_j}{\sum_{k \neq i} \partial \mathcal{M}_i(p_i, z; \boldsymbol{\xi})/\partial p_k} = \frac{\partial \mathcal{M}_i(p_i, z; \boldsymbol{\xi})/\partial z \cdot S_j}{\partial \mathcal{M}_i(p_i, z; \boldsymbol{\xi})/\partial z \cdot \sum_{k \neq i} S_k} = \frac{S_j}{1 - S_i},$$

where we make use of the Shephard's lemma (Envelope condition) for the log expenditure function $\partial z/\partial p_j = S_j$ and $\sum_{k \neq i} S_k = 1 - S_i$. Consequently, the competitor price index is given by (10).

If a stronger condition $\sigma_i = \sigma_i(p_i - z; \boldsymbol{\xi})$ is satisfied, then:

$$\mu_i = \mathcal{M}_i(p_i - z; \boldsymbol{\xi}) \equiv \log \frac{\sigma_i(p_i - z; \boldsymbol{\xi})}{\sigma_i(p_i - z; \boldsymbol{\xi}) - 1},$$

and, using the definitions of Γ_i and Γ_{-i} in (7), we have:

$$\Gamma_i = -\frac{\mathrm{d}\mathcal{M}_i(p_i - z; \boldsymbol{\xi})}{\mathrm{d}p_i} = -\frac{\partial \mathcal{M}_i(p_i - z; \boldsymbol{\xi})}{\partial p_i} - \frac{\partial \mathcal{M}_i(p_i - z; \boldsymbol{\xi})}{\partial z} \frac{\partial z}{\partial p_i} = -\frac{\partial \mathcal{M}_i(p_i - z; \boldsymbol{\xi})}{\partial (p_i - z)}(1 - S_i),$$
$$\Gamma_{-i} = \sum_{j \neq i} \frac{\partial \mathcal{M}_i(p_i - z; \boldsymbol{\xi})}{\partial p_j} = \frac{\partial \mathcal{M}_i(p_i - z; \boldsymbol{\xi})}{\partial z} \sum_{j \neq i} S_j = \Gamma_i.$$

This completes the proof of the proposition. ■

Note that condition in (ii) in the proposition is stronger than the condition in (i), as $\sigma_i(\boldsymbol{p}; \boldsymbol{\xi}) = -\partial q_i(\boldsymbol{p}; \boldsymbol{\xi})/\partial p_i$, and therefore if $\sigma_i = \sigma_i(p_i - z; \boldsymbol{\xi})$ then necessarily $q_i = q_i(p_i, z; \boldsymbol{\xi})$. It is easy to see that the converse is not true, for example if $q_i(p_i, z; \boldsymbol{\xi})$ is not homothetic of degree one in the levels of (p_i, z).

Derivations for the Atkeson-Burstein model Instead of following the standard approach, we derive the results for the Atkeson-Burstein model using the more general Propositions 1 and 2, and their proofs above. We write the nested CES demand schedule in logs:

$$q_i = \log \xi_i + d_s + (\rho - \eta) z - \rho p_i, \tag{A8}$$

where $\eta \geq 1$ and $\rho > \eta$ are the elasticities of substitution across industries and within-industry across products, respectively; $d_s = \log\left(\varpi_s P^\eta Y\right)$ is the industry demand shifter, where ϖ_s is the exogenous shifter, Y is the nominal income in the economy and P is the log aggregate price index, and no firm is large enough to affect Y/P; finally, $z = p_s$ is the log expenditure function equal to the industry price index and given by:

$$z = \frac{1}{1-\rho} \log \sum\nolimits_{i=1}^{N} \exp\{\log \xi_i + (1-\rho)p_i\}. \tag{A9}$$

The Shephard's lemma can be verified to hold for z directly from (A9):

$$\frac{\partial z}{\partial p_i} = e^{\log \xi_i + (1-\rho)(p_i - z)} = \frac{e^{p_i+q_i}}{\sum_{j=1}^{N} e^{p_j+q_j}} = S_i,$$

where the second equality uses demand equation (A8) and the last equality is the definition of the revenue market share S_i. Furthermore, we can use this result to decompose the change in the industry price index as follows:[51]

$$\mathrm{d}z = \sum\nolimits_{j=1}^{N} S_j \mathrm{d}p_j = S_i \mathrm{d}p_i + (1-S_i)\mathrm{d}p_{-i}, \qquad \text{where} \qquad \mathrm{d}p_{-i} \equiv \sum\nolimits_{j \neq i} \frac{S_j}{1-S_i} \mathrm{d}p_j,$$

which corresponds to the index of competitor price changes in (10).

We now calculate σ_i for both cases of Bertrand and Cournot competition:

1. **Price competition (Bertrand)** Recall from (A6) that under Bertrand competition, we simply have $\sigma_i = \epsilon_i$, where

$$\epsilon_i = -\frac{\mathrm{d}q_i}{\mathrm{d}p_i} = \rho - (\rho - \eta) e^{\log \xi_i + (1-\rho)(p_i - z)},$$

and therefore the conditions for the both part of Proposition 2 apply in this case. Therefore, we can rewrite:

$$\epsilon_i = \rho - (\rho - \eta) S_i = \rho(1 - S_i) + \eta S_i. \tag{A10}$$

Taking stock, we have $\epsilon_i = \epsilon(p_i - z; \xi_i)$ given the parameters of the model (ρ, η), and

$$\mu_i = \mathcal{M}_i(p_i - z; \xi_i) = \log \frac{\epsilon(p_i - z; \xi_i)}{\epsilon(p_i - z; \xi_i) - 1}.$$

Using the steps of the proof of part (ii) of Proposition 2, we can calculate:

$$\Gamma_i = -\frac{\mathrm{d}\mu_i}{\mathrm{d}p_i} = -\frac{\partial \mu_i}{\partial p_i} - \frac{\partial \mu_i}{\partial z} S_i = \frac{(\rho - \eta)(\rho - 1) S_i (1 - S_i)}{\epsilon_i(\epsilon_i - 1)},$$
$$\Gamma_{-i} = \frac{\partial \mu_i}{\partial z} \cdot (1 - S_i) = \Gamma_i.$$

In the case of Cobb-Douglas industry aggregator ($\eta = 1$), this simplifies to $\Gamma_i = \Gamma_{-i} = \frac{(\rho-1)S_i}{1+(\rho-1)(1-S_i)}$, which is monotonically increasing in S_i.

2. **Quantity competition (Cournot)** Next consider the case of Cournot competition. Here we

[51] In fact, in this case, such decomposition is also available for the level of the price index, which is a special property in the CES case: $Z = \left[\xi_i P_i^{1-\rho} + (1-\xi_i) P_{-i}^{1-\rho}\right]^{1/(1-\rho)}$ and $P_{-i} = \left[\sum_{j \neq i} \xi_j / (1 - \xi_i) P_j^{1-\rho}\right]^{1/(1-\rho)}$.

follow the steps of the proof of Proposition 1, and first calculate:

$$\delta_{ij} = \frac{\mathrm{d}q_i}{\mathrm{d}p_j} = \frac{\partial q_i}{\partial z}\frac{\partial z}{\partial p_j} = (\rho-\eta)S_j \qquad \text{and} \qquad \zeta_{ijk} = \begin{bmatrix} \epsilon_j = \rho - (\rho-\eta)S_j, & \text{if } k=j, \\ -\delta_{jk} = -(\rho-\eta)S_j, & \text{if } k \neq j. \end{bmatrix}$$

We could directly use this to solve for $\boldsymbol{\zeta}_i'\boldsymbol{Z}_i^{-1}\boldsymbol{\delta}_i$ in (A5). Instead, we calculate $\boldsymbol{\kappa}_i = \boldsymbol{\zeta}_i'\boldsymbol{Z}_i^{-1}$, where the elements are $\kappa_{ij} = \mathrm{d}p_j/\mathrm{d}p_i\big|_{\mathrm{d}q_k=0,k\neq i}$. We do this by noting that:

$$\mathrm{d}q_j = (\rho-\eta)\mathrm{d}z - \rho\mathrm{d}p_j = 0, \qquad j \neq i,$$

implies $\mathrm{d}p_j = (\rho-\eta)/\rho\cdot\mathrm{d}z$ for all $j\neq i$. This makes it easy to solve for $\mathrm{d}z$ as a function of $\mathrm{d}p_i$:

$$\mathrm{d}z = \sum_j S_j\mathrm{d}p_j = S_i\mathrm{d}p_i + \frac{\rho-\eta}{\rho}(1-S_i)\mathrm{d}z \qquad \Rightarrow \qquad \frac{\mathrm{d}z}{\mathrm{d}p_i} = \frac{\rho S_i}{\rho-(\rho-\eta)(1-S_i)},$$

and the expressions for $\kappa_{ij} = \mathrm{d}p_j/\mathrm{d}p_i = (\rho-\eta)S_i/[\rho-(\rho-\eta)(1-S_i)]$ for all $j\neq i$ follow. Substituting this into (A7), we have:

$$\begin{aligned}\sigma_i = \epsilon_i - \sum\nolimits_{j\neq i}\delta_{ij}\kappa_{ij} &= [\rho-(\rho-\eta)S_i] - \frac{(\rho-\eta)^2S_i}{\rho-(\rho-\eta)(1-S_i)}\sum_{j\neq i}S_j \\ &= \rho-(\rho-\eta)S_i\left[1+\frac{(\rho-\eta)(1-S_i)}{\rho-(\rho-\eta)(1-S_i)}\right] \\ &= \frac{\rho\eta}{\rho S_i+\eta(1-S_i)} = \left[\frac{1}{\rho}(1-S_i)+\frac{1}{\eta}S_i\right]^{-1},\end{aligned}$$

replicating (13), which is the conventional expression from Atkeson and Burstein (2008). Again, we have $\sigma_i = \sigma_i(p_i-z;\xi_i)$ and $\mu_i = \mathcal{M}_i(p_i-z,\xi_i) = \log[\sigma_i(p_i-z;\xi_i)/(\sigma_i(p_i-z;\xi_i)-1)]$, satisfying the conditions in both parts of Proposition 2. The remaining derivation of the expression for $\Gamma_i = \Gamma_{-i}$ parallels that in the case of the Bertrand competition above, and results in expressions (14) in the text.

Note the qualitative similarity between the price and quantity oligopolistic competition, where in the former σ_i is a simple average of ρ and η with a weight S_i on ρ, and in the latter σ_i is a corresponding harmonic average, with the same monotonicity properties, given the values of ρ and η. In both cases, $\Gamma_i = \Gamma_{-i} = \Gamma(S_i)$, which is a monotonically increasing function of S_i at least on $S_i \in [0, 0.5]$ for any values of the parameters.

Reduced-form of the model We start with the price decomposition (6) and, under the assumptions of Propositions 2, solve for the reduced form of the model. First, we rewrite (6) as:

$$\left[1+\frac{\Gamma_{it}}{1+\Gamma_{it}}\frac{S_{it}}{1-S_{it}}\right]\mathrm{d}p_{it} = \frac{1}{1+\Gamma_{it}}\mathrm{d}mc_{it} + \frac{\Gamma_{it}}{1+\Gamma_{it}}\frac{\mathrm{d}p_t}{1-S_{it}} + \varepsilon_{it}, \tag{A11}$$

we use the decomposition $\mathrm{d}p_t = \sum_{j=1}^N S_{jt}\mathrm{d}p_{jt} = (1-S_{it})\mathrm{d}p_{-it} + S_{it}\mathrm{d}p_{it}$. Aggregating (A11) across $i = 1..N$ and solving for $\mathrm{d}p_t$, we have:

$$\mathrm{d}p_t = \frac{1}{\sum_{i=1}^N \frac{S_{it}}{1+\tilde{\Gamma}_{it}}} \sum\nolimits_{i=1}^N \left[\frac{S_{it}}{1+\tilde{\Gamma}_{it}}\mathrm{d}mc_{it} + \frac{S_{it}}{1+\frac{S_{it}\tilde{\Gamma}_{it}}{1+\Gamma_{it}}}\varepsilon_{it}\right], \tag{A12}$$

where $\tilde{\Gamma}_{it} \equiv \Gamma_{it}/(1-S_{it})$ and we have used the fact that $\sum_{i=1}^N \frac{S_{it}\tilde{\Gamma}_{it}}{1+\tilde{\Gamma}_{it}} = 1 - \sum_{i=1}^N \frac{S_{it}}{1+\tilde{\Gamma}_{it}}$.

Substituting the solution for $\mathrm{d}p_t$ back into (A11), we obtain the reduced form of the model:

$$\mathrm{d}p_{it} = \frac{1}{1+\tilde{\Gamma}_{it}}\mathrm{d}mc_{it} + \frac{\tilde{\Gamma}_{it}}{1+\tilde{\Gamma}_{it}}\frac{1}{\sum_{j=1}^N \frac{S_{jt}}{1+\tilde{\Gamma}_{jt}}} \sum\nolimits_{j=1}^N \left[\frac{S_{jt}}{1+\tilde{\Gamma}_{jt}}\mathrm{d}mc_{jt} + \frac{S_{jt}}{1+\frac{S_{jt}\tilde{\Gamma}_{jt}}{1+\Gamma_{jt}}}\varepsilon_{jt}\right] + \frac{\varepsilon_{it}}{1+\frac{S_{it}\tilde{\Gamma}_{it}}{1+\Gamma_{it}}},$$

which we can simplify to (20), $\mathrm{d}p_{it} = a_{it}\mathrm{d}mc_{it} + b_{it}\mathrm{d}mc_{-it} + \tilde{\varepsilon}_{it}$, with coefficients given by:

$$a_{it} \equiv \frac{1}{1+\tilde{\Gamma}_{it}} \frac{S_{it} + \sum_{j\neq i}\frac{S_{jt}}{1+\tilde{\Gamma}_{jt}}}{\sum_{j=1}^N \frac{S_{jt}}{1+\tilde{\Gamma}_{jt}}} \qquad \text{and} \qquad b_{it} \equiv \frac{\tilde{\Gamma}_{it}}{1+\tilde{\Gamma}_{it}} \frac{\sum_{j\neq i}\frac{S_{jt}}{1+\tilde{\Gamma}_{jt}}}{\sum_{j=1}^N \frac{S_{jt}}{1+\tilde{\Gamma}_{jt}}},$$

and the competitor marginal cost index defined as:

$$\mathrm{d}mc_{-it} \equiv \sum\nolimits_{j\neq i} \omega^c_{ijt}\mathrm{d}mc_{jt}, \qquad \text{where} \qquad \omega^c_{ijt} \equiv \frac{\frac{S_{jt}}{1+\tilde{\Gamma}_{jt}}}{\sum_{k\neq i}\frac{S_{kt}}{1+\tilde{\Gamma}_{kt}}}.$$

This illustrates the complexity of interpreting the coefficients a_{it} and b_{it} of the reduced form of the model, as well as calculating an appropriate competitor marginal cost index, even in the special case when Proposition 2 applies.

Aggregation and ERPT. Proof of Proposition 3 Assume the conditions of Proposition 2 are satisfied, so that $\Gamma_{-it} = \Gamma_{it}$ and $\mathrm{d}p_t = \sum_{i=1}^N S_{it}\mathrm{d}p_{it}$. Start with the firm-level ERPT expression (25), which we reproduce here as:

$$\psi_{it} = \frac{1}{1+\Gamma_{it}}\varphi_{it} + \frac{\Gamma_{it}}{1+\Gamma_{it}}\Psi_{-it}.$$

Provided the definition of Ψ_{-it} and Ψ_{it} in the text, we can rewrite:

$$\psi_{it} = \frac{1}{1+\Gamma_{it}/(1-S_{it})}\varphi_{it} + \frac{\Gamma_{it}/(1-S_{it})}{1+\Gamma_{it}/(1-S_{it})}\Psi_t,$$

which corresponds to equation (28) in the text with $\kappa_{it} \equiv \frac{\Gamma_{it}}{1-S_{it}+\Gamma_{it}}$. Aggregating (weighting by S_{it}), we solve for Ψ_t:

$$\Psi_t = \frac{1}{\sum_{j=1}^N \frac{S_{jt}}{1+\Gamma_{jt}/(1-S_{jt})}} \sum_{i=1}^N \frac{S_{it}}{1+\Gamma_{it}/(1-S_{it})}\varphi_{it},$$

which is equivalent to expression (29), after noticing that $\sum_{j=1}^{N} \frac{S_{jt}}{1+\Gamma_{jt}/(1-S_{jt})} = 1 - \sum_{j=1}^{N} S_{jt}\kappa_{jt}$, confirming the claim in Proposition 3. ■

Three-type example (Section 4.2) Consider a more general three-type economy, as summarized in the table below:

Type of firm	Cum. share	Import intensity	Markup elasticity
Small Home	λ_S	$\varphi_S \geq 0$	$\Gamma_S \geq 0$
Large Home	λ_L	$\varphi_L = \varphi\ > 0$	$\Gamma_L = \Gamma\ > 0$
Large Foreign	λ_F	$\varphi_F = \varphi^* > \varphi$	$\Gamma_F = \Gamma^* \geq \Gamma$

Within each type, there are many symmetric firms, so that $S_{it} \to 0$ for any individual firm, and hence $\kappa_{it} \to \frac{\Gamma_{it}}{1+\Gamma_{it}}$. Therefore, applying (29) to this special case, we have:

$$\Psi = \frac{\frac{\lambda_S}{1+\Gamma_S}\varphi_S + \frac{\lambda_L}{1+\Gamma}\varphi + \frac{\lambda_F}{1+\Gamma^*}\varphi^*}{\frac{\lambda_S}{1+\Gamma_S} + \frac{\lambda_L}{1+\Gamma} + \frac{\lambda_F}{1+\Gamma^*}},$$

and $\bar{\varphi} = \lambda_S\varphi_S + \lambda_L\varphi + \lambda_F\varphi^*$. The expressions (31) in the text is the special case of this formula when $\varphi_S = \Gamma_S = 0$ and $\Gamma = \Gamma^*$. More generally, it is sufficient to have $\varphi_S < \varphi < \varphi^*$ and $\Gamma_S < \Gamma \leq \Gamma^*$ for $\Psi < \bar{\varphi}$. Indeed, in this case the conditions of Corollary 2 are satisfied.

D General Non-CES Oligopolistic Model

Monopolistic competition under CES demand yields constant markups. In this appendix we relax both assumptions, allowing for general non-CES homothetic demand and oligopolistic competition. This model nests both Kimball (1995) and Atkeson and Burstein (2008).

Consider the following aggregator for the sectoral consumption C:

$$\frac{1}{N}\sum\nolimits_{i\in\Omega} A_i \Upsilon\left(\frac{NC_i}{\xi_i C}\right) = 1, \tag{A13}$$

where Ω is the set of products i in the sector with $N = |\Omega|$ denoting the number of goods, and C_i is the consumption of product i; A_i and ξ_i denote the two shifters (a quality parameter and a demand parameter, respectively); $\Upsilon(\cdot)$ is the demand function such that $\Upsilon(\cdot) > 0, \Upsilon'(\cdot) > 0, \Upsilon''(\cdot) < 0$, and $\Upsilon(1) = 1$. The two important limiting cases are $N \to \infty$ (corresponding to Kimball monopolistic competition) and $\Upsilon(z) = z^{(\sigma-1)/\sigma}$ (corresponding to the CES aggregator).

Consumers allocate expenditure E to the purchase of products in the sector, and we assume that $E = kP^{1-\eta}$, where P is the sectoral price index and η is the elasticity of substitution across sectors (and k is a sectoral demand shifter exogenous to the within-sector equilibrium outcomes). Formally, we write the sectoral expenditure (budget) constraint as:

$$\sum\nolimits_{i\in\Omega} P_i C_i = E. \tag{A14}$$

Given prices $\{P_i\}_{i\in\Omega}$ of all products in the sector and expenditure E, consumers allocate consumption $\{C_i\}$ optimally across products within sectors to maximize the consumption index C:

$$\max_{\{C_i\}_{i\in\Omega}} \Big\{ C \Big| \text{ s.t. } (\text{A13}) \text{ and } (\text{A14}) \Big\}. \tag{A15}$$

The first-order optimality condition for this problem defines consumer demand, and is given by:

$$C_i = \frac{\xi_i C}{N} \cdot \psi\left(x_i\right), \qquad \text{where} \quad x_i \equiv \frac{P_i/\gamma_i}{P/D}, \tag{A16}$$

where $\gamma_i \equiv A_i/\xi_i$ is the quality parameter and $\psi(\cdot) \equiv \Upsilon'^{-1}(\cdot)$ is the demand curve, while $\xi_i C/N$ is the normalized demand shifter.[52] C is sectoral consumption; P is the ideal price index such that $C = E/P$ (hence, P is also the expenditure function) and D is an additional auxiliary variable determined in industry equilibrium, which is needed to characterize demand outside the CES case.[53]

Manipulating the optimality conditions and the constraints in (A15), we show that P and D must

[52] Note that an increase in γ_i directly reduces the effective price for the good in the eyes of the consumers, which corresponds to a shift along the demand curve. At the same time, an increase in ξ_i (holding γ_i constant), shifts out the demand curve holding the effective price unchanged. This is why we refer to ξ_i as the demand shifter, and γ_i as the quality parameter.

[53] Note that the ideal price index P exists since the demand defined by (A13) is homothetic, i.e. a proportional increase in E holding all $\{P_i\}$ constant results in a proportional expansion in C and in all $\{C_i\}$ holding their ratios constant; $1/P$ equals the Lagrange multiplier for the maximization problem in (A15) on the expenditure constraint (A14).

satisfy:[54]

$$\frac{1}{N}\sum\nolimits_{i\in\Omega} A_i \Upsilon\left(\psi\left(\frac{P_i/\gamma_i}{P/D}\right)\right) = 1, \tag{A17}$$

$$\frac{1}{N}\sum\nolimits_{i\in\Omega} \frac{\xi_i P_i}{P}\psi\left(\frac{P_i/\gamma_i}{P/D}\right) = 1. \tag{A18}$$

Equation (A17) ensures that (A13) is satisfied given the demand (A16), i.e. that C is indeed attained given the consumption allocation $\{C_i\}$. Equation (A18) ensures that the expenditure constraint (A14) is satisfied given the allocation (A16). Note that condition (A18) simply states that the sum of market shares in the sector equals one, with the market share given by:

$$S_i \equiv \frac{P_i C_i}{PC} = \frac{\xi_i P_i}{NP}\psi\left(\frac{P_i/\gamma_i}{P/D}\right), \tag{A19}$$

where we substituted in for C_i from the demand equation (A16).

Next, we introduce the demand elasticity as a characteristic of the slope of the demand curve $\psi(\cdot)$:

$$\sigma_i \equiv \sigma(x_i) = -\frac{\mathrm{d}\log\psi(x_i)}{\mathrm{d}\log x_i}, \tag{A20}$$

where x_i is the effective price of the firm as defined in (A16). Outside the CES case, the demand elasticity is non-constant and is a function of the effective price of the firm. One can totally differentiate (A17)–(A18) to show that:

$$\mathrm{d}\log P = \sum\nolimits_{i\in\Omega} S_i\,\mathrm{d}\log P_i,$$

$$\mathrm{d}\log\frac{P}{D} = \sum\nolimits_{i\in\Omega}\frac{S_i\sigma_i}{\sum_{j\in\Omega}S_j\sigma_j}\mathrm{d}\log P_i.$$

Note that the elasticity of demand in this model depends on $x_i = (P_i/\gamma_i)/(P/D)$, and hence P/D is the sufficient statistic for competitor prices, albeit one that differs from the expenditure function P. Yet, from the expressions above, we have:

$$\mathrm{d}\log\frac{P}{D} - \mathrm{d}\log P = \sum\nolimits_{i\in\Omega}\frac{\sigma_i-\bar{\sigma}}{\bar{\sigma}}S_i\mathrm{d}\log P_i,$$

where $\bar{\sigma} \equiv \sum_{j\in\Omega}S_j\sigma_j$. Therefore, $\log(P/D)$ and $\log P$ differ by a second order term in the cross-dispersion of x_i, and hence Proposition 2 applies as an approximation. We can verify the quality of this

[54]In the limiting case of CES, we have $\Upsilon(z) = z^{\frac{\sigma-1}{\sigma}}$, and hence $\Upsilon'(z) = \frac{\sigma-1}{\sigma}z^{-1/\sigma}$ and $\psi(x) = \left(\frac{\sigma}{\sigma-1}x\right)^{-\sigma}$. Substituting this into (A17)–(A18) and taking their ratio immediately pins down the value of D. We have, $D \equiv (\sigma-1)/\sigma$ and is independent of $\{P_j\}$ and other parameters, and hence this auxiliary variable is indeed redundant in the CES case. Given this D, the price index can be recovered from either condition in its usual form, $P = \left[\frac{1}{N}\sum_{j\in\Omega}\left(A_j^{\sigma}\xi_j^{1-\sigma}\right)P_j^{1-\sigma}\right]^{1/(1-\sigma)}$. The case of CES is a knife-edge case in which the demand system can be described with only the price index P, which summarizes all information contained in micro-level prices needed to describe aggregate allocation. More generally, the second auxiliary variable D is needed to characterize the aggregate effects of micro-level heterogeneity. In fact, (P, D) form a sufficient statistic to describe the relevant moments of the price distribution.

approximation using the calibrated Kimball demand model below.

We can now calculate the full effective elasticity of demand, which takes into account the effects of P_i on P and D. Substituting $C = E/P = kP^{-\eta}$ into (A16), we show:

$$\Sigma_i \equiv -\frac{\mathrm{d}\log C_i}{\mathrm{d}\log P_i} = \eta S_i + \sigma_i \left(1 - \frac{S_i\sigma_i}{\sum_{j\in\Omega} S_j\sigma_j}\right), \tag{A21}$$

which generalizes expression (A10) in the CES case, and also nests the expression for the monopolistic competition case where $S_i \equiv 0$. In the general case, the optimal profit-maximizing markup is given by $\Sigma_i/(\Sigma_i - 1)$, and it can be analyzed in the same way we approached it in Section 2.

The key insight is that the market share channel in (A21) operates exactly in the same way as in the CES model of Section 2.1. In the CES model (with $\sigma_i \equiv \rho$ for all i), however, this is the only channel of markup variability: as the firm gains market share, it increases its markup (as long as $\rho > \eta$), and markups become flatter as all firms become smaller in absolute terms, with the limiting case of monopolistic competition and constant markups. More generally, with non-CES demand, the markup elasticity also depends on the properties of the $\sigma(\cdot)$ function in (A20), and markups are non-constant even in the limiting case of monopolistic competition with $S_i \equiv 0$, where the variables that affect the curvature of demand (namely, $\sigma'(\cdot)$) determine the variability of the markup. Nonetheless, as long as $\eta < \sigma_i$, an increase in market share S_i leads to a reduction in the effective elasticity of demand Σ_i, emphasizing the general role the market share plays across oligopolistic models. Furthermore, in the limit of monopolistic competition, non-CES demand can exhibits similar qualitative properties of markup variation as the oligopolistic model under CES demand (see e.g. Gopinath and Itskhoki 2010).

Calibration of the CES model We solve for an industry equilibrium in the domestic market, in which both domestic and foreign firms (exporters) compete together, and the costs of the firms follow exogenous processes disciplined by the data. We analyze simultaneous price setting by firms that are subject to idiosyncratic cost shocks and an aggregate exchange rate shock, affecting firms with heterogeneous intensities. We calibrate the model using data on "typical" Belgian manufacturing industries at NACE 4–digit level of aggregation.

We assume nested CES demand, given in levels by:

$$Q_{it} = \xi_{it} P_{it}^{-\rho} P_t^{\rho-\eta} D,$$

where D is an exogenous demand shifter and P_t is the sectoral price index, as defined under equation (13) in Section 2.1. The strategic complementarities in price setting arising due to oligopolistic (quantity) competition under CES demand, following Atkeson and Burstein (2008). This model has a number of desirable properties for our analysis. First, this model, combined with a realistic firm productivity process described below, delivers the empirically accurate fat-tailed distribution of firm market revenues (Zipf's law). Second, firms with larger market shares charge higher markups and adjust them more intensively in response to shocks, exhibiting greater strategic complementarities in price setting, as we discussed in the text. Third, the model reproduces a large mass of very small firms

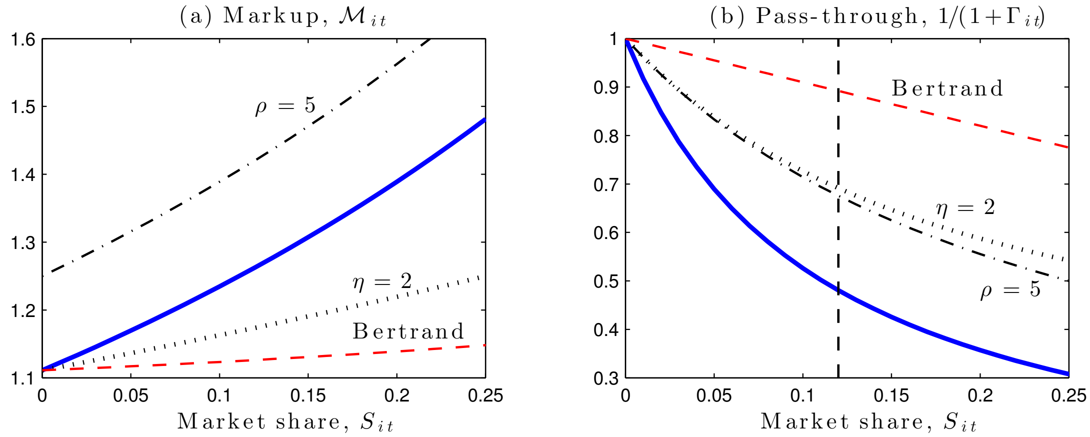

Figure A3: Markups and pass-through in a calibrated model

Note: Solid blue line corresponds to our benchmark case with Cournot competition, $\rho = 10$ and $\eta = 1$. The other lines correspond to respective departures from the baseline case. Left panel plots markups $\mathcal{M}_{it}$ and right panel plots cost pass-through elasticity $1/(1+\Gamma_{it})$, both as functions of the firm's market share S_{it} (see expressions in Section 2.1). In the data, the market share of the largest firm in a typical industry is around 12%, depicted with a vertical dashed line in the right panel.

that charge nearly constant markups and exhibit no strategic complementarities, being effectively monopolistic competitors under constant-elasticity demand. All this is in line with the empirical patterns we document in Section 3.

The empirical success of the Atkeson-Burstein model in matching the firm price behavior relies on the assumptions of Cournot competition and particular values of demand elasticities. We set the elasticity of substitution across 4-digit industries to $\eta = 1$ (corresponding to the Cobb-Douglas aggregator) and within 4-digit industries to $\rho = 10$. This is a conventional calibration in the literature following Atkeson and Burstein (2008), as for example in EMX. In order to reproduce empirical pass-through patterns, the model requires a combination of Cournot competition, a low (effectively Cobb-Douglas) between-industry elasticity and a high within-industry elasticity of demand. Under our baseline parameterization, the largest firm in a typical industry with a market share of 12% has a cost pass-through elasticity of around 0.5, and correspondingly a 0.5 strategic complementarity elasticity, as in this model $\Gamma_{-it} = \Gamma_{it}$. This ensures the model replicates the empirical patterns documented in Section 3, as we illustrated in Table 7 in the text. Any significant departure from this parameterization (towards higher η, lower ρ, or to Bertrand competition) results in a steep drop in the extent of strategic complementarities Γ_{it}, as can be seen in Figure A3 below, and would lead to the model's failure in matching the observed empirical patterns.

The marginal costs of the firms are given by (32), where the price index of domestic inputs W_t and the foreign-currency price index of imported inputs V_t^* are assumed to be common across firms within an industry. We assume $\{W_t, V_t^*, \mathcal{E}_t\}$ follow exogenous processes, reflecting our industry equilibrium focus. In particular, we normalize $W_t \equiv V_t^* \equiv 1$, making $\mathcal{E}_t$ the only source of aggregate shocks, which affects firms with heterogeneous intensity ϕ_i. The nominal exchange rate follows a random walk in logs:

$$e_t = e_{t-1} + \sigma_e u_t, \qquad u_t \sim \text{iid}\, \mathcal{N}(0,1), \tag{A22}$$

where $e_t \equiv \log \mathcal{E}_t$ and $\sigma_e = 0.06$ is the standard deviation of the exchange rate innovation, calibrate to match the volatility of the annual trade-weighted euro exchange rate in the data.

We further assume that firm productivities A_{it} follow a random growth process, with $a_{it} \equiv \log A_{it}$ evolving according to a random walk with drift μ and a lower reflecting barrier at $\underline{a}$:

$$a_{it} = \underline{a} + |\mu + a_{i,t-1} + \sigma_a v_{it} - \underline{a}|, \qquad v_{it} \sim \text{iid}\, \mathcal{N}(0,1) \tag{A23}$$

where σ_a is the standard deviation of the innovation to log productivity. The initial productivities A_{i0} are drawn from a Pareto distribution with the cumulative distribution function $G_0(A) = 1 - \left(e^{\underline{a}}/A\right)^{\theta}$, where θ is the shape parameter and $\underline{a}$ is the lower bound parameter. We set $\mu = -\theta\sigma_a^2/2 < 0$ to ensure that the cross-sectional distribution of productivities stays unchanged over time and given by G_0 (see Gabaix 2009). We normalize $\underline{a} = 0$, and we set $\sigma_a = 0.03$ to match the short-run and long-run persistence of firm market shares (namely, the cross-sectional standard deviation of ΔS_{it} and correlation of S_{it} and $S_{i,t+12}$). Finally, we set the shape parameter of the Pareto productivity distribution $\theta = 8$, which (in combination with the demand elasticity $\rho = 8$) reproduces simultaneously the Zipf's law in firm sales within industries and the size of the largest firm across industries, as well as the overall measures of firm concentration. In particular, we ensure that the 20% of the largest firm account for 60% of the home-market sales, as is the case in the data.

Each industry has domestic and foreign firms, with productivities drawn from the same data generating process. We set the number of domestic firms to 45 and select the number (of top) foreign firms to match the 20% sales share, corresponding to a typical Belgian manufacturing industry. All foreign firms have the same exposure to foreign inputs $\phi_i = \phi^* = 0.7$, reflecting that 30% of their costs come from within the eurozone, and allowing us to match the average exchange rate pass-through into Belgian imports of around 50% (see Table 8). For the domestic firms, we have $\phi_i \in [0, \phi^*]$, positively, yet imperfectly, correlated with firm productivity A_{it}, to match the empirical correlation between ϕ_{it} and S_{it} of 0.3, with the sale-weighted average of import intensity given by $\bar{\phi} = 0.2$.

To calculate the moments in the model, we simulate a large number of industries (10,000) over 13 years, generating a panel of firm marginal costs, prices and market shares, akin to the one we have for the Belgian manufacturing sector. The equilibrium prices are a result of the oligopolistic price setting game in the industry, following (13). For a general equilibrium analysis and a formal estimation of a related model see Gaubert and Itskhoki (2015). We use this simulated dataset to produce the counterfactual results in Tables 7 and 8 in the text.

Calibration of the non-CES (Kimball) model As an alternative quantitative model of variable markups, we consider a monopolistic competition model under non-CES demand. Specifically, we adopt the Klenow and Willis (2006) formulation of the Kimball (1995) demand, given by the following demand schedule (as a special case of (A16) above):

$$C_i = \xi_i \psi\left(\frac{\xi_i P_i}{P/D}\right) C, \qquad \text{where} \qquad \psi(x) = \left[1 - \varepsilon \log\left(\frac{\sigma}{\sigma - 1} x\right)\right]^{\sigma/\varepsilon},$$

where σ and ε control the elasticity and the super-elasticity (elasticity of the elasticity) of the demand schedule respectively:

$$\tilde{\sigma}_i \equiv \tilde{\sigma}(x_i) = -\frac{\partial \log C_i}{\partial \log P_i} = -\frac{\partial \log \psi(x_i)}{\partial \log x_i} = \frac{\sigma}{1 - \varepsilon \log\left(\frac{\sigma}{\sigma-1} x_i\right)},$$

$$\tilde{\varepsilon}_i \equiv \tilde{\varepsilon}(x_i) = \frac{\partial \log \tilde{\sigma}_i}{\partial \log P_i} = \frac{\partial \log \tilde{\sigma}(x_i)}{\partial \log x_i} = \frac{\varepsilon}{1 - \varepsilon \log\left(\frac{\sigma}{\sigma-1} x_i\right)}.$$

Therefore, for $\varepsilon > 0$, this demand features an increasing elasticity of demand with the firm's price, and hence a decreasing markup given by $\frac{\tilde{\sigma}_i}{\tilde{\sigma}_i - 1}$.[55] The elasticity of the markup with respect to both P_i and price index P is given by:

$$\Gamma_i = \Gamma_{-i} = -\frac{\partial \log \frac{\tilde{\sigma}_i}{\tilde{\sigma}_i - 1}}{\partial \log P_i} = \frac{\tilde{\varepsilon}_i}{\tilde{\sigma}_i - 1} = \frac{\varepsilon}{\sigma - 1 + \varepsilon \log\left(\frac{\sigma}{\sigma-1} x_i\right)}$$

is decreasing in the price of the firm (and hence increasing in market share). Lastly, the demand aggregator in (A13) which generates this demand is given by $\Upsilon(z) = 1 + \frac{\sigma-1}{\varepsilon} \varepsilon^{\sigma/\varepsilon} e^{1/\varepsilon} \left[\Gamma\left(\frac{\sigma}{\varepsilon}, \frac{1}{\varepsilon}\right) - \Gamma\left(\frac{\sigma}{\varepsilon}, \frac{z^{\varepsilon/\sigma}}{\varepsilon}\right)\right]$, where $\Gamma(a,b) = \int_b^\infty t^{a-1} e^{-t} \mathrm{d}t$ is the incomplete Gamma-function. With this, P and P/D are determined by solving for the fixed point in (A17)–(A18).

Table A4: Strategic complementarities in the calibrated model

	Atkeson-Burstein				Kimball			
Dep. var.: Δp_{it}	All	Small	Large	Interaction	All	Small	Large	Interaction
Δmc_{it}	0.532	0.899	—	0.900	0.618	0.704	—	0.704
$\Delta mc_{it} \times \text{Large}_{it}$	—	—	0.424	−0.393	—	—	0.576	−0.128
Δp_{-it}	0.417	0.060	—	0.066	0.289	0.237	—	0.238
$\Delta p_{-it} \times \text{Large}_{it}$	—	—	0.529	0.335	—	—	0.339	0.101

We assume the same cost and productivity structure as in the Atkeson-Burstein simulation, and in addition we choose the demand shifter ξ_i to be correlated with firm productivity in order to match the fat-tailed sales distribution in the data.[56] We target the same set of moments in the calibration. In particular, we set $\sigma = 5$ and $\varepsilon = 1.6$ to match the variability of markups and the resulting own cost pass-through and strategic complementarity elasticites. We report this results in Table A4, which

[55]The limiting case with $\varepsilon \to 0$ corresponds to the CES demand with a constant elasticity σ.

[56]Our empirical analysis emphasizes three key features of the data: (i) no strategic complementarities and complete pass-through exhibited by the bulk of small firms; (ii) strong strategic complementarities and incomplete pass-through exhibited by the largest firms; (iii) extremely fat-tailed distribution of firm sales (market shares), referred to as the Zipf's law. We show that the oligopolistic CES model is successful in capturing all of these facts, which at the same time proves to be challenging for the monopolistic competition models with non-CES demand. First, capturing fact (i) requires that demand is asymptotically constant elasticity (CES) as the price of the firm increases and the firm becomes small. Otherwise, the model would produce counterfactual incomplete pass-through for the small firms. Second, jointly capturing facts (ii) and (iii) is another challenge. While non-CES demand can easily produce significant markup variability, resulting in incomplete pass-through and strategic complementarities, this is achieved by means of a declining curvature in demand, resulting in increasing optimal markups and prices, limiting optimal sales of the firm and hence curbing the fatness of the tail of the sales distribution. Avoiding this requires the use of demand shifters ξ_i correlated with the firm productivity.

also reproduces the Atkeson-Burstein calibration results from Table 7 for comparison. As discussed in footnote 56, the Kimball model can reproduce the average pass-through and strategic complementarity elasticities, but has a hard time simultaneously capturing the extent of heterogeneity across firms in these elasticities and the fatness of the right tail of the sales distribution. Therefore, our calibration of the Kimball model ends up understating the amount of heterogeneity in the strategic complementarities across firms. Nonetheless, it captures the qualitative patterns of our estimates in Section 3.

Table A5: Exchange rate pass-through in a quantitative model

	Atkeson-Burstein					Kimball				
	All	Home	Large	Small	Foreign	All	Home	Large	Small	Foreign
$\bar{\varphi}_J$	0.300	0.200	0.245	0.121	0.700	0.300	0.200	0.245	0.122	0.700
Ψ_J	0.238	0.185	0.217	0.131	0.475	0.249	0.196	0.224	0.150	0.456
$\Psi_J - \bar{\varphi}_J$	-0.062	-0.015	-0.028	0.010	-0.225	-0.051	-0.004	-0.021	0.028	-0.244

Finally, Table A5 reports the results of the exchange rate depreciation counterfactual, as in Table 8 in the text, comparing the findings in the Kimball and Atkeson-Burstein calibrations. The two quantitative models agree on the patterns of price and markup adjustment in response to an exchange rate depreciation: the average industry markup declines, small home firms increase markups, while foreign and large home firms reduce their markups, and the markups of all home firms decline on average. However, since the Kimball model does not capture the full extent of heterogeneity in markup elasticities across firms, it produces somewhat more muted movements in aggregate and group-specific markups. Overall, these results illustrate the robustness of the predicted patterns of markup adjustment in response to exchange rate shocks across different models of variable markups, as long as the models are disciplined by the same empirical patterns of markup variability documented in Section 3.

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