International Shocks and Domestic Prices:
How Large Are Strategic Complementarities?

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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 firms' price responses to changes in prices of their competitors. We develop a general framework and an empirical identification strategy to estimate the elasticities of a firm's price response both to its own cost shocks and to the price changes of its competitors. Our approach takes advantage of a new micro-level data set for the Belgian manufacturing sector, which contains detailed information on firm domestic prices, marginal costs, and competitor prices. The rare features of these data enable us to construct instrumental variables to address the simultaneity of price setting by competing firms. We find strong evidence of strategic complementarities, with a typical firm adjusting its price with an elasticity of 35 percent in response to the price changes of its competitors and with an elasticity of 65 percent in response to its own cost shocks. Furthermore, we find substantial heterogeneity in these elasticities across firms, with small firms showing no strategic complementarities and a complete cost pass-through, and large firms responding to their cost shocks and competitor price changes with roughly equal elasticities of around 50 percent. We show, using a tightly calibrated quantitative model, that these findings have important implications for shaping the response of domestic prices to international shocks.

Key words: strategic complementarities, pass-through, exchange rates, prices, mark-up

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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 all 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 accounting 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 *idiosyncratic cost pass-through*) and a response to the price changes of its competitors (the *strategic complementarity* elasticity). An important feature of our accounting framework is that it does not require us to commit to a specific model of demand, market structure and markups to obtain our estimates.

Within our accounting framework, we develop an identification strategy to deal with two major empirical challenges. The first is the endogeneity of the competitor prices, which are determined simultaneously with the price of the firm in the equilibrium of the price-setting game. The second is the measurement error in the marginal cost of the firm. We exploit the rare features of our dataset to construct instrumental variables. In particular, our data contain information not only on the domestic-market prices set by the firm and all of its competitors (both domestic producers and importers), but also measures of the domestic firm marginal costs, which are usually absent from most datasets. We proxy for the exogenous cost shocks to the firms with changes in the unit values of the imported intermediate inputs at a very high level of disaggregation (over 10,000 products by source country). This allows us to instrument for both the prices of the competitors (with their respective cost shocks) and for the usual noisy proxy for the overall marginal cost of the firm measured as the ratio of total variable costs to output. Our results are robust to replacing the firm input price instruments with the firm import-weighted exchange rates, addressing potential endogeneity concerns.

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 0.35.[2] In other words, when the firm's competitors raise their prices by 10%, the firm increases its own price by 3.5% 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

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[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).

[2] In our baseline estimation, the set of a firm's competitors consists of all firms within its 4-digit manufacturing industry, and our estimate averages the elasticity both across firms within industry and across all Belgian manufacturing industries.

cost, holding constant the prices of its competitors, is on average about 0.7, corresponding to a 70% 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, a number of less conventional models that relax either of those assumptions (i.e., CES demand and/or monopolistic competition, as we discuss in detail below) are consistent with our findings, predicting both a positive response to competitors' prices and incomplete pass-through. In our estimation, we cannot reject that the two elasticities sum to one, providing important information to discriminate among models of variable markups.

We further show that the average estimates for all manufacturing firms conceal a great deal of 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 prices. The behavior of these small firms is approximated well by a monopolistic competition model under CES demand, which implies constant markup pricing. In contrast, large firms exhibit strong strategic complementarities and incomplete pass-through of own marginal cost shocks. Specifically, we estimate their idiosyncratic cost pass-through elasticity to be about 55%, and the elasticity of their prices with respect to the prices of their competitors to be about 45%. These large firms, though small in number, account for the majority of sales, and therefore shape the average elasticities in the data.[3]

In order to explore the implications of our empirical estimates of strategic complementarities for the transmission of international shocks into domestic prices, we turn to a calibrated equilibrium model of variable markups. The advantage of this approach is that it enables us to explore aggregate exchange rate pass-through in counterfactual industries that are not typical in Belgian manufacturing, but are more characteristic in other countries. In addition, the calibrated model allows us to study the determinants of industry-level pass-through and its decomposition into the marginal cost and markup channels by types of firms.[4] For our analysis, we adopt the oligopolistic competition model under CES demand, following Atkeson and Burstein (2008). We show that this model, disciplined with the richness of the Belgian micro-data on the joint distribution of firm market shares and import intensities, is successful in capturing the empirical cost pass-through and strategic complementarity patterns in the cross-section of firms. We show that reproducing the observed cross-sectional heterogeneity is central for understanding the patterns of the aggregate exchange rate pass-through into domestic prices.

In the calibrated model, we match the average exchange-rate pass-through (ERPT) into domestic manufacturing prices across typical Belgium industries, equal to 32%, and study the determinants of the variation in ERPT across industries. At the industry level, the two main predictors of pass-through are the average import intensity of domestic firms (operating through the marginal cost channel) and the market share of foreign firms (operating through the markup channel of the domestic firms). We further

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[3]Our baseline definition of a large firm is a firm in the top quintile (largest 20%) of the sales distribution within its 4-digit industry. The cutoff large firm (at the 80th percentile of the sales distribution) has, on average, a 2% market share within its industry. The large firms, according to this definition, account for about 65% of total manufacturing sales.

[4]In principle, this could be done directly in the data without relying on a structural model, however prices in the data are shaped by a variety of simultaneous shocks, making such an analysis infeasible with a sufficient level of precision, while the calibrated model offers a suitable laboratory for this exercise.

show that the within-industry heterogeneity also plays an important role. In particular, "granular" industries with very pronounced large firms exhibit greater pass-through due to their stronger strategic complementarities. In addition, the industries with a strong positive relationship between firm size and import intensity exhibit lower pass-through. Indeed, this pattern of cross sectional heterogeneity limits the average markup adjustment to an exchange rate shock, as the large variable-markup firms benefit little from a devaluation when they rely heavily on imported intermediate inputs.

In our counterfactual exercises, we analyze how much of the aggregate ERPT into domestic prices is driven by the markup adjustment. For the set of industries that are typical in the Belgium economy, the markup adjustment plays a very limited role, with most of the price adjustment through the marginal cost channel due to the high import intensity of Belgian firms. Neither small nor large firms show substantial markup adjustment. While we expect this for small firms, the finding for the large firms is intriguing in light of their substantial strategic complementarities. Indeed, these firms are sensitive to price adjustment by their foreign competitors, but they are also exposed to the exchange rate devaluation through the increased prices of their imported inputs. As a result, they do not gain much of a competitive edge in the domestic market, and thus have little scope to adjust their markups. We next turn to counterfactual industries, which are less typical in Belgian manufacturing, but are more characteristic in other countries. We find that the markup adjustment contributes the most to aggregate ERPT in industries where domestic firms source their inputs locally, which allows them to gain a significant competitive edge over the foreign firms following an exchange rate devaluation. The role for markups is enhanced in industries that additionally face intense foreign competition. In this case, large domestic firms raise their markups in response to the increased prices of their foreign competitors.

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.[5] In contrast, for our estimation we adopt a general accounting 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

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[5]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; orth, 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.

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 marginal cost channel and strategic complementarities. The lack of data on domestic product prices at the firm-level matched with international data shifted the focus of analysis from the response of domestic prices broadly to the response of prices of exporters and importers. For example, Gopinath and Itskhoki (2011) provide indirect evidence using import price data that is consistent with the presence of strategic complementarities in pricing, yet as the authors acknowledge, this evidence could also be consistent with the correlated cost shocks across the firms.[6] Amiti, Itskhoki, and Konings (2014) demonstrate the importance of imported inputs for explaining incomplete ERPT into Belgian export prices. The unavailability of comprehensive measures of competitor prices and market shares prevented these studies from providing direct estimates of strategic complementarities. The new Belgian data helps overcome these limitations and enables us to perform counterfactual analysis.

Although the main international shock we consider is an exchange rate shock, our analysis applies more broadly to other international shocks such as trade reforms and commodity price shocks. Studies that analyze the effects of tariff liberalizations on domestic prices mostly focus 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 firms' marginal costs that is most directly affected by the international shocks.[7]

The rest of the paper is organized as follows. In section 2, we set out the accounting framework to guide our empirical analysis. Section 3 describes the data and presents the empirical results. Section 4 sets up and calibrates an industry equilibrium model and performs counterfactuals. Section 5 concludes.

2 Theoretical Framework

In order to estimate the strength of strategic complementarities in price setting and understand the channels through which international shocks feed into domestic prices, we proceed in two steps. First, we derive our estimating equation within a general accounting framework, building on Gopinath, Itskhoki, and Rigobon (2010) and Burstein and Gopinath (2012). We show that our estimating equation nests a broad class of models, including oligopolistic competition models under very general demand

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[6] 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 markup variation to smooth the effects of exchange rate shocks across markets. Berman, Martin, and Mayer (2012) were first to demonstrate that large firms exhibit lower pass-through, which is consistent with greater strategic complementarities, relative to small firms.

[7] The second part of our analysis, in which we calibrate a model of variable markups to the Belgian micro-level data, is most directly related to the exercise in EMX. Our analysis differs from EMX in that we bring in the import intensities and foreign share distributions, in addition to the markup moments, which we show are critical in determining the importance of strategic complementarities in shaping the aggregate exchange rate pass-through.

and cost structures. Using this framework, we estimate the strength of strategic complementarities in Section 3, and later we use these estimates in our quantitative analysis of the international transmission of shocks in Section 4. For this exercise we commit to a particular model of variable markups, described in Section 2.2, which serves as an example for our more general accounting framework. We close with a discussion of our identification strategy in Section 2.3.

2.1 General accounting 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}:

$$p_{it} \equiv mc_{it} + \mu_{it}, \tag{1}$$

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 (1) 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 (1) 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 reconsider in Section 3. We denote with $\boldsymbol{p}_t \equiv (p_{1t}, .., p_{Nt})$ the vector of prices of all firms in the industry, and with $\boldsymbol{p}_{-it} \equiv (p_{1t}, .., p_{i-1,t}, p_{i+1,t}, .., p_{Nt})$ the vector of prices of all 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 demand given a constant price vector of the firms.

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

$$\mu_{it} = \log \frac{\sigma_{it}}{\sigma_{it} - 1}, \tag{2}$$

which expresses the markup as a function of the curvature of demand, namely the demand elasticity σ_{it}. In fact, the characterization (2) of the optimal markup generalizes beyond the case of monopolistic competition, and also applies in models with oligopolistic competition, whether in prices (Bertrand)

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[8]An alternative approach in the Industrial Organization literature imposes a lot of structure on the demand and competition environment in a given sector in order to back out structurally the implied optimal markup of the firm, and then uses identity (1) to calculate the marginal cost of the firm as a residual (see references in the Introduction).

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 (2). 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:*

$$\tilde{p}_{it} = mc_{it} + \mathcal{M}_i(\tilde{p}_{it}, \boldsymbol{p}_{-it}; \boldsymbol{\xi}_t), \tag{3}$$

given the price vector of the competitors $\boldsymbol{p}_{-it}$.

We provide a formal proof of this intuitive result in Appendix C, and here offer a brief commentary and a discussion of the assumptions. The markup function $\mathcal{M}_i(\boldsymbol{p}_t; \boldsymbol{\xi}_t)$ and the fixed point in (3) formalize the intuition behind the optimal markup expression (2). Note that Proposition 1 does *not* require that competitor prices are equilibrium outcomes, as equation (3) holds for any possible vector $\boldsymbol{p}_{-it}$. Therefore, equation (3) 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 (3) 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 e.g. Atkeson and Burstein 2008), linear (as in e.g. Melitz and Ottaviano 2008), Kimball (as in e.g. Gopinath and Itskhoki 2010), translog (as in e.g. Feenstra and Weinstein 2010), discrete-choice logit (as in e.g. Goldberg 1995), and many others. Our analysis also applies under the general non-homothetic demand

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[9]The perceived elasticity is defined as $\sigma_{it} \equiv -\frac{dq_{it}}{dp_{it}} = -\left[\frac{\partial q_i(\boldsymbol{p}_t; \boldsymbol{\xi}_t)}{\partial p_{it}} + \sum_{j \neq i} \frac{\partial q_i(\boldsymbol{p}_t; \boldsymbol{\xi}_t)}{\partial p_{jt}} \frac{dp_{jt}}{dp_{it}}\right]$, where dp_{jt}/dp_{it} is the conjectured response of the competitors. Under monopolistic competition, $dp_{jt}/dp_{it} \equiv 0$, 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 $dq_{jt}/dq_{it} \equiv 0$ for all $j \neq i$, which results in a system of equations determining $\{dp_{jt}/dp_{it}\}_{j \neq i}$ 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, (3) 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 (3). 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 (3) is the mapping of the best response schedule from quantity space into price space.

system considered by Arkolakis, Costinot, Donaldson, and Rodríguez-Clare (2015; henceforth ACDR), which in turn nests, as they show, a large number of commonly used models of demand.

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, 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.

Our next step in deriving the estimating equation is to totally differentiate the best response condition (3) around some admissible point $(\boldsymbol{p}_t; \boldsymbol{\xi}_t) = (\tilde{p}_{it}, \boldsymbol{p}_{-it}; \boldsymbol{\xi}_t)$, i.e. any point that itself satisfies equation (3). We obtain the following decomposition for the firm's log price differential:

$$\mathrm{d}p_{it} = \mathrm{d}mc_{it} + \frac{\partial \mathcal{M}_i(\boldsymbol{p}_t; \boldsymbol{\xi}_t)}{\partial p_{it}}\mathrm{d}p_{it} + \sum_{j\neq i}\frac{\partial \mathcal{M}_i(\boldsymbol{p}_t; \boldsymbol{\xi}_t)}{\partial p_{jt}}\mathrm{d}p_{jt} + \sum_{j=1}^{N}\frac{\partial \mathcal{M}_i(\boldsymbol{p}_t; \boldsymbol{\xi}_t)}{\partial \xi_{jt}}\mathrm{d}\xi_{jt}, \qquad (4)$$

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 (4) 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 (4) 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 (3), 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

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[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 3.1.

[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 (4) for all firms $i = 1..N$, we can solve for the *equilibrium* perturbation (reduced form) of all prices $\mathrm{d}\boldsymbol{p}_t$ as a function of the exogenous cost and demand shocks $\mathrm{d}(\boldsymbol{mc}_t, \boldsymbol{\xi}_t)$, which we discuss in Section 2.3.

for the optimal price of the firm (according to Proposition 1).

By combining the terms in competitor price changes and solving for the fixed point in (4) for $\mathrm{d}p_{it}$, we rewrite the resulting equation as:

$$\mathrm{d}p_{it} = \frac{1}{1+\Gamma_{it}}\mathrm{d}mc_{it} + \frac{\Gamma_{-it}}{1+\Gamma_{it}}\mathrm{d}p_{-it} + \varepsilon_{it}, \tag{5}$$

where we introduce the following new notation:

$$\Gamma_{it} \equiv -\frac{\partial\mathcal{M}_i(\boldsymbol{p}_t;\boldsymbol{\xi}_t)}{\partial p_{it}} \qquad \text{and} \qquad \Gamma_{-it} \equiv \sum_{j\neq i}\frac{\partial\mathcal{M}_i(\boldsymbol{p}_t;\boldsymbol{\xi}_t)}{\partial p_{jt}} \tag{6}$$

for the *own* and (cumulative) *competitor markup elasticities* respectively, and where the (scalar) *index of competitor price changes* is defined as:

$$\mathrm{d}p_{-it} \equiv \sum_{j\neq i}\omega_{ijt}\mathrm{d}p_{jt} \qquad \text{with} \qquad \omega_{ijt} \equiv \frac{\partial\mathcal{M}_i(\boldsymbol{p}_t;\boldsymbol{\xi}_t)/\partial p_{jt}}{\sum_{k\neq i}\partial\mathcal{M}_i(\boldsymbol{p}_t;\boldsymbol{\xi}_t)/\partial p_{kt}}. \tag{7}$$

This implies that, independently of the demand and competition structure, there exists a theoretically well-defined index of competitor price changes, even under the circumstances 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's i markup elasticity with respect to price change of firm j, the greater is the weight of firm j in the competitor price index. Finally, the residual in (5) is firm i's effective demand shock given by $\varepsilon_{it} \equiv \frac{1}{1+\Gamma_{it}}\sum_{j=1}^{N}\frac{\partial\mathcal{M}_i(\boldsymbol{p}_t;\boldsymbol{\xi}_t)}{\partial\xi_{jt}}\mathrm{d}\xi_{jt}$.

The own markup elasticity Γ_{it} is defined in (6) with a negative sign, as many models imply that a firm's markup function is non-increasing in firm's own price, $\frac{\partial\mathcal{M}_i(\boldsymbol{p}_t;\boldsymbol{\xi}_t)}{\partial p_{it}} \leq 0$. 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 it 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 (5) is the theoretical counterpart to our estimating equation, 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:

$$\psi_{it} \equiv \frac{1}{1+\Gamma_{it}} \qquad \text{and} \qquad \gamma_{it} \equiv \frac{\Gamma_{-it}}{1+\Gamma_{it}}. \tag{8}$$

The coefficient ψ_{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 ψ_{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 (5), we need to measure the competitor price index (7) in the data. We now provide conditions, as well as a way to test them empirically, under which the weights in (7) can be easily measured in the data. 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 (7) 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:*

$$\mathrm{d}p_{-it} \equiv \sum_{j \neq i} \frac{S_{jt}}{1 - S_{it}} \mathrm{d}p_{jt}. \tag{9}$$

(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 (6) are equal:*

$$\Gamma_{-it} \equiv \Gamma_{it}. \tag{10}$$

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 (9) 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 (7). 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 (10) follows from the definitions in (6).

The main assumption of Proposition 2 is that the demand function depends only on (p_{it}, z_t) rather than on $(p_{it}, \boldsymbol{p}_{-it})$, or in words 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 symmetry in preferences,[16] it is satisfied for a broad class of demand models considered in ACDR and

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[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, ψ_{it} is a well-defined counterfactual elasticity, characterizing a firm's best response off equilibrium.

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

[16]Namely, the significance of any firm for all other firms is summarized by the firm's market share. Proposition 2 also rules

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 (10) on markup elasticities implies that the two coefficients in the price decomposition (5) sum to one. In other words, using the notation in (8), it can be summarized as the following parameter restriction:

$$\psi_{it} + \gamma_{it} = 1. \tag{11}$$

We do *not* impose condition (10) and the resulting restriction (11) in our estimation, but instead test it empirically. This also tests the validity of the weaker property (9) in Proposition 2, which we adopt for our measurement of the competitor price changes, and then relax it non-parametrically in Section 3.3.

To summarize, we have established that the price change decomposition in (5) holds across a broad class of models. We are interested in estimating the magnitudes of elasticities ψ_{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. We now briefly describe one structural model, which offers a concrete illustration for the more general discussion up to this point.

2.2 A model of variable markups

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. This model implies constant markups, 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 $\Gamma_{it} \equiv \Gamma_{-it} \equiv 0$, and therefore the cost pass-through elasticity is $\psi_{it} \equiv 1$ and the strategic complementarities elasticity is $\gamma_{it} \equiv 0$. Yet, 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 following Dornbusch (1987) and Krugman (1987).[17] In the following Section 3 we provide direct empirical evidence on the magnitudes of ψ_{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 assumption or the monopolistic competition assumption. As in Krugman (1987) and Atkeson and Burstein (2008), we depart from the monopolistic competition market structure and instead assume oligopolistic competition, while maintaining the CES demand structure.[18] Specifically, customers are assumed to have a CES demand aggregator over a continuum of industries, while each industry's output is a CES aggregator over a *finite number* of products, each produced by a separate firm. The elasticity of substitution across industries is $\eta \geq 1$, while the elasticity of substitution across products within an industry

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out cases in which a sufficient statistic exists but is different from the expenditure function, as is the case for the Kimball demand discussed in Appendix D. We show, nonetheless, that Proposition 2 still provides a good approximation in that case.

[17] Fitzgerald and Haller (2014) offer a direct empirical test of pricing-to-market and Burstein and Gopinath (2012) provide a survey of the recent empirical literature on the topic.

[18] The common alternatives in the literature maintain the monopolistic competition assumption and consider non-CES demand: for example, Melitz and Ottaviano (2008) use linear demand (quadratic preferences), Gopinath and Itskhoki (2010) use Kimball (1995) demand, and Feenstra and Weinstein (2010) use translog demand. In Appendix D, we offer a generalization to the case with both oligopolistic competition and non-CES demand following Kimball (1995).

is $\rho \geq \eta$. Under these assumptions, a firm with a price P_{it} faces demand (with capitals denoting levels):

$$Q_{it} = \xi_{it} D_{st} P_{st}^{\rho-\eta} P_{it}^{-\rho}, \tag{12}$$

where ξ_{it} is the product-specific preference shock and D_{st} is the industry-level demand shifter. The industry price index P_{st} corresponds in this case to the expenditure function, and is given by:

$$P_{st} = \left[\sum\nolimits_{i=1}^{N} \xi_{it} P_{it}^{1-\rho} \right]^{1/(1-\rho)}, \tag{13}$$

where N is the number of firms in the industry. The firms are large enough to affect the price index, but not large enough to affect the economy-wide aggregates that shift D_{st}, such as aggregate real income. Further, we can write the firm's market share as:

$$S_{it} \equiv \frac{P_{it} Q_{it}}{\sum_{j=1}^{N} P_{jt} Q_{jt}} = \xi_{it} \left(\frac{P_{it}}{P_{st}} \right)^{1-\rho}, \tag{14}$$

where the second equality follows from the functional form of firm demand in (12) and the definition of the price index in (13). A firm has a large market share when it charges a low relative price P_{it}/P_{st} (since $\rho > 1$) and/or when its product has a strong appeal ξ_{it} in the eyes of the consumers.

As in much of the quantitative literature following Atkeson and Burstein (2008), as for example in EMX, we assume oligopolistic competition in quantities (i.e., Cournot-Nash equilibrium). While the qualitative implications are the same as in the model with price competition (i.e., Bertrand-Nash), quantitatively Cournot competition allows for greater variation in markups across firms, which better matches the data, as we discuss further in Section 4. Under this market structure, the firms set prices according to the following markup rule:[19]

$$P_{it} = \frac{\sigma_{it}}{\sigma_{it} - 1} MC_{it}, \qquad \text{where} \qquad \sigma_{it} = \left[\frac{1}{\eta} S_{it} + \frac{1}{\rho} (1 - S_{it}) \right]^{-1}, \tag{15}$$

where σ_{it} is the perceived elasticity of demand. Under our parameter restriction $\rho > \eta > 1$, the markup is an increasing function of the firm's market share.

The elasticity of the markup with respect to own and competitor prices is:

$$\Gamma_{it} = -\frac{\partial \log \frac{\sigma_{it}}{\sigma_{it}-1}}{\partial \log P_{it}} = \frac{(\rho - \eta)(\rho - 1)\sigma_{it} S_{it}(1 - S_{it})}{\eta \rho (\sigma_{it} - 1)}, \tag{16}$$

and $\Gamma_{-it} = \Gamma_{it}$, which can be established using the definition in (6). Furthermore, using the general definition in (7), we verify in Appendix C that the index of competitor price changes in this model satisfies (9), and hence both results of Proposition 2 apply. One additional insight from this model is that Γ_{it} is a function of the firm's market share S_{it} alone, given the structural demand parameters ρ and η, that is $\Gamma_{it} \equiv \Gamma(S_{it})$. Furthermore, this function is increasing in market share over the relevant range of mar-

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[19]The only difference in setting prices under Bertrand competition is that $\sigma_{it} = \eta S_{it} + \rho(1-S_{it})$, as opposed to the expression given in (15), and all the qualitative results remain unchanged. Derivations for both cases are provided in Appendix C.

ket shares in the data, and equals zero at zero market share, $\Gamma(0) = 0$.[20] Specifically, small firms have $\Gamma_{it} = \Gamma_{-it} = 0$, and hence exhibit complete pass-through of own cost shocks ($\psi_{it} = 1$) and no strategic complementarities ($\gamma_{it} = 0$), behaving as monopolistic competitors under CES. However, firms with positive market shares have $\Gamma_{it} = \Gamma_{-it} > 0$, and hence incomplete pass-through and positive strategic complementarities in price setting, $\psi_{it}, \gamma_{it} \in (0, 1)$. 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.

2.3   Identification

In order to estimate the two elasticities of interest, ψ_{it} and γ_{it} in the theoretical price decomposition (5), we rewrite this equation in changes over time:

$$\Delta p_{it} = \psi_{it}\Delta mc_{it} + \gamma_{it}\Delta p_{-it} + \varepsilon_{it}, \tag{17}$$

where $\Delta p_{it} \equiv p_{i,t+1} - p_{it}$. Therefore, the estimating equation (17) is a first-order Taylor expansion for the firm's price in period $t + 1$ around its equilibrium price in period t. Estimation of equation (17) is associated with a number of identification challenges. First, it requires obtaining direct measures of firm marginal costs and an appropriate index of competitor prices. Second, instrumental variables are needed to deal with the endogeneity of prices and measurement error in marginal costs. Lastly, the heterogeneity in coefficients ψ_{it} and γ_{it} needs to be accommodated. We now address these challenges.

Measurement of marginal cost   Good firm-level measures of marginal costs are notoriously hard to come by. We adopt the following rather general model of the marginal cost:

$$MC_{it} = \frac{W_{it}^{1-\phi_{it}}V_{it}^{\phi_{it}}}{A_{it}}Y_{it}^{\alpha_i}, \tag{18}$$

where W_{it} and V_{it} are the firm-i-specific cost indexes of domestic and imported inputs, ϕ_{it} is the *import intensity* of the firm (i.e., the expenditure share of imported inputs), A_{it} is the idiosyncratic productivity, and y_{it} is the output index. Finally, $\alpha_i \geq 0$ is the degree of decreasing returns to scale, which is allowed to be firm-specific, but assumed to be constant over time.[21] Note that this model does *not* restrict the production structure to be Cobb-Douglas, as the expenditure elasticity ϕ_{it} is not required to be constant. Denoting the logs of variables with corresponding small letters, we rewrite (18) in log changes:

$$\Delta mc_{it} = \phi_{it}\Delta v_{it} + (1 - \phi_{it})\Delta w_{it} + \Delta\phi_{it}(v_{it} - w_{it}) + \alpha_i\Delta y_{it} - a_{it}. \tag{19}$$

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[20]It is immediate to verify that $\Gamma'(S) > 0$ at least for $S \in [0, 0.5]$, while in our data sectoral market shares in excess of 50% are nearly non-existent, with the typical industry leader commanding a market share of 10–12% of the market (see Section 4). When $\eta = 1$, the case adopted for our calibration, $\Gamma(S) = (\rho - 1)S$, and hence $\Gamma'(S) > 0$, for $S \in [0, 1)$. In Appendix D we show that the role of the market share as a determinant of the markup elasticity is general across all oligopolistic models, yet other firm-level variables may also affect it outside the CES case.

[21]This model does not rule out the possibility of fixed costs, which can give rise to increasing returns to scale.

Under this cost structure, the log changes in marginal costs are equal to the log changes in the average variable costs, independently of the value of the returns to scale parameter α_i:

$$\Delta mc_{it} = \Delta avc_{it}, \tag{20}$$

where $avc_{it} \equiv \log\left(TVC_{it}/Y_{it}\right)$ and TVC_{it} denotes the total variable costs of production. Therefore, we use the change in the log average variable costs from the firm accounting data to measure the change in the log marginal cost. Since this is potentially a very noisy measure of the marginal cost, we deal with the induced measurement-error bias by means of an instrumental variable. As the instrument, we use one component of the marginal cost, which we can measure with great precision in our dataset, namely the change in the log costs of the imported intermediate inputs:

$$\Delta mc_{it}^* = \phi_{it}\Delta v_{it}. \tag{21}$$

We provide further details of the measurement and additional specification tests in Section 3.1.

Measurement of competitor prices   An important advantage of our dataset is that we are able to measure price changes for all of the firm's competitors, including all domestic and all foreign competitors, along with their respective market shares in a given industry. However, constructing the relevant index of competitor price changes requires taking a stand on the weights ω_{ijt} in (7). We follow Proposition 2, and use the discretized version of (9):

$$\Delta p_{-it} = \sum_{j \neq i} \frac{S_{jt}}{1 - S_{it}} \Delta p_{jt}. \tag{22}$$

We test empirically the assumptions underlying Proposition 2, namely the parameter restriction (11). In addition, in Section 3.3, we relax (22) non-parametrically by subdividing the competitors into more homogenous subgroups, in particular based on their origin and size, and estimating separate strategic complementarity elasticities for each subgroup.

Endogeneity and instrumental variables   The next identification challenge is the endogeneity of the competitor prices on the right-hand side of the estimating equation (17). Even though the theoretical equation (5) underpinning the estimating equation is the best response schedule rather than an equilibrium relationship, the variation in competitor prices observed in the data is an equilibrium outcome, in which all prices are set simultaneously as a result of some oligopolistic competition game. Therefore, estimating (5) requires finding valid instruments for the competitor price changes, which are orthogonal with the residual source of changes in markups captured by ε_{it} in (17). Our baseline identification strategy uses the precisely-measured imported component of the firm's marginal cost, Δmc_{jt}^* defined in (21), as the instrument. Specifically, we aggregate Δmc_{jt}^* for $j \neq i$ into an index to instrument for Δp_{-it}. As an alternative strategy, instead of using the measures of marginal costs as instruments, we use their projections on the relevant weighted exchange rates. We discuss additional instruments used, as well as robustness under alternative subsets of the instruments, in Section 3.

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Heterogeneity of coefficients   Finally, the estimating equation (17) features heterogeneity in the coefficients of interest ψ_{it} and γ_{it}. In our baseline, we pool the observations to estimate common coefficients ψ and γ for all firms and time periods, which we interpret as average elasticities across 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 structural model of Section 2.2, the elasticities ψ_{it} and γ_{it} are functions of the market share of the firm within industry (and nothing else). While not entirely general, this observation is not exclusive to the CES-oligopoly model, and is also maintained in a variety of non-CES models, as we discuss in Appendix D. Accordingly, we split our firms into small and large bins, and estimate elasticities separately for each subgroup. We discuss some 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 (17). We use equilibrium variation in marginal costs and prices to estimate an off-equilibrium object, namely a counterpart to the firm's theoretical reaction function (5). Instead, one could estimate the *reduced form* of the model:

$$\Delta p_{it} = \alpha_{it}\Delta mc_{it} + \beta_{it}\Delta mc_{-it} + \tilde{\varepsilon}_{it}, \tag{23}$$

which is an equilibrium relation between the firm's price change and all exogenous shocks of the model.[22] Appendix C provides an explicit solution for the reduced-form coefficients α_{it} and β_{it}, as well as for the theoretically-grounded notion of the competitor marginal cost index Δmc_{-it}.

There are a number of reasons why we choose to estimate the reaction function (17) as opposed to the reduced form (23). The first reason is due to data limitations. Equation (23) 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 (and only proxies for a portion of the marginal cost for foreign competitors). While this would constitute an omitted variable bias in (23), it is not a problem for estimating (17), which only requires an instrument for the index of competitor price changes Δp_{-it}, available in the data.[23]

Second, the coefficients of the reaction function ψ_{it} and γ_{it} have a clear structural interpretation, directly shaped by the firm's markup elasticity Γ_{it} (recall (8)), which is a central object in the international pricing-to-market literature, as well as in the monetary macroeconomics literature (as discussed in Gopinath and Itskhoki 2011). In contrast, the reduced-form coefficients compound various industry equilibrium forces, and are thus much less tractable for structural interpretation. In addition, the estimated reaction function elasticities have an appealing sufficient statistic property for describing the firm's response to various shocks, such as an exchange rate shock, a theme we return to in Section 4.

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[22]Equation (23) is an empirical counterpart to the theoretical fixed-point solution for equilibrium price changes of all firms in the industry, which requires that conditions (5) hold simultaneously for all firms.

[23]Furthermore, it is challenging to construct the appropriate marginal cost index Δmc_{-it}, as its weights depend on the firm-specific pass-through elasticities even when the conditions of Proposition 2 are satisfied (see Appendix C).

3 Empirical Analysis

3.1 Data Description

To empirically implement the general accounting framework of Section 2, we need to be able to measure each variable in equation (17). 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).[24] 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.[25]

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-product at the PC-8-digit level. The domestic unit values are calculated as the ratio of production value

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[24]We only kept firms that reported their main activity to be within the manufacturing sector, defined as NACE 2-digit codes 15 to 36.

[25]Jozef Konings had access to these confidential data during his affiliation with the National Bank of Belgium.

sold domestically to production quantity sold domestically:[26]

$$\Delta p_{it} = \Delta \log \frac{\text{Domestic Value}_{it}}{\text{Domestic Quantity}_{it}} \qquad (24)$$

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.

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 (20), and construct the change in the log marginal cost of firm i as follows:

$$\Delta mc_{it} = \Delta \log \frac{\text{Total Variable Cost}_{it}}{Y_{it}}, \qquad (25)$$

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.[27] 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 (21), which we measure as follows:

$$\Delta mc^*_{it} = \phi_{it} \sum_m \omega^c_{imt} \Delta v_{imt}, \qquad (26)$$

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, and when a firm does not import a specific input m at either $t-1$ or t, this input is dropped from the calculation of Δmc^*_{it}. We also drop all abnormally large jumps in import unit values. Additionally, 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. 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 intermediate input and the imported chocolate as a final good, and hence only

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[26]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, and a much lower share of domestic value sold since most of these revenues come from exports).

[27]More precisely, we calculate the change in the log production quantity as the difference between $\Delta \log$ Revenues and $\Delta \log$ Price index of the firm, and subtract the resulting $\Delta \log Y_{it}$ from $\Delta \log$ Total Variable Cost$_{it}$ to obtain Δmc_{it} in (25).

the imported cocoa would enter in the calculation of the marginal cost variable.

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*. To capture these two different sources of competition, we construct the price indexes for each group of competitors within an industry. Specifically, we follow (22), and calculate the index of competitor price changes as:

$$\Delta p_{-it} = \Delta p^D_{-it} + \Delta p^F_{-it}, \tag{27}$$

where

$$\Delta p^D_{-it} = \sum_{j \in D_i} \frac{S_{jt}}{1 - S_{it}} \Delta p_{jt} \qquad \text{and} \qquad \Delta p^F_{-it} = \sum_{j \in F_i} \frac{S_{jt}}{1 - S_{it}} \Delta p_{jt}, \tag{28}$$

D_i and F_i denote respectively the sets of domestic and foreign firm-product competitors of firm i, and S_{jt} is the firm-product market shares in Belgium in industry s defined as the ratio of the firm-product domestic sales to the total market size.[28] Only the imports categorized as final goods enter in the construction of the foreign competitor price index, i.e. any imports that are not included in the construction of the marginal costs.

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 (26). Here, we describe the construction of the three additional instruments we use to address the endogeneity of the competitors' 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 Δp^D_{-it} in (28)) of each domestic competitor's foreign component of marginal cost:

$$\Delta mc^*_{-it} = \sum_{j \in D_i} \frac{S_{jt}}{1 - S_{it} - \sum_{\ell \in F_i} S_{\ell t}} \Delta mc^*_{jt},$$

with the weights normalized to sum to one over the subset of domestic competitors D_i (see footnote 28). 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 coun-

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[28]In the denominator in (28), S_{it} is the cumulative market share of firm i in industry s (identified by the given product of the firm), which constitutes a slight abuse of notation to avoid numerous additional subscripts. Note that $\sum_{j \in F_i} S_{jt}$ is the cumulative market share of all foreign firms in the industry of firm i, and $\sum_{j \in D_i} S_{jt}$ is the cumulative market share of all domestic firms net of firm i in the same industry. Therefore, $\sum_{j \in D_i} S_{jt} + \sum_{j \in F_i} S_{jt} = 1 - S_{it}$, and the sum of the weights in (28) equals one. In practice, we measure S_{jt} as the average of t and $t-1$ market shares of firm-product j.

tries, which we denote with Δe_{it}.[29]

For foreign competitors, direct measures of marginal costs are unavailable in our data, and thus we construct alternative instruments. For the non-euro foreign firms, we proxy for their marginal costs using the industry import-weighted exchange rate:

$$\Delta e_{st} = \sum\nolimits_k \omega^e_{skt} \Delta e_{kt},$$

where k indexes source countries and ω^e_{skt} is the share of competitors from country k in industry s. Finally, for the euro foreign firms, we construct a proxy for their marginal costs using their export prices to European destination other than Belgium. We construct this instrument in two steps. In the first step, we take Belgium's largest euro trading partners (Germany, France, and Netherlands, which account for 80% of Belgium's imports from the euro area) and calculate weighted averages of the change in their log export prices to all euro area countries, except Belgium. Then for each product (at the CN 8-digit level) we have the log change in these export price indexes for each of the three countries. In the second step, we aggregate these up to the 4-digit industry level, using the value of imports of each product into Belgium as import weights. The idea is that movements in these price indexes should positively correlate with movements in Belgium's main euro trading partners' marginal costs without being affected by the demand conditions in Belgium. We denote this instrument with Δp^{EU}_{st}. Summary statistics for all variables are provided in the Appendix Table A1.

3.2 Empirical Results

We now turn to estimating the strength of strategic complementarities in price setting across Belgian manufacturing industries using the general accounting framework developed in Section 2. We do this by regressing the annual change in log firm-product prices on the changes in the firm's log marginal cost and its competitors' price index, as in equation (17). This results in two estimated average elasticities, the own cost pass-through elasticity ψ and the strategic complementarities elasticity γ (see (8)). Under the conditions of Proposition 2, these two elasticities sum to one, resulting in parameter restriction (11), which we test empirically without imposing it in estimation. Section 2.2 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.

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. In the first two columns of panel A, we estimate equation (17) using OLS, with year fixed effects in column 1 and with both year and industry fixed effects in column 2. The coefficients on

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[29]Formally, in parallel with (26), $\Delta e_{it} = \phi_{it} \sum_m \omega^c_{imt} \Delta e_{mt}$, 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. Note that if firm i does not import outside the euro area, $\Delta e_{it} \equiv 0$. 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.

Table 1: Strategic complementarities

Panel A: Baseline estimates

Dep. var.: Δp_{it}	OLS		IV	
	(1)	(2)	(3)	(4)
Δmc_{it}	0.348***	0.348***	0.667***	0.757***
	(0.040)	(0.041)	(0.117)	(0.150)
Δp_{-it}	0.400***	0.321***	0.467***	0.315**
	(0.079)	(0.095)	(0.143)	(0.151)
# obs.	64,815	64,815	64,815	64,815
Industry F.E.	no	yes	no	yes
H_0: $\psi + \gamma = 1$	0.75	0.67	1.13	1.07
[p-value]	[0.00]	[0.00]	[0.17]	[0.52]
Overidentification J-test χ^2 and [p-value]			0.04 [0.98]	0.06 [0.97]
Weak Instrument F-test			129.6	115.2

Panel B: First stage regressions

Dep. var.:	Column (3)		Column (4)	
	Δmc_{it}	Δp_{-it}	Δmc_{it}	Δp_{-it}
Δmc^*_{it}	0.614***	0.173***	0.597***	0.174***
	(0.111)	(0.039)	(0.014)	(0.033)
Δmc^*_{-it}	0.392***	0.468**	0.379***	0.580***
	(0.098)	(0.148)	(0.124)	(0.106)
Δe_{st}	−0.222	0.270**	−0.169	0.343**
	(0.230)	(0.120)	(0.258)	(0.144)
Δp^{EU}_{st}	0.194***	0.304***	0.215***	0.274***
	(0.054)	(0.053)	(0.049)	(0.053)
Industry F.E.	no	no	yes	yes
First stage F-test [p-value]	46.92 [0.00]	22.39 [0.00]	41.24 [0.00]	33.53 [0.00]

Notes: All regressions are weighted by lagged domestic firm sales and include year fixed effects, with robust standard errors clustered at the industry level. In panel B, the first (last) two columns present the first stage regressions corresponding to column 3 (4) in panel A. 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 (11) on the sum of the coefficients) cannot be rejected in both IV specifications, while it is rejected in OLS specifications.

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 (25), 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 (17) 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 (26).[30] 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 panel A, with and without industry fixed effects respectively, and report the corresponding first-stage regressions in panel B of Table 1. In order to be valid, the instruments need to be orthogonal to the residual ε_{it} in (17), which reflects shocks to demand and perceived quality of the product. Our instruments are plausibly uncorrelated with this residual, and we confirm the validity of the instruments with the Hansen overidentification J-tests (reported in Table 1.A), which the data passes with very large p-values. We offer a further discussion of the validity of the instruments in Section 3.3. Our instruments also pass the weak identification tests, with the F-stat over 100, well above the critical value of around 12.

The coefficients in the first-stage results are economically meaningful. In the firm marginal cost Δmc_{it} equations, the largest coefficient of around 0.6 is on the firm's own foreign component of the marginal cost Δmc_{it}^*, while the competitor marginal cost index Δmc_{-it}^* has a coefficient of about 0.4, both highly statistically significant. This reflects the positive correlation between the cost shocks across firms, yet this correlation is moderate in size (equal to 0.27), allowing for sufficient independent variation in the two variables, necessary for identification.[31] The industry weighted exchange rate Δe_{st} has an insignificant effect after controlling for the foreign components of the marginal costs, which likely already contains the sufficient information. For the competitor price Δp_{-it} equations, all of the instruments are positive and significant, as expected, with the largest coefficient of around 0.5 on the domestic competitors' foreign-component of marginal costs Δmc_{-it}^*. These patterns are the same for the regressions with and without the industry effects.

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.A. We see that the coefficient on the firm's marginal cost almost doubles in size compared to the OLS results in columns 1–2. Moreover, the two coefficients now sum to one, supporting the parameter restriction (11).[32] This implies that the data are consistent

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[30]One way to see that Δmc_{it}^* is more precisely measured than Δmc_{it} is with the projection of Δmc_{it} on Δmc_{it}^*, which results in a large and highly significant coefficient of 0.97, while the inverse projection yields a coefficient of close to zero (0.04). This is suggestive that Δmc_{it} is a good proxy for the marginal cost of the firm, yet a very noisy one. The formal first stage, reported in Table 1.B, regresses Δmc_{it} simultaneously on Δmc_{it}^* and all other instruments.

[31]Formally, identification requires that Δmc_{it} is not too closely correlated with Δp_{-it}, which in theory requires sufficiently uncorrelated shocks to marginal costs across firms. In the data, the correlation between Δmc_{it} and Δp_{-it} is only 0.09.

[32]The bottom part of Table 1.A reports the sums of the coefficients along with the p-values for the test of equality to one. In the IV regressions, the sum of the coefficients is slightly above one and well within the confidence bounds for the test of

with the class of models identified in Proposition 2, and our approach to measuring the competitor price index according to (9) is not at odds with the data. Nonetheless, we offer additional robustness tests, which relax the structure imposed on the competitor price index, in Section 3.3.

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 ψ of around 0.65–0.75. At the same time, firms exhibit substantial strategic complementarities, adjusting their prices with an average elasticity γ in the range of 0.30–0.45 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 3–4.5% in the absence of any own cost shocks, thus entirely translating into an increase in the firm's markup. These estimates are very stable, falling within this range across various specifications and subsamples, as we report in Section 3.3. The estimates of γ and ψ offer a direct quantification of the strength of strategic complementarities in price setting across Belgian manufacturing firms. Using (8), we can convert these estimates to recover the average markup elasticity Γ of about 0.6 (recall that we cannot reject $\Gamma_{-it} = \Gamma_{it}$). This estimate is largely in line with the values suggested by Gopinath and Itskhoki (2011) based on the analysis of various indirect pieces of evidence.[33]

Heterogeneity   The results in Table 1.A 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 the firm's size. We begin with 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 (17) 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 0.93, insignificantly different from 1, and a small and insignificant coefficient of 0.08 on the competitor price index. In contrast, large firms have a smaller coefficient on marginal cost and a larger coefficient on the competitor price index, both significant and both around 0.5. 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, as in the first two columns: the two elasticities for the small firms are estimated at 0.95 and 0.14, while these elasticities for the large firms are 0.63 ($= 0.95 - 0.32$) and 0.42 ($= 0.14 + 0.28$). Despite these differences between the large and small firms, the sum of the elasticities for each group still equals one, consistent with Proposition 2 and the structural model of Section 2.2. Consequently,

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equality to unity. When we estimate the constrained version of equation (17) in unreported results, imposing the restriction that the coefficients sum to one, the estimate of the coefficient on the firm's marginal cost is unaffected, equal to 0.7, consistent with the reported unconstrained results.

[33]Gopinath and Itskhoki (2011) further discuss the relationship of these estimates with the calibrations of the strategic complementarities in popular monetary macro models. The markup elasticity Γ plays an important role in the New Keynesian literature, as it directly affects the slope of the New Keynesian Phillips curve. In order to obtain substantial amplification of monetary non-neutrality, the literature has adopted rather extreme calibrations with $\Gamma > 5$, an order of magnitude above our estimates. 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).

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Table 2: Strategic complementarities: Heterogeneity

Large$_i$ defined as:	Employment $\geq$ 100			Market Share		Industry
				Top 20%	Above 2%	$\times$ Year F.E.
Sample:	Small	Large	All	All	All	All
Dep. var.: Δp_{it}	(1)	(2)	(3)	(4)	(5)	(6)
Δmc_{it}	0.929***		0.949***	0.947***	0.883***	0.938***
	(0.152)		(0.201)	(0.226)	(0.192)	(0.129)
$\Delta mc_{it} \times$ Large$_i$		0.599**	−0.315	−0.270	−0.284	−0.297*
		(0.237)	(0.351)	(0.356)	(0.305)	(0.178)
Δp_{-it}	0.078		0.142	0.063	0.016	
	(0.189)		(0.225)	(0.180)	(0.126)	
$\Delta p_{-it} \times$ Large$_i$		0.469**	0.279	0.355	0.509**	
		(0.202)	(0.319)	(0.325)	(0.308)	
# obs.	49,462	15,353	64,815	64,815	64,815	64,815
Overid. J-test	4.99	0.03	6.48	2.68	2.02	—
χ^2 and [p-value]	[0.08]	[0.98]	[0.17]	[0.61]	[0.73]	
Weak IV F-test	89.1	27.7	59.1	54.3	53.8	211.5

Notes: Regressions in columns 1 to 5 include industry fixed effects and year fixed effects, with robust standard errors clustered at the industry level; observations are weighted with lagged domestic firm sales; and the instrument set is as in Table 1. Column 6 includes industry-times-year fixed effects and drops the competitor price variables, with standard errors clustered at the firm level. The specification in column 6 is exactly identified with two endogenous variables and two instruments Δmc_{it}^* and $\Delta mc_{it}^* \times$ Large$_i$. The definition of Large$_i$ is employment-based in columns 1–3 and 6 and market-share-based in columns 4–5, as described in the text. All specifications include variable Large$_i$ in levels. Table A4 reports the first stage.

constraining the coefficients to sum to one in columns 1 to 3 yields the same results (unreported).

In the next two columns we re-estimate the specification in column 3 using alternative definitions of large firms based on a firm's market shares within its respective 4-digit industry. In column 4, we define large firms to be those in the top 20% of their 4-digit industry and in column 5 those with average market shares exceeding 2% within their industry. We find virtually unchanged results. In the last column, we show that the specification in column 3 is also robust to including industry times year fixed effects to replace 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]

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 ($\psi \approx 1$) and almost no strategic complementarities in price setting ($\gamma \approx 0$), consistent with the 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 2.2.

[34]Since the variation in Δp_{-it} is mostly at the industry-year level, including industry times year fixed effects effectively controls for competitor prices and makes it impossible to identify the strategic complementarity elasticity. The own pass-through elasticity, however, is identified from the within-industry-year firm-specific variation in Δmc_{it}.

At the same time, the large firms behave very differently, exhibiting both incomplete pass-through of cost shocks (around 60%) and strong strategic complementarities in price setting (up to 47%).[35] 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.A. In Section 4 we explore the implications of these estimates for the counterfactual effects of international shocks on domestic prices and markups using a calibrated model.

3.3 Robustness

In this section, we address a number of potential concerns regarding the baseline results of Section 3.2 by showing the robustness of our findings to different samples, alternative instrument sets, and various measures of the competitor price index.

Alternative samples   First, 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. In column 1 of Table 3, we reestimate our baseline specification from column 4 of Table 1.A with all variables constructed using two-year differences instead of the annual differences used in the baseline regressions. We see that the coefficients are very similar in both cases, albeit somewhat less precisely estimated with two-year differences as the sample size shrinks. In particular, the sum of the two elasticities is still close to one. This suggests that the sticky price bias does not play a major role in our baseline estimation using annual price changes.

Second, there is the issue of how to define an intermediate input. There is no clear way of determining whether a firm is importing a final good or an intermediate input. In column 2, we use a more narrow definition of what constitutes an intermediate input in the construction of the foreign component of the marginal cost variable, Δmc_{it}^*. We define an imported input to exclude the firm's imports within any 8-digit industry in which it has sales in any year (as in the baseline) and additionally exclude imports in any CN-8-digit industry in which it exports. We see from column 2 that the coefficients are the same as in the baseline definition. Our results are also robust to other ways of defining intermediate

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[35]In Appendix Table A3, we provide evidence that these heterogeneity results are not driven by spurious correlations in the data. In particular, we show that results for large firms are not driven by exporters, where we limit the sample to large firms with less than 10% of revenues coming from exports; nor by intra-firm trade, where we limit the sample to large firms that had sales or purchases from their international affiliates that accounted for less than half a percent of their total sales at any time during the sample. Along similar lines, we show that our results for small firms are not driven by nonimporters. For the subset of small importing firms, for which there is non-trivial variation in our baseline instrumental variable Δmc_{it}^*, we consider both importers from within and from outside the euro area, and in both cases find nearly identical results as for the full subsample of small firms. In all of these cases, we find the results are the same as in Table 2. In addition, Appendix Table A4 reports the first-stage regressions corresponding to columns 1–3 of Table 2, showing consistent patterns for both small and large firms.

Table 3: Robustness: alternative samples

Dep. var.: Δp_{it}	Two-period differences (1)	Alternative input definition (2)	Main product (3)	Alternative industry level	
				5-digit (4)	6-digit (5)
Δmc_{it}	0.642***	0.654***	0.658***	0.750***	0.628***
	(0.245)	(0.193)	(0.173)	(0.139)	(0.154)
Δp_{-it}	0.434*	0.407***	0.374*	0.410***	0.525***
	(0.234)	(0.157)	(0.200)	(0.150)	(0.155)
# obs.	50,600	64,694	27,027	63,511	59,732

Notes: All regressions are counterpart to column 4 of Table 1: in particular, all regressions include the same set of instruments (passing weak instrument and overidentification tests), as well as industry and year fixed effects, with observations weighted by lagged domestic firm sales and robust standard errors clustered at the industry level; in addition, the null that the coefficients sum to one is not rejected in any of the specifications. Column 1 is in 2-period (year) differences. Column 2 uses a stricter definition of intermediate inputs: it excludes any import in a 8-digit industry that the firm produces and any CN 8-digit code that the firm exports. Column 3 only includes observations in the firm's largest 8-digit product category in terms of domestic sales. Columns 4 and 5 define all competition variables relative to 5- and 6-digit industries (around 270 and 320 industries) respectively.

inputs, in particular, to further restricting inputs to exclude any product within the firm's own 4-digit industry.

A third potential concern is that the marginal cost variable is at the firm level whereas our unit of observation is at the firm-product level, resulting in a measurement error. It is generally difficult to assign costs across products within firms (see DLGKP for one approach). To check that this multiproduct issue is not biasing our results (in particular, biasing downwards the coefficient on the own marginal cost Δmc_{it}), we reestimate our baseline equation with a subsample limited to only include each firm's main product, defined as the 8-digit product with the firm's largest domestic sales. We see from column 3 that our results are quantitatively robust to limiting the sample to the firms' main product, suggesting at most a limited role for a potential measurement error bias.

The final two columns of Table 3 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 4 and 5 we redefine the competition variables at the more narrow 5- and 6-digit industries, respectively. We find the results to be qualitatively robust under these alternative definitions, with the extent of strategic complementarities somewhat increasing with the more disaggregated industry definitions.

Alternative sets of instruments Although our instruments jointly pass the overidentification J-test, one may still be concerned with the validity of each of the instruments, which may be challenged on different grounds. We show in Table 4 that our findings are not sensitive to dropping any one instrument used in the baseline estimation (Table 1). Since the potential source of endogeneity for different instruments is not the same, this suggests that either all of the instruments are jointly valid or all of them are invalid and there is some improbable pattern of correlation between the instruments and the

Table 4: Robustness: alternative sets of instruments

Exclude:	p_{st}^{EU}	Δe_{st}		Δmc_{-it}^*	Δmc_{it}^* and Δmc_{-it}^*	
Include:	—	—	Δw_{it}	—	$\Delta e_{it}, \Delta e_{-it}$	$+\Delta w_{it}, \Delta w_{-it}$
Dep. var.: Δp_{it}	(1)	(2)	(3)	(4)	(5)	(6)
Δmc_{it}	0.757***	0.777***	0.670***	0.748***	0.595	0.407**
	(0.175)	(0.195)	(0.157)	(0.136)	(0.461)	(0.196)
Δp_{-it}	0.314	0.291	0.402**	0.330*	0.462	0.648***
	(0.204)	(0.196)	(0.161)	(0.173)	(0.459)	(0.206)
# obs.	64,815	64,815	64,815	64,815	64,736	64,698

Notes: All regressions are counterpart to column 4 of Table 1, as described in the notes to Table 3. 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 baseline set of instruments as in Table 1 and includes Δmc_{it}^*, Δmc_{-it}^*, Δe_{st} and Δp_{st}^{EU}. Each column of the table drops one (or two) of these instruments in turn. Column 1 drops international competitor prices Δp_{st}^{EU}. Column 2 and 3 drop industry import-weighted exchange rate Δe_{st}, while column 3 also adds firm-level log wage rate change Δw_{it}. Column 4 drops Δmc_{-it}^*. Columns 5 and 6 drop both own and competitor marginal cost instruments Δmc_{it}^* and Δmc_{-it}^* and add firm and competitor import-weighted exchange rate changes Δe_{it} and Δe_{-it}; column 6 in addition adds firm and competitor log wage rate changes Δw_{it} and Δw_{-it}.

residuals (for further discussion, in a different context, see Duranton and Turner 2012).

We experiment with different subsets of the baseline instrument set, by first dropping the proxy for the marginal costs of euro zone foreign competitors, Δp_{st}^{EU}. We see from column 1 of Table 4 that there is no material change in the point elasticities (relative to column 4 of Table 1.A), but the standard errors on the competitor price index are a bit higher. In column 2, we instead drop the industry import-weighted exchange rate, Δe_{st}, leaving our instrument set free of any exchange rate variables. This again leads to quantitatively the same estimates. In column 3, simultaneously with dropping the exchange rate, we add the log change in the firm's wage rate Δw_{it} (calculated as the ratio of the wage bill to employment) to the instrument set, which restores the statistical significance of the strategic complementarities elasticity. Our results, therefore, are not dependent on the use of the exchange rate or euro country export prices as instruments.

In columns 4–6, we experiment with dropping marginal cost measures from the instrument set to address the potential concern that the imported components of the marginal cost variables may be endogenous with the demand shocks of the firms, due to either firm quality upgrading or upward sloping firm-level supply curves for inputs. Specifically, column 4 drops the competitor imported marginal cost index Δmc_{-it}^*, while columns 5 and 6 drop in addition the firm's own imported marginal cost measure Δmc_{it}^*. We instead use as instruments the firm import-weighted log exchange rate change Δe_{it} and, by analogy, the competitor index Δe_{-it} (column 5). We add to this set the firm's wage rate change Δw_{it} and the index of competitor wage rate changes Δw_{-it} (column 6). In all three cases, we find similar elasticities to our baseline estimates.[36] Overall, our baseline IV results are robust to alterna-

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[36]When we omit Δmc_{it}^* from the instrument set, and instead rely on firm-level exchange rates, we estimate a somewhat smaller own pass-through elasticity and a larger strategic complementarity elasticity. This may reflect a different local average treatment effect (LATE) associated with the firm-level exchange rate instrument Δe_{it}, for which $\Delta e_{it} \equiv 0$ for all firms that

Table 5: Robustness: alternative measures of competitor prices

Dep. var.: Δp_{it}	Domestic vs Foreign	Largest competitor		Competitors outside firm's 4-d. industry		With Δmc_{-it}
	(1)	(2)	(3)	(4)	(5)	(6)
Δmc_{it}	0.764*** (0.173)	0.689*** (0.201)	0.852* (0.507)	0.845*** (0.158)	0.755*** (0.143)	0.767*** (0.163)
Δp_{-it}			0.676 (1.417)		0.293 (0.353)	0.372 (0.389)
Δp^D_{-it}	0.258 (0.407)					
Δp^F_{-it}	0.387 (0.411)					
Δp^L_{-it}		0.441 (0.293)	−0.529 (2.136)			
Δp_{-st}				−11.29 (8.13)	−1.333 (16.835)	
Δmc^D_{-it}						−0.073 (0.406)
# obs.	64,815	64,815	64,815	64,815	64,815	64,772

Notes: All regressions build on the baseline specification in column 4 of Table 1 (see notes to Table 3). Column 1 splits the competitor price index Δp_{-it} into domestic and foreign components Δp^D_{-it} and Δp^F_{-it}, according to (27)–(28). Columns 2 and 3 include the log price change of the firm's largest competitor in the industry, denoted with Δp^L_{-it}. Columns 4 and 5 include competitor price index outside the firm's own 4-digit industry, denoted Δp_{-st}. Column 6 includes domestic competitor marginal costs Δmc^D_{-it} (the measure of foreign competitor marginal costs is unavailable in our data).

tive instrument subsets, when we dispense with either the exchange rate instruments or the imported marginal cost instruments.

Competitor prices and placebo tests   Our final set of robustness tests addresses potential concern about the measurement of the competitor price index Δp_{-it}. So far, we have constructed it using competitor market shares as weights, following Proposition 2, and our results have supported the testable implication of Proposition 2 in the form of parameter restriction (11). Nonetheless, we check for the robustness of our measure. First, there might be concern with the imposition of the same elasticity across different competitors. In column 1 of Table 5, we allow a firm to be differentially sensitive to its domestic and foreign competitors in the home market. Specifically, we split the overall competitor price index Δp_{-it} into its domestic and foreign components Δp^D_{-it} and Δp^F_{-it}, as defined in (27)–(28), and estimate two separate coefficients. We find the two estimated elasticities to be insignificantly different from each other, as well as quantitatively close to the common elasticity estimated in the baseline specification in column 4 of Table 1.A, which suggests that restricting the strategic complementarity elasticity to be the same in response to domestic and foreign competitors is not at odds with the data.

do not import inputs outside the euro area, while the imported marginal cost Δmc^*_{it} is non-zero even for firms importing only from within the euro area (see Section 3.1).

In columns 2 and 3 we instead allow for the possibility that the firms follow only the largest firm in the industry, and are not sensitive to the prices of other competitors, as in an industry-leader model. We test this by including in the regression the log price change of the largest competitor in the industry, replacing Δp_{-it} in column 2 and along with Δp_{-it} in column 3. In both cases we find insignificant coefficients on the price change of the largest firm. Furthermore, in column 3, where the two competitor price change variables are included together, the coefficient on the price change of the largest firm is negative, while the coefficient on the competitor price index remains positive. These results imply that there is no extraordinary role for the largest firm in the industry, beyond its effect on the industry price index proportional to its market share, as captured by our baseline competitor price index Δp_{-it}.

The remaining three columns of Table 5 offer two different types of placebo tests. In columns 4 and 5, we include a competitor price index constructed using the price changes of products outside the firm's own 4-digit industry, Δp_{-st}. Provided that our definition of an industry is correct, the prices of products outside that industry should not matter. This is indeed what we find, where the coefficient on this outside price index is negative with huge standard errors, and in column 5 the point estimate on the within-industry competitor price index Δp_{it} remains unchanged relative to the baseline. Lastly, column 6 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.

4 Strategic Complementarities and Exchange Rate Shocks

In this section, we consider the effect of an exchange rate shock on domestic prices. We use the framework developed in Section 2 to delve into the mechanisms by which international shocks are transmitted into domestic prices, in light of the significant strategic complementarities we identified in the firm-level empirical analysis of Section 3. To this end, we use a quantitative model, tightly calibrated to capture the cross-sectional heterogeneity we observe in the Belgian manufacturing industries. We show how the interaction between firm-level strategic complementarities and import intensities shape the aggregate markup and price responses to exchange rate shocks.

4.1 From micro to macro

We provide a general framework to account for exchange rate pass-through (ERPT) into costs, markups and prices, starting at the firm level and aggregating up to the industry level, by specializing the price decomposition in equation (5) to the case of an exchange rate shock de_t (with $de_t > 0$ corresponding to a domestic currency depreciation). Assuming that the idiosyncratic demand shifters $\{\xi_{it}\}$ are not systematically correlated with the exchange rate shock, i.e. $\mathbb{E}\{d\varepsilon_{it}/de_t\} = 0$, which is realistic in the context of individual products in differentiated industries, we can write the projection of equation (5) onto exchange rates as:

$$\psi_{it} = \frac{1}{1 + \Gamma_{it}}\varphi_{it} + \frac{\Gamma_{it}}{1 + \Gamma_{it}}\Psi_{-it}, \tag{29}$$

where $\psi_{it} \equiv \mathbb{E}\{dp_{it}/de_t\}$ is ERPT into firm-i's price, $\Psi_{-it} \equiv \mathbb{E}\{dp_{-it}/de_t\} = \sum_{j\neq i} \frac{S_{jt}}{1-S_{it}}\psi_{jt}$ is ERPT into its competitor prices, and $\varphi_{it} \equiv \mathbb{E}\{dmc_{it}/de_t\}$ is its marginal cost sensitivity to exchange rate. Note that we rely here on Proposition 2, which implies competitor price index (9) and $\Gamma_{-it} = \Gamma_{it}$.

From (29) we can see that an exchange rate shock affects domestic prices through two distinct mechanisms. The first is a direct effect, which operates via marginal costs, due to changing prices of imported (and possibly also domestic) inputs, summarized by φ_{it} in (29). We expect φ_{it} to be larger for firms that source a bigger share of intermediate inputs internationally. The second, indirect, effect operates through the interaction of strategic complementarities ($\Gamma_{it} > 0$) and the comovement of the competitors' final goods prices with exchange rates ($\Psi_{-it} > 0$). We expect individual domestic firms to exhibit higher ERPT in environments with greater foreign competition, resulting in larger Ψ_{-it}.

To see how a firm's markup responds to exchange rate shocks, we rearrange (29) as follows:

$$\mathbb{E}\left\{\frac{d\mu_{it}}{de_t}\right\} = \psi_{it} - \varphi_{it} = \frac{\Gamma_{it}}{1+\Gamma_{it}} \cdot \left[\Psi_{-it} - \varphi_{it}\right]. \tag{30}$$

This equation makes it clear that the firm adjusts its markup in response to an exchange rate shock only when two conditions are simultaneously met: (1) $\Gamma_{it} > 0$, i.e. the firm has a variable markup and exhibits strategic complementarities in pricing; and (2) $\varphi_{it} \neq \Psi_{-it}$, i.e. the firm's costs are affected differentially from the average price response of its competitors. Note that the firm's markup can either decrease or increase, depending on whether its costs increased by more or less than the prices of its competitors. The conventional view is that a currency depreciation makes domestic firms more competitive and raises markups in the domestic market (see discussion in Burstein and Gopinath 2012). However, equation (30) makes clear that the markup adjustment by domestic firms in the domestic market is more nuanced. It shows that the logic underlying the conventional view does apply when a firm's costs increase by less then the price of its average competitor. In that case, domestic firms gain competitiveness and increase their markups. By contrast, if a firm sources a large share of its inputs internationally (with $\varphi_{it} \gg 0$) and competes in an industry with few foreign firms ($\Psi_{-it} \approx 0$), it would lose competitiveness and thus reduce its markup.

To go from micro to macro, we combine the expressions for ψ_{it} for all firms in the industry, as they are jointly determined in equilibrium, and solve for the aggregate industry ERPT (see Appendix C):

$$\Psi_t \equiv \sum_{i=1}^{N} S_{it}\psi_{it} = \frac{1}{\sum_{i=1}^{N} \frac{S_{it}}{1+\Gamma_{it}/(1-S_{it})}} \sum_{i=1}^{N} \frac{S_{it}\varphi_{it}}{1+\Gamma_{it}/(1-S_{it})}, \tag{31}$$

This expression highlights how the cross-firm heterogeneity in $\{\varphi_{it}, \Gamma_{it}, S_{it}\}$ matters for aggregate pass-through Ψ_t. In particular, holding constant the aggregate cost shock, $\varphi_t \equiv \sum_{i=1}^{N} S_{it}\varphi_{it}$, the aggregate pass-through into prices is lower ($\Psi_t < \varphi_t$) when larger firms are simultaneously characterized by stronger strategic complementarities Γ_{it} and higher import intensities φ_{it}. If, instead, for all firms $\varphi_{it} \equiv \varphi_t$ or $\Gamma_{it} \equiv \Gamma \geq 0$, then $\Psi_t = \varphi_t$, and hence the effect of strategic complementarities washes out in the aggregate. In what follows, we discipline the joint heterogeneity in $\{\varphi_{it}, \Gamma_{it}, S_{it}\}$ using the Belgian data to quantify these effects.
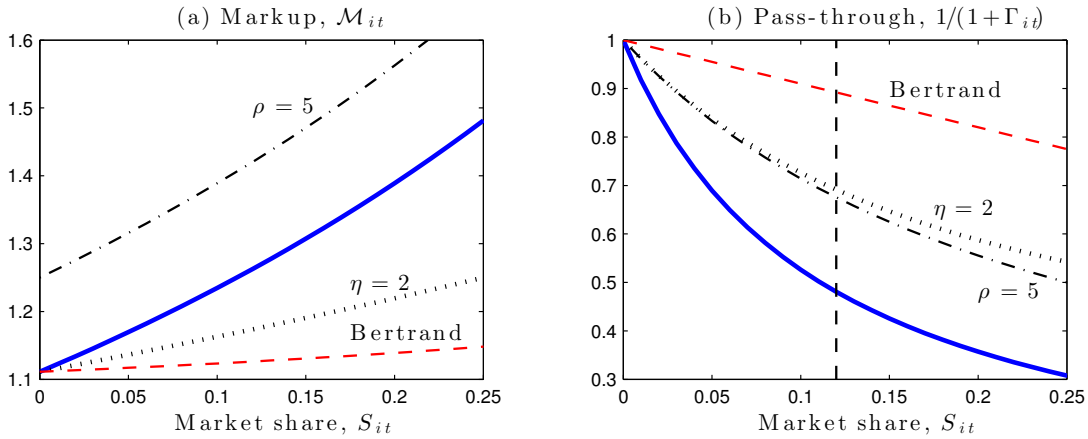
Figure 1: Markups and pass-through in a calibrated model

Note: Solid blue line corresponds to our benchmark case with Cournot competition, $\rho = 10$ and $\eta = 1.01$. 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 2.2). 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.

4.2 Strategic complementarities in a calibrated 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.[37]

The demand and competition structure of the model are as in Sections 2.2, with 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 (see Section 2.2 and Figure 1). Third, the model reproduces a large mass of very small firms 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.[38]

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[37]We focus on industries that are important in terms of their overall size and in terms of their share of domestic firms. To capture "typical" Belgian industries, we select industries based on the following criteria: (i) we start with the top half of the industries in terms of market size, which together account for over 90% of the total manufacturing sales in Belgium; (ii) out of these, we drop industries with a foreign share greater than 75% in any one year (a total of 10 such industries); (iii) we drop industries with less than 10 domestic firms in any one year; and (iv) we drop industries if the largest market share is less than 2% or greater than 32% (corresponding to the 5th and 95th percentiles respectively). After this process, we end up with 38 industries (out of a total of 166), which account for around half of the total domestic sales.

[38]We argue, in Appendix D, that jointly matching these features of the data is challenging for alternative models of heterogeneous variable markups, based on monopolistic competition and non-CES (e.g., Kimball) demand.

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 $\eta = 1.01$ 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 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 show below in Table 9. Yet, any significant departure from this parameterization results in a steep drop in the extent of strategic complementarities Γ_{it}, as can be seen in Figure 1, and would lead to the model's failure in matching the observed empirical patterns.

The marginal cost of a firm is modeled in a similar way as in Section 2.3, with

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

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 denote the nominal exchange rate by $\mathcal{E}_t$, and A_{it} is the effective idiosyncratic productivity of the firm, which in addition to physical productivity captures the idiosyncratic variation in input prices across firms. We further assume that the exchange rate exposure $\varphi_i \in [0, 1]$ in (32) is firm-specific and constant over time.[39] 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, as we describe in detail below. Finally, we assume that the nominal exchange rate follows a random walk in logs:

$$e_t = e_{t-1} + \sigma_e u_t, \qquad u_t \sim \text{iid } \mathcal{N}(0, 1), \tag{33}$$

where $e_t \equiv \log \mathcal{E}_t$ and σ_e is the standard deviation of the exchange rate innovation.

We 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 $\underline{a}$:

$$a_{it} = \underline{a} + |\mu + a_{i,t-1} + \sigma_a v_{it} - \underline{a}|, \qquad v_{it} \sim \text{iid } \mathcal{N}(0, 1) \tag{34}$$

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). This completes the specification of the cost processes for the firms. Given the costs, we calculate the equilibrium market shares and prices according to (13)–(15).

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[39] Amiti, Itskhoki, and Konings (2014) show that this assumption is empirically justified, as over 85% of variation in import

Table 6: Parameter values

η	ρ	θ	$\underline{a}$	μ	σ_a	σ_e
1.01	10	8	0	-0.0036	0.03	0.06

Table 7: Moments across industries

	Moment	Data	Model
1.	Number of Belgian firms	41.0 (48.1) [22.0 − 87.0]	48.0 (48.0) [39.0 − 57.0]
2.	Foreign share	0.362 (0.377) [0.139 − 0.611]	0.378 (0.384) [0.237 − 0.538]
3.	Share of firms from outside EZ	0.081 (0.107) [0.011 − 0.254]	0.096 (0.115) [0.037 − 0.214]
4.	Top Belgian firm market share	0.100 (0.117) [0.049 − 0.209]	0.111 (0.127) [0.058 − 0.214]
5.	Pareto shape of the sales distribution	1.042 (1.047) [0.628 − 1.470]	1.045 (1.065) [0.855 − 1.299]
6.	Standard deviation of ΔS_{it}	0.0026 (0.0038) [0.0016 − 0.0077]	0.0037 (0.0042) [0.0026 − 0.0055]
7.	Correlation of S_{it} and $S_{i,t+12}$	0.898 (0.846) [0.690 − 0.983]	0.844 (0.808) [0.598 − 0.961]
8.	Average import intensity, $\bar{\phi}_s$	0.301 (0.288) [0.080 − 0.437]	0.276 (0.282) [0.197 − 0.367]
9.	Average import intensity outside EZ, $\bar{\phi}_s^X$	0.052 (0.069) [0.009 − 0.161]	0.057 (0.065) [0.031 − 0.111]

Note: The table reports median (mean) with [10th−90th percentiles] for the distribution of variables across industries, in the data and in the simulated model. Foreign share is the sales share of all foreign firms (European and non-European) in the Belgian market, and the share of the Euro Zone (EZ) firms equals the Foreign share minus Share of firms from outsize EZ (moment 2 minus moment 3). Average import intensity is the sales weighted import intensity (defined as the cost share of imported inputs) of the firms within industry; $\bar{\phi}_s^E = \bar{\phi}_s - \bar{\phi}_s^X$ is the import intensity from within the EZ.

Table 8: Exchange rate pass-through regressions

	Sectoral price indexes			Domestic firm-level		
	Δp_{st}	Δp_{st}^D	Δp_{st}^F	Δp_{it}	Δmc_{it}	Δmc_{it}^*
Data	0.489 (0.061)	0.311 (0.085)	0.642 (0.059)	0.279 (0.187)	0.395 (0.187)	0.246 (0.040)
Model	0.447	0.308	0.687	0.306	0.272	0.274

Note: The table reports the coefficients from the ERPT regressions of price changes on Δe_t (the trade-weighted nominal exchange rate in the data). In the left panel, $\Delta p_{st}, \Delta p_{st}^D, \Delta p_{st}^F$ are log changes in price indexes in industry s (market-share weighted averages) for all, domestic and foreign firms, respectively. In the right panel, we regress log changes in the individual product prices, marginal costs and imported component of the marginal cost on Δe_t, weighting observations by revenues. The estimates in the model are averaged over 50 simulations, reducing the sampling error to virtually zero. For the regressions in the data, we report standard errors clustered at the industry level in parenthesis.

Calibration and model fit   The calibrated parameters are summarized in Table 6 and the moments in the model and the data in Table 7.[40] Given the demand elasticities η and ρ, we set the parameters of the productivity process $(\theta, \bar{a}, \mu, \sigma_a)$ to match the moments of the market share distribution across firms and their evolution over time (moments 4–7 in Table 7). In particular, given the calibrated number of firms, a combination of θ and ρ 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 measure of firm concentration. For example, both in the data and in the model, the largest Belgian firm in an average industry has a market share of 11–12%, and it varies from 5% to 21% from the 10th to the 90th percentile of industries.[41] The choice of $\underline{a}$ and μ simply ensures that this distribution stays stable over time, and the choice of σ_a allows us to match the short-run and long-run persistence of firm market shares (moments 6 and 7).

In a given industry, there are firms of three types: N_B domestic Belgian firms, N_E foreign Euro-Zone (EZ) firms, and N_X foreign non-EZ firms. Following Eaton, Kortum, and Sotelo (2012), the numbers of each type of firms across industries are drawn from Poisson distributions with means $\bar{N}_B$, $\bar{N}_E$ and $\bar{N}_X$, respectively. We calibrate $\bar{N}_B = 48$, equal to the average number of Belgian firms across industries (moment 1 in Table 7). We do not directly observe the numbers of EZ and non-EZ firms in the Belgian market, and we set $\bar{N}_E = 21$ and $\bar{N}_X = 9$ to match the average sales shares of all products from these regions, which equal 27% (=38%−11%) and 11% respectively (moments 2 and 3). Upon entry, the productivities of firms from each region are drawn from the same distribution $G_0(A)$, which results in the same market share distribution within each firm type, with the difference across types summarized by the number of entrants and reflected in the cumulative sales shares.[42]

Turning to the international shock, we assume that the innovation for the exchange rate process has a standard deviation of $\sigma_e = 0.06$, which closely approximates the dynamics of the Belgian trade-weighted nominal exchange rate in the data. From equation (32), we see that the exposure to exchange rate shocks is firm-specific, given by $\{\varphi_i\}$, which we exogenously assign across firms, reproducing the observed empirical patterns. We assume that all foreign EZ (non-EZ) firms have a common exchange rate exposure φ^E (φ^X), with $\varphi^X > \varphi^E$. In contrast, the domestic firms are heterogeneous in their exchange rate exposure φ_i, which is shaped by their import intensity ϕ_i. Specifically, we set:

$$\varphi_i = \phi_i^E \chi^E + \phi_i^X \chi^X + (1 - \phi_i^E - \phi_i^X)\chi^B, \tag{35}$$

where (ϕ_i^E, ϕ_i^X) are firm-specific import intensities from within and outside the EZ respectively, and

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intensity ϕ_{it} is cross-sectional, and within a firm ϕ_{it} is not responsive to exchange rate movements over horizons of 3–5 years.

[40]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. Due to the *granularity* of firm productivity draws in the model, each simulated industry looks different even when we use the same data generating process for all industries. This enables us to match not only the means and medians across industries, but also the variation in the moments across industries (see Table 7). For further analysis of the effect of granularity in a related model see Gaubert and Itskhoki (2015).

[41]Importantly, the model matches not only the size of the largest firm, but also the spacing of the next firms in the market share distribution, as reflected in the estimated Pareto shape parameters. Both in the data and in the model, we estimate the shape parameters by running a $\log(rank_i - 1/2)$ on log revenues of firm i for firms with above-median revenues in their industry, as suggested by Gabaix and Ibragimov (2011).

[42]Eaton, Kortum, and Sotelo (2012) and Gaubert and Itskhoki (2015) provide conditions for an equivalent characterization in a generalized environment with variable and fixed trade costs and under full general equilibrium.

Table 9: Strategic complementarities in the calibrated model

Dep. var.: Δp_{it}	All firms	Bottom 80% vs top 20% of firms		
		Small firms	Large firms	Interaction
Δmc_{it}	0.737	0.939	—	0.939
$\Delta mc_{it} \times \text{Large}_{it}$	—	—	0.643	−0.295
Δp_{-it}	0.261	0.060	—	0.060
$\Delta p_{-it} \times \text{Large}_{it}$	—	—	0.357	0.297

Note: The regressions parallel column 4 of Table 1.A and columns 1, 2 and 4 of Table 2. Δp_{-it} is calculated as in the data according to (22) and Large_{it} is a dummy for whether the firm belongs to the top quintile of firms by market shares (i.e., the largest 20% of firms by sales) within each industry. Observations are weighted by firm sales. All regressions are IV regressions using firm marginal costs as instruments. Instrumenting using $\phi_i \Delta e_t$ results in the same parameter estimates, while OLS (weighted LS) results in downward biased estimate of strategic complementarities. The reported coefficients are averages of the estimates over 50 simulations, each with 1000 industries, to exclude small sample variation.

(χ^E, χ^X, χ^B) are ERPT elasticities into input prices, including locally-sourced inputs χ^B, which we assume to be common across firms and satisfy $\chi^X > \chi^E > \chi^B$.

We assign (ϕ_i^E, ϕ_i^X) across firms as in the data, using a bootstrap procedure conditional on firm size, which we describe in Appendix B.1. Table 7 (moments 8 and 9) shows that we match the average sectoral import intensity, both from within and from outside the Euro Zone. On average, the share of imported inputs in total costs is around 28%, with about 6% imported from outside the EZ. In addition, we match the distribution of firm import intensities conditional on firm size.[43] This leaves us with five parameters to calibrate, $(\varphi^E, \varphi^X, \chi^E, \chi^X, \chi^B)$. We choose the values of these parameters to match the aggregate pass-through elasticities in the data (for trade-weighted exchange rate). We set the pass-through into domestic input prices at $\chi^B = 0.1$, and the pass-through into both final and intermediate goods at $\chi^E = \varphi^E = 0.65$ from within the EZ and at $\chi^X = \varphi^X = 1$ from outside the EZ. This allows us to match the empirical pass-through patterns into the industry price indexes for all firms combined, and domestic and foreign firms separately, as we report in the left panel of Table 8. This calibration is also consistent with the pass-through patterns into micro product-level prices and marginal costs of the Belgian firms (right panel of Table 8), as well as the aggregate ERPT into import prices (see Appendix B.1). This completes the calibration of the model.

Strategic complementarities Before turning to counterfactuals, we verify that the calibrated model reproduces the empirical patterns of strategic complementarities in price setting. We show this by rerunning our main empirical specifications of Section 3 on the data simulated from the model and report the results in Table 9. In parallel with our baseline Tables 1 and 2, we regress the firm's price on its marginal cost and competitor prices (all in log changes). We do it first for the full sample of firms, then separately for the 80% of the smallest firms and 20% of the largest firms by sales within each industry, and finally pooling all firms and introducing an interaction dummy for large firms. Table 9 shows that

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[43]In particular, firm import intensity $\phi_i \equiv \phi_i^E + \phi_i^X$ has a correlation of 0.25 with firm market share, while the relative share of non-EZ imports ϕ_i^X / ϕ_i does not systematically correlate with firm market share (see Appendix B.1).

the model nails the coefficients on Δmc_{it}, both for the full sample of firms and for the sub-samples of small and large firms, as well as the lack of strategic complementarities for the small firms, but slightly under-predicts the strategic complementarity elasticity for the large firms (0.36 versus 0.42=0.06+0.36 in column 4 of Table 2).[44] This confirms that the model captures the salient features of price setting in the data, and can be used for counterfactual analysis.

4.3 Exchange rate and domestic prices

We use the calibrated model to explore the impulse response of an economy to a 10% exchange rate devaluation, with a particular emphasis on the role of markups in shaping the price responses. The model is calibrated to reproduce the average ERPT into domestic prices of 32%. Although this number may seem high, and is probably explained by the above-average openness of the Belgian economy, the underlying mechanisms driving ERPT are common across countries. That is, price setting of domestic firms responds to an exchange rate shock through two channels: the marginal cost channel due to imported inputs and the strategic complementarities (markup) channel due to competition from the foreign firms. By decomposing the aggregate ERPT into these channels by types of firms and studying the heterogeneity of responses across industries with different characteristics, we gain important insights into understanding the differential aggregate ERPT across countries.

Decomposing ERPT Table 10 decomposes the ERPT into the marginal cost and markup channel by firm type. For the domestic firms, the large firms exhibit a higher ERPT relative to the small firms (36% versus 24%). This difference is due to both a greater response of their marginal costs (as large firms are 45% more import intensive) and markup adjustment, with the markup adjustment playing a relatively bigger role for the large firms: 11% versus 5.5%. This difference is, nonetheless, small, which might seem surprising in light of the large difference in the strength of strategic complementarities between the two types of firms in Table 9 (indeed, a six-fold difference). A closer inspection of equation (30) provides the explanation. While large firms have a much higher Γ_{it}, a devaluation also leads to substantial increases in their marginal costs because of their high import intensity. As a result, with φ_{it} only slightly lower than Ψ_t, the markup adjustment by large firms is limited. The small firms exhibit almost no strategic complementarities ($\Gamma_{it} \approx 0$) and barely adjust markups.[45] Therefore, the marginal cost channel dominates the markup channel for the price adjustment of both small and large firms, but for different reasons. Hence, at the aggregate, the markup response of domestic firms is muted, and the markup channel accounts for less than 10% of the overall ERPT into domestic firm prices.

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[44]Given the empirical standard errors, this is not a statistically significant difference. Note that in the model, the sum of the coefficients on marginal cost and competitor price is exactly 1, while in the data the two point estimates sum to 1.07, which explains why the model cannot perfectly match both elasticities. Appendix Figure A1 further illustrates the pass-through and strategic complementarity elasticities across firms by market share bins: the model predicts strategic complementarity elasticities as large as 50% for firms with market shares over 10% within their industries, but such firms are rare, as in the data.

[45]A back-of-the envelope calculation based on (30) suggests that the markup response for the large firms should be $\Gamma_{it}/(1+\Gamma_{it}) \cdot [\Psi_{-it} - \varphi_{it}] \approx 0.36 \cdot (0.46 - 0.32) = 0.05$, consistent with what we find in Table 10 (i.e., 0.36·0.11=0.04). Appendix Figure A2 illustrates the decomposition of domestic firm ERPT into the marginal cost and markup components by more disaggregated bins of firm size, and we find that for the largest few firms the markup adjustment can account for as much as a quarter of the overall ERPT.

Table 10: ERPT. Decomposition

	Domestic firms			Foreign firms	All firms
	All	Small	Large		
Price ERPT	0.319	0.236	0.361	0.680	0.459
Percentage contribution:					
— marginal cost	90.3	94.5	88.9	110.9	102.0
— markup	9.7	5.5	11.1	−10.9	−2.0

Note: The table reports average ERPT into domestic industry prices, and its decomposition into the marginal cost and markup contributions (in percent), by types of firms. Large firms defined as before, above the 80th percentile of sales within industry (corresponding to a 1.4% market share cutoff), with the 20% of the largest firms accounting for 65% of sales. ERPT coefficients are impulse responses, obtained by averaging over 50 two-period simulations with 200 industries each, with only a 10% exchange rate devaluation between the two periods and no productivity innovations over initial draws. Price and marginal cost are industry indexes (sales weighted averages of log price and marginal cost changes, respectively) and the industry markup index equals the difference between the price and the marginal cost indexes (in log changes).

For the foreign firms, we note from Table 10 that they reduce markups in response to an exchange rate devaluation, while the domestic firms increase markups, consistent with the conventional view. Interestingly, the overall markup response in the industry (taking together all domestic and foreign firms) is close to zero, in parallel with the findings in ACDR in the context of a different model and parameterization. In our case, however, this finding is not a robust feature of the theoretical mechanism, and changes substantially across calibrations. The aggregate markup can increase or decrease in response to an exchange rate shock, depending on the cost and competition structure of the industry, as we show in our counterfactual analysis below.

Heterogeneity across industries   In our simulation, the aggregate ERPT into domestic firm prices varies from 26% to 37% from the 10th to the 90th percentile of industries, with a 32% ERPT for the median industry. To understand what is driving these differential effects, we regress industry level ERPT into domestic prices on industry characteristics. From column 1 in Table 11, we see that the industry's overall import intensity (i.e., the sales-weighted import intensity of individual domestic firms) explains over three quarters of the variation in ERPT across industries, supporting our finding in Table 10 that the marginal cost channel (in particular, through imported intermediates) dominates the overall price adjustment by the domestic firms. Columns 2 and 3 of Table 11 reinforce this result: once we control for the fraction of imports outside the Euro Zone and the distribution of import intensities across firms within industry, the explanatory power for pass-through variation reaches 87%.

Note from column 3 that a strong positive correlation between import intensity and market share, holding overall import intensity constant, reduces the industry's ERPT. This is in line with the logic of equation (30), as in this case the large firms are hit harder by exchange rate shocks, and consequently increase their markups less, if at all, resulting in lower pass-through. A one-standard-deviation increase in this correlation reduces the industry ERPT by a quarter of a standard deviation. This highlights the role of the within-industry heterogeneity for the aggregate pass-through patterns, following the logic of equation (31).

Table 11: ERPT. Variation across industries

Dep. var.: Ψ_s^D	(1)	(2)	(3)	(4)	(5)
Average import intensity	0.887	0.839	0.913		0.871
Import intensity outside EZ		0.077	0.113		0.103
Correlation ϕ_i^B and S_i			-0.294		-0.240
Foreign share				0.324	0.222
Top domestic firm market share				0.516	0.227
R^2	0.786	0.790	0.866	0.177	0.905

Note: The table reports the standardized coefficients and R^2s from the regression of industry ERPT elasticity into domestic prices (Ψ_s^D) on various industry-level variables. Each standardized coefficient shows the effect of a one standard deviation increase of the predictor on the change in Ψ_s^D measured in units of standard deviations. The correlation between ϕ_i^B and S_i is the within-industry correlation between the overall firm import intensity and its market share. The other variables are as defined in Table 7. The sampling is as described in Table 10.

Another notable difference across industries is the large variation in the degree of foreign competition (see Table 7, moments 2). In column 4 of Table 11, we find rather surprisingly that this variation explains less than 18% of the variation in ERPT, with one standard deviation increase in the foreign share accounting for only a third of a standard deviation increase in the industry's ERPT. Since the foreign share affects the ERPT into domestic prices only indirectly, through the markup adjustment of the domestic firms, this pattern is again in line with our earlier finding of the limited role of the markup channel for the domestic firms. Note that in this regression we also control for the size of the largest domestic firm in the industry. The presence of very large firms in the industry results in a higher aggregate ERPT, as these firms are both more import intensive and increase their markups when the exchange rate depreciates.[46] This again emphasizes the role of the within-industry heterogeneity for the aggregate pass-through patterns. Combining all explanatory variables together in column 5, we find that they jointly account for over 90% of the variation in ERPT across industries.[47]

Counterfactual industries   We now assess when markup adjustment is important in driving aggregate ERPT by considering a set of industries that are not typical in Belgium, but may be typical in other countries. We consider three different sets of counterfactual industries. First, we consider industries with no foreign competition (i.e., zero foreign share), while in the Belgian data the foreign share is 14% at the 10th percentile of industries (Table 7, moment 2). We leave the cost structure of the domestic firms as in the baseline calibration. The left panel of Table 12 shows that the absence of foreign competition reverses the direction of the markup channel effect of the price response to the exchange rate shocks,

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[46]Without controlling for the presence of large firms, the foreign share loses its explanatory power altogether, as a high foreign share correlates simultaneously with the importance of foreign competition and a lack of large domestic firms, which as we discussed have offsetting effects on the ERPT into domestic firms.

[47]While the relationship between ERPT and these industry characteristics is very pronounced, detecting it empirically is difficult, as the measures of ERPT by industry are very noisy. Indeed, even in the simulated model, when we reintroduce productivity shocks, the exchange rate shocks account for only a small variation in firm prices and price indexes across industries. As a result, the explanatory power in the regression in column 5 of Table 11 falls from 90% to 10%. This makes it virtually impossible to estimate this relationship in the data, thus requiring a model-based analysis.

Table 12: ERPT. Counterfactuals

	No Foreign Competition			Large Foreign Share			No Foreign Inputs		
	All	Small	Large	All	Small	Large	All	Small	Large
Price ERPT	0.266	0.226	0.292	0.391	0.240	0.447	0.161	0.114	0.185
Percentage contribution:									
— marginal cost	106.0	98.7	109.9	76.0	93.3	72.5	62.1	87.7	54.1
— markup	−6.0	1.3	−9.9	24.0	6.7	27.5	37.9	12.3	45.9

Note: The Table reports analogous results that parallel those in the Domestic firms columns of Table 10 (see table notes for details), for counterfactual sets of industries (as described in the text).

leaving only the marginal cost channel to push prices up. The resulting ERPT into domestic firm prices is 27% versus 32% in the baseline calibration (see Table 10), and the difference in these coefficients is almost entirely accounted for by the differential markup adjustment of the large firms (a negative 10% contribution versus a positive 11% in the baseline). Interestingly, an exchange rate devaluation results in a reduction of the aggregate markup, in contrast with the conventional wisdom (see Section 4.1). This is because the small firms do not adjust markups due to the lack of strategic complementarities, while the large firms adjust markups downwards in response to a shock that adversely affects their costs. According to (30), this is the case with $\varphi_i > \Psi_{-i}$ for the large firms, which implies a reduction in their markups. This illustrates that the direction of the markup adjustment by the large firms depends on whether their average competitor is a small domestic firm or a foreign firm.

Second, the middle panel of Table 12, in contrast, analyzes industries with a large foreign share equal to 67%, as opposed to 61% in the data at the 90th percentile of industries (and 38% for the average industry). We again leave the cost structure of the domestic firms unchanged, and the greater pass-through in this case is fully due to a stronger response of markups, as the typical competitor in the industry is now a foreign firm, heavily exposed to the exchange rate shocks. The overall ERPT into domestic firm prices increases from 32% to 39%, with a quarter of the overall ERPT now due to markups (versus 10% in the baseline). Again, all of the differential response is driven by the large firms, for which the markup adjustment now accounts for 28% of the price response (versus 11% in the baseline).

Third, the right panel of Table 12, considers industries in which foreign competition is the same as in the baseline calibration, but domestic firms do not source any inputs internationally, while in the data import intensity is 8% at the 10th percentile of industries (Table 7, moment 8). This case corresponds to the many stylized theoretical models of pricing-to-market, which assume no international input sourcing. In this case, the ERPT into marginal costs equals $\chi^B = 0.1$ for all domestic firms independently of size, and all of the heterogeneity in their overall price adjustment is accounted for by changes in markups in response to foreign competitor price changes. The small firms exhibit little strategic complementarities and thus barely change their markups. In contrast, the large firms increase their markups substantially, accounting for almost a half of their overall ERPT (in comparison with 11% in the baseline). At the aggregate, the markup now accounts for almost 40% of the overall price adjustment to an exchange rate shock.[48] The overall ERPT into domestic prices in this case is only 16%,

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[48]In fact, there are two features of this counterfactual which increase the role of the markup adjustment by domestic firms:

much lower than the average for Belgian manufacturing.

In sum, this section shows how the structure of foreign competition and the joint distribution of market shares and import intensities across domestic firms determine the importance of markup adjustment for aggregate exchange rate pass-through into domestic prices.

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 3.5% in response to a 10% increase in the prices of its competitors, holding its own marginal cost constant. Furthermore, there is vast heterogeneity in the strength of strategic complementarities across firms. The small firms show no strategic complementarities and a complete pass-through of their cost shocks into prices, behaving as CES monopolistic competitors. In contrast, the 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 important properties of firm markups without imposing strong structural assumption on demand, competition or production.

Our empirical estimates provide the key ingredients necessary to analyze the transmission of an aggregate international shock into domestic prices. In particular, we study the counterfactual response of an economy to an exchange rate devaluation, using a calibrated model of variable markups that is tightly disciplined by the joint distribution of firm import intensities and market shares in the data. For a typical Belgian manufacturing industry, we find a limited role for the markup adjustment in shaping the response of domestic prices to an exchange rate shock, despite the substantial strategic complementarities in price setting characteristic of the large domestic firms. This finding is due to the unusually high openness of the Belgian market in intermediate inputs. In particular, the Belgian firms' high import-intensive cost structure makes them directly exposed to the exchange rate fluctuations and thus dilutes any competitive edge they would otherwise have over foreign competitors following an exchange rate devaluation. However, this is not the case for all industries. Indeed, we find that the markup adjustment accounts for a substantial portion of exchange rate pass-through in industries with low import intensity (as well as a low correlation of import intensity with firm size) and with greater foreign competition. These results help explain why different studies for different countries produce wildly different ERPT estimates, and provide a path to understanding how aggregate domestic prices respond to international shocks.

(i) the lower average import intensity of domestic firms, which renders them more competitive relative to foreign firms when exchange rate depreciates; and (ii) the lack of correlation between exchange rate exposure and firm size, which increases average markup adjustment (recall the analysis following Table 11). We also carry out two additional counterfactuals. First, we assign a common import intensity equal to the average of 0.282 to all domestic firms independently of size, which results in a 14% contribution of markup to ERPT relative 9.7% in the baseline. Second, we make all small firms non-importers and proportionally increase the import intensity of large firms to keep the average industry import intensity constant at 0.282. In this case, the domestic markups stay effectively unchanged, as the large domestic firms gain no competitive grounds against foreign firms.

A Additional Empirical and Quantitative Results

Table A1: Summary Statistics

Level	Variable	5 pctl	Mean	Median	95 pctl	St.dev.
Firm-product	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	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_{it}^{xeu}	0.000	0.032	0.003	0.168	0.071
Industry	# of firms	6	65	40	310	80
(NACE 4-digit)	$\max S_{it}$	0.013	0.098	0.063	0.313	0.110
	S_{st}^D	0.111	0.565	0.588	0.901	0.238
	S_{st}^F	0.080	0.369	0.315	0.864	0.236

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_{it}^{xeu} are the firm import intensities (shares in total variable costs) for intermediate inputs from outside Belgium and from outside the euro zone respectively (see also Table A2 below); $\max S_{it}$ is the largest market share of a domestic (Belgian) firm within an industry; and S_{st}^D and S_{st}^F are the cumulative market shares of domestic (Belgian) and foreign products within industry s. The statistics characterize our sample distributions across observations, which are at the firm-product-year level, except the industry variables which are at the industry-year levels.

Table A2: Import intensity by firm size

	All	Large	Small	
Fraction $\phi_{it} > 0$	0.701	0.984	0.638	Note: The reported averages are across firm-year observations, explaining the difference with the first column from the corresponding entries in Table A1. Large (small) firms are firms with average employment of at least (less than) 100 employees. Over 95% of large firms import intermediate inputs from outside euro area, while 49.1% of small firms import from outside the euro area and 63.8% import from outside of Belgium.
Average ϕ_{it}	0.150	0.221	0.134	
Fraction $\phi_{it}^{xeu} > 0$	0.576	0.958	0.491	
Average ϕ_{it}^{xeu}	0.032	0.059	0.026	

Table A3: Robustness: large and small firms

Sample	Large		Small	
	Export share < 0.1	FDI share < 0.005	$\phi_i > 0$	$\phi_i^{xeu} > 0$
	(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=100 threshhold. Column 1 only includes large firms with export shares less than 10%. Column 2 only includes large firms with foreign sales or purchases less than 0.005% of their total sales. Column 3 (4) only includes firms with positive imports of intermediates from outside Belgium (Eurozone).

Table A4: First-stage Results

	Column (1)		Column (2)		Column (3)			
	Δmc_{it}	$\Delta p_{-i,t}$	Δmc_{it}	$\Delta p_{-i,t}$	Δmc_{it}	Δmc_{it} $\times$Large$_i$	$\Delta p_{-i,t}$	$\Delta p_{-i,t}$ $\times$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_{st}	-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)
$\Delta e_{st} \times$ Large$_i$					0.18	0.03	-0.13	0.23*
					(0.30)	(0.28)	(0.13)	(0.12)
$\Delta mc^*_{-i,t}$	0.71***	0.68***			0.53***	-0.20***	0.73***	-0.05*
	(0.20)	(0.14)			(0.21)	(0.07)	(0.17)	(0.57)
$\Delta mc^*_{-i,t} \times$ 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^{EU}_{st}	0.16***	0.15***			0.20***	0.02	0.17***	-0.01
	(0.06)	(0.05)			(0.07)	(0.02)	(0.05)	(0.01)
$\Delta p^{EU}_{st} \times$ 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.
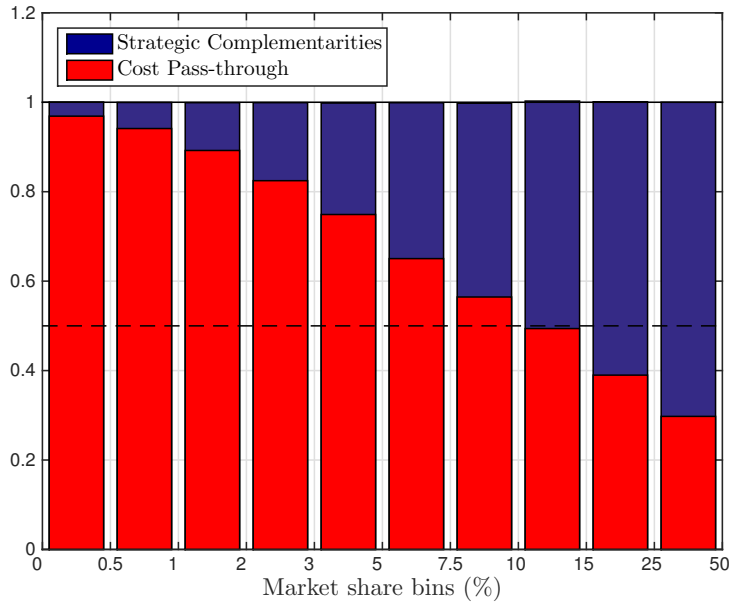
Figure A1: Marginal costs vs strategic complementarities, by firm size

Note: The red and blue bars depict coefficients $\psi_{it} = 1/(1 + \Gamma_{it})$ and $\gamma_{it} = \Gamma_{-it}/(1 + \Gamma_{it})$ from the main regression specification (17), estimated by bins of firms with similar market shares (unweighted), using the model-simulated dataset. The figure expands on the heterogeneity analysis reported in columns 2 and 3 of Table 9. The x-axis indicates the market share bins, where the numbers correspond to market share intervals: $[0, 0.5\%), [0.5\%, 1\%), .., [25\%, 50\%]$. The bin cutoffs were chosen to keep all bins of comparable size (both in terms of number of firms and in terms of sales): the bin of the smallest firms with market share below 0.5% contains 30% of firms, which however account for only 7% of sales; the bin of the largest firms contains 0.1% of firms, but they account for over 2% of sales; other bins account for between 8% and 15% of sales.
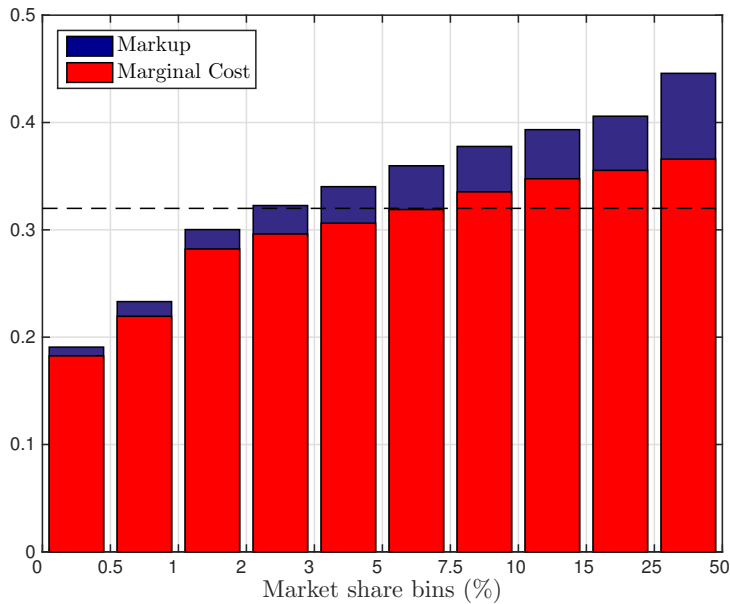

Figure A2: ERPT into firm prices, by firm size. Marginal cost vs markup channels

Note: Regressions of log change in firm marginal costs (red bars) and prices (sum of red and blue bars, where blue bars measure ERPT into firm markups) on log change in the exchange rate for the counterfactual exercise of Section 4.3, by bins of firms with similar market shares (as described in Figure A1 above). The figure expands on the heterogeneity analysis reported in columns 2 and 3 of Table 10. Dashed line indicates the average pass-through across all firms.

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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.

B.1 Calibration of firm import intensity

We describe here our bootstrap procedure for calibrating the import intensity ϕ_i of the Belgian firms. In the initial period, we draw for each firm a vector of the cost share of EZ and non-EZ imported inputs (ϕ_i^E, ϕ_i^X), such that the overall import intensity of the firm is $\phi_i = \phi_i^E + \phi_i^X$. To do so, in each industry we rank firms by productivity in descending order. We pick one of the Belgian industries in our sample (see footnote 37) at random with replacement, and rank all firms there as well. We assign ϕ_i of the top firm in the simulated industry to equal that in the randomly chosen Belgian industry. For the second firm, we take ϕ_i for the second firm in another randomly drawn Belgian industry. We continue this procedure for the first 20 firms in each simulated industry. For the remaining firms (number 21 onwards), we assign either zero import intensity (with the same probability as in the data for the small firms, specifically 45%) or the average import intensity of the importing small firms in a randomly chosen industry. We repeat this procedure for each of the simulated industries. Upon assigning ϕ_i to every firm in the simulation, we determine ϕ_i^X of the firms, by drawing an importing firm at random from all industries in the data and using its ϕ_i^X/ϕ_i ratio. This procedure is motivated by the fact that the ϕ_i^X/ϕ_i ratio in the data is not systematically correlated with firm size. Lastly, $\phi_i^E = \phi_i - \phi_i^X$ is determined as a residual. We show that this procedure results in the same cross-industry distribution of average industry import intensities (overall and from outsize the EZ) as in the data (Table 7, moments 8 and 9). It also captures the correlation between firm import intensities and market shares.

Lastly, we comment on the choice of $(\varphi^E, \varphi^X, \chi^E, \chi^X)$. In the data, the pass-through elasticities into Belgian import prices are 0.83 and 0.82 for the final goods and intermediate inputs respectively, which discipline the average magnitude of (φ^E, φ^X) and (χ^E, χ^X) respectively. For final goods, the import price pass-through from within the EZ and outside the EZ are 0.70 and 0.91 respectively, while for the intermediate goods these elasticities are 0.49 and 1.30, with much larger standard errors. To broadly match these numbers, we choose $\varphi^E = \chi^E = 0.65$ and $\varphi^X = \chi^X = 1$. This calibration also ensures the fit of the pass-through moments in Table 8.

C   Derivations and Proofs

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

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

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:

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

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:

$$h_{-i}(p_i, \boldsymbol{p}_{-i}; \boldsymbol{\xi}) = -\left(\boldsymbol{q}_{-i}(p_i, \boldsymbol{p}_{-i}; \boldsymbol{\xi}) - \boldsymbol{q}_{-i}^*\right). \quad \text{(A3)}$$

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:

$$\left(1 - \epsilon_i + \epsilon_i e^{-\mu_i}\right) + \sum_{k \neq i} \lambda_{ik} \zeta_{iki} = 0,$$

$$\forall j \neq i \qquad \left(-\delta_{ij} + \delta_{ij} e^{-\mu_i}\right) + \sum_{k \neq i} \lambda_{ik} \zeta_{ikj} = 0,$$

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. $\blacksquare$

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:

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

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 (7) 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 (9).

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 (6), 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 rewrite the demand schedule (12) in logs:[49]

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

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[49]Note that $d_s = \log D_s$ and, with nested CES, $D_s = \varpi_s Y/P$, where ϖ_s is the exogenous industry demand shifter, Y is the nominal income in the economy and P is the log aggregate price index, so that Y/P is the real income in the economy, and no firm is large enough to affect Y/P.

where the log industry price index

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

can be verified to also be the log expenditure function. In particular, the Shephard's lemma follows 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:[50]

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

which corresponds to the index of competitor price changes in (9).

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

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

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

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

$$\Gamma_{-i} = \frac{\partial \mu_i}{\partial z} \cdot (1 - S_i) = \Gamma_i.$$

2. **Quantity competition (Cournot)** Next consider the case of Cournot competition. Here we follow the steps of the proof of Proposition 1, and first calculate:

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

---

[50]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 $P_{-i} = \left[\sum_{j \neq i} \xi_j/(1-\xi_i)P_j^{1-\rho}\right]^{1/(1-\rho)}$.

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 $\kappa_{ij} = \mathrm{d}p_j/\mathrm{d}p_i|_{\mathrm{d}q_k=0,k\neq i}$. 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:

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

replicating (15), 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 derivations are straightforward, and the resulting expressions are provided 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 (5) and, under the assumptions of Propositions 2, solve for the reduced form of the model. First, we rewrite (5) 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:

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

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:

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

which we can simplify to (23), $\mathrm{d}p_{it} = \alpha_{it}\mathrm{d}mc_{it} + \beta_{it}\mathrm{d}mc_{-it} + \tilde{\varepsilon}_{it}$, with coefficients given by:

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

and the competitor marginal cost index defined as:

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

This illustrates the complexity of interpreting the coefficients α_{it} and β_{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   Project (A12) onto $\mathrm{d}e_t$:

$$\Psi_t \equiv \mathbb{E}\left\{\frac{\mathrm{d}p_t}{\mathrm{d}e_t}\right\} = \frac{1}{\sum_{i=1}^{N}\frac{S_{it}}{1+\Gamma_{it}/(1-S_{it})}}\sum_{i=1}^{N}\frac{S_{it}}{1+\Gamma_{it}/(1-S_{it})}\varphi_{it},$$

with the marginal cost projection denoted $\varphi_{it} \equiv \mathbb{E}\{\mathrm{d}mc_{it}/\mathrm{d}e_t\}$ and ε_{it} assumed orthogonal to $\mathrm{d}e_t$, which we state formally as:

$$\mathbb{E}\left\{\frac{\mathrm{d}\varepsilon_{it}}{\mathrm{d}e_t}\right\} = \frac{\text{cov}(\mathrm{d}\varepsilon_{it}, \mathrm{d}e_t)}{\text{var}(\mathrm{d}e_t)} = 0.$$

Furthermore, we denote the aggregate ERPT into marginal costs by $\varphi_t \equiv \sum_{i=1}^{N}S_{it}\varphi_{it}$. The ERPT into the aggregate markup is then given by:

$$\Psi_t - \varphi_t = \frac{\sum_{i=1}^{N}S_{it}\varphi_{it}\left[\frac{1}{1+\Gamma_{it}/(1-S_{it})} - \sum_{j=1}^{N}\frac{S_{jt}}{1+\Gamma_{jt}/(1-S_{jt})}\right]}{\sum_{j=1}^{N}\frac{S_{jt}}{1+\Gamma_{jt}/(1-S_{jt})}} = \frac{\text{cov}(\varphi_{it}, \tilde{\psi}_{it})}{\sum_{j=1}^{N}\tilde{\psi}_{jt}},$$

where $\tilde{\gamma}_{it} \equiv 1/[1+\Gamma_{it}/(1-S_{it})]$. Therefore, a positive correlation between φ_{it} and $\tilde{\Gamma}_{it} = \Gamma_{it}/(1-S_{it})$ results in a downward adjustment in markup in response to an exchange rate devaluation ($\mathrm{d}e_t > 0$).

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:

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

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, as in Section 2.2).

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

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

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:

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

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

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

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.[51] C is sectoral consumption; P is the ideal price index such that $C = E/P$ and D is an additional auxiliary variable determined in industry equilibrium, which is needed to characterize demand outside the CES case.[52]

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

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[51] 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.

[52] 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:[53]

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

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

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:

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

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

Given this, we can calculate the full elasticity of demand, which takes into account the effects of P_i on P and D. Substituting $C = E/P = \alpha P^{-\eta}$ 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.

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[53]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.

The key insight is that the market share channel in (A21) operates exactly in the same way as in the CES model of Section 2.2. In the CES model, however, this is the only channel of markup adjustment: 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. See Klenow and Willis (2006) and Gopinath and Itskhoki (2010) for an example of non-CES Kimball demand under monopolistic competition, which exhibits similar qualitative properties of markup variation as the oligopolistic model under CES demand.

Empirical challenge for non-CES models   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. This puts a significant constraint on the admissible models, ruling out a number of popular examples (especially if one requires simultaneously matching the incomplete pass-through characteristic for the entire industry on average). 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 (or rather demand complementarities in this case), this is achieved by means of a declining curvature in demand, as the firms price falls. The necessary implication of this is that the demand elasticity will be falling towards one, at which point the firms choose not to grow any further, violating the empirical Zipf's law, which suggests that the largest firm is a lot larger than the second-largest firm. Generating Zipf's law requires that demand becomes asymptotically constant elasticity (CES) as the firm price decreases. This, however, would result in counterfactually little markup variability for the largest firms, creating an even greater issue for the model.

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