How strong are strategic complementarities in price setting across firms? Are these strategic complementarities important in shaping the response of domestic prices to international shocks? 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 that does not rely on a particular model of variable markups, which allows us to estimate the elasticities of a firm’s price response to both its own cost shocks and to the price changes of its competitors. Our approach takes advantage of the new micro-level dataset that we construct for the Belgian manufacturing sector, which contains the necessary information on firms’ domestic prices, their marginal costs, and competitors’ prices. The rare features of these data enable us to develop an identification strategy that takes into account the simultaneity of price setting by competing firms. We find strong evidence of strategic complementarities: a typical firm changes its price with an elasticity of 35% in response to the price changes of its competitors and with an elasticity of 65% in response to its own cost shocks. We further show there is a lot of heterogeneity in these elasticities across firms, with small firms exhibiting no strategic complementarities and complete cost pass-through, while large firms responding to their cost shocks and competitor price changes with roughly equal elasticities of around 50%. To explore the implications of these findings for the transmission of international shocks into domestic prices, we calibrate a model of variables markups to match the salient features we identify in the data. We use the calibrated model to study counterfactual scenarios for the response of costs, markups and prices to an exchange rate devaluation across firms and industries.

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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 adopt 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).\(^2\) An important feature of our accounting framework is that it does not require us to commit to a particular 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 competitors’ 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 firms. The rare features of our dataset enable us to construct good instruments. In particular, our dataset contains 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 firms’ marginal costs, which are usually absent from most datasets. Specifically, our dataset includes the unit values of imported intermediate inputs purchased by Belgian firms at a very high level of disaggregation (over 10,000 products by source country). We use the changes in the unit values of the imported inputs as measures of the exogenous cost shocks to the firms, which 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. We check our identification strategy by validating that our instruments are both strong and pass the over-identification tests.

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

\(^1\)In macroeconomics, the presence of strategic complementarities in price setting across firms is central to generating persistent effects of monetary shocks in models of staggered price adjustment (see e.g. Kimball 1995, and the literature that followed).

\(^2\)We use the word idiosyncratic to emphasize that this cost pass-through elasticity is a counterfactual object which holds constant the prices of the firm’s competitors. Also note that the strategic complementarity elasticity could, in principle, be negative if the prices of the firms were strategic substitutes.
35–40 percent. In other words, when the firm’s competitors raise their prices by 10 percent, the firm increases its own price by 3.5–4 percent in the absence of any movement in its marginal cost, and thus entirely translating into an increase in its markup. At the same time, the elasticity of the firm’s price to its own marginal cost, holding constant the prices of its competitors, is on average 60–65 percent. 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 percent) 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.

We further show that the average estimates for all manufacturing firms conceal a great deal of heterogeneity in the elasticities across firms. 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 a 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 50–55 percent, and the elasticity of their prices with respect to the prices of their competitors to be 45–50 percent. These large firms, though small in number, account for the majority of sales, and therefore shape the average elasticities in the data.

The estimated elasticities of firm price responses are the fundamental primitives that shape the transmission of international shocks into domestic prices and quantities. Aggregate shocks affect firms through a variety of channels. For concreteness, consider the effect of an exchange rate shock. Firms adjust prices in response to an exchange rate movement both because it affects their marginal costs (e.g., due to the presence of imported intermediate inputs) and the prices of their competitors (e.g., the importers into the domestic market). How much of the exchange rate shock is passed through into the aggregate industry price depends on a range of factors, including the import intensity of firms, the fraction of industry sales accounted for by foreign firms, and the extent of strategic complementarities in price setting across firms. For Belgium, we find that the aggregate pass-through into producer prices is quite high, at 50 percent, relative to findings in other studies (see, e.g. Goldberg and Campa 2010). To a large extent this is due to the unusual openness of the Belgian market both to foreign competition and to the sourcing of foreign intermediate inputs. We take advantage of the international openness of Belgium to construct powerful instruments, which are essential for our identification, as we explain...

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3In 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. We calculate the competitor price index as the average weighted by sales of the competitor-firms.

4Our baseline definition of a large firm is a firm in the top quintile (20 percent) 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 percent market share within its industry. The large firms, according to this definition, account for about 65 percent of total manufacturing sales.

5More precisely, the deeper primitives are the markup elasticities and the curvature of the cost (i.e., the return to scale), which we can recover from our estimates. Our aggregate estimates imply markup elasticities with respect to the firm’s own price and the price of its competitors both equal to 0.6. Furthermore, we do not impose the assumption of constant marginal costs in our estimation, but instead verify that this hypothesis is not rejected by the data.
below. Nevertheless, the fundamental forces of price setting that we estimate in the Belgian market are likely to apply in other markets as well, and therefore we expect our estimates of the primitive elasticities to generalize to other environments.

In order to explore the more general implications of our empirical estimates for the international transmission of shocks into domestic prices, we exploit the heterogeneity across Belgian industries through a prism of a calibrated equilibrium model of variable markups. We use the model to simulate an artificial dataset with many industries, disciplined by the observed variation across the Belgian manufacturing sector. This allows us to slice the data in a number of ways in order to unpack the heterogeneity across firms and industries underlying our results from the regression analysis. This also enables us to consider counterfactual industry structures in terms of the extent of foreign competition and international input sourcing that are more characteristic for countries less open than Belgium. We use the calibrated model to study the effect of an exchange rate devaluation on firm-level prices, costs, and markups, as well as on aggregate price indexes across heterogeneous industries.

This calibration exercise requires taking a stand on a particular model of variable markups. In our baseline analysis, we adopt a model of oligopolistic competition under CES demand, following Atkeson and Burstein (2008), and the appendix extends the analysis to allow for non-CES Kimball (1995) demand. We first show that the calibrated model successfully matches the joint distribution of firm market shares and import intensities within industries, as well as the average strength of and cross-sectional heterogeneity in strategic complementarities that we document in the data. In the model, firms set variable markups and adjust them in response to own cost shocks and changes in the competitor prices. Furthermore, larger firms have greater markup variability, as they find it more profitable to adjust their markups in order to maintain their market shares. In contrast, small firms choose to maintain their markups (which are small to begin with) at the expense of a drop in their market shares.

The simulation results for the average industry show that, despite substantial strategic complementarities in price setting, the adjustment of markups in response to an exchange rate shock is quite modest. We show that this is because the largest Belgian firms, which are most sensitive to the prices of their international competitors, are themselves directly exposed to exchange rate movements through the imported inputs channel. As a result, these firms choose not to adjust markups as much because a devaluation also makes their inputs more expensive, hence there is not as much scope to simultaneously increase markups and obtain a competitive edge relative to their foreign competitors. The small firms, which do not import much of their intermediate inputs, in contrast do not exhibit strong strategic complementarities, and as a result also end up not changing much their markups.

We show, however, that exchange rate pass-through varies considerably across industries. For example, in industries with stronger foreign competition, there is more markup adjustment because a nominal devaluation still allows the large domestic firms to gain a considerable competitive edge against their average competitor within the industry. Similarly, the markup adjustment is larger for industries with a smaller exposure to foreign intermediate inputs. Finally, markup adjustment is also larger in more “granular” industries, where a greater share of the domestic market is served by a single

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6In principle, this exercise can be done using data alone, but the precision of estimates drops once we start slicing the data more finely across industries, and so we use a tightly-calibrated model to fill in this gap.
domestic firm. This is because the strategic complementarities are mostly exhibited by the very large firms, as we document in the data.

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. In contrast, for our estimation we adopt a general accounting framework, and our identification relies instead on the instrumental variables, thus providing direct model-free evidence on the importance of strategic complementarities in price setting.

The few studies that have focused on the pass-through of exchange rate shocks into domestic consumer and producer prices have mostly relied on aggregate industry level data (see, e.g. Goldberg and Campa 2010). The more disaggregated empirical studies that use product-level prices (Auer and Schoenle 2013, Cao, Dong, and Tomlin 2012, Pennings 2012) have typically not been able to match the product-level price data with firm characteristics, prices of local competitors, and in particular 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 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.

Amiti, Itskhoki, and Konings (2014) develop an identification strategy to decompose the variation across exporters in the exchange rates pass-through into the markup and marginal cost channels in the absence of direct data on prices of local competitors, which excludes the possibility of a counterfactual analysis. By constructing a more comprehensive dataset of firm prices and costs, this paper overcomes many of the limitations of the previous studies.

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 or commodity price shocks. Studies

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7 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). 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 elasticity. Nonetheless, with enough observations, one can use our method to reconstruct the entire markup function for the firms.

8 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.
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, De Loecker, Goldberg, Khandelwal, and Pavcnik (2012) analyze the Indian trade liberalization and Edmond, Midrigan, and Xu (2015) study a counterfactual trade liberalization in Taiwan, both finding evidence of procompetitive effects of a reduction in output tariffs. These studies take advantage of the 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.\footnote{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 Edmond, Midrigan, and Xu (2015). Our analysis differs in that we bring in more direct moments of markup variation across firms, which we estimate in the first part of the paper to discipline the calibration of the model’s parameters.}

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 and cost structures. Using this framework, we estimate the strength of strategic complementarities in Section 3. Second, we use these estimates in our quantitative analysis in Section 4, where we explore the heterogeneity in our results and the aggregate implications of pass-through. For this exercise we will need to commit to a particular model of variable markups, which we describe in Section 2.2. We choose a popular model introduced by Krugman (1987) and further developed by Atkeson and Burstein (2008), with oligopolistic competition and CES demand, which nests into our more general accounting framework. An advantage of this model, which we illustrate, is that it generates heterogeneity in markups consistent with our data. 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 and log markup:

\[ \log p_{it} \equiv \log mc_{it} + \log \mu_{it}, \tag{1} \]

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 a minimum necessary structure on the equilibrium environment, which allows us 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.  

We focus on a given industry \( s \) with \( N \) competing firms, denoted with \( i \in \{1, \ldots, N\} \), 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 \( p_t \equiv (p_{1t}, \ldots, p_{Nt}) \) the vector of prices of all firms in the industry, and with \( p_{-it} \equiv (p_{1t}, \ldots, p_{i-1,t}, p_{i+1,t}, \ldots, p_{Nt}) \) the vector of prices of all firm-\( i \)’s competitors, and we make use of the notational convention \( p_t \equiv (p_{it}, p_{-it}) \). We consider an invertible demand system, which constitutes a one-to-one mapping between any vector of prices \( p_t \) and a corresponding vector of quantities demanded \( q_t \equiv (q_{1t}, \ldots, q_{Nt}) \), given the vector of demand shifters \( \xi_t = (\xi_{1t}, \ldots, \xi_{Nt}) \):

\[
q_{it} = q_i(p_t; \xi_t), \quad i \in \{1, \ldots, N\}.
\]

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 statically optimal log markup of the firm:

\[
\mu_{it} = \log \frac{\sigma_{it}}{\sigma_{it} - 1},
\]

which expresses the markup as a function of the curvature of demand, namely the demand elasticity \( \sigma_{it} \). 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) or in quantities (Cournot). More precisely, for any demand and competition structure, there exists a perceived demand elasticity function of firm \( i \), \( \sigma_{it} \equiv \sigma_i(p_t; \xi_t) \), such that the firm’s optimal static markup satisfies (2). Outside the monopolistic competition case, \( \sigma_{it} \) depends both on the curvature of demand and the assumed equilibrium behavior of the competitors (i.e., constant competitor prices under Bertrand and constant quantities under Cournot competition).

We summarize this logic in:

\footnote{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).}

\footnote{The perceived elasticity is defined as \( \sigma_{it} \equiv \frac{dq_{it}}{dp_{it}} = \left[ \frac{\partial q_i(p_t; \xi_t)}{\partial p_{it}} + \sum_{j \neq i} \frac{\partial q_j(p_t; \xi_t)}{\partial p_{jt}} \frac{dp_{jt}}{dp_{it}} \right] \), where \( \frac{dp_{jt}}{dp_{it}} \) is the assumed (conjectured) response of the competitors. Under monopolistic competition, \( \frac{dp_{jt}}{dp_{it}} \equiv 0 \), and the perceived elasticity is determined by the curvature of demand alone. The same is true under and oligopolistic price (Bertrand) competition. Under oligopolistic quantity (Cournot) competition, the assumption is that \( \frac{dq_{it}}{dp_{it}} \equiv 0 \), which requires that \( \frac{dp_{jt}}{dp_{it}} \equiv -\frac{\partial q_j(p_t; \xi_t)}{\partial p_{it}} / \frac{\partial q_i(p_t; \xi_t)}{\partial p_{jt}} \) is a non-zero function of \( (p_t; \xi_t) \), contributing to the value of the demand elasticity perceived by the firm.}
Proposition 1 For any given invertible demand system and any given competition structure, there exists a markup function \( \mu_{it} = M_i(p_{it}, \mathbf{p}_{-it}; \xi_t) \), such that the firm’s static profit-maximizing price \( \tilde{p}_{it} \) is the solution to the following fixed point equation:

\[
\tilde{p}_{it} = mc_{it} + M_i(\tilde{p}_{it}, \mathbf{p}_{-it}; \xi_t),
\]

given the price vector of the competitors \( \mathbf{p}_{-it} \).

We provide a formal proof of this intuitive result in Appendix D.1, and here offer a brief commentary and a discussion of assumptions. The markup function \( M_i(p_t; \xi_t) \) and the fixed point in (3) formalizes the common-sense logic 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 \( \mathbf{p}_{-it} \). Therefore, equation (3) characterize 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). The full industry equilibrium is achieved when equations corresponding to (3) hold for every firm \( i \in \{1, \ldots, N\} \) 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 Itskhiok 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 system considered by Arkolakis, Costinot, Donaldson, and Rodriguez-Clare (2015), 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. Gopinath and Itskhiok 2010) or inventory management (as e.g. Alessandria, Kaboski, and Miderigan 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. 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 $N$). Note that the markup function $M_i(\cdot)$ 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 price-setting behavior of the firms. In particular, the implication of Proposition 1 is that competitor prices $p_{-it}$ form a sufficient statistic for firm-$i$’s pricing decision, which hence does not directly depend on the competitors’ marginal costs $mc_{-it} \equiv \{mc_{jt}\}_{j \neq i}$, a property we test empirically 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 $(p_t; \xi_t) = (\tilde{p}_{it}, p_{-it}; \xi_t)$, i.e. any point that itself satisfies equation (3). We obtain the following decomposition for the firm’s log price differential:

$$dp_{it} = dmc_{it} + \frac{\partial M_i(p_t; \xi_t)}{\partial p_{it}} dp_{it} + \sum_{j \neq i} \frac{\partial M_i(p_t; \xi_t)}{\partial p_{jt}} dp_{jt} + \sum_{j=1}^{N} \frac{\partial M_i(p_t; \xi_t)}{\partial \xi_{jt}} d\xi_{jt}, \quad (4)$$

Note that the markup function $M_i(\cdot)$ is not an equilibrium object as it can be evaluated for an arbitrary price vector $p_t = (p_{it}, p_{-it})$, 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 $dmc_{it}$, the prices of its competitors $\{dp_{jt}\}_{j \neq i}$, and the demand shifters $\{d\xi_{jt}\}_{j=1}^{N}$. 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. Importantly, note that the perturbation to the optimal price of the firm does not depend on the shocks to competitor marginal costs, as competitor prices provide a sufficient statistic for the optimal price of the firm (according to Proposition 1).

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

$$dp_{it} = \frac{1}{1 + \Gamma_{it}} dmc_{it} + \frac{\Gamma_{-it}}{1 + \Gamma_{it}} dp_{-it} + \varepsilon_{it}, \quad (5)$$

dynamic. In this case, the realized markup $\mu_{it}$ 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.

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.

If we combine together equations (4) for all firms $i \in \{1, ..., N\}$, we can solve for the equilibrium perturbation of all prices $(dp_{1t}, ..., dp_{Nt})$ as a function of the exogenous cost and demand shocks $(dmc_{1t}, ..., dmc_{Nt}, d\xi_{1t}, ..., d\xi_{Nt})$, which constitutes the reduced form of the model, as we discuss further in Section 2.3.
where we introduce the following new notation:

\[ \Gamma_{it} \equiv -\frac{\partial M_i(p_t; \xi_t)}{\partial p_{it}} \quad \text{and} \quad \Gamma_{-it} \equiv \sum_{j \neq i} \frac{\partial M_i(p_t; \xi_t)}{\partial p_{jt}} \]

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

\[ d p_{-it} \equiv \sum_{j \neq i} \omega_{ijt} d p_{jt} \quad \text{with} \quad \omega_{ijt} \equiv \frac{\partial M_i(p_t; \xi_t)}{\partial p_{jt}} / \sum_{k \neq i} \frac{\partial M_i(p_t; \xi_t)}{\partial p_{kt}}. \]

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 \( d p_{-it} \) aggregates the individual price changes across all firm’s competitors, \( d p_{jt} \) for \( j \neq i \), using endogenous (firm-state-specific) weights \( \omega_{ijt} \), which are defined to sum to one. These weights depend on the relative markup elasticity: the larger is the firm’s 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

\[ \varepsilon_{it} \equiv \frac{1}{1 + \Gamma_{it}} \sum_{j=1}^{N} \frac{\partial M_i(p_t; \xi_t)}{\partial \xi_{jt}} d \xi_{jt}. \]

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 \( d p_{it} \) into responses to its own cost shock \( d mc_{it} \), the competitor price changes \( d p_{-it} \), and the demand shifters captured by the residual \( \varepsilon_{it} \). The two coefficients of interest are:

\[ \psi_{it} \equiv \frac{1}{1 + \Gamma_{it}} \quad \text{and} \quad \gamma_{it} \equiv \frac{\Gamma_{-it}}{1 + \Gamma_{it}}. \]

The coefficient \( \psi_{it} \) 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 \( \gamma_{it} \) 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.\(^{16}\) The coefficients \( \psi_{it} \) and

\(^{16}\)This abuses the terminology somewhat since \( \gamma_{it} \) 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, \( \gamma_{it} \) 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
\( \gamma_{it} \) are shaped by the markup elasticities \( \Gamma_{it} \) and \( \Gamma_{-it} \): higher own markup elasticity reduces the own cost pass-through, as markups are more accommodative of shocks, while 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 under which the weights in (7) can be approximated by firm market shares (see proof in Appendix D.1). We later test these conditions empirically in Section 3.2, as well as relax them non-parametrically in Section 3.3.

**Proposition 2** If a sufficient statistic for competitors’ prices in firm demand is a sectoral log expenditure function \( e_t \), i.e. \( q_{it} = q_i(p_{it}, e_t; \xi_t) \), then the weights in the competitor price index (7) are proportional to the sectoral revenue market shares \( S_{jt} \) of the competitor firms \( j \neq i \) and given by \( \omega_{ijt} \equiv \frac{S_{jt}}{1 - S_{it}} \), and hence the index of competitor price changes simplifies to:

\[
\text{d}p_{-it} \equiv \sum_{j \neq i} \frac{S_{jt}}{1 - S_{it}} \text{d}p_{jt} \tag{9}
\]

If, in addition, the perceived demand elasticity depends only on the relative price, i.e. \( \sigma_{it} = \sigma_i(p_{it} - e_t; \xi_t) \), the two markup elasticities in (6) are equal:

\[
\Gamma_{-it} \equiv \Gamma_{it}. \tag{10}
\]

The expenditure function is defined in a standard way, and its main property for the purposes of Proposition 2 is the Shephard’s lemma: the elasticity of the expenditure function with respect to firm-\( j \)’s price equals firm-\( j \)’s market share, \( \partial e_t / \partial p_{jt} = S_{jt} \).\(^\text{17}\) This clarifies why the relevant weights in the competitor price index (9) are proportional to the market shares. Indeed, under the assumptions of Proposition 2, the markup function can be also written as \( M_i(p_{it}, e_t; \xi_t) \), or \( M_i(p_{it} - e_t; \xi_t) \), and the results of the proposition follow from the definitions in (6) and (7).\(^\text{18}\)

While the assumptions underlying Proposition 2 are not innocuous, and in particular impose symmetry across firms,\(^\text{19}\) they are satisfied for a broad class of demand models considered in Arkolakis, by the firm induces its competitors to change their prices as well because of strategic complementarities. Nonetheless, \( \psi_{it} \) is a well-defined counterfactual elasticity, characterizing firm’s best response off equilibrium.

\(^\text{17}\)The log expenditure function is given by \( e_t = \log \min_{i\in Q_{it}} \left\{ \sum_{i=1}^N p_{it} Q_i \cdot U(Q_i; Q_t) = 1 \right\} \), where \( U(\cdot) \) is the preference aggregator and \( Q_i \) is the (sectoral) consumption aggregator. Shephard’s lemma follows from the Envelope theorem.

\(^\text{18}\)Replacing \( M_i(p_t; \xi_t) \) with \( M_i(p_{it}, e_t; \xi_t) \) in (6) and (7), we have:

\[
\Gamma_{-it} = \frac{\partial M_i(p_{it}, e_t; \xi_t)}{\partial e_t} \sum_{j \neq i} \frac{\partial e_t}{\partial p_{jt}} = (1 - S_{it}) \frac{\partial M_i(p_{it}, e_t; \xi_t)}{\partial e_t} \quad \text{and} \quad \omega_{ijt} = \frac{\partial M_i(p_{it}, e_t; \xi_t) / \partial p_{jt}}{- \Gamma_{-it}} = \frac{S_{jt}}{1 - S_{it}}.
\]

Under the additional assumption that \( M_i(p_{it} - e_t; \xi_t) \), we have \( M_i(p_{it} - e_t; \xi_t) / \partial p_{it} = - M_i(p_{it} - e_t; \xi_t) / \partial e_t \), and therefore from (6):

\[
\Gamma_{it} = - \left[ \frac{\partial M_i(p_{it}, e_t; \xi_t)}{\partial p_{it}} + S_{it} \frac{\partial M_i(p_{it}, e_t; \xi_t)}{\partial e_t} \right] = \Gamma_{-it}.
\]

\(^\text{19}\)Namely, the significance of any firm for all other firms is summarized by the firm’s market share. Proposition 2 also rules out cases in which a sufficient statistic for competitor prices exists but is different from the expenditure function, as is the case in the version of Kimball demand discussed in Appendix F. We show, however, that Proposition 2 still provides a good quantitative approximation in that case.
Costinot, Donaldson, and Rodríguez-Clare (2015) and Parenti, Thissé, 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 these 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.

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 \( \psi_{it} \) and \( \gamma_{it} \) in this decomposition, as they have a sufficient statistic property for analyzing the response of firm prices to shocks. At the same time, the structural interpretation of these elasticities depends on a specific model. Before turning to our empirical identification strategy, we briefly describe one specific structural model, which offers a concrete illustration for our 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 \( \Gamma_{it} \equiv \Gamma_{it}^-=0 \), 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).\(^{20}\) In the following Section 3 we provide direct empirical evidence on the magnitudes of \( \psi_{it} \) and \( \gamma_{it} \), 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.\(^{21}\) Specifically, consumers (or 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

\(^{20}\) Fitzgerald and Haller (2014) offers a direct empirical test of pricing to market and Burstein and Gopinath (2012) provide a survey of the recent empirical literature on the topic.

\(^{21}\) 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 F, we offer a generalization to the case with both oligopolistic competition and non-CES demand following Kimball (1995), as well as consider the quantitative implication of non-CES demand for our analysis.
elasticity of substitution across industries is \( \eta \geq 1 \), while the elasticity of substitution across products within an industry is \( \rho \geq \eta \). Under these circumstances, the demand faced by a firm is:

\[
Q_{it} = \xi_{it} D_{st} P_{st}^{\rho - \eta} P_{it}^{-\rho},
\]

where \( \xi_{it} \) is the product-specific preference shock (normalized to sum to one across the firms in the industry), \( D_{st} \) is the industry-level demand shifter, \( P_{st} \) is the industry price index and \( P_{it} \) is the firm’s price, with corresponding small letters denoting the logs.

The industry price index \( P_{st} \) equals the expenditure function, and is defined according to:

\[
P_{st} = \left[ \sum_{i=1}^{N} \xi_{it} P_{it}^{1-\rho} \right]^{1/(1-\rho)},
\]

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.\(^{22}\)

Further, we can write the firm’s market share as:

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

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 in the eyes of the customers (i.e., a large demand shifter \( \xi_{it} \)).

As in much of the quantitative literature following Atkeson and Burstein (2008), for example Edmond, Midrigan, and Xu (2015), 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:\(^{23}\)

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

where \( \sigma_{it} \) 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.

\(^{22}\)In general, \( D_{st} = \varpi_{st} Y_t / P_t \), where \( \varpi_{st} \) is the exogenous industry demand shifter, \( Y_t \) is the nominal income in the economy and \( P_t \) is the aggregate price index, so that \( Y_t / P_t \) is the real income in the economy. We assume that the firms are too small to affect \( P_t \) or \( Y_t \), and hence the only effect of a firm on the industry demand is through the industry price index \( P_{st} \).

\(^{23}\)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 E.
The elasticity of 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), it can be verified that the index of competitor price changes in this model satisfies (9), and hence both results of Proposition 2 apply in this case.\(^{24}\) One additional insight from this model is that \( \Gamma_{it} \) is a function of the firm’s market share \( S_{it} \) alone, given the structural demand parameters \( \rho \) and \( \eta \):

\[ \Gamma_{it} \equiv \Gamma(S_{it}). \tag{17} \]

Furthermore, this function is increasing in market share over the relevant range of market shares in the data, and equals zero at zero market share, \( \Gamma(0) = 0.\(^{25}\) This implies that small firms with \( S_{it} \approx 0 \), have \( \Gamma_{it} = \Gamma_{-it} \approx 0 \) and must exhibit complete pass-through of own cost shocks (\( \psi_{it} = 1 \)) and no strategic complementarities (\( \gamma_{it} = 0 \)), just like in the monopolistic competition case. Indeed, such firms are monopolistic competitors. However, firms with positive market shares have \( \Gamma_{it} = \Gamma_{-it} > 0 \), and hence have incomplete pass-through and positive strategic complementarities in price setting vis-à-vis their competitors, \( \psi_{it}, \gamma_{it} \in (0, 1) \). The intuition behind these differences in markup elasticities between small and large firms can be explained as follows. Smaller unproductive firms have small markups and hence limited capacity to adjust them in response to shocks, while larger firms have more scope to adjust their larger markups in order to maintain their market shares.\(^{26}\) We will test for this heterogeneity in the data.

### 2.3 Identification

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

\[ \Delta p_{it} = \psi_{it} \Delta m c_{it} + \gamma_{it} \Delta p_{-it} + \varepsilon_{it}, \tag{18} \]

\(^{24}\)Indeed, both requirements of Proposition 2 are satisfied in this case. Since the price index \( P_{it} \) also equals the (sectoral) expenditure function, the demand expression in (12) immediately implies \( q_{it} = q(p_{it}, \varepsilon_i; \xi_{it}) \) in logs. Furthermore, the expression for the perceived demand elasticity in (15) and market share (14) together imply that \( \sigma_{it} = \sigma(p_{it} - \varepsilon_i; \xi_{it}) \).

Beyond the more general results of Proposition 2, this model also admits an index of competitor prices in levels:

\[ P_{-it} = \left[ \sum_{j \neq i} \frac{\xi_{jt}}{\xi_{it}} P_{jt}^{1 - \rho} \right]^{1/(1 - \rho)}, \]

so that the overall price index can be expressed as \( P_{it} = (\xi_{it} P_{-it}^{1 - \rho} + (1 - \xi_{it}) P_{it}^{1 - \rho})^{1/(1 - \rho)} \). The expression in changes (9) for \( \Delta p_{-it} \) can then be verified directly by log-differentiation, using (14). Finally, the competitor markup elasticity can be equivalently defined in this case as \( \Gamma_{-it} \equiv \partial \log \frac{\sigma_{it}}{\sigma_{it} - 1} / \partial \log P_{-it} \), instead of the more general definition in (6).

\(^{25}\)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 we adopt in our calibration, \( \Gamma(S) = (\rho - 1) S \), and hence \( \Gamma'(S) > 0 \), for \( S \in [0, 1] \).

\(^{26}\)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, as we show in Appendix F.
where \( \Delta p_{it} \equiv p_{i,t+1} - p_{it} \). Therefore, the estimating equation (18) 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 (18) is associated with a number of identification challenges. First of all, it requires obtaining direct measures of firms’ marginal costs and an appropriate index of competitor prices. Next, an instrumental variable strategy is needed to deal with the endogeneity of prices and possibly also marginal costs. Lastly, the heterogeneity in coefficients \( \psi_{it} \) and \( \gamma_{it} \) needs to be accommodated. We now address these challenges in turn:

1. **Measurement of marginal cost \( \Delta mc_{it} \).** Good firm-level measures of marginal costs are notoriously hard to come by. We adopt the following rather general model of the marginal cost:

\[
MC_{it} = W_{it}^{1-\phi_{it}} V_{it}^{\phi_{it}} \frac{Y_{it}^{\alpha_i}}{A_{it}},
\]

or equivalently in log changes:

\[
\Delta mc_{it} = \phi_{it} \Delta v_{it} + (1 - \phi_{it}) \Delta w_{it} + \Delta \phi_{it} (v_{it} - w_{it}) + \alpha_i \Delta y_{it} - a_{it},
\]

where \( w_{it} \) and \( v_{it} \) are the firm-\( i \)-specific log cost indexes of domestic and imported inputs, \( \phi_{it} \) is the fraction of expenditure spent on imported inputs (i.e., import intensity of the firm), \( a_{it} \) is the log productivity and \( y_{it} \) is the log output index. Importantly, this model does not restrict the production structure to be Cobb-Douglas, as the expenditure elasticity \( \phi_{it} \) is not required to be constant. We allow the degree of decreasing returns to scale \( \alpha_i \geq 0 \) to be firm-specific, but require it to be constant over time.\(^{27}\)

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 \( \alpha_i \):

\[
\Delta mc_{it} = \Delta avc_{it},
\]

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:

\[
\Delta mc^{*}_{it} = \phi_{it} \Delta v_{it}.
\]

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

2. **Measurement of competitor prices \( \Delta p_{-it} \).** 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

\(^{27}\)Note that this model does not rule out the possibility of fixed costs, which can give rise to increasing returns to scale.
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 \( \omega_{ijt} \) in (7). We follow Proposition 2, and use the discretized version of (9):

\[
\Delta p_{\cdot it} = \sum_{j \neq i} S_{jt} \left( \frac{S_{jt}}{1 - S_{it}} \right) \Delta p_{jt}.
\]  

(23)

We test empirically the assumptions underlying Proposition 2, namely the parameter restriction (11). In addition, in Section 3.3, we relax (23) 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.

3. Endogeneity and instrumental variables. The next identification challenge is the endogeneity of the competitor prices on the right-hand side of the estimating equation (18). 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 \( \varepsilon_{it} \) in (18). Our baseline identification strategy uses the precisely-measured imported component of the firm’s marginal cost, \( \Delta mc^*_j \) defined in (22), as the instrument. Specifically, we aggregate \( \Delta mc^*_j \) for \( j \neq i \) into an index to instrument for \( \Delta p_{\cdot it} \). 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.

4. Heterogeneity of coefficients. Finally, the estimating equation (18) features heterogeneity in the coefficients of interest \( \psi_{it} \) and \( \gamma_{it} \). In our baseline, we pool the observations to estimate common coefficients \( \psi \) and \( \gamma \) for all firms and time periods, which we interpret as average elasticities across firms. The two concerns here are the use of the IV estimation, which complicates the interpretation of the estimates as the averages, and the possibility of unobserved heterogeneity, which may result in biased estimates. We deal with these concerns 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 \( \psi_{it} \) and \( \gamma_{it} \) are functions of the market share of the firm and nothing else within industry. 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 F. Accordingly, we split our firms into small and large, and estimate elasticities separately for each subgroup. We discuss some additional splits of the sample in Section 3.3.

We close this section with a brief discussion of our choice of estimating equation (18). 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:
\[ \Delta p_{it} = \alpha_{it} \Delta mc_{it} + \beta_{it} \Delta mc_{-it} + \xi_{it}, \]
which is an equilibrium relation between the firm’s price change and all exogenous shocks of the model. In Appendix D.3, we provide an explicit solution for the reduced-form coefficients \( \alpha_{it} \) and \( \beta_{it} \), as well as for the theoretically-grounded notion of the competitor marginal cost index \( \Delta mc_{-it} \).

There are a number of reasons why we choose to estimate the reaction function (18) as opposed to the reduced form (24). The first reason is due to data limitations. Equation (24) requires measures of the full marginal cost for all firms in order to construct \( \Delta mc_{-it} \), and we have comprehensive measures of marginal costs available only 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 (24), it is not a problem for estimating (18), which only requires an instrument for the index of competitor price changes \( \Delta p_{-it} \), fully available to us.

Lastly, and importantly given our focus, the coefficients of the reaction function \( \psi_{it} \) and \( \gamma_{it} \) have a clearer structural interpretation than the reduced-form coefficients \( \alpha_{it} \) and \( \beta_{it} \). As we show in (8), the elasticities \( \psi_{it} \) and \( \gamma_{it} \) are directly shaped by a firm’s markup elasticity \( \Gamma_{it} \), 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, as we show in Appendix D.3, 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 exchange rate shocks, a theme we return to in Section 4.

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 (18). We do this by combining three different datasets for Belgium manufacturing firms for the period 1995 to 2007 at the annual frequency, provided to us by the National Bank of Belgium. 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

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28Equation (24) 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.

29Even if the full measures of the competitor marginal costs were available, it would be difficult to construct the appropriate marginal cost index \( \Delta mc_{-it} \), as the weights in this index depend on the firm-specific pass-through elasticities even when the conditions of Proposition 2 are satisfied (see Appendix D.3).
the first 4 digits of the PC 8-digit code). 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 C.

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. As in Section 2, we use index $i$ for firm-products and index $s$ for industries.

**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 $\Delta p_{it}$, 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 sold domestically to production quantity sold domestically:

$$\Delta p_{it} = \Delta \log \frac{\text{Domestic Value}_{it}}{\text{Domestic Quantity}_{it}}$$  \hspace{1cm} (25)

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

$$\Delta m_{C_{it}} = \Delta \log \frac{\text{Total Variable Cost}_{it}}{Y_{it}},$$  \hspace{1cm} (26)

\[30\] 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).
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.\(^{31}\) 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 \( \Delta mc_{it} \) 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 (22), which we measure as follows:

\[
\Delta mc_{it}^r = \phi_{it} \sum_m \omega_{cimt} \Delta v_{imt},
\]

where \( \phi_{it} \) 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 \( \Delta v_{imt} \) are the changes in the log unit values of the firm’s imported intermediate inputs (in euros). The weights \( \omega_{cimt} \) 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 \( \Delta mc_{it}^r \). 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 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 (23), and calculate the index of competitor price changes as:

\[
\Delta p_{it} = \Delta p_{D-it} + \Delta p_{F-it}
\]

where

\[
\Delta p_{D-it} = \sum_{j \in D_i} \frac{S_{jt}}{1 - S_{it}} \Delta p_{jt} \quad \text{and} \quad \Delta p_{F-it} = \sum_{j \in F_i} \frac{S_{jt}}{1 - S_{it}} \Delta p_{jt},
\]

\( D_i \) 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.\(^{32}\) Only the imports categorized as final goods enter

\(^{31}\) More precisely, we calculate the change in the log production quantity as the difference between \( \Delta \log \text{Revenues} \) and \( \Delta \log \text{Price index of the firm} \), and subtract the resulting \( \Delta \log Y_{it} \) from \( \Delta \log \text{Total Variable Cost}_{it} \) to obtain \( \Delta mc_{it} \) in (26).

\(^{32}\) In the denominator in (29), \( S_{it} \) 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
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 we have at least two 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 $\Delta mc_{it}$ is the foreign component of the marginal cost $\Delta mc^*_{it}$, defined above in (27). Here, we describe the construction of the three additional instruments we use to address the endogeneity of the competitors’ prices in $\Delta p_{it}$, each proxying for the marginal costs of the different types of competitors. For the domestic competitors, we use a weighted average (in parallel with $\Delta p^D_{it}$ in (29)) 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 32). In the robustness Section 3.3, we replace the marginal cost instruments $\Delta mc^*_{it}$ and $\Delta mc^*_{it}$ with the corresponding firm-level exchange rates, weighted by firm import intensities from specific source countries, which we denote with $\Delta e_{it}$.33

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 the marginal costs using the industry import-weighted exchange rate:

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

where $k$ indexes source countries and $\omega^e_{skt}$ 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 as import weights the value of imports of each product into Belgium. The idea is that movements in these price indexes should positively correlate with movements in Belgium’s main euro trading partners’ marginal costs without domestic firms net of firm $i$ in the same industry. Therefore, $\sum_{j \in D_i} S_{jt} + \sum_{\ell \in F_i} S_{\ell t} = 1 - S_{it}$, and the sum of the weights in (29) equals one. In practice, we measure $S_{jt}$ as the average of $t$ and $t - 1$ market shares of firm-product $j$.

33Formally, in parallel with (27), $\Delta e_{it} = \phi_{it} \sum_m \omega^e_{int} \Delta e_{mt}$, that is we replaced the input price changes $\Delta v_{int}$ with the corresponding bilateral exchange rate changes $\Delta e_{mt}$, 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.
being affected by the demand conditions in Belgium. We denote this instrument with $\Delta p_{t}^{EU}$. 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 (18). This results in two estimated average elasticities, the own cost pass-through elasticity $\psi$ and the strategic complementarities elasticity $\gamma$ (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 (18) using OLS, with year fixed effects in column 1 and with both year and industry fixed effects in column 2. The coefficients on both the firm’s marginal cost and on the competitors’ price index are positive, of similar magnitudes and significant, yet the two coefficients only sum to 0.7, violating the parameter restriction of Proposition 2. These estimates, however, are likely to suffer from endogeneity bias due to the simultaneity of price setting by the firm and its competitors $\Delta p_{it}$, as well as from downward bias due to measurement error in our marginal cost variable $\Delta mc_{it}$. Indeed, while our proxy for marginal cost, as described in equation (26), 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 (18) using instrumental variables. For the firm’s marginal cost, we instrument with the foreign component of its marginal cost $\Delta mc_{it}^{*}$, as defined in equation (27). 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 $\varepsilon_{it}$ in (18), which reflects shocks to demand and perceived quality of the good. 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 Sec-

---

34One way to see that $\Delta mc_{it}^{*}$ is more precisely measured than $\Delta mc_{it}$ is with the projection of $\Delta mc_{it}$ on $\Delta mc_{it}^{*}$, 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 $\Delta mc_{it}$ 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 $\Delta mc_{it}$ simultaneously on $\Delta mc_{it}^{*}$ and all other instruments.
### Table 1: Strategic complementarities

#### Panel A: Baseline estimates

<table>
<thead>
<tr>
<th>Dep. var.: $\Delta p_{it}$</th>
<th>OLS</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>$\Delta mc_{it}$</td>
<td>0.348***</td>
<td>0.348***</td>
</tr>
<tr>
<td></td>
<td>(0.040)</td>
<td>(0.041)</td>
</tr>
<tr>
<td>$\Delta p_{-it}$</td>
<td>0.400***</td>
<td>0.321***</td>
</tr>
<tr>
<td></td>
<td>(0.079)</td>
<td>(0.095)</td>
</tr>
<tr>
<td># obs.</td>
<td>64,815</td>
<td>64,815</td>
</tr>
<tr>
<td>Industry F.E.</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>$H_0$: $\psi + \gamma = 1$</td>
<td>0.75 [0.00]</td>
<td>0.67 [0.00]</td>
</tr>
<tr>
<td>$\chi^2$ and [p-value]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weak Instrument $F$-test</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.

#### Panel B: First stage regressions

<table>
<thead>
<tr>
<th>Dep. var.: $\Delta mc^*_it$</th>
<th>Column (3)</th>
<th>Column (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\Delta mc_{it}$</td>
<td>$\Delta p_{-it}$</td>
</tr>
<tr>
<td>$\Delta mc^*_it$</td>
<td>0.614***</td>
<td>0.173***</td>
</tr>
<tr>
<td></td>
<td>(0.111)</td>
<td>(0.039)</td>
</tr>
<tr>
<td>$\Delta mc^*_{-it}$</td>
<td>0.392***</td>
<td>0.468**</td>
</tr>
<tr>
<td></td>
<td>(0.098)</td>
<td>(0.148)</td>
</tr>
<tr>
<td>$\Delta e_{st}$</td>
<td>-0.222</td>
<td>0.270**</td>
</tr>
<tr>
<td></td>
<td>(0.230)</td>
<td>(0.120)</td>
</tr>
<tr>
<td>$\Delta p^E_{st}$</td>
<td>0.194***</td>
<td>0.304***</td>
</tr>
<tr>
<td></td>
<td>(0.054)</td>
<td>(0.053)</td>
</tr>
</tbody>
</table>

Industry F.E. | no | yes | yes |
First stage $F$-test | 46.92 | 22.39 | 41.24 | 33.53 |
[p-value] | [0.00] | [0.00] | [0.00] | [0.00] |
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 $\Delta mc_{it}$ equations, the largest coefficient of around 0.6 is on the firm's own foreign component of the marginal cost $\Delta mc^*_{it}$, while the competitor marginal cost index $\Delta mc^*_{-it}$ 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.\footnote{Formally, identification requires that $\Delta mc_{it}$ is not too closely correlated with $\Delta p_{-it}$, which in theory requires sufficiently uncorrelated shocks to marginal costs across firms. In the data, the correlation between $\Delta mc_{it}$ and $\Delta p_{-it}$ is merely 0.09, while the correlation between $\Delta mc_{it}$ and $\Delta mc_{-it}$ is 0.44, still sufficiently less than 1.}

The industry weighted exchange rate $\Delta e_{st}$ 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 $\Delta p_{-it}$ equations, all of the instruments are positive and significant, as would be expected, with the largest coefficient of around 0.5 on the domestic competitors' foreign-component of marginal costs $\Delta mc^*_{-it}$. 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 \footnote{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 equality to unity. When we estimate the constrained version of equation (18), 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.} This implies that the data are consistent with the class of models identified in Proposition 2, and our approach to measuring the competitor price index according to (9) is not at odds with the data. Nonetheless, we offer additional robustness, which relaxes 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 $\psi$ of around 0.65–0.75. At the same time, firms exhibit substantial strategic complementarities, adjusting their prices with an average elasticity $\gamma$ 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 $\gamma$ and $\psi$ 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 $\Gamma$ 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.\footnote{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 $\Gamma$ 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...
Table 2: Strategic complementarities: Heterogeneity

<table>
<thead>
<tr>
<th>Sample: Large_i defined as:</th>
<th>Employment ≥ 100</th>
<th>Market Share Top 20%</th>
<th>Above 2%</th>
<th>Industry ×Year F.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>Large</td>
<td>All</td>
<td>All</td>
<td>All</td>
</tr>
<tr>
<td>Dep. var.: Δp_{it}</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>Δmc_{it}</td>
<td>0.929***</td>
<td>0.949***</td>
<td>0.947***</td>
<td>0.883***</td>
</tr>
<tr>
<td>(0.152)</td>
<td>(0.201)</td>
<td>(0.226)</td>
<td>(0.192)</td>
<td>(0.129)</td>
</tr>
<tr>
<td>Δmc_{it} × Large_i</td>
<td>0.599**</td>
<td>−0.315</td>
<td>−0.270</td>
<td>−0.284</td>
</tr>
<tr>
<td>(0.237)</td>
<td>(0.351)</td>
<td>(0.356)</td>
<td>(0.305)</td>
<td>(0.178)</td>
</tr>
<tr>
<td>Δp_{−it}</td>
<td>0.078</td>
<td>0.142</td>
<td>0.063</td>
<td>0.016</td>
</tr>
<tr>
<td>(0.189)</td>
<td>(0.225)</td>
<td>(0.180)</td>
<td>(0.126)</td>
<td></td>
</tr>
<tr>
<td>Δp_{−it} × Large_i</td>
<td>0.469**</td>
<td>0.279</td>
<td>0.355</td>
<td>0.509**</td>
</tr>
<tr>
<td>(0.202)</td>
<td>(0.319)</td>
<td>(0.325)</td>
<td>(0.308)</td>
<td></td>
</tr>
<tr>
<td># obs.</td>
<td>49,462</td>
<td>15,353</td>
<td>64,815</td>
<td>64,815</td>
</tr>
<tr>
<td>Overid. J-test</td>
<td>4.99</td>
<td>0.03</td>
<td>6.48</td>
<td>2.68</td>
</tr>
<tr>
<td>χ² and [p-value]</td>
<td>[0.08]</td>
<td>[0.98]</td>
<td>[0.17]</td>
<td>[0.61]</td>
</tr>
<tr>
<td>Weak IV F-test</td>
<td>89.1</td>
<td>27.7</td>
<td>59.1</td>
<td>54.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 Δmc_{it} × 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.

**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 (18) 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, 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 $\Delta p_{-it}$. 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.\footnote{Since the variation in $\Delta p_{-it}$ 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 $\Delta mc_{it}$.}

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. 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%).\footnote{In Appendix Table A2, 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 $\Delta mc_{it}$, 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, we report the first-stage regressions corresponding to columns 1–3 in Appendix Table A3, which show consistent patterns for both small and large firms.}

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,
### Table 3: Robustness: alternative samples

<table>
<thead>
<tr>
<th>Dep. var.: $\Delta p_{it}$</th>
<th>Two-period differences</th>
<th>Alternative input definition</th>
<th>Main product</th>
<th>Alternative industry level</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta mc_{it}$</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td></td>
<td>0.642***</td>
<td>0.654***</td>
<td>0.658***</td>
<td>0.750***</td>
</tr>
<tr>
<td></td>
<td>(0.245)</td>
<td>(0.193)</td>
<td>(0.173)</td>
<td>(0.139)</td>
</tr>
<tr>
<td>$\Delta p_{it}$</td>
<td>0.434*</td>
<td>0.407***</td>
<td>0.374*</td>
<td>0.410***</td>
</tr>
<tr>
<td></td>
<td>(0.234)</td>
<td>(0.157)</td>
<td>(0.200)</td>
<td>(0.150)</td>
</tr>
</tbody>
</table>

# 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.

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, $\Delta mc_{it}^*$. 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 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 De Loecker, Goldberg, Khandelwal, and Pavcnik 2012,
**Table 4: Robustness: alternative sets of instruments**

<table>
<thead>
<tr>
<th>Exclude:</th>
<th>Include:</th>
<th>Dep. var.: $\Delta p_{it}$</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$p_{it}^{EU}$</td>
<td>-</td>
<td>-</td>
<td>$\Delta w_{it}$</td>
<td>-</td>
<td>$\Delta e_{it}$</td>
<td>$\Delta mc_{it}^{<em>}$ and $\Delta mc_{-it}^{</em>}$</td>
</tr>
<tr>
<td>$\Delta mc_{it}$</td>
<td></td>
<td></td>
<td>0.757***</td>
<td>0.777***</td>
<td>0.670***</td>
<td>0.748***</td>
<td>0.595</td>
<td>0.407***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.175)</td>
<td>(0.195)</td>
<td>(0.157)</td>
<td>(0.136)</td>
<td>(0.461)</td>
<td>(0.196)</td>
</tr>
<tr>
<td>$\Delta p_{-it}$</td>
<td></td>
<td></td>
<td>0.314</td>
<td>0.291</td>
<td>0.402**</td>
<td>0.330*</td>
<td>0.462</td>
<td>0.648***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.204)</td>
<td>(0.196)</td>
<td>(0.161)</td>
<td>(0.173)</td>
<td>(0.459)</td>
<td>(0.206)</td>
</tr>
</tbody>
</table>

# 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 $\Delta mc_{it}^{*}$, $\Delta mc_{-it}^{*}$, $\Delta e_{it}$ and $\Delta p_{it}^{EU}$. Each column of the table drops one (or two) of these instruments in turn. Column 1 drops international competitor prices $\Delta p_{it}^{EU}$. Column 2 and 3 drop industry import-weighted exchange rate $\Delta e_{it}$, while column 3 also adds firm-level log wage rate change $\Delta w_{it}$. Column 4 drops $\Delta mc_{-it}^{*}$. Columns 5 and 6 drop both own and competitor marginal cost instruments $\Delta mc_{it}^{*}$ and $\Delta mc_{-it}^{*}$ and add firm and competitor import-weighted exchange rate changes $\Delta e_{it}$ and $\Delta e_{-it}$; column 6 in addition adds firm and competitor log wage rate changes $\Delta w_{it}$ and $\Delta w_{-it}$.

**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 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, $\Delta p_{it}^{EU}$. 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 columns 2, we instead drop the industry import-weighted exchange rate, $\Delta e_{st}$, 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 $\Delta w_{it}$ (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 slopping firm-level supply curves for inputs. Specifically, column 4 drops the competitor imported marginal cost index $\Delta mc^*_{it}$, while columns 5 and 6 drop in addition the firm’s own imported marginal cost measure $\Delta mc_{it}$. We instead use as instruments the firm import-weighted log exchange rate change $\Delta e_{it}$ and, by analogy, the competitor index $\Delta e_{-it}$ (column 5). We add to this set the firm’s wage rate change $\Delta w_{it}$ and the index of competitor wage rate changes $\Delta w_{-it}$ (column 6). In all three cases, we find similar elasticities to our baseline estimates. Overall, our baseline IV results are robust to alternative instrument subsets, both when we dispense with 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 $\Delta p_{-it}$. 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 $\Delta p_{-it}$ into its domestic and foreign components $\Delta p^D_{-it}$ and $\Delta p^F_{-it}$, as defined in (28)–(29), 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.

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 $\Delta p_{-it}$ in column 2 and along with $\Delta p_{-it}$ 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

---

40 When we omit $\Delta mc^*_{it}$ 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 $\Delta e_{it}$, for which $\Delta e_{it} \equiv 0$ for all firms that do not import inputs outside the euro area, while the imported marginal cost $\Delta mc^*_{it}$ is non-zero even for firms importing only from within the euro area (see Section 3.1).
<table>
<thead>
<tr>
<th>Dep. var.: $\Delta p_{it}$</th>
<th>Domestic vs Foreign</th>
<th>Largest competitor</th>
<th>Competitors outside firm’s 4-d. industry</th>
<th>With $\Delta mc_{it}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>$\Delta mc_{it}$</td>
<td>0.764***</td>
<td>0.689***</td>
<td>0.852*</td>
<td>0.845***</td>
</tr>
<tr>
<td></td>
<td>(0.173)</td>
<td>(0.201)</td>
<td>(0.507)</td>
<td>(0.158)</td>
</tr>
<tr>
<td>$\Delta p_{it}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.676</td>
<td></td>
<td></td>
<td>0.293</td>
</tr>
<tr>
<td></td>
<td>(1.417)</td>
<td></td>
<td></td>
<td>(0.353)</td>
</tr>
<tr>
<td>$\Delta p_{it}^D$</td>
<td>0.258</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.407)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta p_{it}^E$</td>
<td>0.387</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.411)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta p_{st}$</td>
<td>0.441</td>
<td>-0.529</td>
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</tr>
<tr>
<td></td>
<td>(0.293)</td>
<td>(2.136)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta p_{st}$</td>
<td></td>
<td></td>
<td>-11.29</td>
<td>-1.333</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(8.13)</td>
<td>(16.835)</td>
</tr>
<tr>
<td>$\Delta mc_{it}^D$</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.406)</td>
</tr>
<tr>
<td># obs.</td>
<td>64,815</td>
<td>64,815</td>
<td>64,815</td>
<td>64,815</td>
</tr>
</tbody>
</table>

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 $\Delta p_{it}$ into domestic and foreign components $\Delta p_{it}^D$ and $\Delta p_{it}^E$, according to (28)–(29). Columns 2 and 3 include the log price change of the firm’s largest competitor in the industry, denoted with $\Delta p_{it}^L$. Columns 4 and 5 include competitor price index outside the firm’s own 4-digit industry, denoted $\Delta p_{st}$. Column 6 includes domestic competitor marginal costs $\Delta mc_{it}^D$ (the measure of foreign competitor marginal costs is unavailable in our data).

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 affect on the industry price index proportional to its market share, as captured by our baseline competitor price index $\Delta p_{it}$.

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, $\Delta p_{st}$. 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 $\Delta p_{it}$ remains unchanged relative to the baseline. Lastly, column 6 includes the marginal cost index for the firm’s competitors $\Delta mc_{it}$, which according to Proposition 1 should have no effect on firm pricing once we control for competitor prices $\Delta p_{it}$. This theoretical prediction is again borne out by the data.
4 Strategic Complementarities in a Calibrated Model

In this section we provide a quantitative analysis of a model of variable markups and strategic complementarities. Specifically, we consider the role of strategic complementarities in shaping the equilibrium response to shocks of both firm-level and aggregate markups and prices across industries. We focus on an exchange rate shock, which affects the pricing decisions of firms through two channels: it has a direct effect on marginal costs of the firms, in particular when firms source intermediate inputs internationally, as well as an indirect effect through the competitor prices, in the presence of strategic complementarities and in particular when some of the competitors are international firms. We do this in the context of a specific structural model outlined in Section 2.2 and calibrated to match the empirical patterns documented in Section 3.2. Before turning to the calibration and quantitative analysis, we briefly describe the logic of how strategic complementarities across and heterogeneity across firms shape the aggregate responses to shocks in an equilibrium environment.

4.1 From micro to macro

Specializing our price decomposition equation (5) to the case of an exchange rate shock $d_e$, we have:

$$\psi_{it} = \frac{1}{1 + \Gamma_{it}} \varphi_{it} + \frac{\Gamma_{it}}{1 + \Gamma_{it}} \Psi_{-it},$$ \hspace{1cm} (30)

where $\psi_{it} \equiv \frac{dp_{it}}{de_{it}}$ is firm-$i$’s exchange rate pass-through, $\varphi_{it} \equiv \frac{dm_{it}}{de_{it}}$ is the effect of exchange rate on firm-$i$’s marginal cost, and $\Psi_{-it} \equiv \sum_{j \neq i} \frac{S_{jt}}{1 - S_{it}} \psi_{jt}$ is the exchange rate pass-through into competitor prices. Note that we use the price index (9) from Proposition 2, as well as its other implication that $\Gamma_{-it} = \Gamma_{it}$, which is borne out by the data. We also assume that demand shocks $\xi_t$ are uncorrelated with the exchange rate, and therefore $d\xi_{it}/de_{it} = 0$ in expectation (indeed, we can think of $\{\psi_{it}, \varphi_{-it}, \Psi_{-it}\}$ as characterizing expected responses). Expression (30) illustrates that firm ERPT is increasing in its marginal cost sensitivity to exchange rate $\varphi_{it}$, which is likely to be larger for importing firms, and with the exchange rate sensitivity of competitor prices $\Psi_{-it}$ provided strategic complementarities are present, $\Gamma_{it} > 0$.

We can further convert (30) into an equation for the response of firm markup to exchange rate:

$$\frac{d\mu_{it}}{de_t} = \frac{dp_{it}}{de_{it}} - \frac{dm_{it}}{de_{it}} = \frac{\Gamma_{it}}{1 + \Gamma_{it}} \cdot [\Psi_{-it} - \varphi_{it}].$$ \hspace{1cm} (31)

This equation makes it clear that the firm adjust its markup in response to an exchange rate shock only if two conditions are satisfied: (1) its markup is variable and its pricing exhibits strategic complementarities ($\Gamma_{it} > 0$) and (2) its cost are affected differentially from the average price response of its competitors ($\varphi_{it} \neq \Psi_{-it}$). Note that the firm’s markup can both decrease or increase, depending on whether its costs increased by more or less relative to the prices of its competitors. Indeed, if the costs increase by less, the firm gains competitive grounds in the industry, and therefore finds it optimal to increase its markup. The lesson from (31) is that the markup adjustment by domestic firms in the domestic market is more nuanced. The standard logic is that, when a currency depreciates, domestic
firms become more competitive and raise markups (equation (31) spells out that \( \varphi_{it} < \Psi_{-it} \) is a necessary condition for this to happen). However, if a domestic firm sources lots of inputs internationally (with \( \varphi_{it} \gg 0 \)) and competes in an industry with few international firms (with \( \Psi_{-it} \approx 0 \)), it might end loosing its competitive position and reducing its markup. In the following section we explore the markup response across firms in a calibrated model.

Equation (30) characterizes the individual firm’s price response to an exchange rate shock as a function of price responses of its competitors, which are jointly determined in equilibrium. We can combine the expressions for \( \psi_{it} \) for all \( i = 1...N \) firms in the industry, and calculate the aggregate industry ERPT, defined as \( \Psi_t = \sum_{i=1}^{N} S_{it} \psi_{it} \). We have:

\[
\Psi_t = \frac{1}{1 - \sum_{i=1}^{N} S_{it} \tilde{\Gamma}_{it}} \sum_{i=1}^{N} S_{it} \varphi_{it},
\]

(32)

where \( \tilde{\Gamma}_{it} \equiv \Gamma_{it} / (1 - S_{it}) \). Note that heterogeneity in \( \{ \varphi_{it}, \Gamma_{it}, S_{it} \} \) matters for aggregate pass-through \( \Psi_t \). In particular, holding constant the aggregate size of the shock to the industry \( \varphi_t \equiv \sum_{i=1}^{N} S_{it} \varphi_{it} \), the aggregate pass-through into prices is lower (\( \Psi_t < \varphi_t \)) when the largest firms both exhibit stronger strategic complementarities (with large \( \Gamma_{it} \)) and import more inputs internationally (with large \( \varphi_{it} \)), which empirically is the relevant case. If instead, \( \tilde{\Gamma}_{it} = \tilde{\Gamma} \) or \( \varphi_{it} = \varphi_t \) for all firms, then \( \Psi_t = \varphi_t \), and strategic complementarities have no bite at the aggregate. We now turn to our quantitative model, which disciplines the cross-sectional heterogeneity using our empirical estimates, to quantify the importance of strategic complementarities for aggregate pass-through.

4.2 Parameterization and calibration

The building blocks of the model are as in Sections 2.2, with the core mechanism being the oligopolistic (quantity) competition under CES demand structure, following Atkeson and Burstein (2008). We focus on an industry equilibrium in the domestic market, in which both domestic and foreign (importing) firms compete, and the costs of the firms follow exogenous processes disciplined by the data. We analyze the joint price setting by different firms that are subject to idiosyncratic cost shocks, as well as an aggregate exchange rate shock, which affects the firms with heterogeneous intensities.

We consider a representative industry, and then simulate a large number of such industries for 13 years, as in our data. We calibrate the model using data on 4-digit industries in the Belgian economy, focusing on industries that are important in terms of their overall size and in terms of their share of domestic firms. To capture a “representative” Belgian industry, we select industries based on the following criteria: (i) we start with the top half of the industries in terms of market size, which in total account for over 90% of the total manufacturing sales in Belgium; (ii) out of these, we drop industries that are dominated by foreign firms and hence domestic firms have tiny market shares. We drop industries where the foreign share is greater than 75% in any one year; (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 greater than 32% or less than 2%. 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. We summarize the calibrated parameters and the moments in the model and in the data in Tables 6 and 7 respectively.

In a given industry, there are firms of three types: \( N_B \) domestic Belgian firms, \( N_E \) foreign European firms, and \( N_X \) foreign non-European firms. To approximate one of the features of the Belgian market, the respective number of firms \((N_B, N_E, N_X)\), are all 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 mean number of Belgian firms across typical Belgian industries.\(^{41}\) We do not directly observe the numbers of European and non-European firms in the Belgian market, so 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% and 11%, respectively. Our approach is based on Eaton, Kortum, and Sotelo (2012), where conditional on entry, all firms are symmetric in terms of their cost draws, and thus market share distributions are the same for all three types of firms. As such, the expected number of entrants directly pins down the expected sales shares of the three types of firms. Our calibrations match the average sales shares of the three types of firms across sectors, as well as the variation across sectors in these shares (see Table 7), which we use in our counterfactuals in Section 4.4.

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

\[
MC_{it} = \frac{W_t^{1-\phi_i}(V_t^*E_t)^{\phi_i}}{\Omega_{it}},
\]

where \( W_t \) is the price index of domestic inputs, \( V_t^* \) is the foreign-currency price index of foreign (imported) inputs, \( E_t \) is the nominal exchange rate, and \( \Omega_{it} \) is the effective idiosyncratic productivity of the firm. Note that even though the input prices do not have an \( i \) subscript this specification does not rule out the idiosyncratic heterogeneity in input prices. Here, the variation in input prices across firms is rolled into the effective idiosyncratic productivity term \( \Omega_{it} \), which in logs can be written as \( \omega_{it} = \tilde{\omega}_{it} - (1 - \phi_i)\tilde{w}_{it} - \phi_i\tilde{v}_{it} \), where \( \tilde{w}_{it} \) and \( \tilde{v}_{it} \) measure the idiosyncratic log deviations of firm’s cost indexes from industry averages, \( w_t \) and \( v_t \). We further assume that exchange rate exposure \( \varphi_i \) in (33) is firm-specific and constant over time.\(^{42}\) Note that the exchange rate exposure \( \varphi_i \) differs from import intensity \( \phi_i \) in (19) by the factor of exchange rate pass-through into imported input prices. This can be seen as as a type of normalization since we will assume that \( V_t^* \) does not move with the nominal exchange rate, while in the data the pass-through into import prices is incomplete. This pass-through incompleteness is captured by choosing \( \varphi_i < \phi_i \), as we discuss below.

We assume that \( \{W_t, V_t^*, E_t\} \) follow exogenous processes. In particular, we let the nominal exchange rate follow a random walk in logs:

\[
e_t = e_{t-1} + \sigma_e u_t,
\]

\(^{41}\)In the data, the number of Belgian firms varies across industries from 22 to 87 at the 10th and 90th percentiles, while in the model-simulated industries it varies less, from 40 to 57 (see Table 7). Modeling entry and adding variation in fixed entry costs across industries would allow the model to match this variation as well, but we abstract from it in our calibration.

\(^{42}\)As we showed in Amiti, Itskhoki, and Konings (2014), this assumption is justified in the data, where over 85% of variation in import intensity \( \phi_{it} \) is cross-sectional, and within a firm \( \phi_{it} \) is not responsive to exchange rate movements over horizons of 3–5 years.
Table 6: Calibrated parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Moment in the data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected number firms:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Belgian</td>
<td>$\bar{N}_B = 48$</td>
<td>Number of Belgian firms</td>
</tr>
<tr>
<td>– European union</td>
<td>$\bar{N}_E = 21$</td>
<td>Sales share</td>
</tr>
<tr>
<td>– Non-EU</td>
<td>$\bar{N}_X = 9$</td>
<td>Sales share</td>
</tr>
<tr>
<td>Elasticity of substitution:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>– across sectors</td>
<td>$\eta = 1$</td>
<td>Pass-through heterogeneity</td>
</tr>
<tr>
<td>– within sectors</td>
<td>$\rho = 8$</td>
<td>Pass-through heterogeneity</td>
</tr>
<tr>
<td>Productivity distribution:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Pareto shape parameter</td>
<td>$k = 6.6$</td>
<td>Size distribution of firms</td>
</tr>
<tr>
<td>– St.dev. of innovation</td>
<td>$\sigma_\omega = 0.034$</td>
<td>$\text{std}(\Delta s_{it}) = 0.0042$</td>
</tr>
<tr>
<td>– Drift</td>
<td>$\mu = -k\sigma_\omega^2/2$</td>
<td>Distribution stationarity</td>
</tr>
<tr>
<td>– Reflecting barrier</td>
<td>$\omega = 0$</td>
<td>Normalization</td>
</tr>
<tr>
<td>St.dev. of $\Delta e_t$</td>
<td>$\sigma_e = 0.06$</td>
<td>Trade-weighted ER</td>
</tr>
<tr>
<td>Exchange rate exposure:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>– European firms</td>
<td>$\chi_E = 0.8$</td>
<td>Aggregate pass-through</td>
</tr>
<tr>
<td>– Non-EU firms</td>
<td>$\chi_X = 1$</td>
<td>Aggregate pass-through</td>
</tr>
<tr>
<td>– Belgian firms</td>
<td>$\psi_B \phi_B + \psi_E \phi_E + \psi_X \phi_X$</td>
<td>Pass-through into input prices</td>
</tr>
<tr>
<td>– Pass-through</td>
<td>$\psi_B = 0.15$, $\psi_E = 0.6$, $\psi_X = 1$</td>
<td>import intensity</td>
</tr>
<tr>
<td>– Import intensity</td>
<td>$\phi_E, \phi_X \sim \text{Beta}$</td>
<td>Import intensity</td>
</tr>
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</table>

Note:

Table 7: Moments

<table>
<thead>
<tr>
<th>Moment</th>
<th>Data</th>
<th>Model</th>
<th>Moment</th>
<th>Data</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of firms:</td>
<td></td>
<td></td>
<td>Sales share:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Belgian</td>
<td>41 (48)</td>
<td>48</td>
<td>– Belgian</td>
<td>0.64 (0.62)</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>[22,87]</td>
<td>[40,57]</td>
<td></td>
<td>[0.39,0.86]</td>
<td>[0.46,0.77]</td>
</tr>
<tr>
<td>– EU</td>
<td>– 21</td>
<td></td>
<td>– EU</td>
<td>0.26 (0.27)</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[0.12,0.42]</td>
<td>[0.14,0.41]</td>
</tr>
<tr>
<td>– Non-EU</td>
<td>– 9</td>
<td></td>
<td>– Non-EU</td>
<td>0.08 (0.11)</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[0.01,0.25]</td>
<td>[0.04,0.22]</td>
</tr>
<tr>
<td>Inverse Herfindahl Index for Belgian firms</td>
<td>16.4 (20.8)</td>
<td>13.7</td>
<td>Top Belgian market share</td>
<td>10.0% (11.7%)</td>
<td>11.2%</td>
</tr>
<tr>
<td></td>
<td>[7.1,138.4]</td>
<td>[6.5,24.3]</td>
<td></td>
<td>[4.9%,20.9%]</td>
<td>[5.6%,23.2%]</td>
</tr>
<tr>
<td>$\text{std} (\Delta s_{it})$</td>
<td>0.0042</td>
<td>0.0042</td>
<td>$\text{corr}(S_{it}, \phi_i^B)$</td>
<td>0.26 (0.24)</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[0.00,0.44]</td>
<td></td>
</tr>
<tr>
<td>$\text{corr}(S_{it}, S_{it+12})$</td>
<td>0.90 (0.85)</td>
<td>0.88</td>
<td>$\text{corr}(S_{it}, \phi_i^X / \phi_i^B)$</td>
<td>0.05 (0.08)</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>[0.69,0.98]</td>
<td></td>
<td></td>
<td>[-0.03, 0.37]</td>
<td></td>
</tr>
</tbody>
</table>

Note: The table reports medians (means) across sectors and underneath in the brackets the 10th and 90th percentiles across sectors.
Figure 1: Market share distribution

Note: A log-log plot of the industry rank of the firm (1 for largest, 2 for second largest, etc) against its market share relative to the largest firm (i.e., equal to 1 for the largest firm and decreasing for other firms). For example, the second largest firm in a median industry is on average 47 log points (or 38%) smaller than the largest firm, both in the simulated model and in the data. The figure plots the median realizations across sectors in the simulated data, as well as the median, the 10th percentile and the 90th percentile across sectors in the Belgian data.

where \( e_t \equiv \log \mathcal{E}_t \), \( u_t \sim iid \mathcal{N}(0, 1) \), and \( \sigma_e \) is the standard deviation of the log change in the exchange rate. The initial value of the exchange rate is equal to one, that is \( e_0 = 0 \). We set the standard deviation of the exchange rate to \( \sigma_e = 0.06 \). Overall, this process closely approximates the Belgian trade-weighted exchange rate in the data. In some of our simulations we use the specific realizations of the exchange rate from the data. For simplicity, we normalize \( W_t \equiv V_t^* \equiv 1 \), which reflects the industry-equilibrium nature of our exercise.

Firm productivities \( \Omega_{it} \) are assumed to follow a random growth process:

\[
\omega_{it} = \mu + \omega_{i,t-1} + \sigma_\omega v_{it},
\]

where \( \omega_{it} \equiv \log \Omega_{it} \), \( \mu \) is the drift, \( v_{it} \sim iid \mathcal{N}(0, 1) \), and \( \sigma_\omega \) is the standard deviation of the innovation to log productivity. Additionally, we impose a reflecting barrier at \( \omega \), in which case the productivity process becomes:

\[
\omega_{it} = \begin{cases} 
\mu + \omega_{i,t-1} + \sigma_\omega v_{it}, & \text{if } \omega > \omega, \\
\omega - \left( \mu + \omega_{i,t-1} + \sigma_\omega v_{it} - \omega \right), & \text{otherwise.}
\end{cases}
\]

That is, the process follows equation (34) as long as it stays above the lower bound \( \omega \), and otherwise it reflects from the lower bound by the amount the process in equation (34) would undershoot \( \omega \) without the reflection. The initial productivities are drawn from a Pareto distribution, \( \Omega_{i0} \sim iid \text{Pareto}(k, e\omega) \), where \( k \) is the shape parameter and \( \omega \) is the lower bound for \( \omega_{i0} = \log \Omega_{i0} \) (which acts as a normalization in our model). That is, the cumulative distribution function for \( \Omega_{i0} \) is given by \( G_0(\Omega) = 1 - (\Omega/e\omega)^{-k} \) for \( \Omega \geq e\omega \). When \( \mu = -k\sigma_\omega^2/2 < 0 \), the reflecting barrier in (35) ensures that the cross-sectional distribution of \( \Omega_{it} \) stays unchanged at \( G_0(\cdot) \), as discussed e.g. in Gabaix (2009).
In our calibration, we set $k = 6.6$ and $\sigma_\omega = 0.034$, which given the other parameters of the model (in particular the demand elasticity $\rho$, see below), allows us to match the market share distribution across firms, and its dynamics. In particular, we match the standard deviation of changes in market shares over time, and the cross-sectional correlation in firm market shares over the 13 years of the data (see Table 7). The largest domestic firm in a typical industry has a market share of about 11%, while the second-largest firm is about 38% smaller, both in the simulated model and in the data (see Table 7 and Figure 1). In the simulated model, the variation in the top-firm market share between the first and last deciles of industries is 5.6% to 23.2%, which closely approximates the variation across the Belgian industries in the data (4.9% to 20.9%). Figure 1 further shows that the firm size distribution within sectors is closely approximated by a Zipf’s law, both in the data and in the simulated model.

Lastly, we calibrate the distribution of exchange rate exposure, $\varphi_i$, across firms. For foreign firms we set $\varphi_i = \chi_E = 0.8$ for European non-Belgian firms and $\varphi_i = \chi_X = 1$ for non-EU firms. Since we do not observe this information directly in the data, this calibration allows us to match the aggregate pass-through into the prices of these two types of firms, as we discuss below. In contrast, the information on the import intensity of the Belgian firms can be read off the data. As shown in Amiti, Itskhoki, and Konings (2014), larger firms are more import intensive than small firms. We make sure to capture this feature of the data in our calibration.\footnote{In Amiti, Itskhoki, and Konings (2014) we motivated this regularity using a model of selection into importing due to Halpern, Koren, and Szeidl (2011). Here we opt instead in favor of calibrating the import intensity directly as we want to capture the available data as close as possible. This would have been also possible in the model using a very flexible specification of import fixed costs, but then the two approaches become virtually identical.} We assume a firm’s import intensity is given in the initial period and stays fixed during the life of the firm in the sample. This is of course an approximation, as some firms grow large and become more import intensive over their lifetime, and vice versa. But as we argued in the previous paper, this simplification is a good approximation as firms’ import intensities tend to be stable over a horizon of 3–5 years and do not respond much to exchange rate movements.
Furthermore, in our calibration, while the productivity of the firms evolves over time, and so do market shares, nonetheless market shares are very persistent with an autocorrelation over 13 years (i.e., the length of our sample) above 0.85, as in the data (see Table 7). For Belgian firms, we match the intensity of both imports from within the EU and outside the EU, by fitting a four-parameter Beta distribution to these import intensities in the data separately for each of the first 40 firms in the industry by market share. For other firms we assign the values of the 40th firm. The four parameters of the distribution correspond to the lower and upper bounds, as well as the mean and the median. Further details of this calibration are provided in the appendix. Figure 2 plots the kernel densities of import intensity from outside Belgium and outside the euro area across all firms (in Panel (a)), as well as the conditional means of these import intensities by within-sector firm rank both in the data and in the model (in Panel (b)).

The correlation of import intensity and market share is around 0.25 both in the model and in the data, and larger firms also tend to import a larger fraction of intermediates from outside the euro area, which we also capture in our calibration. The exchange rate exposure, $\varphi_i$, for the Belgian firms is related to their import intensities according to:

$$\varphi_i = \phi_E \psi_E + \phi_X \psi_X + (1 - \phi_E - \phi_X) \psi_B,$$

where $\psi_\ell$ for $\ell \in \{B, E, X\}$ reflect the exchange rate pass-through into the prices of imported inputs from $\ell$. We calibrate $\psi_E = 0.6, \psi_X = 1$ and $\psi_B = 0.15$ to match the aggregate pass-through regressions.

This specifies the distribution of costs for the firms in each period $t$, $\{MC_{it}\}$. Given the costs, we calculate the equilibrium prices $\{P_{it}\}$ according to (15), which involves solving a fixed point using (14) and (??), and then find the equilibrium industry price index $P_{st}$ according to (13). We also calculate the market shares $\{S_{it}\}$ according to (14). We then calculate the measured log change in the industry price index and in the price of competitors, in the same way we calculate it in the data in Section 3.1.

We set the elasticity of substitution across the 4-digit sectors to $\eta = 1$, as is conventional in the literature following Atkeson and Burstein (2008) (see, for example, Edmond, Midrigan, and Xu 2015), and we also experiment with larger elasticities (e.g., $\eta = 2$). The model requires a large within-industry elasticity, or more precisely a large gap between $\rho$ and $\eta$ in order to generate significant markup variability as in the data (see (16)). We set the elasticity of substitution within industries to $\rho = 8$, which is in line with our estimates of the within industry elasticity of substitution using the Belgian firm-product level data using the Broda and Weinstein (2006) methodology, and in line with the literature following Atkeson and Burstein (2008) (see, for example, Edmond, Midrigan, and Xu 2015). To illustrate the mechanism in the model and the role of the demand parameters, Figure 3 plots the variation in markups $M_{it}$ and pass-through $\Psi_{it} \equiv 1/(1 + \Gamma_{it})$ across firms as a function of their market shares $S_{it}$ over the relevant range $[0, 0.25]$. The same graph also contrasts the alternative specifications with the same parameters, but under price (Bertrand) competition, and under quantity competition for two

---

44We shut down the heterogeneity in $\xi_{it}$ and focus on productivity $\Omega_{it}$ as the only source of heterogeneity across firms.

45Note that this is larger than the conventional estimates for 4-digit industries (see e.g. Broda and Weinstein 2006) that use product-level data. Our estimates are higher because it is at the firm-product level.
Figure 3: Markups and pass-through in a calibrated model

Note: Solid blue line corresponds to our benchmark case with Cournot competition, $\rho = 8$ and $\eta = 1$. The other lines correspond to respective departures from the baseline case. Panel (a) plots markups $M_{it}$ and Panel (b) plots (idiosyncratic cost) pass-through $1/(1 + \Gamma_{it})$, both as a function of market share $s_{it}$.

alternative sets of parameters, $\eta = 2$ in one, and $\rho = 5$ in the other. Although both Cournot and Bertrand models produce the same qualitative results, it is clear from the graph that Bertrand grossly under-predicts the degree of heterogeneity of pass-through across firms, suggesting that pass-through for firms with a 10% market share is around 90%. In contrast, our data shows that pass-through for large firms is 50-60%, which is much more in line with the Cournot model under our parameterization. Similarly, increasing $\eta$ or reducing $\rho$ makes it harder to fit the data quantitatively.

4.3 Simulation results

Using the calibrated model, we simulate a panel of firm prices across 200 industries and 13 time periods, corresponding to the structure of our dataset. Given the calibrated exogenous marginal cost process in (33), we use the model to solve for the (Cournot-Nash) equilibrium of the simultaneous price setting game. In addition to firm market shares and prices, we calculate the evolution of sectoral price indexes as calculated by statistical agencies (and in the same way we did with the Belgian data in Section 3.1).

With this simulated panel dataset, we run the same regression specifications as in Tables 1.A and 2. First, we analyze the response of prices, marginal costs and markups to exchange rate movements across different categories of firms, in parallel with the regressions using the Belgian data, reported in Table A2 of Appendix A. This acts as a specification check on the model, as we can contrast the pass-through patterns across firms in the simulated data with those documented earlier in the Belgian data. We then turn to a more direct analysis of the strategic complementarities in price setting.

Exchange rate pass-through In Table 8, we report the results from two regression specifications. In the first row, we report the sector-level specification in which we regress the log change in the industry price index $\Delta \log P_{st}$, as well as a similarly constructed industry index of the change in the
Table 8: Industry pass-through regressions

<table>
<thead>
<tr>
<th></th>
<th>All /firms</th>
<th>Domestic /firms</th>
<th>Foreign /firms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MC</td>
<td>Price</td>
<td>MC</td>
</tr>
<tr>
<td>Industry-level</td>
<td>0.494</td>
<td>0.488</td>
<td>0.286</td>
</tr>
<tr>
<td>Firm-level pooled</td>
<td>0.473</td>
<td>0.464</td>
<td>0.268</td>
</tr>
</tbody>
</table>

Note: Data generated for 1000 industries over 10 years, which essentially eliminates sampling error in coefficient estimates. Industry-level regressions are run with industry being a unit of observation without weighting, regressing sectoral cost and price index changes on exchange rate changes (all in logs). Firm-level regressions have firm log change in costs and prices as a unit of observation, regressing it on log exchange rate change and pooling the coefficients across all firms in all sectors, weighting observations by firm sales (market shares).

Figure 4: Exchange rate pass-through into marginal costs and prices, by market share bins

Note: Regressions of log change in firm marginal costs and prices on log change in the exchange rate, pooled across firms, by bins of firm market share; the x-axis indicates the bins, where the numbers correspond to market share intervals: [0, 0.5%), [0.5%, 1%),...[25%, 40%). The red bars correspond to the ERPT into firm marginal costs, the sum of red and blue bars correspond to the ERPT into firm prices, and the blue bars are the ERPT into firm markups. The bin cutoffs were chosen to keep all bins of comparable size (both in terms of number of firms and in terms of sales, see Table A5): the bin of the smallest firms with market share below 0.5% contains over 40% of firms, which however account for just over 10% of sales; the bin of the largest firms contains less than 0.5% of firms, but they account for almost 5% of sales.
log marginal cost of all firms $\Delta \log MC_{st}$, on the change in the log exchange rate $\Delta \log \mathcal{E}_t$, with the unit of observation being an industry-year. We construct the price and marginal cost indexes for the full sample of all firms, and for the subsamples of domestic and foreign firms separately. Columns (2), (4), (6) of Table 8 correspond to columns (5), (6) and (7) of Table A4 in the appendix: the sectoral pass-through rates in the model are 0.49, 0.32 and 0.79 for all, domestic and foreign firms respectively, in parallel with 0.49, 0.31 and 0.64 pass-through estimated with the Belgian dataset. The marginal cost regressions for the domestic and foreign firms recover closely the respective calibrated average exposures to foreign inputs. We match closely the exchange rate pass-through into the marginal costs of the domestic firms: it is equal to 0.25 in the data and 0.27 in the model (compare the coefficient in column 3 in Table A4 with the equivalent coefficient reported in the second line of column 3 of Table 8).

Next, note the similarity in the sectoral-level coefficients for marginal costs and prices for the sample of all firms (both equal to 49%), reflecting that at the aggregate there is little markup adjustment on average across domestic and foreign firms. At the same time, the price of domestic firms move somewhat more than the marginal costs (32% versus 29%), reflecting the markup adjustment in response to exchange rate shocks. In contrast, the foreign firm’s prices move less than their marginal cost (79% versus 87%). Therefore, an exchange rate devaluation results in an increase in markup by domestic firms and a reduction in markups by foreign firms, which nearly offset each other.

These regression results imply a small markup adjustment by domestic firms in response to an exchange rate shock. This, however, masks a great deal of heterogeneity in markup responses across firms, which we explore in Figure 4. The figure plots exchange rate pass-through into marginal costs (red bars), markups (blue bars) and prices (sum of the red and blue bars) from the pooled firm-product-year regressions estimated by bins of firm market shares. The firms in the smallest bin have market shares below 0.5%, while the largest bin contains firms with market shares above 25% (Table A5 in the appendix displays the percentiles of the unweighted and sales-weighted distributions of firm market shares).

Figure 4 shows that both pass-through into marginal costs and the response of markups increase with the size of the firm. In our calibration, as in the data, larger firms are on average more import intensive, and therefore have marginal costs more exposed to the exchange rate movements, explaining the increasing pattern of pass-through into the marginal cost. At the same time, large firms in the model exhibit greater strategic complementarities in price setting, consistent with our findings in Section 3. Since a subset of the competitors are foreign firms with large exposures of costs to exchange rate movements, the larger domestic firms will increase markups in response to an exchange rate devaluation, which in the first place caused a loss of competitiveness by their foreign competitors. Small domestic firms, in contrast, keep their markups largely unchanged even when their competitors respond to the exchange rate movements. Quantitatively, the elasticity of markup adjustment is over 10% for firms with market shares above 5%, and for the very largest firms it is as high as 20% (the blue bars in Figure 4).
Table 9: Pass-through heterogeneity across firms

<table>
<thead>
<tr>
<th>Dep. var.</th>
<th>Without size interaction</th>
<th>With size interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta \log MC_{it}$</td>
<td>0.775</td>
<td>0.951</td>
</tr>
<tr>
<td>$\Delta \log MC_{it} \times \text{Large}_{it}$</td>
<td>$-$</td>
<td>$-$</td>
</tr>
<tr>
<td>$\Delta \log P_{-i,t}$</td>
<td>0.201</td>
<td>0.047</td>
</tr>
<tr>
<td>$\Delta \log P_{-i,t} \times \text{Large}_{it}$</td>
<td>$-$</td>
<td>0.248</td>
</tr>
</tbody>
</table>

Note: Large$_{it}$ is a dummy for top 20th quintile of firms within each sector according to market shares. Observations are weighted by firm sales (market shares).

Figure 5: Marginal costs vs strategic complementarities: pass-through into firm prices, by market share bins

Note: Regressions of log change in firm prices on log change in firm marginal costs and competitor price index (5), pooled across firms, by bins of firm market share (bins as in Figure 4). The red bars correspond to the idiosyncratic pass-through into firm prices (i.e., pass-through of idiosyncratic movements in the firm’s marginal cost, formally equal to $\Gamma_{it}/(1 + \Gamma_{it})$), and the blue bars correspond to the pass-through of competitor price movement into firm prices (i.e., the strategic complementarity effect given by $\Gamma_{-i,t}/(1 + \Gamma_{it})$).
Strategic complementarities  We now examine the implications of the model for our main empirical relationship (5), which we reproduce here again:

\[ \Delta \log P_{it} = \frac{1}{1 + \Gamma_{it}} \Delta \log MC_{it} + \frac{\Gamma_{-i,t}}{1 + \Gamma_{it}} \Delta \log P_{-i,t} + \varepsilon_{it}. \]

We use the simulated panel data from the calibrated model, and run the regression of the log change in firm prices on the log change in its marginal cost (which we measure directly) and the log change in the prices of its competitors (calculated as in Section 3.1). We then interact the coefficients on the marginal costs and competitor prices with an indicator of whether the firm is among the top quintile (20%) of firms by market share (roughly corresponding to a 2% market share) within industries. We report the results in Table 9, which correspond to the empirical regressions in column (4) of Table 1.A and column (6) of Table 2, respectively.

First, we find that strategic complementarity elasticity is equal on average to 20% in the model, consistent qualitatively with our empirical findings, albeit somewhat below our empirical estimates of 30–45% in Table 1.A. The model predicts that small firms exhibit no strategic complementarities and complete pass-through of cost shocks, just like in the data (columns 1 and 4 of Table 2). At the same time, the large firms exhibit incomplete pass-through and strategic complementarities in price setting with their competitors. Here the results are consistent with the data both qualitatively and quantitatively. Indeed, the interaction terms in the second column of Table 9 in the model are about 25%, while in the data we find the interaction terms to be between 25 and 35% (see columns 3 and 6 of Table 2). Therefore, the model is consistent with the data, even though it somewhat underpredicts the extent of strategic complementarities if judged based on our empirical point estimates. Further, as in the data, the coefficients on competitor prices and own marginal cost sum approximately to one, as predicted by a first-order approximation to the model in (5) and given that the model implies \( \Gamma_{-i,t} = \Gamma_{it} \).

To further explore this heterogeneity in pass-through, we reestimate our basic equation separately for 10 bins of size, in terms of market shares, and present the results in Figure 5. We find a monotonic and steep increase in the extent of strategic complementarities (blue bars) with firm size, as well as a corresponding decrease in the pass-through of own idiosyncratic cost shocks (red bars). The small firms exhibit no strategic complementarities and complete pass-through from their own marginal cost shocks, while for firms with market shares of 10% or more, the own cost pass-through elasticity and the elasticity with respect to competitor prices are equal at about 50%.46

4.4 Counterfactuals

In the counterfactual, we consider the effect of a 10% devaluation of the euro. The aggregate pass-through of such a shock into the domestic prices of the domestic firms is 35%, consistent with our empirical findings in Table A4. We now decompose this price adjustment into the contribution of different types of firms by size and into the contribution of the marginal costs and markups. Table 10 reports the results. First, about 10% percent of the largest firms, which account for almost 50% of

46The sum of the coefficients is declining below 1 for the large firms, an implication of the model we need to explore further.
sales, contribute about 60% to aggregate pass-through. The remaining 40% of pass-through comes from the smallest 90% of firms. The contribution of the large firms to pass-through is greater than their sales share for two reasons: one, marginal costs of these firms are more exposed to the exchange rate movements (see Table A5), and two, these firms exhibit greater strategic complementarities and increase their markups when the euro depreciates (as many of their competitors are foreign firms, which lose competitiveness in the Belgian market after a devaluation). Indeed, over three quarters of the markup adjustment in response to a devaluation is accounted for by the large firms. However, in aggregate, movements in markups of the domestic firms in response to a devaluation are very modest, accounting for only about 10% of overall price increases, while 90% of price increases are due to the movements in marginal costs. We now investigate why markup adjustment in response to a devaluation is rather limited, despite substantial strategic complementarity forces present in the model.

**Table 10: Pass-through decomposition**

<table>
<thead>
<tr>
<th></th>
<th>Small Firms</th>
<th>Large Firms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marginal Cost</td>
<td>39.3%</td>
<td>51.1%</td>
</tr>
<tr>
<td>Markup</td>
<td>2.2%</td>
<td>7.4%</td>
</tr>
<tr>
<td></td>
<td>41.5%</td>
<td>58.5%</td>
</tr>
</tbody>
</table>

Note: Aggregate pass-through into domestic prices equals 0.35, and is decomposed into four components. 90.4% of smallest firms contribute 50% of aggregate sales and 41.4% of aggregate pass-through, almost all of it through marginal costs. 9.6% of the largest firms also account for 50% aggregate sales, but 58.5% of aggregate pass-through, with markups accounting for about 13% of it. At the aggregate, markups account only for 9.6% of pass-through.

The three panels of Figure 6 plot the response of prices, markups and marginal costs, respectively, across firms sorted by both exchange rate exposure of marginal costs and by size (market share). Firms with large market shares and firms with high exchange rate exposure exhibit the largest pass-through of exchange rate into prices (see panel one). The pass-through of exchange rate into marginal cost does not depend on the size of the firm controlling for its exchange rate exposure (see panel two). Therefore, the largest markup adjustment happens by large firms with little exchange rate exposure (see panel three). This is intuitive because even though the large firms have the strongest strategic complementarities, they only come into play when the shocks hitting the competitors do not directly affect the firm itself. If the firm is also exposed to the shock through its marginal costs, it does not gain a competitive edge, and has less room to adjust markup.

This can be seen formally from the price change equation (5), which we rearrange for markup (using $\Delta \mu_{it} = \Delta p_{it} - \Delta mc_{it}$) and projecting on the exchange rate movement as:

$$\frac{\Delta \mu_{it}}{\Delta e_t} = \frac{\Gamma_{it}}{1 + \Gamma_{it}} \left[ \frac{\Delta p_{-i,t}}{\Delta e_t} - \frac{\Delta mc_{it}}{\Delta e_t} \right].$$

(36)

Therefore, for markups to move, it is not only necessary to have strong strategic complementarities in price setting (large $\Gamma_{it}$), but also to not be exposed to the same shock as your competitors, i.e. $\frac{\Delta p_{-i,t}}{\Delta e_t} \gg \frac{\Delta mc_{it}}{\Delta e_t}$. This latter condition often fails in the cross section of firms: from Table A5 we know that large firms with strong strategic complementarities are themselves heavily exposed to
Figure 6: Exchange rate pass-through into firm markup

Note: Pass-through into markup (markup elasticity with respect to exchange rate) by bins of exchange rate exposure and market share.
exchange rate fluctuations due to their import intensity. As a result, most firms either exhibit weak strategic complementarities, or are themselves exposed to the exchange rate movement, explaining the limited response of the markups to a devaluation. Importantly, this is not evidence of the lack of strategic complementariness, which are strong in the model, as we have shown in Table 9 and Figure 5.

**Heterogeneity across industries** We next study the variation across industries in our simulated dataset. Importantly, the data comes from the same data generating process in all industries, yet discreteness of draws results in heterogeneity of industries on various dimensions. We explore three types of differences across industries. The results are reported in the three panels of Figure 7.

First, in panel (a) of Figure 7 we explore the difference across industries in the market share of foreign firms, which varies in the simulated dataset from 30% to 50% between the 10th and the 90th percentiles of industries. The pass-through into domestic prices increases with the extent of foreign competition in the industry, and this effect is entirely due to the greater response of domestic firms’ markups in these industries. Specifically, in an industry at the top decile of foreign competition (the most left bar in Figure 7a) the pass-through into prices is 37% versus 33% in the sector in the bottom decile, with the entire difference due to markups. The effects are modest for the same reason discussed above: both terms in the product on the right-hand side of (36) are not large.

In the second exercise, in panel (b) of Figure 7, we rank industries by the size of the top firm within an industry. At the bottom decile of industries, the largest firms have a market share of less than 6%, while at the top decile, the firms can be as large as 20%. Sorting industries this way results in the largest cross-sectional variation in pass-through, from 32% at the bottom decile to almost 40% in the top decile, with about two-thirds of the variation due to markups and one-third of variation due to marginal costs. Intuitively, larger firms exhibit stronger strategic complementarities, explaining the stronger response of markups in the industries with large firms. Larger firms are also more import intensive, explaining the stronger response of the marginal costs. These two effects reinforce each other in contributing to the movements in prices.

Our last slice of the data in panel (c) of Figure 7 splits the industries by the realized correlation between the size of the firms and their import intensity. At the bottom decile the correlation between market shares and import intensity is around zero, while in the top decile this correlation is greater than 0.55. This split of industries is interesting because it allows us to compare industries where large firms are heavily exposed to exchange rates directly versus industries in which large firms are not exchange rate exposed. Surprisingly, there is no pattern of exchange rate pass-through into the sectoral price index across this split of industries. This however masks a lot of offsetting heterogeneity. Indeed, in industries with large correlation between market shares and import intensity, the pass-through is high

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47Strictly speaking, in this exercise we rank industries by the fraction of domestic firms proxying for the domestic firm market share. In the appendix we discuss the alternative sorting of industries based on the market share of domestic firms (see Figure A1). In that case, the foreign share varies more, from 25% to 55%. However, the effects of foreign competition are confounded in that case by variation in the average size of domestic firms, and the pass-through effects are dulled. Specifically, industries with a large domestic market share have a smaller response of domestic markups (because typical competitor of domestic firms are other domestic firms in such industries); but simultaneously a large domestic share is correlated with large domestic firms, which have a greater exposure to the exchange rate movements, and hence a larger pass-through into marginal costs. On net, the pass-through into domestic prices varies little in this case across industries.
Figure 7: Heterogeneous response across industries

Note:
due to the large exchange rate exposure of the dominant firms. However, at the same time, this limits the extent of markup adjustment, because the largest firms do not gain a competitive edge in the aftermath of a devaluation, while the small firms do not exhibit much of strategic complementarities (recall again (36)). The circumstance are different in the industries with little correlation between market shares and import intensity. There, the largest firms are not exchange rate exposed, which limits the pass-through into marginal costs, however as a result they respond strongly with their markups, as a devaluation gives them a sharp competitive edge.

The three exercises above illustrate the mechanism of strategic complementarities in a calibrated model for a devaluation. It sheds light on which industries we should expect to have greater exchange rate pass-through into the sectoral price of the domestic products. The direction of the effects across industries is intuitive, however their quantitative magnitude is modest, even in the environment with strong strategic complementariness in price setting, as in our model. This highlights the challenge of statistically identifying these mild patterns in the data by estimating pass-through regression across industries, and emphasizes the role of the model in shedding light on the mechanisms in the data.

5 Conclusion

In this paper we provide direct evidence on the extent of strategic complementarities between firms in price setting. We use highly disaggregated Belgian data, in which we estimate a regression of firm log price changes on the changes in its log marginal cost and the changes in the log of its competitors price index. To deal with the simultaneity problem, we instrument for the competitors’ price change using measures of changes in their marginal costs. We find that the firms respond to their own cost shocks, holding their competitors’ price constant, with an elasticity of about 60-65%, while the elasticity of the price with respect to the competitor prices is 35-40%. This elasticity is our estimate of the size of strategic complementarities in price setting. These estimates characterizes averages across Belgian manufacturing firms, however they hide a great deal of heterogeneity across firms. Namely, the majority of the small firms, with market shares below 1-2% within their industries, exhibit no strategic complementarities and fully pass-through the shocks to their marginal costs into their prices. In contrast, large firms exhibit significant strategic complementarities, passing-through slightly more than a half of their cost movements into prices, and responding to the price changes of their competitors with an elasticity of slightly below 50%. These results are based on a very general framework in which we do not need to commit to a particular model. But the results are based on Belgian data, which is far more open globally than many other countries. In order to apply these insights more generally, we exploit the heterogeneity in the Belgian data in market shares and import intensities, as well as openness to foreign competition in final goods, across industries, and the firm heterogeneity within industries, to simulate data which we use to calibrate a model of variable markups that fits our general framework, namely the model from Atkeson and Burstein (2008).

In the calibration, we focus on an industry equilibrium model with oligopolistic competition under CES demand, resulting in variable markups. Using this model, we explore a number of counterfactuals studying the heterogeneous response of prices and markups to an exchange rate shock, across firms.
and industries. In a model calibrated to typical Belgian industries, we find a moderate adjustment of markups in response to an exchange rate devaluation, despite substantial presence of strategic complementarities in price setting. We show that this is because the large Belgian firms are themselves directly exposed to the exchange rate fluctuations by means of imported intermediate inputs, which play a significant role in their production costs. These are the firms that account for the majority of sales and are, in principle, a position to increase their markups in response to a rise in their market shares. However, the exposure of their marginal cost to exchange rate movements does not allow them a significant competitive edge against importers in the aftermath of a nominal devaluation.
## A Additional Empirical Results

### Table A1: Summary Statistics

<table>
<thead>
<tr>
<th>Level</th>
<th>Variable</th>
<th>5%ile</th>
<th>Mean</th>
<th>Median</th>
<th>95%ile</th>
<th>St.dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firm-product</td>
<td>$\Delta p_{it}$</td>
<td>-0.363</td>
<td>0.013</td>
<td>0.003</td>
<td>0.400</td>
<td>0.235</td>
</tr>
<tr>
<td></td>
<td>$\Delta p_{-it}$</td>
<td>-0.061</td>
<td>0.012</td>
<td>0.008</td>
<td>0.093</td>
<td>0.054</td>
</tr>
<tr>
<td></td>
<td>$S_{it}$</td>
<td>0.000</td>
<td>0.010</td>
<td>0.001</td>
<td>0.044</td>
<td>0.039</td>
</tr>
<tr>
<td>Firm</td>
<td>$L_{it}$</td>
<td>9.9</td>
<td>168.9</td>
<td>36.1</td>
<td>666.8</td>
<td>515.1</td>
</tr>
<tr>
<td></td>
<td>$\Delta mc_{it}$</td>
<td>-0.262</td>
<td>0.022</td>
<td>0.015</td>
<td>0.330</td>
<td>0.212</td>
</tr>
<tr>
<td></td>
<td>$\Delta mc^*_{it}$</td>
<td>-0.050</td>
<td>0.002</td>
<td>0.000</td>
<td>0.041</td>
<td>0.029</td>
</tr>
<tr>
<td></td>
<td>$\phi_{it}$</td>
<td>0.000</td>
<td>0.148</td>
<td>0.109</td>
<td>0.452</td>
<td>0.156</td>
</tr>
<tr>
<td></td>
<td>$\phi^e_{it}$</td>
<td>0.000</td>
<td>0.032</td>
<td>0.003</td>
<td>0.168</td>
<td>0.071</td>
</tr>
<tr>
<td>Industry</td>
<td>$\max S_{it}$</td>
<td>0.013</td>
<td>0.098</td>
<td>0.063</td>
<td>0.313</td>
<td>0.110</td>
</tr>
<tr>
<td>(NACE 4-digit)</td>
<td>$S^D_{it}$</td>
<td>0.111</td>
<td>0.565</td>
<td>0.588</td>
<td>0.901</td>
<td>0.238</td>
</tr>
<tr>
<td></td>
<td>$S^F_{it}$</td>
<td>0.080</td>
<td>0.369</td>
<td>0.315</td>
<td>0.864</td>
<td>0.236</td>
</tr>
<tr>
<td># of firms</td>
<td>6</td>
<td>65</td>
<td>40</td>
<td>310</td>
<td>80</td>
<td></td>
</tr>
</tbody>
</table>

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; $\phi_{it}$ and $\phi^e_{it}$ 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 A1* below); $\max S_{it}$ is the largest market share of a domestic (Belgian) firm within an industry; and $S^D_{it}$ and $S^F_{it}$ 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 A1*: Import intensity by firm size

<table>
<thead>
<tr>
<th></th>
<th>All</th>
<th>Large</th>
<th>Small</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraction $\phi_{it} &gt; 0$</td>
<td>0.701</td>
<td>0.984</td>
<td>0.638</td>
</tr>
<tr>
<td>Average $\phi_{it}$</td>
<td>0.150</td>
<td>0.221</td>
<td>0.134</td>
</tr>
<tr>
<td>Fraction $\phi^e_{it} &gt; 0$</td>
<td>0.576</td>
<td>0.958</td>
<td>0.491</td>
</tr>
<tr>
<td>Average $\phi^e_{it}$</td>
<td>0.032</td>
<td>0.059</td>
<td>0.026</td>
</tr>
</tbody>
</table>

Note: The reported averages are across firm-year observations, explaining the difference of 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.

### Table A2: Robustness: placebo tests for large and small firms

<table>
<thead>
<tr>
<th>Sample</th>
<th>Large</th>
<th>Small</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Export share &lt; 0.1</td>
<td>FDI share &lt; 0.005</td>
</tr>
<tr>
<td>$\Delta mc_{it}$</td>
<td>0.648***</td>
<td>0.518**</td>
</tr>
<tr>
<td></td>
<td>(0.227)</td>
<td>(0.220)</td>
</tr>
<tr>
<td>$\Delta p_{-it}$</td>
<td>0.441**</td>
<td>0.550***</td>
</tr>
<tr>
<td></td>
<td>(0.187)</td>
<td>(0.188)</td>
</tr>
<tr>
<td># obs.</td>
<td>7,941</td>
<td>14,389</td>
</tr>
</tbody>
</table>

Notes: Large and small sample based on employment=100 threshold. Column 1 only includes large firms with export shares less than 10%. Column 2 only includes large firms where foreign sales or purchases are less than 0.005% of total sales. Column 3 only keeps small firms that import inputs from outside Belgium. Column 4 only keeps small firms that import inputs from outside eurozone.
<table>
<thead>
<tr>
<th></th>
<th>Column (1)</th>
<th>Column (2)</th>
<th>Column (3)</th>
<th>Column (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\Delta mc_{it}$</td>
<td>$\Delta p_{i,t}$</td>
<td>$\Delta mc_{it}$</td>
<td>$\Delta p_{i,t}$</td>
</tr>
<tr>
<td>$\Delta mc_{it}$</td>
<td>0.54***</td>
<td>0.12***</td>
<td>0.54***</td>
<td>-0.02</td>
</tr>
<tr>
<td></td>
<td>(0.09)</td>
<td>(0.03)</td>
<td>(0.09)</td>
<td>(0.01)</td>
</tr>
<tr>
<td>$\Delta mc_{it} \times \text{Large}_i$</td>
<td>0.09***</td>
<td>0.64***</td>
<td>0.07***</td>
<td>0.19***</td>
</tr>
<tr>
<td></td>
<td>(0.15)</td>
<td>(0.04)</td>
<td>(0.15)</td>
<td>(0.05)</td>
</tr>
<tr>
<td>$\Delta e_{st}$</td>
<td>-0.24</td>
<td>0.45***</td>
<td>-0.31</td>
<td>-0.15</td>
</tr>
<tr>
<td></td>
<td>(0.20)</td>
<td>(0.15)</td>
<td>(0.27)</td>
<td>(0.14)</td>
</tr>
<tr>
<td>$\Delta e_{st} \times \text{Large}_i$</td>
<td>0.18</td>
<td>0.03</td>
<td>0.03</td>
<td>-0.13</td>
</tr>
<tr>
<td></td>
<td>(0.30)</td>
<td>(0.28)</td>
<td>(0.30)</td>
<td>(0.13)</td>
</tr>
<tr>
<td>$\Delta mc^*_{i,t}$</td>
<td>0.71***</td>
<td>0.68***</td>
<td>0.53***</td>
<td>-0.20***</td>
</tr>
<tr>
<td></td>
<td>(0.20)</td>
<td>(0.14)</td>
<td>(0.21)</td>
<td>(0.07)</td>
</tr>
<tr>
<td>$\Delta mc^*_{i,t} \times \text{Large}_i$</td>
<td>0.30**</td>
<td>0.52***</td>
<td>-0.19</td>
<td>-0.54***</td>
</tr>
<tr>
<td></td>
<td>(0.14)</td>
<td>(0.10)</td>
<td>(0.24)</td>
<td>(0.15)</td>
</tr>
<tr>
<td>$\Delta p^{EU}_{st}$</td>
<td>0.16***</td>
<td>0.15***</td>
<td>0.20***</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>(0.06)</td>
<td>(0.05)</td>
<td>(0.07)</td>
<td>(0.02)</td>
</tr>
<tr>
<td>$\Delta p^{EU}_{st} \times \text{Large}_i$</td>
<td>0.23***</td>
<td>0.32***</td>
<td>0.02</td>
<td>0.21***</td>
</tr>
<tr>
<td></td>
<td>(0.06)</td>
<td>(0.05)</td>
<td>(0.08)</td>
<td>(0.06)</td>
</tr>
</tbody>
</table>

Notes:
Table A4: Exchange Rate Projections

<table>
<thead>
<tr>
<th>Dep. var.:</th>
<th>Firm-level regressions</th>
<th>Industry-level regressions</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta e_{st} )</td>
<td>(1) ( \Delta p_{it} )</td>
<td>(5) ( \Delta p_{st} )</td>
</tr>
<tr>
<td>( \Delta e_{st} )</td>
<td>(2) ( \Delta m_{c_{it}} )</td>
<td>(6) ( \Delta p_{st}^{D} )</td>
</tr>
<tr>
<td>( \Delta e_{st} )</td>
<td>(3) ( \Delta m_{c_{it}}^{*} )</td>
<td>(7) ( \Delta p_{st}^{F} )</td>
</tr>
<tr>
<td>( \Delta e_{st} )</td>
<td>(4) ( \Delta v_{it} )</td>
<td>( r^{2} )</td>
</tr>
<tr>
<td>( \Delta e_{st} )</td>
<td>( 0.279 )</td>
<td>( 0.489^{***} )</td>
</tr>
<tr>
<td>( \Delta e_{st} )</td>
<td>( 0.395^{**} )</td>
<td>( 0.311^{***} )</td>
</tr>
<tr>
<td>( \Delta e_{st} )</td>
<td>( 0.246^{***} )</td>
<td>( 0.651^{***} )</td>
</tr>
<tr>
<td>( \Delta e_{st} )</td>
<td>( 0.651^{***} )</td>
<td>( 0.642^{***} )</td>
</tr>
<tr>
<td>( \Delta e_{st} )</td>
<td>( 0.489^{***} )</td>
<td>( 0.061 )</td>
</tr>
<tr>
<td>( \Delta e_{st} )</td>
<td>( 0.311^{***} )</td>
<td>( 0.085 )</td>
</tr>
<tr>
<td>( \Delta e_{st} )</td>
<td>( 0.651^{***} )</td>
<td>( 0.059 )</td>
</tr>
<tr>
<td># obs.</td>
<td>64,815</td>
<td>1,921</td>
</tr>
<tr>
<td>Adj. ( R^{2} )</td>
<td>0.001</td>
<td>0.058</td>
</tr>
</tbody>
</table>

Notes: Regressions do not include fixed effects. \( \Delta e_{st} \) is the log change in industry import-weighted exchange rate. \( \Delta p_{it} \) is the log change in firm-product price. \( \Delta m_{c_{it}} \) is the log change in firm marginal cost. \( \Delta m_{c_{it}}^{*} \) is the log change in the imported component of the firm marginal cost. \( \Delta v_{it} \) is the log change in the industry price index. \( \Delta p_{st} \) is the log change in the industry price index of imported (domestic) goods. Firm-level regressions (columns 1-4) are weighted by lagged domestic value. Industry-level regressions (columns 5-7) are weighted by number of observations within each industry.

B Additional Quantitative Results

We first describe briefly the properties of the calibrated model, which help better understand the transmission mechanism in the model, and then proceed with our counterfactual—a response to a 10% devaluation of the euro. Table A5 summarizes some cross-sectional properties of the model. The rows correspond to firms at different percentiles of the size distribution reported in first column. The second column then reports the corresponding percentile in terms of sales, reflecting the skewness in the sales distribution in the model. Specifically, 1 percent of firms in the model account for 15 percent of sales, while 5 percent of firms account for over 37 percent of sales. This can also be seen in the third column where we report the market shares of the corresponding firms: a median firm in the calibrated model has a market share of 0.57% within its industry, while a firm at the 95th percentile has a market share of just below 5% in its industry. The largest firms in the simulated dataset have market shares in excess of 20%, but show up only in every third-fourth industry (assuming we have 200 industries). The last two columns of Table A5 show that larger firms are more import intensive and hence more exposed to exchange rate movements, and also have larger markups. Namely, small firms have a markup around 14%, while the typical largest firm in an industry with a market shares of 10–12% has a markups around 30%.

Table A5: Market share, exchange rate exposure, and markup distributions in the model

<table>
<thead>
<tr>
<th>Firm percentiles</th>
<th>Sales percentile</th>
<th>Market share (%)</th>
<th>Exchange rate exposure</th>
<th>Markup</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>5.3</td>
<td>0.36</td>
<td>0.199</td>
<td>1.147</td>
</tr>
<tr>
<td>50</td>
<td>14.2</td>
<td>0.57</td>
<td>0.244</td>
<td>1.149</td>
</tr>
<tr>
<td>75</td>
<td>29.6</td>
<td>1.13</td>
<td>0.289</td>
<td>1.156</td>
</tr>
<tr>
<td>90</td>
<td>49.3</td>
<td>2.62</td>
<td>0.333</td>
<td>1.174</td>
</tr>
<tr>
<td>95</td>
<td>62.7</td>
<td>4.60</td>
<td>0.363</td>
<td>1.198</td>
</tr>
<tr>
<td>97.5</td>
<td>74.0</td>
<td>7.51</td>
<td>0.392</td>
<td>1.236</td>
</tr>
<tr>
<td>99</td>
<td>85.1</td>
<td>12.45</td>
<td>0.425</td>
<td>1.305</td>
</tr>
<tr>
<td>99.5</td>
<td>90.7</td>
<td>16.62</td>
<td>0.450</td>
<td>1.371</td>
</tr>
<tr>
<td>99.75</td>
<td>94.4</td>
<td>21.67</td>
<td>0.472</td>
<td>1.460</td>
</tr>
</tbody>
</table>

Note: Domestic firms only. Note that \( \rho/(\rho - 1) = 1.143 \) and corresponds to the markup of a zero-market-share firm.
Figure A1 below presents the results of a counterfactual, which parallels that in Figure 7a, i.e. in which we sort sectors by the foreign share, however instead of sorting by number of foreign firms, we sort by the sales share. The results are different because foreign share is correlated (negatively) with the market share of the top Belgian firm (see Figure A1d), and as a result the variation in markup due to greater foreign competition is offset by variation in markup due to difference in size of the largest domestic firm, which leads to the absence of a clear pattern across industries.

Figure A1: Heterogenous response across sectors: Domestic share

Note:
C 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 a small proportion of the observations, 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 percent 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.
D Derivations and Proofs

TOO BE COMPLETED

D.1 Price setting (proof of Proposition 1)

D.2 Reduced-form of the model

D.3 Reduced form and aggregation

We now briefly discuss the implications of the above analysis for the pass-through of shocks into firm prices and aggregate (industry-level) price indexes. The magnitudes of the two coefficients in (5), $\psi_{it}$ and $\gamma_{it}$, inform us of the relative importance of the marginal cost and markup channels in transmitting shocks into prices. For example, consider an exchange rate shock, $\Delta e_t$, which in general affects both the marginal costs of the firm (e.g., through the prices of imported inputs) and the prices of its competitors (e.g., the foreign firms competing in the domestic market). To get the total effect from exchange rates into prices, we need to combine these coefficients with information on how sensitive each of these components is to exchange rates shocks. Denote by $\varphi_{it}$ the elasticity of a firm’s marginal cost with respect to the exchange rate, which we refer to as the exchange rate exposure of the firm, and with $\Psi_{-i,t}$ the equilibrium exchange rate pass-through into the prices of the firm’s competitors. For the sake of this example, we assume that other changes in markup $\varepsilon_{it}$ are unrelated to changes in the exchange rate. We can then express the full elasticity of the firm’s price to the exchange rate shock as:

$$\Psi_{it} = \psi_{it}\varphi_{it} + \gamma_{it}\Psi_{-i,t}$$

(A1)

where the first term is the marginal cost channel and the second term is the markup (or strategic complementarities) channel.

Equation (A1) illustrates the rich set of determinants of the exchange rate pass-through into the prices of individual firms. Next consider what shapes the industry-level pass-through, which aggregates the responses $\Psi_{it}$ across firms within the industry. In Appendix D, we show that the response of the industry $s$ price index to an exchange rate shock is given by:

$$\Psi_{st} = \frac{1}{1 - \sum_i S_{it}\gamma_{it}} \sum_i S_{it}\psi_{it}\varphi_{it}.$$  

(A2)

This equation emphasizes the role of heterogeneity in the quadruplet $(S_{it}, \varphi_{it}, \psi_{it}, \gamma_{it})$ across firms in shaping the aggregate pass-through, as we further discuss in the appendix. In the following sections, we characterize this heterogeneity in the data and study its quantitative implications for the effect of exchange rate shocks on domestic prices and markups.

48 Alternatively, one can define $\Psi_{it}$, $\varphi_{it}$ and $\Psi_{-i,t}$ as the regression coefficients of the log change in firm’s price, marginal cost and competitors price index on the log change in the exchange rate.
We can transform (5):

\[
\Delta p_{it} = \frac{1}{1 + \Gamma_{it}} \Delta mc_{it} + \frac{\Gamma_{-i,t}}{1 + \Gamma_{it}} [(1 - \omega_{it}) \Delta P_{-i,t} + \omega_{it} \Delta p_{it}] + \varepsilon_{it}
\]

\[
\Rightarrow \left[ 1 + \frac{\omega_{it} \Gamma_{-i,t}}{1 - \omega_{it}} \right] \Delta p_{it} = \frac{1}{1 + \Gamma_{it}} \Delta mc_{it} + \frac{\Gamma_{-i,t}/(1 - \omega_{it})}{1 + \Gamma_{it}} \Delta P_{t} + \varepsilon_{it}
\]

\[
\Rightarrow \Delta p_{it} = \frac{1}{1 + \Gamma_{it} + \frac{\omega_{it} \Gamma_{-i,t}}{1 - \omega_{it}}} \Delta mc_{it} + \frac{\Gamma_{-i,t}/(1 - \omega_{it})}{1 + \Gamma_{it} + \frac{\omega_{it} \Gamma_{-i,t}}{1 - \omega_{it}}} \Delta P_{t} + \tilde{\varepsilon}_{it}, \quad (A3)
\]

where \( \Delta P_{t} = (1 - \omega_{it}) \Delta P_{-i,t} + \omega_{it} \Delta p_{it} = \sum_{i} \omega_{it} \Delta p_{it} \) is the approximate price index. Note that if \( \Gamma_{-i,t} = \Gamma_{it} \), then denominator can be simplified:

\[
1 + \Gamma_{it} + \frac{\omega_{it} \Gamma_{-i,t}}{1 - \omega_{it}} = 1 + \frac{\Gamma_{it}}{1 - \omega_{it}},
\]

and hence the sum of coefficients is still equal to one, yet the coefficient on own marginal cost is larger in this alternative decomposition relative to (??). In what follows, we denote \( \tilde{\Gamma}_{it} \equiv \Gamma_{it} + \frac{\omega_{it} \Gamma_{-i,t}}{1 - \omega_{it}} \). Then we can aggregate (A3) in the following way:

\[
\Delta P_{t} = \sum_{i} \left\{ \frac{\omega_{it}}{1 + \tilde{\Gamma}_{it}} \Delta mc_{it} + \frac{\tilde{\Gamma}_{-i,t}}{1 + \tilde{\Gamma}_{it}} \Delta P_{t} + \omega_{it} \tilde{\varepsilon}_{it} \right\}
\]

\[
\Rightarrow \Delta P_{t} = \frac{1}{1 - \sum_{i} \frac{\omega_{it} \Gamma_{-i,t}}{1 + \tilde{\Gamma}_{it}}} \sum_{i} \left\{ \frac{\omega_{it}}{1 + \tilde{\Gamma}_{it}} \Delta mc_{it} + \omega_{it} \tilde{\varepsilon}_{it} \right\}
\]

\[
\Rightarrow \Delta p_{it} = \frac{1}{1 + \tilde{\Gamma}_{it}} \Delta mc_{it} + \frac{\tilde{\Gamma}_{-i,t}}{1 + \tilde{\Gamma}_{it}} \sum_{j} \left\{ \frac{\omega_{jt}}{1 + \tilde{\Gamma}_{jt}} \Delta mc_{jt} + \omega_{jt} \tilde{\varepsilon}_{jt} \right\} + \tilde{\varepsilon}_{it}.
\]

We also define

\[
\Delta MC_{t} = \sum_{i} \omega_{it} \Delta mc_{it}, \quad \Delta M_{t} = \sum_{i} \omega_{it} \Delta \mu_{it} = \sum_{i} \omega_{it}(\Delta p_{it} - \Delta mc_{it}) = \Delta P_{t} - \Delta MC_{t}
\]

\[
= -\frac{1}{1 - \sum_{i} \frac{\omega_{it} \Gamma_{-i,t}}{1 + \tilde{\Gamma}_{it}}} \sum_{i} \left[ \frac{\tilde{\Gamma}_{it}}{1 + \tilde{\Gamma}_{it}} - \sum_{j} \frac{\omega_{jt} \tilde{\Gamma}_{-j,t}}{1 + \tilde{\Gamma}_{jt}} \right] \omega_{it} \Delta mc_{it} + \frac{\sum_{i} \omega_{it} \tilde{\varepsilon}_{it}}{1 - \sum_{i} \frac{\omega_{it} \Gamma_{-i,t}}{1 + \tilde{\Gamma}_{it}}}
\]

Now consider the effects of the exchange rate movements on aggregate (sectoral) marginal costs,
prices, and markups:

\[
\Psi_{MC} = \sum_i \omega_i \phi_{it},
\]

\[
\Psi_P = \frac{1}{1 - \sum_i \omega_i \frac{\Gamma_{it}}{1 + \Gamma_{it}}} \sum_i \frac{\omega_i \phi_{it}}{1 + \Gamma_{it}},
\]

\[
\Psi_M = -\frac{1}{1 - \sum_i \omega_i \frac{\Gamma_{it}}{1 + \Gamma_{it}}} \sum_i \left[ \frac{\Gamma_{it}}{1 + \Gamma_{it}} - \sum_j \frac{\omega_j \Gamma_{jt}}{1 + \Gamma_{jt}} \right] \omega_i \phi_{it}
\]

where we assume that \( \tilde{\epsilon}_{it} \) is orthogonal with exchange rate shocks, \( \phi_{it} \equiv \text{cov}(\Delta p_{it}, \Delta e_t) / \text{var}(\Delta e_t) \), \( \Psi_P = \text{cov}(\Delta P_t, \Delta e_t) / \text{var}(\Delta e_t) \), and \( e_t \) is the log of the nominal exchange rate.

We can split the price into domestic and foreign components, \( \Delta P_t = (1 - S_{Ft}) \Delta P_{Dt} + S_{Ft} \Delta P_{Ft} \), and following similar steps, we can calculate:

\[
\Delta P_{Dt} = \frac{1}{1 - \sum_{i \in I_D} \omega_i^{\text{D}} \frac{\Gamma_{it} (1 - S_{Ft})}{1 + \Gamma_{it}}} \sum_{i \in I_D} \omega_i^{\text{D}} \left[ \frac{\Delta m_{act}}{1 + \Gamma_{it}} + \tilde{\epsilon}_{it} + \frac{\Gamma_{it} S_{Ft} \Delta P_{Ft}}{1 + \Gamma_{it}} \right]
\]

where \( I_D \) is the subset of domestic firm-products and \( \omega_i^{\text{D}} = \omega_i / \left( \sum_{i \in I_D} \omega_i \right) \), and \( S_{Ft} = \sum_{i \notin I_D} \omega_i \) is the foreign share of sales.

Pass-through into marginal costs, prices and markups of domestic firms only:

\[
\Psi_{MC}^D = \sum_{i \in I_D} \omega_i^{\text{D}} \phi_{it},
\]

\[
\Psi_P^D = \frac{1}{1 - \sum_{i \in I_D} \omega_i^{\text{D}} \frac{\Gamma_{it} (1 - S_{Ft})}{1 + \Gamma_{it}}} \sum_{i \in I_D} \left[ \frac{\omega_i^{\text{D}} \phi_{it}}{1 + \Gamma_{it}} + \frac{\omega_i^{\text{D}} \Gamma_{it} S_{Ft} \Psi_P^F}{1 + \Gamma_{it}} \right],
\]

\[
\Psi_M^D = \Psi_P^D - \Psi_{MC}^D
\]

### E Derivations for Atkeson-Burstein model

### F General Model

Monopolistic competition under CES demand yields constant markups. In this section we relax both assumptions, allowing for both general non-CES homothetic demand and oligopolistic competition. Our model nests both Kimball (1995) and Dixit and Stiglitz (1977) with large firms (as in Krugman 1987, Atkeson and Burstein 2008).
Consider the following aggregator for the sectoral consumption \( C \):

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

where \( \Omega \) 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 \( \xi_i \) denote the two shifters (a quality parameter and a demand parameter, respectively, as will become clear later); \( \Upsilon(\cdot) \) is the demand function such that \( \Upsilon(\cdot) > 0, \Upsilon'(\cdot) > 0, \Upsilon''(\cdot) < 0 \) and \( \Upsilon(1) = 1 \).

There are two important limiting cases that we consider. First, in the limiting case of \( N \to \infty \), the demand aggregator becomes:

\[
\frac{1}{|\Omega|} \int_{i \in \Omega} A_i \Upsilon \left( \frac{|\Omega| C_i}{\xi_i C} \right) di = 1,
\]

where now \(|\Omega|\) is the mass of products in the sector. This limiting case corresponds to the Kimball (1995) demand model, as used for example in Klenow and Willis (2006) and Gopinath and Itskhoki (2010).

The second limiting case obtains when the demand aggregator becomes a power function, \( \Upsilon(z) = z^{(\sigma-1)/\sigma} \), which corresponds to the conventional CES aggregator which we can rewrite as:

\[
C = \left[ N^{-1/\sigma} \sum_{i \in \Omega} \left( A_i \xi_i \right)^{\frac{\sigma-1}{\sigma}} C_i^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}},
\]

which for finite \( N \) corresponds to the demand structure in the pricing-to-market papers of Krugman (1987) and Atkeson and Burstein (2008) and for infinite \( N \) is the standard monopolistic competition model of Dixit and Stiglitz (1977), later used in Krugman (1980) and much of the macro and international literature.

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 \( \eta \) is the elasticity of substitution across sectors. This assumption corresponds to the case of the CES aggregator of sectoral outputs, when each sector is too small to affect economy-wide price index. Formally, we write the sectoral expenditure (budget) constraint as:

\[
\sum_{i \in \Omega} P_i C_i = E.
\]

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 \( C \):

\[
\max_{\{C_i\}_{i \in \Omega}} \left\{ C \mid \text{s.t. (A4) and (A7)} \right\}.
\]

The first-order optimality condition for this problem defines consumer demand (see appendix for derivation), and is given by

\[
C_i = \frac{\xi_i C}{N} \cdot \psi(x_i), \quad \text{where } x_i \equiv \frac{P_i}{\gamma_i P/D}.
\]
In this expression, $\gamma_i \equiv A_i / \xi_i$ is the quality parameter and $\psi(\cdot) \equiv \Upsilon^{\prime -1}(\cdot)$ is the demand curve, while $\xi_i C/N$ is the normalized demand shifter, where $C$ 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 that is needed to characterize demand outside the CES case.\footnote{Note that the ideal price index $P$ exists since the demand defined by (A4) 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 (A8) subject to the expenditure constraint (A7).} Note that an increase in $\gamma_i$ 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 $\xi_i$ (holding $\gamma_i$ constant), shifts out the demand curve holding the effective price unchanged. This is why we refer to $\xi_i$ as the demand shifter, and $\gamma_i$ as the quality parameter.

We show in the appendix that $P$ and $D$ are defined by:\footnote{In the limiting case of CES, we have $\Upsilon(z) = z^{\sigma -1}$, 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 (A10)–(A11) 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:}

\[
\frac{1}{N} \sum_{i \in \Omega} A_i \Upsilon \left( \psi \left( \frac{P_i / \gamma_i}{P/D} \right) \right) = 1, \tag{A10}
\]

\[
\frac{1}{N} \sum_{i \in \Omega} \xi_i P_i \psi \left( \frac{P_i / \gamma_i}{P/D} \right) = 1. \tag{A11}
\]

Equation (A10) ensures that (A4) is satisfied given the demand (A9), i.e. that $C$ is indeed attained given the consumption allocation $\{C_i\}$. Equation (A11) ensures that the expenditure constraint (A7) is satisfied given the allocation (A9). Note that condition (A11) simply states that the sum of market shares in the sector equals one, with the market share given by

\[
s_i \equiv \frac{P_i C_i}{PC} = \frac{\xi_i P_i}{NP} \psi \left( \frac{P_i / \gamma_i}{P/D} \right), \tag{A12}
\]

where we substituted in for $C_i$ from the demand equation (A9). In addition, we introduce the demand elasticity as a characteristic of the slope of the demand curve $\psi(\cdot)$:

\[
\sigma_i \equiv \sigma(x_i) = -\frac{\text{d} \log \psi(x_i)}{\text{d} \log x_i}, \tag{A13}
\]

where $x_i$ is the effective price of the firm as defined in (A9). Outside the CES case, the demand elasticity is non-constant and is a function of the effective price of the firm. We further show in the appendix

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. As will become clear later, $(P,D)$ are sufficient statistics to describe the relevant moments of the price distribution, which at the first-order approximation could be thought of as measures of the average price and the dispersion of prices.
the following results for the effects of changes in the individual firm prices on aggregate variables $P$ and $D$:

$$\frac{d \log P}{d \log P_i} = \sum_{i \in \Omega} s_i \frac{d \log P_i}{d \log P_i},$$

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

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 (A9), we have:

$$\Sigma_i \equiv -\frac{d \log C_i}{d \log P_i} = \eta s_i + \sigma_i \left(1 - \frac{s_i \sigma_i}{\sum_{j \in \Omega} s_j \sigma_j}\right),$$ \hspace{1cm} (A14)

where $\sigma_i$ is given in (A13). With this demand elasticity, the firm profit maximization problem under constant returns to scale production, $\Pi_i = \max P_i [P_i - MC_i] C_i$, yields the following expression for the optimal price:

$$P_i = \mathcal{M}_i MC_i, \quad \mathcal{M}_i \equiv \frac{\Sigma_i}{\Sigma_i - 1}.$$ 

The two analytically tractable cases are: (1) monopolistic competition with $s_i \to 0$ for all $i \in \Omega$, and (2) CES demand with $\sigma_i \equiv \sigma$ for all $i$. Indeed in those two cases, the formula in (A14) simplifies considerably: $\Sigma_i = \sigma_i$ in the former and $\Sigma_i = \eta s_i + \sigma (1 - s_i)$ in the latter. The latter case corresponds to Atkeson and Burstein (2008) and has been studied in Amiti, Itskhoki, and Konings (2014), where we showed that the markup elasticity is symmetric:

$$\Gamma_i \equiv -\frac{\partial \log \mathcal{M}_i}{\partial \log P_i} = \frac{d \log \mathcal{M}_i}{d \log P_i} = \frac{(\rho - 1)(\rho - \eta) s_i}{\Sigma_i (\Sigma_i - 1)},$$

and is increasing in the market share $s_i$. Therefore, for that case we can write:\hspace{1cm} $51$

$$d \log P_i = \frac{1}{1 + \Gamma_i} d \log MC_i + \frac{\Gamma_i}{1 + \Gamma_i} d \log P + \epsilon_i, \hspace{1cm}$$

In the case of monopolistic competition under non-CES demand, the markup elasticity is somewhat different, and can be written as:

$$d \log P_i = \frac{1}{1 + \Gamma_i} d \log MC_i + \frac{\Gamma_i}{1 + \Gamma_i} d \log \frac{P}{D} + \epsilon_i,$$

where $\Gamma_i$ is defined in the same way, but now does not depend on $s_i$, but rather depends on the relative effective price of the firm $x_i$, as we discuss further below. Also note that $d \log (P/D)$ is different

\hspace{1cm} $51$An alternative expression is

$$d \log P_i = \frac{1}{1 + \Gamma_i} d \log MC_i + \frac{\Gamma_i'}{1 + \Gamma_i'} d \log P_{-i} + \epsilon_i,$$

where $\Gamma_i' \equiv (1 - s_i) \Gamma_i$ and $P_{-i}$ is the competitor price index such that $P = \left[ (\xi_i \gamma_i') P_i^{1-\sigma} + (1 - \xi_i \gamma_i') P_{-i}^{1-\sigma} \right]^{1/(1-\sigma)}.$
from $\log P$, and $\log D$ is not necessarily orthogonal with $\log P$. Nonetheless, if variation in $P_i$ is
dominated by firm-idiosyncratic shocks, then $\log D$ would indeed be close to orthogonal to $\log P$,
as we show numerically in the following section.

The more general case with both non-CES demand and oligopolistic competition is analytically
intractable, and we analyze it numerically in the next section.

Before turning to a more special case of the Kimball demand, we discuss briefly some of its gen-
eral properties. First, Kimball demand is homothetic and separable in the sense that the cross-partial
elasticities are symmetric for all varieties (as is also the case for the most common parameterization
of the translog demand, see Feenstra ??). Second, Kimball demand nests CES as a special case. Third,
Kimball demand (given in (A9)) for variety $i$ in general depends on the own price of the variety $P_i$ and
only the two moments of the price distribution $\{P_i\}$—the two auxiliary variables $P$ and $D$, defined in
(A10)–(A11).52 These auxiliary variables summarize all relevant information contained in the distribu-
tion of prices $\{P_i\}$ and, roughly speaking, capture the mean and the variance of this distribution, as we
illustrate below. In the limiting case of the CES, the ideal price index $P$ is the unique sufficient statistic
for demand, while $D = (1 - 1/\sigma)$ is constant in this case and does not depend on the distribution
of prices.

F.1 Klenow-Willis aggregator

For our quantitative analysis, we adopt a tractable specification of the Kimball aggregator introduced
by Klenow and Willis (2006). Specifically, the demand curve in this case is given by:

$$\psi(x_i) = \left[1 - \bar{\varepsilon} \log \left(\frac{\bar{\sigma}}{\bar{\sigma} - 1} x_i\right)\right]^\bar{\sigma}/\bar{\varepsilon},$$

(A15)

where $x_i$ is the effective price of the firm, as defined in (A9). The two demand parameters $\bar{\sigma} > 1$ and
$\bar{\varepsilon} \geq 0$ control respectively the elasticity of demand and the elasticity of markup for a representative
firm. In the limiting case of $\bar{\varepsilon} = 0$, the demand in (A15) converges to a constant elasticity demand curve
with $\sigma = \bar{\sigma}$. The appendix provides a closed-form expression for $\Upsilon(\cdot)$, which gives rise to the demand
curve in equation (A15).

For concreteness, we specialize to the case of the monopolistic competition ($N \to \infty$ and $s_i \to 0$
for all $i \in \Omega$), and briefly discuss the cross-sectional properties of this demand. The demand elasticity

52These two auxiliary variables corresponds to the the Lagrange multipliers in the consumer optimization, corresponding
to constraints (A7) and (A4) respectively (see the appendix).
Furthermore, the markup elasticity \( \Gamma \) is the least price (corresponding to the choke-off price \( \bar{\varepsilon} \) by \( \psi \) while the CES limit is log-linear. Second, in contrast to the CES limit, it has a choke-off price defined to the CES demand. First, it is log-concave (as can be immediately observed from (A15)), and hence the idiosyncratic pass-through rate \( M \) therefore both markups \( M_i \) and markup elasticity \( \Gamma_i \) are decreasing in the effective relative price \( x_i \), and hence the idiosyncratic pass-through rate \( \Psi_i \equiv 1/(1 + \Gamma_i) \) is increasing in \( x_i \).

The Klenow-Willis demand with \( \varepsilon > 0 \) has a few notable properties, whereas the limit of \( \varepsilon \rightarrow 0 \) correspond to the CES demand. First, it is log-concave (as can be immediately observed from (A15)), while the CES limit is log-linear. Second, in contrast to the CES limit, it has a choke-off price defined by \( \psi(\hat{x}) = 0 \) and equal to \( \hat{x} = \frac{\sigma-1}{\sigma} e^{1/\varepsilon} \). Third, there is a least price below which the elasticity demand is below one (and hence inconsistent with profit maximization), as defined by \( \sigma(\bar{\varepsilon}) = 1 \) and given by \( \bar{\varepsilon} = \frac{\sigma-1}{\sigma} e^{-(\sigma-1)/\varepsilon} < 1 \). Note that at this price the markup becomes infinite, \( M(\bar{\varepsilon}) = \infty \), and therefore in equilibrium this price can be charged only by firms with zero marginal costs, and in the absence of such firms, every firm charges an effective price strictly above \( \bar{x} \). Lastly, the idiosyncratic pass-through \( \Psi(x_i) \) varies from zero for the firm with a least price \( \bar{\varepsilon} \) to a maximum of \( \bar{\Psi} = \frac{1}{1+\varepsilon/\sigma} \) for the firm with the choke-off price \( \bar{x} \). We illustrate these properties in Figure A2 in the appendix.

Finally, we discuss the properties of the industry equilibrium. Note that the price of each firm can be written as \( P_i = M(x_i)MC_i \), where \( x_i = \frac{P_i/MC_i}{P/D} \) is the effective relative price of the firm, and \( P \) and \( D \) are the solution to (A10)–(A11). This defines a joint fixed point problem for the aggregate variables \( P \) and \( D \), as well as for the individual prices \( \{P_i\} \). The firm fixed point problem has an implicit closed form solution given by:

\[
P_i = P \cdot W\left(\exp\left\{\frac{\bar{\varepsilon}}{\sigma} \frac{MC_i}{P}\right\}\right), \quad \text{where} \quad P \equiv \frac{\sigma-1}{\sigma} e^{-\frac{\sigma-1}{\varepsilon}} \cdot \frac{P}{D} \tag{A20}
\]

is the least price (corresponding to \( \varepsilon \)), and \( W(\cdot) \) is the Lambert W function, defined as the solution to \( W(z)e^{W(z)} = z \).

\footnote{Note that with this demand, the elasticity of elasticity with respect to quantity is constant: \( d\log \sigma_i/d\log C_i = \varepsilon/\bar{\varepsilon} \). Furthermore, the markup elasticity \( \Gamma_i \) is proportional to the level of markup \( M_i \) (we introduce both below): \( \Gamma_i/M_i = \varepsilon/\bar{\varepsilon} \).}
There exists no closed-form solution for $P$ and $D$ in general. We provide the implicit equations defining $P$ and $D$—the counterparts of (A10)–(A11)—for the case of Klenow-Willis demand in the appendix. Here we discuss a special tractable case with $\bar{\sigma} = \bar{\varepsilon} > 1$ and $\xi_i = A_i \equiv 1$ for illustration purposes, while the appendix offers derivations and general expressions. When $\bar{\sigma} = \bar{\varepsilon}$, the utility aggregator has a simple closed form given by

$$\Upsilon(z_i) = 1 + (\sigma - 1)(1 - \exp((1 - z_i)/\sigma)).$$

Using this expression, we can simplify and manipulate the sector equilibrium conditions (A10)–(A11) to yield the following results:

$$P = \bar{P} \cdot [1 - \bar{\sigma}T], \quad \text{(A21)}$$

$$D = \frac{\bar{\sigma} - 1}{\sigma} \frac{P}{\bar{P}} = \frac{\bar{\sigma} - 1}{\sigma} (1 - \bar{\sigma}T), \quad \text{(A22)}$$

where $\bar{P} \equiv \frac{1}{|\Omega|} \int_{i \in \Omega} P_i \, di$ is the average price and $T \equiv \frac{1}{|\Omega|} \int_{i \in \Omega} \frac{P_i}{\bar{P}} \log \frac{P_i}{\bar{P}} \, di$ is the Theil index of price dispersion in the industry. Therefore, the mean and dispersion (measured by the Theil index) of prices form a sufficient statistic for the industry equilibrium, as they allow to recover both $P$ and $D$. The ideal price index $\bar{P}$ equals the average price in the industry adjusted for the dispersion of prices: given the average price $\bar{P}$, the ideal price index is lower the larger is the dispersion of prices $T$ and/or the larger is the elasticity of substitution parameter $\bar{\sigma}$. The second auxiliary variable $D$ measures the departure of the price index from the average price, and hence is decreasing in the dispersion of prices. This example illustrates the role of the two auxiliary variables $P$ and $D$, and while it corresponds to a very special case of the model, it provides more general insights about the types of the moments of the price distribution, which shift the demand schedules.

**F.2 Derivation of demand**

Denote by $\lambda$ and $\mu$ the Lagrange multipliers on demand aggregator (A4) and the expenditure constraint (A7) respectively. The first order conditions for $C$ and $C_j$ are respectively:

$$1 = \lambda \sum_{j \in \Omega} A_j \Upsilon'\left(\frac{NC_j}{\xi_j C}\right) \frac{C_j}{\xi_j C^2},$$

$$\mu P_j = \lambda A_j \Upsilon'\left(\frac{NC_j}{\xi_j C}\right) \frac{1}{\xi_j C}.$$

Denote by $P \equiv 1/\mu$, which is the ideal price index such that $PC = E$ under the optimal consumption allocation, and by

$$D \equiv C = \sum_{j \in \Omega} \frac{A_j C_j}{\xi_j C} \Upsilon'\left(\frac{NC_j}{\xi_j C}\right).$$

With this notation, we can rewrite the optimality conditions to obtain the product demand function:

$$C_j = \frac{\xi_j C}{N} \psi\left(\frac{P_j/\gamma_j}{P/D}\right), \quad \gamma_j \equiv A_j/\xi_j, \quad \psi(\cdot) \equiv \Upsilon'^{-1}(\cdot).$$
Given \( P = E/C \), \( P \) and \( D \) are determined from the two constraints on the problem (A4) and (A7), which can be rewritten as:

\[
\frac{1}{N} \sum_{j \in \Omega} A_j \Upsilon \left( \psi \left( \frac{P_j/\gamma_j}{P/D} \right) \right) = 1,
\]

\[
\frac{1}{N} \sum_{j \in \Omega} \xi_j P_j \psi \left( \frac{P_j/\gamma_j}{P/D} \right) = 1,
\]

which we reproduce in the main text as (A10) and (A11). This fully characterizes the solution to the consumer’s problem and hence the demand schedule. Note that equation (A11) is simply the statement that the sum of market shares in the industry equals 1, since the market share of a product is given by:

\[
s_j = \frac{P_j C_j}{PC} = \frac{\xi_j P_j}{NP} \cdot \psi \left( \frac{P_j/\gamma_j}{P/D} \right) = \frac{\xi_j P_j \psi \left( \frac{P_j/\gamma_j}{P/D} \right)}{\sum_{i \in \Omega} \xi_i P_i \psi \left( \frac{P_i/\gamma_i}{P/D} \right)},
\]

where we substituted demand (A9) for \( C_j \) and expressed \( P \) out using (A11). In the CES case, we have \( \psi(x) = \left( \frac{\sigma}{\sigma-1} x \right)^{-\sigma} \), and the expression for market share simplifies to:

\[
s_j = \frac{\left(A_j \xi_j 1-\sigma \right) P_j 1-\sigma}{\sum_{i \in \Omega} \left(A_j \xi_i 1-\sigma \right) P_i 1-\sigma} = \frac{A_j \xi_j 1-\sigma}{N} \left( \frac{P_j}{P} \right)^{1-\sigma},
\]

where \( P \) is defined in (??).

Finally, we defined the elasticity and the super-elasticity of demand:

\[
\tilde{\sigma}_j = \tilde{\sigma}(x_j) \equiv -\frac{d \log \psi(x_j)}{d \log x} = -\frac{x_j \psi'(x_j)}{\psi(x_j)},
\]

\[
\tilde{\varepsilon}_j = \tilde{\varepsilon}(x_j) \equiv \frac{d \log \psi(x_j)}{d \log x} \frac{x_j \psi'(x_j)}{\psi(x_j)}.
\]

### F.3 Large firms

Denote by \( Z = D/P \) and take a full log differential of (A10)–(A11) with respect to \( (P_i, P, Z) \) for some \( i \in \Omega \) and holding \( P_j \) for all \( j \neq i \) constant:

\[
\frac{d \log Z}{d \log P_i} = -\frac{A_j}{N} \left( \frac{Z P_j}{\gamma_j} \right)^2 \psi' \left( \frac{Z P_j}{\gamma_j} \right),
\]

\[
\frac{d \log P}{d \log P_i} = \frac{\xi_i P_i}{NP} \left[ \psi \left( \frac{Z P_i}{\gamma_i} \right) + \frac{Z P_i}{\gamma_i} \psi' \left( \frac{Z P_i}{\gamma_i} \right) \right] + \frac{d \log Z}{d \log P_i} \sum_{j \in \Omega} \frac{\xi_j P_j Z P_j}{NP} \psi' \left( \frac{Z P_j}{\gamma_j} \right),
\]

where in manipulating the differential of (A10) we used the fact that \( \Upsilon' \left( \psi(x) \right) \equiv x \) by definition of \( \psi(\cdot) \) as the inverse function of \( \Upsilon'(\cdot) \). Using the definition of the market share \( s_j \) and the elasticity of
demand $\tilde{\sigma}_j$, we can rewrite:

$$\frac{d \log Z}{d \log P_i} = - \frac{D\xi_i P_i \psi \left( \frac{ZP_i}{\gamma_i} \right) \tilde{\sigma}_i}{\sum_{j \in \Omega} D_{\xi_i} P_j \psi \left( \frac{ZP_j}{\gamma_j} \right) \tilde{\sigma}_j} = - s_i \tilde{\sigma}_i,$$

$$\frac{d \log P}{d \log P_i} = s_i (1 - \tilde{\sigma}_i) - \frac{d \log Z}{d \log P_i} \sum_{j \in \Omega} s_j \tilde{\sigma}_j = s_i.$$

Profit maximization:

$$\Pi_j = \max_{P_j} \left\{ [P_j - MC_j] C_j \right\},$$

where

$$C_j = \frac{\xi_j E_{N\pi}}{NP_j} \cdot \psi \left( ZP_j / \gamma_j \right).$$

FOC:

$$1 + [1 - MC_j / P_j] \cdot \frac{d \log C_j}{d \log P_j} = 0,$$

where we have:

$$\frac{d \log C_j}{d \log P_j} = - \eta s_j - \tilde{\sigma}_j \left[ 1 - \frac{s_j \tilde{\sigma}_j}{\sum_{i \in \Omega} s_i \tilde{\sigma}_i} \right],$$

and therefore price-setting satisfies:

$$P_j = M_j MC_j, \quad M_j = \frac{\tilde{\sigma}_j \left[ 1 - \frac{s_j \tilde{\sigma}_j}{\sum_{i \in \Omega} s_i \tilde{\sigma}_i} \right] + \eta s_j}{\tilde{\sigma}_j \left[ 1 - \frac{s_j \tilde{\sigma}_j}{\sum_{i \in \Omega} s_i \tilde{\sigma}_i} \right] + \eta s_j - 1}.$$

As $s_j \to 0$, we have $M_j = \tilde{\sigma}_i/ (\tilde{\sigma}_i - 1)$. When $\varepsilon \to 0$ and hence $\tilde{\sigma}_j \equiv \sigma$ for all $j$, we have:

$$M_j = \frac{\sigma (1 - s_j) + \eta s_j}{\sigma (1 - s_j) + \eta s_j - 1}.$$

We need to derive:

$$\Gamma_j \equiv - \frac{d \log M_j}{d \log P_j} =,$$

$$\Gamma_P \equiv \frac{d \log M_j}{d \log P} =,$$

$$\Gamma_D \equiv \frac{d \log M_j}{d \log D} =$$

### F.4 Klenow and Willis demand

Figure A2 plots these cross-sectional relationships (for $\sigma = 4$ and various values of $\varepsilon$), from which we can draw a number of useful lessons. Figure A2a shows that for $\varepsilon > 0$ there is a finite choke-off price above which firms cannot sell positive quantities; this choke-off price corresponds to the level at which markups equals 1 in Figure A2c and, consequently, the price is equal to marginal cost (intersects
45°-line) in Figure A2f. Figure A2b illustrates that for low enough prices the elasticity of demand is less than unity, \( \sigma_i < 1 \), which is inconsistent with firm optimization; therefore, optimizing firms always choose a price at least to ensure demand with unit-elasticity, \( \sigma(x) = 1 \)—this can be seen in Figure A2c as the markup goes to infinity, in Figure A2e as the pass-through goes to zero, and in Figure A2f as the price asymptotes (on the left) and becomes insensitive to the marginal cost. Finally, Figure A2e shows that the maximal pass-through rates (for the smallest firms) are low when \( \varepsilon \) is large (below 60% for \( \varepsilon = 3 \) and below 45% for \( \varepsilon = 6 \)); when \( \varepsilon \) is small (1), the pass-through varies moderately between 60% and 80%—this means we need an intermediate level of \( \varepsilon \in [1.5, 2.5] \) to match the data.

F.5 Special case of \( \tilde{\varepsilon} = \bar{\sigma} \)

With \( \tilde{\varepsilon} = \bar{\sigma} > 1 \), we can take the integral defining \( \Upsilon(y) \) analytically, as \( \Gamma(1, y) = \int_y^\infty e^{-t} dt = e^{-y} \).

Therefore, in this case, we have:

\[
y_i = \psi(x_i) = 1 - \sigma \log \left( \frac{\sigma}{\sigma - 1} x_i \right), \quad x_i = \frac{P_i}{\gamma_i} \frac{P}{D},
\]

\[
\Upsilon(y_i) = 1 + (\sigma - 1) \left[ 1 - \exp \left\{ (1 - y_i)/\sigma \right\} \right]
\]

and thus

\[
\Upsilon(\psi(x_i)) = \sigma(1 - x_i).
\]

Substituting this into (A10)--(A11), we have (in the monopolistic competition limit):

\[
\frac{\sigma}{|\Omega|} \int_{i \in \Omega} A_i \left( 1 - \frac{P_i/\gamma_i}{P/D} \right) \, di = 1,
\]

\[
\frac{1}{|\Omega|} \int_{i \in \Omega} \frac{\xi_i P_i}{P} \left[ 1 - \sigma \log \left( \frac{\sigma}{\sigma - 1} \frac{P_i}{P/D} \right) \right] \, di = 1.
\]

The first of these defines the ratio \( P/D \):

\[
\frac{P}{D} = \frac{\sigma \cdot \mathbb{E}\{\xi_i P_i\}}{\sigma \cdot \mathbb{E}\{A_i\} - 1},
\]

where \( \mathbb{E}\{\cdot\} \) denotes a population average of a variable. Using the expression \( P/D \), we can express out the price index \( P \) from the second condition as:

\[
P = \mathbb{E}\{\xi_i P_i\} \cdot \left[ 1 - \sigma \mathbb{E}\left\{ \frac{\xi_i P_i}{\mathbb{E}\{\xi_i P_i\}} \cdot \log \left( \frac{\xi_i P_i}{\mathbb{E}\{\xi_i P_i\}} \frac{1}{\mathbb{E}\{A_i\} - 1} \right) \right\} \right].
\]
Figure A2: Klenow-Willis specification of Kimball demand
It is natural to impose the following normalization: 
\[E\{A_i\} = \frac{1}{|\Omega|} \int_{i \in \Omega} A_i \, di = 1.\]
In that case, the expression simplify to:

\[
\frac{P}{D} = \frac{\sigma}{\sigma - 1} E\{\xi_i P_1\},
\]

\[
P = E\{\xi_i P_1\} \cdot \left[ 1 - \sigma T\{\xi_i P_1\} + \sigma \frac{E\{\xi_i P_1 \log A_i\}}{E\{\xi_i P_1\}} \right],
\]

where \(T\{\xi_i P_1\}\) is the Theil inequality index for \(\{\xi_i P_1\}\) defined as

\[
T\{\xi_i P_1\} = \frac{1}{|\Omega|} \int_{i \in \Omega} \frac{\xi_i P_1}{E\{\xi_i P_1\}} \log \left( \frac{\xi_i P_1}{E\{\xi_i P_1\}} \right) \, di.
\]
References


 EDMOND, C., V. MIDRIGAN, AND D. Y. XU (2015): “Competition, Markups, and the Gains from Interna-


