

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

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September 22, 2015

PRELIMINARY AND INCOMPLETE

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Abstract

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 variable 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

¹In 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).

²We 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.³ 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.⁴

The estimated elasticities of firm price responses are the fundamental primitives that shape the transmission of international shocks into domestic prices and quantities.⁵ 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

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.⁶ 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

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.⁷ 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 Itshhoki (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.⁸ Amiti, Itshhoki, 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

⁷A 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.

⁸Gopinath and Itshhoki (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 \(2012\)](#) 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.⁹

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. Using this general framework, we estimate the strength of strategic complementarities in Section 3. Second, for the quantitative analysis, we will need to commit to a particular model. In Section 2.2 we describe a popular model of variable markups under oligopolistic competition with CES demand, introduced by [Krugman \(1987\)](#) and further developed by [Atkeson and Burstein \(2008\)](#). This model is another example that fits our more general accounting framework, which we adopt for calibration and quantitative analysis in Section 4. 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:

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

where our convention is to use small letters for logs and capital letters for the levels of the corresponding variables. This identity can also be viewed as the definition of a firm’s realized log markup, whether or not it is chosen optimally by the firm and independently of the details of the equilibrium environment. Since datasets with precisely measured firm marginal costs are usually unavailable, equation (1) cannot

⁹The 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 \(2012\)](#). 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.

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 change in equation (4) below, which can be estimated in the data to recover important properties of the firm’s markup.¹⁰

We focus on a given industry s with N competing firms, denoted with $i \in \{1, \dots, N\}$, 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, and for now we abstract from the issue of multi-product firms, which we reconsider in Section 3. Therefore, for now i indexes both firms and products. We denote with $\mathbf{p}_t \equiv (p_{1t}, \dots, p_{Nt})$ the vector of prices of all firms in the industry, and with $\mathbf{p}_{-i,t} \equiv (p_{1t}, \dots, p_{i-1,t}, p_{i+1,t}, \dots, p_{Nt})$ the vector of prices of all firm i ’s competitors, and we make use of the notational convention $\mathbf{p}_t \equiv (p_{it}, \mathbf{p}_{-i,t})$.

In order to derive our estimating equation, we rely on two assumptions. First, we require that the demand system is *invertible*, i.e. that there exists a one-to-one mapping between any vector of prices \mathbf{p}_t and a corresponding vector of quantities demanded $\mathbf{q}_t \equiv (q_{1t}, \dots, q_{Nt})$. Second, we focus on static profit maximization and rule out the dynamic considerations in the price setting. Beyond these two assumptions (which we discuss in more detail below), we need *not* impose any further structure on demand or industry competition, and can immediately prove our main result characterizing the price-setting behavior of the firms as follows:

Proposition 1 *For any given invertible demand system and any given competition structure, there exists a markup function $\mu_{it} = \mathcal{M}_i(p_{it}, \mathbf{p}_{-i,t}; \boldsymbol{\xi}_t)$, where $\boldsymbol{\xi}_t = (\xi_{1t}, \dots, \xi_{Nt})$ is the vector of demand shifters for all firms in the industry, such that the firm’s static profit-maximizing price \tilde{p}_{it} is the solution to the following fixed point equation:*

$$\tilde{p}_{it} = mc_{it} + \mathcal{M}_i(\tilde{p}_{it}, \mathbf{p}_{-i,t}; \boldsymbol{\xi}_t), \quad (2)$$

given the price vector of the competitors $\mathbf{p}_{-i,t}$.

We provide a formal proof of this proposition in Appendix D.1, and here offer a discussion of the assumptions and the result. First, the assumption of an invertible demand system is a mild technical requirement, which allows us to fully characterize the market outcome in terms of a vector of prices, with the corresponding vector of quantities recovered by inversion of the demand system. An intuitive necessary requirement for this assumption to hold is that the firm’s demand is strictly monotonic in its own price. 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 arbitrary large but finite elasticity of substitution between varieties, which approximates arbitrarily well the case of perfect substitutes (see Kucheryavyy 2012). Note that this assumption does not rule out most popular demand systems, including CES (as in e.g. Atkeson and Burstein 2008), linear (as in e.g. Melitz and Ottaviano 2008), Kimball (as in e.g. Gopinath and Itskhoki 2010), translog (as in e.g. Feenstra and Weinstein 2010), discrete-choice logit (as in e.g. Goldberg 1995), and many others.

¹⁰An 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).

The second assumption, that the firms are *static profit maximizers*, excludes dynamic price-setting considerations such as menu costs (as e.g. in [Gopinath and Itskhoki 2010](#)) or inventory management (as e.g. in [Alessandria, Kaboski, and Midrigan 2010](#)). It is possible to generalize our framework to allow for dynamic price-setting, however in that case the estimating equation would be sensitive to the specific dynamic structural model.¹¹ Instead, in Section 3, we offer an empirical robustness check, 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). In the context of an oligopolistic market, our framework allows for both price (Bertrand) and quantity (Cournot) competition. Note that the markup function $\mathcal{M}_i(\cdot)$ depends on the demand and competition structure, that is, it changes from one structural model to the other. Proposition 1 emphasizes that for any such structure, there exists a corresponding markup function, which describes price-setting behavior of the firms.

The proof of Proposition 1 establishes that under any demand and competition structure, the firm's profit maximization results in the optimal log markup given by:

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

for some $\sigma_{it} \equiv \sigma_i(p_{it}, \mathbf{p}_{-i,t}; \boldsymbol{\xi}_t)$, which is non-constant in general (outside the monopolistic-competition-CES case) and can be thought of as the firm's *perceived* elasticity of demand. In fact, σ_{it} depends both on the curvature (elasticity) of demand and the assumed equilibrium behavior of the competitors (i.e., constant competitor prices under Bertrand and quantities under Cournot competition), which in turn are functions of the vector of prices and demand shifters alone.¹² Finally, note that Proposition 1 does *not* require that competitor prices are equilibrium outcomes, as equation (2) holds for any possible vector $\mathbf{p}_{-i,t}$. Therefore, equation (2) characterizes both the on- and off-equilibrium behavior of the firm given its competitors' prices, and thus with a slight abuse of terminology we refer to it in what follows as the firm's *best response* schedule (or *reaction function*).¹³ The full industry equilibrium is achieved

¹¹The adopted structural interpretation of our estimates is specific to the flexible-price model, where μ_{it} is the static profit-maximizing oligopolistic markup. Nonetheless, our statistical estimates are still informative even when price setting is dynamic. In this case, the realized markup μ_{it} is not necessarily statically optimal for the firm, yet its estimated elasticity is still a well-defined object, which can be analyzed using a calibrated model of dynamic price setting (e.g., a Calvo staggered price setting model or a menu cost model, as in [Gopinath and Itskhoki 2010](#)). We choose not to pursue this alternative approach due to the nature of our data, as we discuss in Section 3.1.

¹²The perceived elasticity can be defined as

$$\sigma_{it} \equiv -\frac{dq_{it}}{dp_{it}} = -\left[\frac{\partial q_i(p_{it}, \mathbf{p}_{-i,t}; \boldsymbol{\xi}_t)}{\partial p_{it}} + \sum_{j \neq i} \frac{\partial q_i(p_{it}, \mathbf{p}_{-i,t}; \boldsymbol{\xi}_t)}{\partial p_{jt}} \frac{\partial p_{jt}}{\partial p_{it}} \right],$$

where $q_{it} = q_i(p_{it}, \mathbf{p}_{-i,t}; \boldsymbol{\xi}_t)$ is the firm's demand schedule. Under monopolistic and oligopolistic price (Bertrand) competition, the competitors' price response is (assumed to be) $\partial p_{jt} / \partial p_{it} = 0$, and the perceived elasticity is determined by the curvature of demand alone. Under oligopolistic quantity (Cournot) competition the same is assumed for the competitors' quantity response (i.e., $\partial q_{jt} / \partial q_{it} = 0$), which requires that $\{\partial p_{jt} / \partial p_{it}\}_{j \neq i}$ is such that for all $j \neq i$ $q_j(\mathbf{p}_t; \boldsymbol{\xi}_t)$ remain unchanged in response to an adjustment in p_{it} . Therefore, in this case $\partial p_{jt} / \partial p_{it} = -\frac{\partial q_j(\mathbf{p}_t; \boldsymbol{\xi}_t) / \partial p_{it}}{\partial q_j(\mathbf{p}_t; \boldsymbol{\xi}_t) / \partial p_{jt}}$ is a non-zero function of $(\mathbf{p}_t; \boldsymbol{\xi}_t)$, contributing to the value of the perceived elasticity by the firm.

¹³In fact, when the competition is oligopolistic in prices, (2) is formally the reaction function. When competition is mo-

when equations corresponding to (2) hold for every firm $i \in \{1, \dots, N\}$ in the industry, that is all firms are on their best response schedules.

We next totally differentiate the best response condition (2) around some admissible point $(\mathbf{p}_t; \boldsymbol{\xi}_t) = (\tilde{p}_{it}, \mathbf{p}_{-i,t}; \boldsymbol{\xi}_t)$ that satisfies this equation:

$$dp_{it} = dmc_{it} + \frac{\partial \mathcal{M}_i(\mathbf{p}_t; \boldsymbol{\xi}_t)}{\partial p_{it}} dp_{it} + \sum_{j \neq i} \frac{\partial \mathcal{M}_i(\mathbf{p}_t; \boldsymbol{\xi}_t)}{\partial p_{jt}} dp_{jt} + \sum_{j=1}^N \frac{\partial \mathcal{M}_i(\mathbf{p}_t; \boldsymbol{\xi}_t)}{\partial \xi_{jt}} d\xi_{jt}, \quad (3)$$

Note that the markup function $\mathcal{M}_i(\cdot)$ is not an equilibrium object as it can be evaluated for an arbitrary price vector $\mathbf{p}_t = (p_{it}, \mathbf{p}_{-i,t})$, and therefore (3) 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 (3) 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 (2), and thus it holds for arbitrary perturbations to competitor prices.¹⁴ Also 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 (3) for dp_{it} , we rewrite the resulting equation as:

$$dp_{it} = \frac{1}{1 + \Gamma_{it}} dmc_{it} + \frac{\Gamma_{-i,t}}{1 + \Gamma_{it}} dp_{-i,t} + \varepsilon_{it}, \quad (4)$$

where we introduce the following new notation:¹⁵

$$\Gamma_{it} \equiv -\frac{\partial \mathcal{M}_i(\mathbf{p}_t; \boldsymbol{\xi}_t)}{\partial p_{it}} \quad \text{and} \quad \Gamma_{-i,t} \equiv \sum_{j \neq i} \frac{\partial \mathcal{M}_i(\mathbf{p}_t; \boldsymbol{\xi}_t)}{\partial p_{jt}} \quad (5)$$

for the *own* and *cumulative competitor markup elasticities*, respectively, and define the (scalar) *index of competitor price changes* as

$$dp_{-i,t} \equiv \sum_{j \neq i} \omega_{ijt} dp_{jt} \quad \text{with} \quad \omega_{ijt} \equiv \frac{\partial \mathcal{M}_i(\mathbf{p}_t; \boldsymbol{\xi}_t) / \partial p_{jt}}{\sum_{k \neq i} \partial \mathcal{M}_i(\mathbf{p}_t; \boldsymbol{\xi}_t) / \partial p_{kt}}. \quad (6)$$

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

opolistic, there is no strategic motive in the price-setting of the firm, but the competitor prices nonetheless can affect the curvature of firm's demand and hence its optimal price, as captured by equation (2). This characterization also applies in models of oligopolistic competition in quantities, where the best response is formally defined in the quantity space. Under these circumstances, (2) is the mapping of the best response schedule from the space of quantities into the space of prices, which is always possible given our invertibility requirement.

¹⁴If we combine together equations (3) for all firms $i \in \{1, \dots, N\}$, we can solve for the equilibrium perturbation of all prices $(dp_{1t}, \dots, dp_{NT})$ as a function of the exogenous cost and demand shocks $(dmc_{1t}, \dots, dmc_{NT}, d\xi_{1t}, \dots, d\xi_{Nt})$, which constitutes the reduced form of the model, as we discuss further in Section 2.3.

¹⁵Since many models predict $\partial \mathcal{M}_i(\mathbf{p}_t; \boldsymbol{\xi}_t) / \partial p_{it} \leq 0$ and $\partial \mathcal{M}_i(\mathbf{p}_t; \boldsymbol{\xi}_t) / \partial p_{jt} \geq 0$, we have chosen to define the own elasticity with a negative sign and the competitor elasticity with a positive sign to keep these derived parameters non-negative.

demand does not admit a well-defined ideal price index. The index of competitor price changes $dp_{-i,t}$ aggregates the individual price changes across all firm's competitors, dp_{jt} for $j \neq i$, using endogenous (firm-state specific) weights ω_{ijt} , which are defined to sum to one. These weights depend on the relative markup elasticity: the larger is the firm's i markup elasticity with respect to price change of firm j , the greater is the weight of firm j in the competitor price index. Finally, the residual in (4) is firm i 's effective demand shock given by $\varepsilon_{it} \equiv \frac{1}{1+\Gamma_{it}} \sum_{j=1}^N \frac{\partial \mathcal{M}_i(\mathbf{p}_t; \boldsymbol{\xi}_t)}{\partial \xi_{jt}} d\xi_{jt}$.

Equation (4) is the theoretical counterpart to the estimating equation, which is the focus of our empirical analysis in Section 3. It decomposes the price change of the firm dp_{it} into responses to its own cost shock dmc_{it} , the competitor price changes $dp_{-i,t}$, and the exogenous demand shifts captured by the residual ε_{it} . The two coefficients of interest are:

$$\psi_{it} \equiv \frac{1}{1 + \Gamma_{it}} \quad \text{and} \quad \gamma_{it} \equiv \frac{\Gamma_{-i,t}}{1 + \Gamma_{it}}. \quad (7)$$

The coefficient ψ_{it} measures the *own* (or idiosyncratic) *cost pass-through* of the firm, i.e. the elasticity of the firm's price with respect to its marginal cost, holding the prices of its competitors constant.¹⁶ Coefficient γ_{it} measures the strength of *strategic complementarities* in price setting, as it is the elasticity of the firm's price with respect to the prices of its competitors.¹⁷

Note that coefficients ψ_{it} and γ_{it} are shaped by the markup elasticities Γ_{it} and $\Gamma_{-i,t}$. These elasticities are non-constant, in general, and vary across firms and states (or time periods), as we further discuss below. Since we expect both markup elasticities to be non-negative, we correspondingly anticipate the two coefficients in (4) to lie between zero and one. Furthermore, these two coefficient are generally related. In particular, in a wide class of models $\Gamma_{-i,t} \equiv \Gamma_{it}$, which in turn implies that the two coefficients sum to one:

$$\psi_{it} + \gamma_{it} = 1. \quad (8)$$

a restriction that we can evaluate in the data without imposing it in estimation.¹⁸

In summary, we have established that price change decomposition in (4) holds across a broad class of models. At the same time, the magnitudes of the coefficients in this equation and the structural interpretation of the markup elasticities depend on the specific model. However, we are interested in these elasticities ψ_{it} and γ_{it} independently of the specific structural interpretation, as they have a *sufficient statistic* property for analyzing the response of firm prices to shocks, such as an exchange rate shocks, as we discuss further in Section 2.3. And now, we consider the details of one specific structural

¹⁶Note that in models of oligopolistic competition, constant competitor prices do not in general constitute an equilibrium response to an idiosyncratic cost shock for a given firm. This is because price adjustment by the firm induces its competitors to change their prices as well because of strategic complementarities. Nonetheless, ψ_{it} is a well-defined counterfactual elasticity, characterizing firm's best response off equilibrium.

¹⁷This abuses the terminology somewhat since γ_{it} can be non-zero even under monopolistic competition when firm's behavior is non-strategic, yet the complementarities in pricing still exist via the curvature of demand. In this case, the term *demand complementarity* may be more appropriate. Furthermore, γ_{it} could, in principle, be negative, in which case the prices of the firms are strategic substitutes.

¹⁸This property holds, for example, in the models with a well-defined concept of a competitor price index under the additional requirement that firm's demand depends only on the relative price of the firm (i.e., the ratio of the firm's price to the price index of its competitors). The two cases we consider in detail in this paper—namely, oligopolistic competition under CES demand and monopolistic competition under general Kimball (1995) demand—satisfy this property.

model, which offers a concrete illustration for our more general and abstract derivations 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 $\Gamma_{it} = \Gamma_{-i,t} = 0$, 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 \(1987\)](#).¹⁹ In the following Section 3 we provide direct empirical evidence on the magnitudes of ψ_{it} and γ_{it} , both of which we find to lie strictly between zero and one.

In order to capture these empirical patterns in a model, one needs to depart from either the CES assumption or the monopolistic competition assumption. We follow [Atkeson and Burstein \(2008\)](#) and depart from the monopolistic competition market structure and instead assume oligopolistic competition, while maintaining the CES demand structure.²⁰ 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 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:

$$Q_{it} = \xi_{it} D_{st} P_{st}^{\rho-\eta} P_{it}^{-\rho}, \quad (9)$$

where ξ_{it} is the product-specific preference shock, D_{st} is the industry-level demand shifter, P_{it} is the firm's price and P_{st} is the industry price index.

The industry price index is defined according to:

$$P_{st} = \left[\sum_{i=1}^N \xi_{it} P_{it}^{1-\rho} \right]^{\frac{1}{1-\rho}}, \quad (10)$$

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.²¹

¹⁹[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.

²⁰The 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 \(1995\)](#).

²¹In general, $D_{st} = \varpi_{st} Y_t / P_t$, where ϖ_{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} .

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

$$S_{it} \equiv \frac{P_{it}Q_{it}}{\sum_{j=1}^N P_{jt}Q_{jt}} = \xi_{it} \left(\frac{P_{it}}{P_{st}} \right)^{1-\rho}, \quad (11)$$

where the second equality follows from the functional form of firm demand in (9). 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 ξ_{it}).

As in much of the quantitative literature following [Atkeson and Burstein \(2008\)](#), for example [Edmond, Midrigan, and Xu \(2012\)](#), 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:²²

$$P_{it} = \frac{\sigma_{it}}{\sigma_{it} - 1} MC_{it}, \quad (12)$$

where

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

Under our parameter restriction $\rho > \eta > 1$, the markup is an increasing function of the firm's market share.

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

$$\Gamma_{it} = - \frac{\partial \log \frac{\sigma_{it}}{\sigma_{it}-1}}{\partial \log P_{it}} = \frac{(\rho - \eta)(\rho - 1)\sigma_{it}S_{it}(1 - S_{it})}{\eta\rho(\sigma_{it} - 1)}, \quad (14)$$

$$\Gamma_{-i,t} = \frac{\partial \log \frac{\sigma_{it}}{\sigma_{it}-1}}{\partial \log P_{-i,t}} = \Gamma_{it}, \quad (15)$$

where $P_{-i,t}$ is the competitor price index defined as:

$$P_{-i,t} = \left[\sum_{j \neq i} \frac{\xi_{jt}}{1 - \xi_{it}} P_{jt}^{1-\rho} \right]^{\frac{1}{1-\rho}}, \quad (16)$$

so that, according to (10), the following decomposition is satisfied: $P_{st} = [\xi_{it}P_{it}^{1-\rho} + (1-\xi_{it})P_{-i,t}^{1-\rho}]^{1/(1-\rho)}$.

Note that in this model, all competitors are symmetric in the sense that their prices have an effect on the firm's demand only through their effect on the industry price index, but not directly. The model structural counterpart to the index of competitor price changes (6) is simply:

$$d \log P_{-i,t} = \sum_{j \neq i} \frac{S_{jt}}{1 - S_{it}} d \log P_{jt}, \quad (17)$$

²²The only difference in setting prices under Bertrand competition is that $\sigma_{it} = \eta S_{it} + \rho(1 - S_{it})$, as opposed to (13), and all the qualitative results remain unchanged. Derivations for both cases are provided in Appendix E.

that is the market-share-weighted log change of individual competitor prices. Furthermore, the own and the competitor price elasticities are equal, $\Gamma_{-i,t} = \Gamma_{it}$, and therefore the parameter restriction (8) is satisfied.

In addition, it is easy to see that the markup elasticity is a function of the market share:

$$\frac{\partial \log \Gamma_{it}}{\partial \log S_{it}} = \frac{1 - 2S_{it}}{1 - S_{it}} + \frac{\Gamma_{it}}{\rho - 1}. \quad (18)$$

Therefore, $S_{it} < 1/2$ is a sufficient (but not a necessary) condition for the markup elasticity Γ_{it} to increase with market share. In our data, market shares in excess of 50% are nearly non-existent. Further, note from equation (14) that when $S_{it} \approx 0$, then $\Gamma_{it} \approx 0$, and firms have complete pass-through and no strategic complementarities ($\psi_{it} = 1$ and $\gamma_{it} = 0$), just like in the monopolistic competition case. Indeed such firms are monopolistic competitors. However, firms with positive market shares have $\Gamma_{it} = \Gamma_{-i,t} > 0$, and hence have incomplete pass-through of idiosyncratic shocks and positive strategic complementarities in price setting vis-à-vis their competitors, $\psi_{it}, \gamma_{it} \in (0, 1)$.

The difference in the markup elasticity between small and large firms is intuitive. When setting prices to maximize profits, each firm decides on an optimal balance between its markup and market share. Smaller unproductive firms have both small markups and small market shares, while large productive firms have large markups and market shares. In response to a negative cost shock, the small firms are forced to increase prices and reduce their market shares because they cannot afford to reduce markup, which would make them unprofitable altogether given the small initial markup. By contrast, the large firms choose to maintain market shares and adjust markups, which are large to begin with and can take a cut.

Finally, the price change decomposition in (4) applies to this model with the residual given by:

$$\varepsilon_{it} = \frac{\gamma_{it}}{(\rho - 1)(1 - S_{it})} d\xi_{it}.$$

Therefore, the sources of the residual in (4) in this model are the demand (preference or quality) shocks that affect the market share of the firm and hence its markup. The structural assumption here is that changes in costs do not impact the exogenous demand shifter, ξ_{it} , however alternative scenarios can also be considered (as we discuss in Section 3).

2.3 Identification

In order to estimate our two elasticities of interest – the coefficients ψ_{it} and γ_{it} in the theoretical price decomposition equation (4) – we rewrite these equation in changes over time:

$$\Delta p_{it} = \psi_{i,t} \Delta m c_{it} + \gamma_{i,t} \Delta p_{-i,t} + \varepsilon_{it}, \quad (19)$$

where $\Delta p_{it} \equiv p_{i,t+1} - p_{it}$. Therefore, the estimating equation (19) is the first order Taylor expansion for the firm's price in period $t + 1$ around its equilibrium price in period t .

Estimation of equation (19) is associated with a number of identification challenges. First of all, it

requires obtaining direct measures of firms' marginal costs and competitors' prices. Good firm-level measures of marginal costs are notoriously hard to come by, and we use the change in the log average accounting costs as the proxy for the change in the log marginal cost. Since this is a very noisy measure of the marginal cost, we need to 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 accurately in our dataset. Consider for simplicity the case of constant returns to scale in production. Then, one can write the marginal cost of the firm as:

$$MC_{it} = \frac{W_{it}^{1-\phi_{it}} V_{it}^{\phi_{it}}}{\Omega_{it}}, \quad (20)$$

where W_{it} is the firm-specific cost index of domestic inputs, V_{it} is the cost index of imported intermediate inputs, ϕ_{it} is the fraction of expenditure spent on imported inputs by the firm (i.e., *import intensity* of the firm), and Ω_{it} is the firm's productivity. Note that (20) does not restrict the production structure to Cobb-Douglas as the expenditure elasticity ϕ_{it} is not required to be constant over time or across firms. Rewriting (20) in log changes, we have:

$$\Delta mc_{it} = \phi_{it} \Delta v_{it} + (1 - \phi_{it}) \Delta w_{it} + \Delta \phi_{it} (v_{it} - w_{it}) - \omega_{it}. \quad (21)$$

Our instrument is the change in the cost of the imported intermediate inputs, which we denote with

$$\Delta mc_{it}^* = \phi_{it} \Delta v_{it}, \quad (22)$$

and which we can measure very accurately in our constructed dataset. In Section 3 we discuss the details of construction of this variable and why we expect it to be exogenous to the residual ε_{it} of the estimating equation (19). In Appendix D.2, we further show that our identification approach, which relies on the average variable cost as the proxy for marginal cost instrumented by a component of the marginal cost, is valid even when firms operate a decreasing returns to scale technology.²³

An important advantage of our dataset is that we are able to measure price changes for all firm's competitors including all domestically-produced and imported products. The second identification challenge we deal with is the endogeneity of the competitor prices on the right-hand side of the estimating equation (19). Even though the theoretical equation (4) 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 (4) requires finding valid instruments for the competitor price changes, which are orthogonal with the residual source of changes in markups captured by ε_{it} in (19). In Section 3 we discuss in the detail the instruments used, with the main instruments being the portion of the competitors' marginal costs that we can measure accurately, Δmc_{jt}^* for $j \neq i$.

²³Intuitively, avc_{it} differs from mc_{it} by the curvature parameter that captures the returns to scale, which nets out when we take tike differences for a given firm, even when the degree of returns to scale varies in the cross-section of firm.

Third, we need to measure empirically the relevant index of competitor price changes (6), which involves endogenous weights ω_{ijt} . Our baseline approximation is to proxy for ω_{ijt} using the competitor market shares, $\omega_{ijt} = S_{jt}/(1 - S_{it})$, which results in the following proxy for the index of competitor price changes:

$$\Delta p_{-i,t} = \sum_{j \neq i} \frac{S_{jt}}{1 - S_{it}} \Delta p_{jt}. \quad (23)$$

Note that this index is exact for the parametric model of Section 2.2 which features nested CES demand (cf equation (17)). In addition, it offers a first order approximation in a number of models with monopolistic competition, for example those based on the Kimball demand. However, more generally the weights in (23) may be biased relative to the theoretical weights defined by (6). In the data, we can address this concern non-parametrically, by subdividing the competitors into more homogenous subgroups (e.g., based on their origin) and estimating separate strategic complementarity elasticity for each subgroup.²⁴

Finally, the estimating equation (19) features heterogeneity in the coefficients of interest ψ_{it} and γ_{it} . In our baseline, we pool the observation to estimate common coefficients ψ and γ for all firms and time periods, which we interpret as average elasticities across the 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. Again, we deal with these concerns non-parametrically, by splitting our observations (firms) into subgroups, which we expect to have more homogenous elasticities. In particular, guided by the structural model of Section 2.2, the elasticities ψ_{it} and γ_{it} are functions of the market share of the firm 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.²⁵

We close this section with a brief discussion of our choice of the estimating equation (19), which is a counterpart to the firm's reaction function (4). That is, we develop an instrumental variable strategy to estimate an off-equilibrium object (the reaction function), using equilibrium variation in marginal costs and prices. Instead one could estimate the *reduced form* of the model:

$$\Delta p_{it} = \alpha_{it} \Delta mc_{it} + \beta_{it} \Delta mc_{-i,t} + \tilde{\varepsilon}_{it}, \quad (24)$$

which is an equilibrium relation between the firm's price change and exogenous shocks to marginal costs and demand. Equation (24) is an empirical counterpart to the theoretical fixed-point solution for equilibrium price changes, which requires that conditions (4) hold simultaneously for all firms i in the industry. In Appendix D.4, we provide explicit solution for the reduced-form coefficients α_{it} and β_{it} in (24), as well as for the theoretically-grounded notion of the competitor marginal cost index $\Delta mc_{-i,t}$.

There are a number of reasons why we choose to estimate the reaction function (19) as opposed

²⁴Formally, as the amount of data increases and the heterogeneity in ω_{ijt} within more narrow subgroups shrinks, this non-parametric procedure yields consistent estimates independently of the actual weights ω_{ijt} .

²⁵Alternatively, one can address the last two challenges by taking a stand of a specific structural model and using our baseline estimates, even if misspecified, to quantitatively discipline the models by means of indirect inference approach.

to the reduced form (24). First is the data limitation, which limits us from measuring a proxy for the marginal cost of foreign competitors. While this constitutes an omitted variable on the right-hand side of (24), it is not a concern in estimation of (19), since we estimate the reaction functions for domestic firms only, for which we can construct all required right-hand side variables in (19).²⁶ Second, even in the absence of data limitations, constructing the appropriate index of competitor marginal costs $\Delta mc_{-i,t}$ is a more challenging task than that of competitor prices $\Delta p_{-i,t}$, as we show in Appendix D.4. Even when (A2) measures the ideal index of competitor price changes, its counterpart for the marginal costs is not appropriate, since the competitor marginal costs should be weighted not only by market shares of the competitors, but also by the extent of their cost pass-through in equilibrium.

Lastly, and importantly given our focus, the coefficients of the reaction function ψ_{it} and γ_{it} have a much clearer structural interpretation than the reduced-form coefficients α_{it} and β_{it} . As we show in (7), the elasticities ψ_{it} and γ_{it} have a very concise expression in terms of the firm's markup function elasticity, which are easy to interpret, while the reduced-form coefficients confound a number of complex industry equilibrium effects and are thus much less tractable for structural interpretation (see Appendix D.4). In addition, the estimated reaction function elasticities have an appealing sufficient statistic property for describing the firm's behavior in response to various shocks, for example an exchange rate shock. That is, (ψ_{it}, γ_{it}) are sufficient for describing the response of the firm to an exchange rate shock, provided we know the firm's own cost and its competitor price sensitivity to the exchange rate, and independently of the response of other firm's costs to the exchange rate.

3 Empirical Analysis

3.1 Data Description

To empirically implement the general accounting framework of Section 2.1, we need to be able to measure each variable in equation (4). We do this by combining three different data sets for the period 1995 to 2007 at the annual frequency. The first data set is firm-product level production data (PRODCOM) from the National Bank of Belgium, collected by Statistic Belgium. A rare feature of these data is the highly disaggregated information on values and quantities of all products produced by manufacturing firms in Belgium, 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 firms' exports. Firms in the Belgium 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 Belgium firms with a minimum of 10 employees, which covers at least 90% of production value in each NACE 4-digit industry (that is, 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.

²⁶Note that reaction functions can be estimated one at a time, provided valid instruments, since they are off-equilibrium objects and do not require estimation of all reaction functions simultaneously.

The second data set, on imports and exports, is also from the National Bank of Belgium, 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 data sets is more complicated (and described in the data appendix).

The third data set, on firm characteristics, comes from the Belgian Business Registry. 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 their main economic activity within a 5-digit NACE industry, but there is no individual firm-product level data available from this data set.

We combine these three data sets for the period 1995 to 2007 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 Δp_{it} , where i corresponds to a firm-product at the PC-8-digit level. The domestic unit values are calculated as the ratio of production sold domestically to quantity sold domestically:²⁷

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

We clean the data by dropping the observations for which the year-to-year log change in domestic unit values is greater than 200% or less than minus 66%.

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 data sets 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 construct the change in the log marginal cost of firm i as follows:

$$\Delta mc_{it} = \Delta \log \frac{\text{Total Variable Cost}_{it}}{Y_{it}}, \quad (26)$$

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.²⁸ 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. This is likely to be a noisy measure of the

²⁷In order to get at the domestic portion of total production, we need to net out the firm's exports. One complication in constructing domestic sales is the issue of carry-along-trade (see Bernard, Blanchard, Van Beveren, and Vandenbussche 2012), which arises 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 in terms of value and quantity (dropping 11% of the observations and 15% of the production value, which amounts to a much lower share of domestic value sold since most of this production is exported).

²⁸More precisely, we calculate the change in the log production quantity as the difference between $\Delta \log$ Revenues and $\Delta \log$ Price index of the firm, and subtract the resulting $\Delta \log Y_{it}$ from $\Delta \log$ Total Variable Cost _{it} to obtain Δmc_{it} in (26).

firm-product marginal cost. Therefore, we construct the foreign-input component of a firm's marginal cost, defined as follows:

$$\Delta mc_{it}^* = \sum_m \omega_{imt} \Delta v_{imt}, \quad (27)$$

where m indexes a firm's imported inputs at the country of origin and CN-8-digit product level, Δv_{imt} are the changes in the log unit values of the firm's imported intermediate inputs, and the weights are the average of t and $t - 1$ firm import shares. We drop any change in import unit values greater than 200% and less than 66%. We also 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 Belgium market, Belgium firms in the PRODCOM sample face competition from other Belgium firms in the PRODCOM sample that produce and sell their goods in Belgium (which we refer to as domestic firms) as well as from Belgium firms not in the PRODCOM sample who import their goods and sell them in the Belgium market (which we refer to as foreign firms). To capture these two different sources of competition, we construct competitor price indexes for each at the industry level. The import price competition index faced by each firm in industry s is the weighted average log change in the import price of goods imported by its competitors:

$$\Delta p_{st}^F = \sum_{j \in F_s} \omega_j \Delta p_{jt}, \quad (28)$$

where F_s is the set of the foreign firm-product competitors of the firm in industry s . Only the imports categorized as final goods enter in the construction of this variable, i.e. any imports that are not included in the construction of the marginal costs. We also split this variable into two components, separating euro and noneuro countries. The euro grouping comprise a time-invariant group, which includes all euro countries except Slovenia and Slovakia who were late joiners with volatile exchange rates in the years before becoming members.

Similarly, the domestic price competition variable for each firm in industry s is constructed as the weighted average log change in the domestic price of goods sold by its competitors:

$$\Delta p_{-i,t}^D = \sum_{j \in D_s, j \neq i} \omega_{jt}^{-i} \Delta p_{jt}, \quad (29)$$

where D_s is the set of domestic firm-products in industry s . An overall competitors price index is constructed as the weighted average of the foreign and domestic indexes:

$$\Delta p_{-i,t} = (1 - \theta_{-i,t}) \Delta p_{-i,t}^D + \theta_{-i,t} \Delta p_{st}^F \quad (30)$$

where $\theta_{-i,t}$ is the foreign market share in industry s sales net of sales by firm i . A firm i market share in industry s sold in Belgium is defined as the ratio of the firm's sales to the total market size. We define an industry at the NACE 4-digit level and include all industries for which we have at least 2 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. Our results are robust to more disaggregated industries at the 5-digit and 6-digit levels.

Instruments The instrument to address the measurement error in firms' marginal cost was defined above in equation (27). Here, we describe the construction of the three instruments we use to address the endogeneity of the competitors' prices, each proxying for the marginal costs of the different types of competitors. For the domestic competitors, we use a weighted average (in parallel with (29)) of each domestic competitor's foreign component of marginal cost as defined in (27):

$$\Delta mc_{-i,t}^* = \sum_{j \in D_s, j \neq i} \omega_{jt}^{-i} \Delta mc_{jt}^*.$$

For the non-euro foreign firms, we proxy for their marginal costs using a weighted average of exchange rates, defined at the 4-digit industry level:

$$\Delta e_{st} = \sum_k \theta_{kt}^s \Delta e_{kt},$$

where k indexes countries and θ_{kt}^s is the share of competitors from country k in industry s .²⁹ This is the same exchange rate measure we use in the exchange rate pass-through regressions.

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 zone) and calculate weighted averages of the change in their log export prices to all euro zone countries, except Belgium. Then for each product (at the CN 8-digit level) we have the log change in each export price index for each of these 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. We denote this instrument with Δp_{st}^{EU} .

3.2 Empirical Results

In this section, we estimate the strength of strategic complementarities in price setting across Belgian manufacturing industries using the general accounting framework developed in Section 2.1. We do this by regressing the change in log firm-product prices on the changes in the firm's log marginal cost and

²⁹The exchange rates are average annual rates from the IMF. These are reported for each country relative to the US dollar, which we convert to be relative to the euro.

its competitors' price index, as in equation (4). The coefficient on the marginal cost variable, which we denote ψ_{it} in (7), is the idiosyncratic cost pass-through into prices, i.e. the pass-through coefficient from a marginal cost shock holding the competitors' prices constant. The coefficient on the competitor price variable, which we denote γ_{it} in (7), is the elasticity of firm price with respect to the prices of its competitors, i.e. the extent of the strategic complementarities in price setting. These coefficients are fundamental primitives that shape firm's pricing strategies, and in particular the response to the aggregate shocks such as exchange rate movements.

According to most theories, we should expect both coefficients to lie between zero and one. If the markup elasticity, Γ_{it} were symmetric for both own price and competitor price, the two coefficients in equation (4) would sum to one as in equation (8). Effectively, this implies the equation would be over-identified. That is, if we know the coefficient on the marginal cost variable, we can infer the value of the coefficient on the competitor price index. However, we do not impose this restriction in the estimation. Instead, we estimate both of the coefficients freely and then test if the two do in fact sum to one.

Baseline estimates Table 1 reports the results. In the first two columns we estimate equation (4) using weighted least squares without instrumenting, 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.

These estimates, however, are likely to suffer from endogeneity bias due to the simultaneity of price setting by the firm and its competitors, as well as from downward bias due to measurement error. 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 this concern, we instrument for the firm's marginal cost using the foreign component of its marginal cost, as defined in equation (27), which is more precisely measured than the other components of the firm's marginal cost.³⁰ In turn, in order to address the endogeneity of competitors' prices, we construct three proxy measures of competitors' marginal costs to instrument for the competitor price index: (i) the weighted average of the price of imported inputs of domestic competitors; (ii) the industry-level exchange rate to capture changes in marginal costs of non-euro exporters to Belgium; and (iii) a proxy for the marginal costs of the euro exporters, as defined in section 3.1. Using these instruments, we reestimate equation (4) in columns 3 and 4, with and without industry fixed effects correspondingly.

In order to be valid, the instruments need to be orthogonal with the residual ε_{it} in (4). The structural model of Section 2.2 suggests that ε_{it} reflects shocks to demand and perceived quality of the good. Our instruments are plausibly uncorrelated with this residual. We confirm the validity of these instruments with the Hansen overidentification J -tests in Table 1 with very large p -values. Additionally, we show

³⁰Formally, our right-hand-side variable is Δmc_{it} and we instrument it with the Δmc_{it}^* . The coefficient in the first-stage projection of Δmc_{it} on Δmc_{it}^* is large and significant (see Appendix Table A1), while the inverse projection yields a coefficient of close to zero, together confirming both that Δmc_{it} is a proxy for the marginal cost of the firm, but a very noisy one.

Table 1: Strategic complementarities: baseline estimates

Dep. var.: Δp_{it}	OLS		IV	
	(1)	(2)	(3)	(4)
Δmc_{it}	0.348*** (0.040)	0.348*** (0.041)	0.667*** (0.117)	0.757*** (0.150)
$\Delta p_{-i,t}$	0.400*** (0.079)	0.321*** (0.095)	0.467*** (0.143)	0.315** (0.151)
# obs.	64,815	64,815	64,815	64,815
Industry F.E.s	no	yes	no	yes
Instrumental Vars	no	no	yes	yes
Weak Instr. F -test			129.61	115.16
Overid. J -test [χ^2 p -value]			0.04 [0.98]	0.06 [0.97]
$H_0: \bar{\psi} + \bar{\gamma} = 1$ [p -value]	0.75 [0.00]	0.67 [0.00]	1.13 [0.17]	1.07 [0.52]

Notes: All regressions are weighted by lagged domestic firm sales and include year fixed effects. The instrument set comprises Δmc_{it}^* , Δe_{st} , $\Delta mc_{-i,t}^*$, p_{st}^{EU} , as discussed in Section 3.1. The IV regressions pass the weak instrument test with F -stats well above critical values and pass all over-identification tests. The first-stage IV regressions are reported in Appendix Table A1.

that our results are robust to alternative instrument sets in the Appendix Table A3. Lastly, we confirm that the instruments pass the weak identification tests, with the F -stat higher than 100, much above the critical value of around 12.

Appendix Table A1 presents the first-stage regressions that correspond to columns 3 and 4 in Table 1. For the first-stage regression for firm marginal cost, we see that the highest coefficient is the firm-level foreign component of marginal cost. The competitor marginal cost index is also positive and significant as similar shocks are likely hitting all firms. However, even though these two variables are positively correlated, the correlation is only 0.28 indicating there is sufficient independent variation in the two variables. The industry-level exchange rate is insignificant in the marginal cost first-stage regression, probably because the foreign component of marginal costs already contains that information. In the competitors' price index first-stage regression, all the instruments are positive and significant, with the largest coefficient on the domestic competitors' marginal cost. These patterns are the same for the regressions with the industry effects in the next two columns.

From column 3–4 in Table 1, where equation (4) is estimated using instrumental variables, 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 coefficients on the firm marginal cost and competitor price index now sum to one, consistent with restriction (8) implied by many theoretical models of variable markups, as discussed in Section 2.³¹

³¹The sums of the coefficients are reported in the bottom row of Table 1, along with a p -value for the test of equality to one. In the instrumental variables regressions (columns 3–4), the sum of the coefficients is slightly above one, and well within the conservative confidence bounds for the test of equality to unity. When we estimate the constrained version of equation (4), 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 unconstrained results in columns 3–4.

These results show that firms exhibit incomplete pass-through of their own cost shocks with an average elasticity of 65–75% (i.e., $\bar{\psi} = 0.65\text{--}0.75$), in the absence of competitor price adjustment. At the same time, the firms exhibit substantial strategic complementarities, adjusting their prices with an elasticity of 30–45% in response to the price changes of their competitors (i.e., $\bar{\gamma} = 0.3\text{--}0.45$). In other words, when a firm’s competitors raise their prices by 10%, the firm raises its price by 3–4.5% in the absence of any own cost shocks, thus entirely translating into an increase in the firm’s markup.

Our estimate of $\bar{\gamma}$ offers a direct estimate of the strength of strategic complementarities in price setting across manufacturing firms. From the estimates of $\bar{\gamma}$ and $\bar{\psi}$, and using (7), we can recover the more primitive objects, namely the average elasticity of the markups with respect to the price of the firm (recall, that we cannot reject $\Gamma_{-i,t} = \Gamma_{it}$). Specifically, we find $\bar{\Gamma}$ is around 0.55, that is a firm reduces its markup by 5.5%, when its price goes up by 10%. This estimate is largely in line, albeit slightly lower, than the values suggested by [Gopinath and Itskhoki \(2011\)](#) based on the analysis of various indirect pieces of evidence.³²

Robustness There are a number of potential concerns regarding the estimation in Table 1, which we address in Table 2. First, if prices are sticky then the markup of a firm would mechanically change in response to a cost shock and may not in fact have anything to do with changes in competitor prices. In column 1, we reestimate our baseline specification from column 4 of Table 1 with all variables calculated 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, which suggests that sticky prices are unlikely to be the main driving force behind our results.

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. We define an intermediate imported input to only include the firm’s imports outside any 4-digit industry in which the firm has sales in any year. That definition is very conservative and significantly reduces the share of imports in the construction of the foreign marginal cost variable. Nevertheless, we see that although the size of the coefficient on the marginal cost variable in column 2 of Table 2 is a bit smaller than in column 4 of Table 1, which utilizes our baseline definition of intermediate inputs, we cannot reject that the two coefficients are of the same magnitude.

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. It is generally difficult to assign costs across products within firms.³³ To check that this multiproduct issue is not muddying our results, we reestimate column 3 with a subsample limited to only including each firm’s main product (defined as the 8-digit product with the

³²[Gopinath and Itskhoki \(2011\)](#) further discuss the relationship of these estimates with the calibrations of the strategic complementarities in popular monetary macro models. As they show, the markup elasticity $\bar{\Gamma}$ plays an important role in the New Keynesian literature, as it directly affects the coefficient on the output gap in the New Keynesian Phillips curve. In order to obtain substantial amplification of monetary non-neutrality, the literature has adopted rather extreme calibrations with $\bar{\Gamma} = 10$ —an order of magnitude above our estimates. Our results, however, do not imply that strategic complementarities in price setting are unimportant for monetary business cycles, yet this mechanism alone cannot account for the full extent of monetary non-neutralities and it needs to be reinforced by other mechanisms (such as roundabout production in [Basu 1995](#)).

³³ See [De Loecker, Goldberg, Khandelwal, and Pavcnik \(2012\)](#) for one approach.

Table 2: Strategic complementarities: robustness

Dep. var.: Δp_{it}	Two-period differences (1)	Alternative input definition (2)	Main product (3)	5-digit industry (4)	6-digit industry (5)
Δmc_{it}	0.642*** (0.245)	0.684*** (0.148)	0.658*** (0.173)	0.750*** (0.167)	0.494*** (0.139)
$\Delta p_{-i,t}$	0.434* (0.234)	0.388* (0.200)	0.374* (0.200)	0.410*** (0.147)	0.654*** (0.131)
# obs.	50,600	64,320	27,027	63,511	53,882

Notes: All regressions are estimated using instrumental variables with the same instrument set as in Table 1. All specifications are weighted by lagged domestic firm sales and include industry fixed effects and year fixed effects. Column 1 is in 2-period differences. Column 2 uses a stricter definition of inputs than the baseline case: it excludes any import in a 4-digit industry (an average of 160 industries) that the firm produces. Column 3 only includes the firm’s largest 8-digit product category in terms of domestic sales. Column 4 defines all competition variables relative to 5-digit industries (around 270 industries). Column 6 defines all competition variables relative to 6-digit industries (around of 325 industries).

firm’s largest domestic sales). We see from column 3 that our results are robust to limiting the sample to the firms “main” product.

Finally, there is the question of how to define an industry. So far, we have defined an industry at the 4-digit NACE level, which divides around 1,500 8-digit product codes into about 160 industries in our sample. In columns 4 and 5, we experiment with defining the competition variables at the more narrowly defined 5-digit and 6-digit industries, respectively. We find that strategic complementarities are positive and significant in these specifications, with the coefficient getting larger with more disaggregated industry definitions.

Heterogeneity The results in Tables 1 and Table 2 provide us with average coefficients for the idiosyncratic pass-through and strategic complementarities across Belgian manufacturing. Our baseline estimates suggest that firms pass through on average around two-third to three-quarters of their marginal cost shocks into their prices, and they respond with an elasticity of around 30–45% to the price changes of their competitors. The general accounting framework of Section 2 suggests, however, that these elasticities may vary with firm-product characteristics. The model of Section 2.2 offers a particular structural interpretation of how these elasticities may vary systematically with firm size (see equation (18)). In Table 3, 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, which we measure in terms of the firm’s employment and its market share.

Our first measure of size defines a large firm (dummy $\text{Large}_{it} = 1$) as any firm that has at least 100 workers on average over the sample period. In column 1 we present the results from estimating equation (4) for the sub-sample of small firms and in column 2 for the sub-sample of large firms separately. From column 1, we see that small firms have a larger coefficient on their marginal cost, equal to 0.98, and an insignificant coefficient of 0.07 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

Table 3: Strategic complementarities: heterogeneity

Large defined as: Sample:	Employment ≥ 100			Top 20% market share		
	Small	Large	All	Small	Large	All
Dep. var.: Δp_{it}	(1)	(2)	(3)	(4)	(5)	(6)
Δmc_{it}	0.929*** (0.152)	0.599** (0.237)	0.949*** (0.201)	0.947*** (0.200)	0.662*** (0.204)	0.947*** (0.226)
$\Delta mc_{it} \times \text{Large}_{it}$			-0.315 (0.351)			-0.270 (0.356)
$\Delta p_{-i,t}$	0.078 (0.189)	0.469** (0.202)	0.142 (0.225)	0.003 (0.177)	0.432** (0.210)	0.063 (0.180)
$\Delta p_{-i,t} \times \text{Large}_{it}$			0.279 (0.319)			0.355 (0.325)
# obs.	49,462	15,353	64,815	52,452	12,363	64,815
Weak Instr. F -test	89.12	27.73	59.08	106.82	19.95	54.25
Overid. J -test	4.99	0.03	6.48	2.56	0.12	2.68
$[\chi^2 p\text{-value}]$	[0.08]	[0.98]	[0.17]	[0.29]	[0.94]	[0.61]

Notes: All regressions have industry fixed effects and year fixed effects. Robust standard errors are clustered at the industry level. Observations are weighted with lagged domestic firm sales. Instrument set: Δe_{st} , Δmc_{it}^* , $\Delta mc_{-i,t}^*$, p_{st}^{EU} .

significant and both roughly equal to 0.5. In column 3, we use the full sample of firms and interact both coefficients with a Large_{it} dummy and we find a similar pattern (albeit with more noisy estimates). Constraining the coefficients to sum to one in columns 1 to 3 yields the same results (unreported). We reestimate columns 1–3 using the firm’s market share instead of employment to define a ‘large’ firm, with market share (averaged over time) of a product within a 4-digit industry. We find the results are robust to using different market share cutoffs to define a large firm, and in columns 4–6 we report the results when a firm is defined to be large if it is among the top 20% of firms in the industry in terms of domestic sales. The results in columns 4–6 replicate those in columns 1–3.³⁴

The results in Table 3 suggest a lot of heterogeneity in firm’s pass-through elasticities and strategic complementarities in price setting. Namely, the majority of the small firms exhibit complete pass-through of cost shocks ($\psi_{it} = 1$) and no strategic complementarities ($\gamma_{it} = 0$), 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 act very differently, exhibiting both incomplete pass-through and strong strategic complementarities in price setting with their competitors. Specifically, the strategic complementarities elasticity for these firms is as high as 47%, while the own cost pass-through elasticity is around 60%. Since these largest firms account for the majority of market sales, their behavior drives

³⁴An alternative definition of large firms is if their market share exceeds 2% within the 4-digit industry. In addition, we verify that our results are not driven by exporters or intra-firm trade. Specifically, we reestimate the specifications in Table 3 for the set of large firms that export less than 10% of their total output, and see that the strategic complementarities are almost the same as in column 2 of Table 3. We also consider a sample of large firms which drops any firm that had sales or purchases from affiliates that accounted for at least half a percent of their total sales at any time during the sample, and find that strategic complementarities are a little stronger at 0.55 for this subsample of firms.

the average patterns across firms in Table 1. In the next section we explore the implications of these estimates for the counterfactual effects of international shocks on domestic prices and markups using a calibrated model.

4 Strategic Complementarities in a Calibrated Model

In this section we provide a numerical analysis of the model of variable markups and strategic complementarities. 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, as we describe below. We analyze the joint price setting by different firms that are subject to idiosyncratic cost shocks, as well as an aggregate shock. The specific aggregate shock we consider is an exchange rate shock, which affects the firms with heterogeneous intensities.

We start by describing our parameterization and calibration, and show that the model fits the salient features of the data including the joint distribution of market share and import intensity across firms, as well as the extent of strategic complementarities in price setting that we documented in Section 3. We then use the calibrated model to study how firms of different size and import intensities change their markups in response to idiosyncratic and aggregate cost shocks. Finally, we consider a counterfactual 10% exchange rate devaluation to study the markup adjustment and aggregate exchange rate pass-through into domestic prices across sectors that differ in the extent of foreign competition, dependence on imported inputs and in their within-sector firm-size heterogeneity.

4.1 Parameterization and calibration

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 4 and 5 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 and N_X), are all drawn from Poisson distributions with means

Table 4: Calibrated parameters

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

Note:

Table 5: Moments

Moment	Data	Model	Moment	Data	Model
Number of firms:			Sales share:		
– Belgian	41 (48) [22,87]	48 [40,57]	– Belgian	0.64 (0.62) [0.39,0.86]	0.62 [0.46,0.77]
– EU	–	21 [16,27]	– EU	0.26 (0.27) [0.12,0.42]	0.26 [0.14,0.41]
– Non-EU	–	9 [5,13]	– Non-EU	0.08 (0.11) [0.01,0.25]	0.09 [0.04, 0.22]
Inverse Herfindahl Index for Belgian firms	16.4 (20.8) [7.1,38.4]	13.7 [6.5,24.3]	Top Belgian market share	10.0% (11.7%) [4.9%,20.9%]	11.2% [5.6%,23.2%]
$\text{std}(\Delta S_{it})$	0.0042	0.0042	$\text{corr}(S_{it}, \phi_i^B)$	0.26 (0.24) [0.00,0.44]	0.28
$\text{corr}(S_{it}, S_{i,t+12})$	0.90 (0.85) [0.69, 0.98]	0.88	$\text{corr}(S_{it}, \phi_i^X / \phi_i^B)$	0.05 (0.08) [-0.03, 0.37]	0.14

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

\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.³⁵ 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 5), which we use in our counterfactuals in Section 4.3.

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

$$MC_{it} = \frac{W_t^{1-\varphi_i} (V_t^* \mathcal{E}_t)^{\varphi_i}}{\Omega_{it}}, \quad (31)$$

where W_t is the price index of domestic inputs, V_t^* is the foreign-currency price index of foreign (imported) inputs, \mathcal{E}_t is the nominal exchange rate, and Ω_{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 Ω_{it} , which in logs can be written as $\omega_{it} = \tilde{\omega}_{it} - (1 - \phi_{it})\tilde{w}_{it} - \phi_{it}\tilde{v}_{it}$, 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 φ_i in (31) is firm-specific and constant over time.³⁶ Note that the exchange rate exposure φ_i differs from import intensity ϕ_i in (20) by the factor of exchange rate pass-through into imported input prices. This can be seen 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 $\{W_t, V_t^*, \mathcal{E}_t\}$ follow exogenous processes. In particular, we let the nominal exchange rate follow a random walk in logs:

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

where $e_t \equiv \log \mathcal{E}_t$, $u_t \sim iid\mathcal{N}(0, 1)$, and σ_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

³⁵In 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 5). 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.

³⁶As we showed in [Amiti, Itskhoki, and Konings \(2014\)](#), this assumption is justified in the data, where over 85% of variation in import intensity ϕ_{it} is cross-sectional, and within a firm ϕ_{it} is not responsive to exchange rate movements over horizons of 3–5 years.

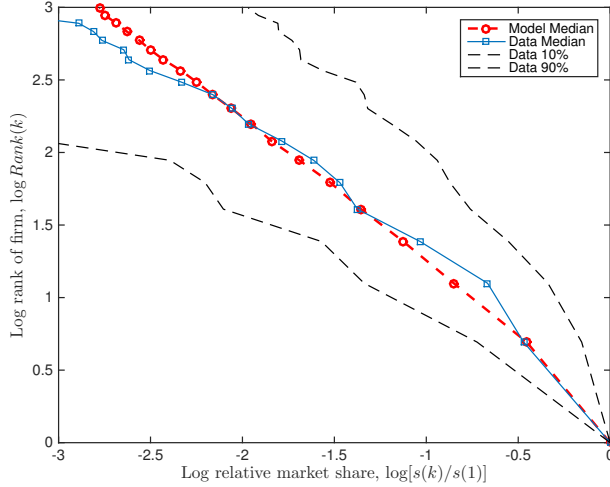


Figure 1: Market share distribution

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.

industry-equilibrium nature of our exercise.

Firm productivities Ω_{it} are assumed to follow a random growth process:

$$\omega_{it} = \mu + \omega_{i,t-1} + \sigma_{\omega} v_{it}, \quad (32)$$

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

$$\omega_{it} = \begin{cases} \mu + \omega_{i,t-1} + \sigma_{\omega} v_{it}, & \text{if } > \underline{\omega}, \\ \underline{\omega} - (\mu + \omega_{i,t-1} + \sigma_{\omega} v_{it} - \underline{\omega}), & \text{otherwise.} \end{cases} \quad (33)$$

That is, the process follows equation (32) as long as it stays above the lower bound $\underline{\omega}$, and otherwise it reflects from the lower bound by the amount the process in equation (32) would undershoot $\underline{\omega}$ without the reflection. The initial productivities are drawn from a Pareto distribution, $\Omega_{i0} \sim iid\text{Pareto}(k, e^{\underline{\omega}})$, where k is the shape parameter and $\underline{\omega}$ 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 Ω_{i0} is given by $G_0(\Omega) = 1 - (\Omega/e^{\underline{\omega}})^{-k}$ for $\Omega \geq e^{\underline{\omega}}$. When $\mu = -k\sigma_{\omega}^2/2 < 0$, the reflecting barrier in (33) ensures that the cross-sectional distribution of Ω_{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 ρ , 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 5). The largest domestic firm in a typical industry has a market share of about 11%, while

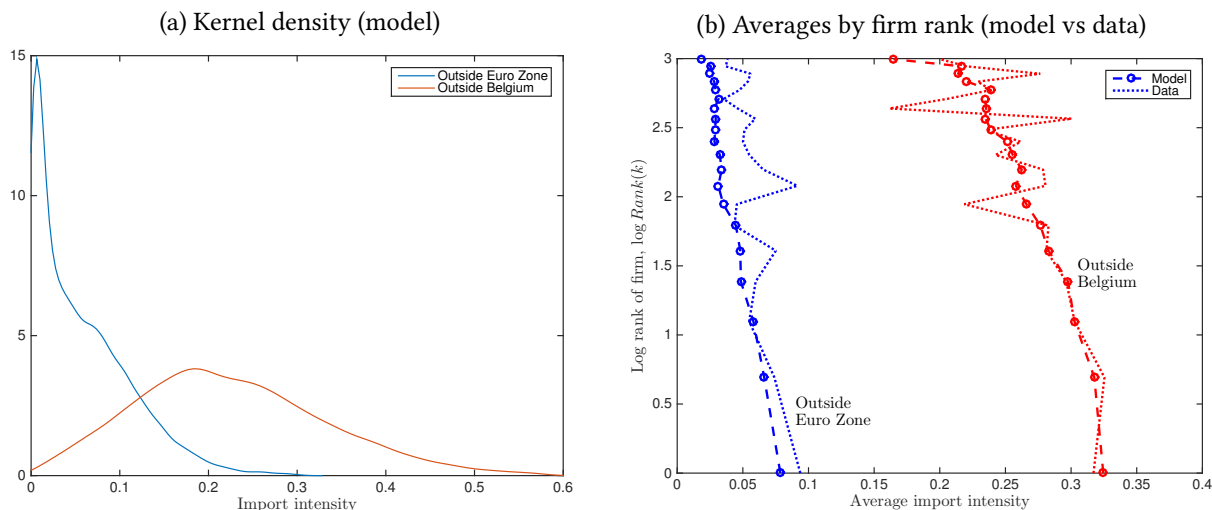


Figure 2: Import intensity

Note:

the second-largest firm is about 38% smaller, both in the simulated model and in the data (see Table 5 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, φ_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.³⁷ 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 5). 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

³⁷In [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.

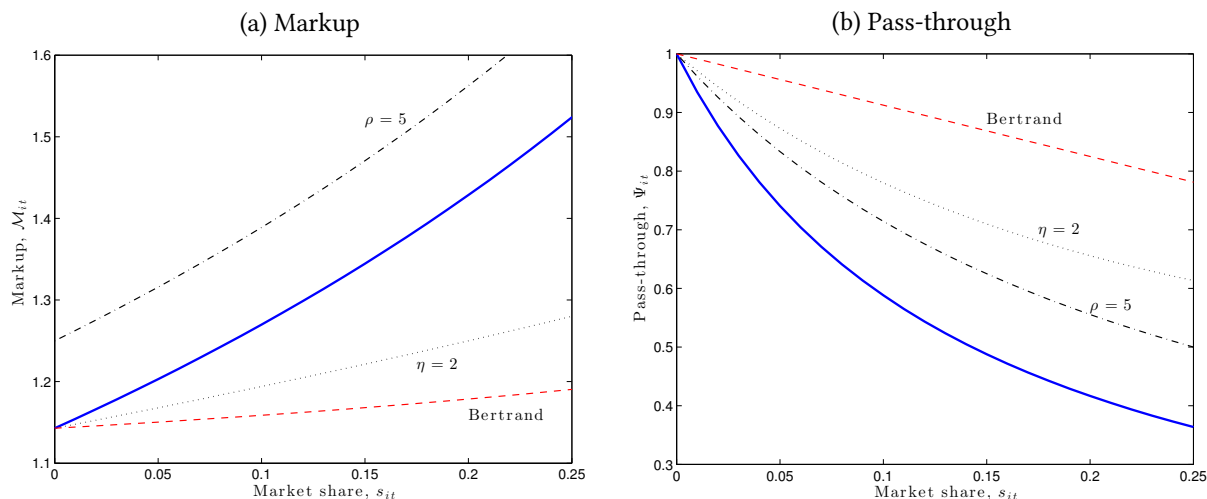


Figure 3: Markups and pass-through in a calibrated model

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 \mathcal{M}_{it} and Panel (b) plots (idiosyncratic cost) pass-through $1/(1 + \Gamma_{it})$, both as a function of market share s_{it} .

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 Zone 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 zone, which we also capture in our calibration. The exchange rate exposure, φ_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 ψ_ℓ for $\ell \in \{B, E, X\}$ reflect the exchange rate pass-through into the prices of imported inputs from ℓ . 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 (12), which involves solving a fixed point using (11) and (13), and then find the equilibrium industry price index P_{st} according to (10). We also calculate the market shares $\{S_{it}\}$ according to (11).³⁸ 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 2012),

³⁸We shut down the heterogeneity in ξ_{it} and focus on productivity Ω_{it} as the only source of heterogeneity across firms.

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 ρ and η in order to generate significant markup variability as in the data (see (14)). 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 Belgium firm-product level data using the Broda and Weinstein (2006) methodology,³⁹ and in line with the literature following Atkeson and Burstein (2008) (see, for example, Edmond, Midrigan, and Xu 2012). To illustrate the mechanism in the model and the role of the demand parameters, Figure 3 plots the variation in markups \mathcal{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 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 η or reducing ρ makes it harder to fit the data quantitatively.

4.2 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 (31), 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 and 3. 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 Belgium 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 6, we report the results from two regression specification. 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 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 6 correspond to columns (5), (6) and (7) of Table A2 in the appendix: the sectoral pass-through

³⁹Note 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.

Table 6: Industry pass-through regressions

	All firms		Domestic firms		Foreign firms	
	MC	Price	MC	Price	MC	Price
Industry-level	0.494	0.488	0.286	0.321	0.866	0.792
Firm-level pooled	0.473	0.464	0.268	0.308	0.836	0.751

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).

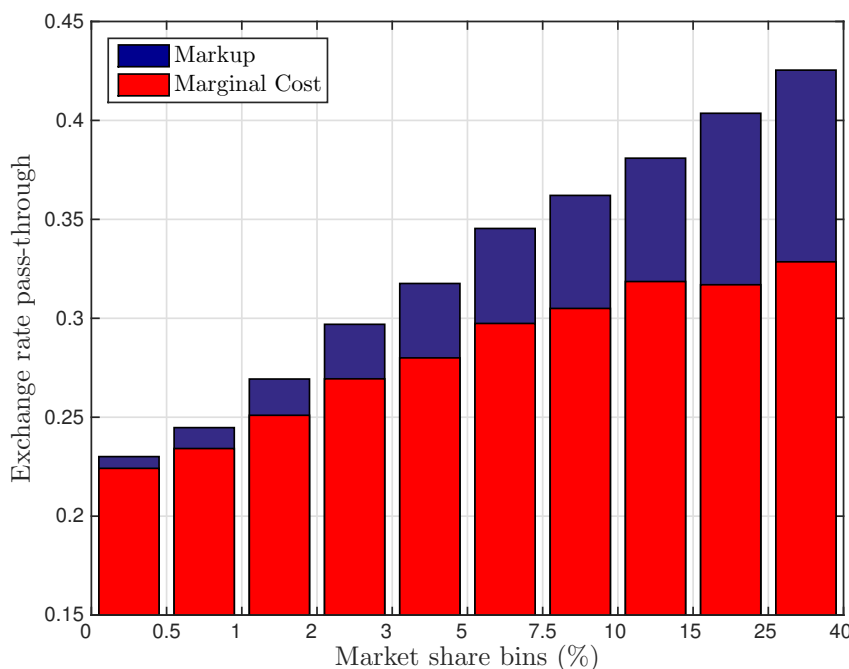


Figure 4: Exchange rate pass-through into marginal costs and prices, by market share bins

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 A4): 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.

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 A2 with the equivalent coefficient reported in the second line of column 3 of Table 6).

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 A4 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).

Strategic complementarities We now examine the implications of the model for our main empirical relationship (4), which we reproduce here again:

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

Table 7: Pass-through heterogeneity across firms

Dep. var.: $\Delta \log P_{it}$	Without size interaction	With size interaction
$\Delta \log MC_{it}$	0.775	0.951
$\Delta \log MC_{it} \times \text{Large}_{it}$	—	-0.259
$\Delta \log P_{-i,t}$	0.201	0.047
$\Delta \log P_{-i,t} \times \text{Large}_{it}$	—	0.248

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).

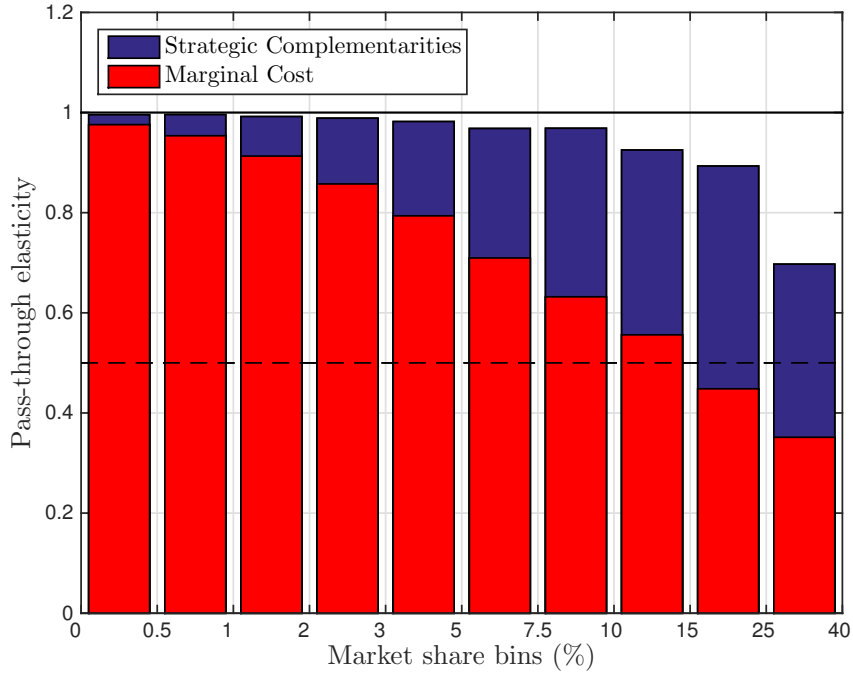


Figure 5: Marginal costs vs strategic complementarities: pass-through into firm prices, by market share bins

Note: Regressions of log change in firm prices on log change in firm marginal costs and competitor price index (4), 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 $\Gamma_{-i,t}/(1 + \Gamma_{it})$).

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 7, which correspond to the empirical regressions in column (4) of Table 1 and column (6) of Table 3, 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. 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 3). 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 7 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 3). 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 (4) 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%.⁴⁰

4.3 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 A2. 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 8 reports the results. First, about 10% percent of the largest firms, which account for almost 50% of 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 A4), 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

⁴⁰The sum of the coefficients is declining below 1 for the large firms, an implication of the model we need to explore further.

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 8: Pass-through decomposition

	Small Firms	Large Firms	
Marginal Cost	39.3%	51.1%	90.4%
Markup	2.2%	7.4%	9.6%
	41.5%	58.5%	0.350

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 (4), which we rearrange for markup (using $\Delta\mu_{it} = \Delta p_{it} - \Delta mc_{it}$) and projecting on the exchange rate movement as:

$$\frac{\Delta\mu_{it}}{\Delta e_t} = \frac{\Gamma_{it}}{1 + \Gamma_{it}} \left[\frac{\Delta p_{-i,t}}{\Delta e_t} - \frac{\Delta mc_{it}}{\Delta e_t} \right]. \quad (34)$$

Therefore, for markups to move, it is not only necessary to have strong strategic complementarities in price setting (large Γ_{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 A4 we know that large firms with strong strategic complementarities are themselves heavily exposed to 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 7 and Figure 5.

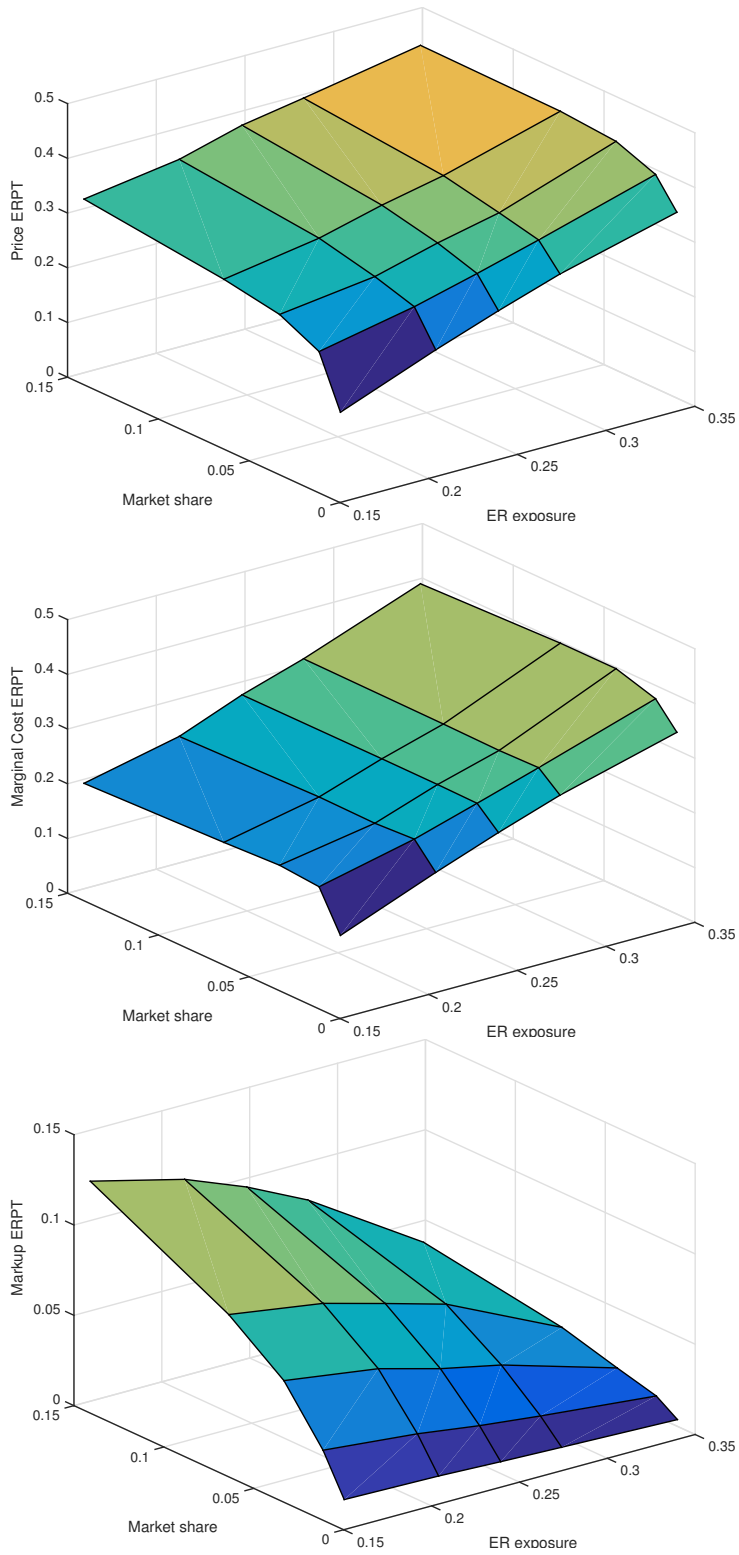
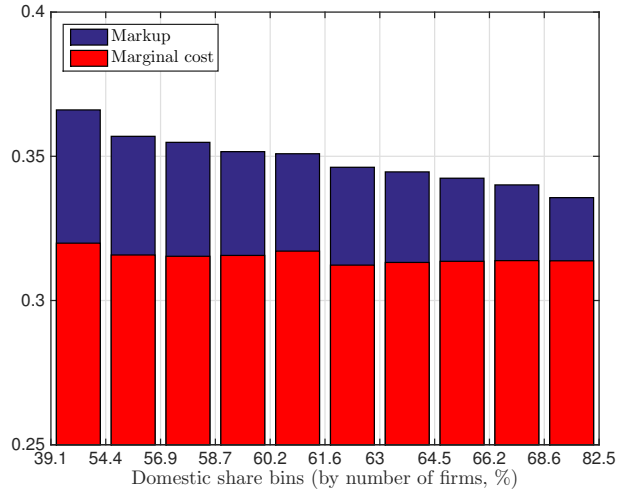


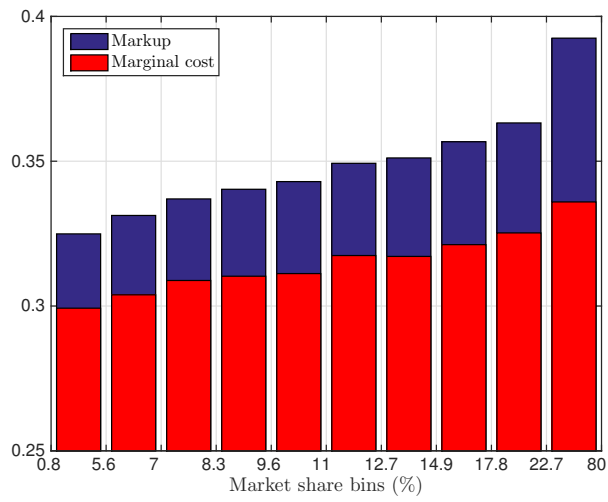
Figure 6: Exchange rate pass-through into firm markup

Note: Pass-through into markup (markup elasticity with respect to exchange rate) by bins of exchange rate exposure and market share.

(a) Domestic share (number of firms)



(b) Max market share



(c) Correlation S_{it} and φ_i

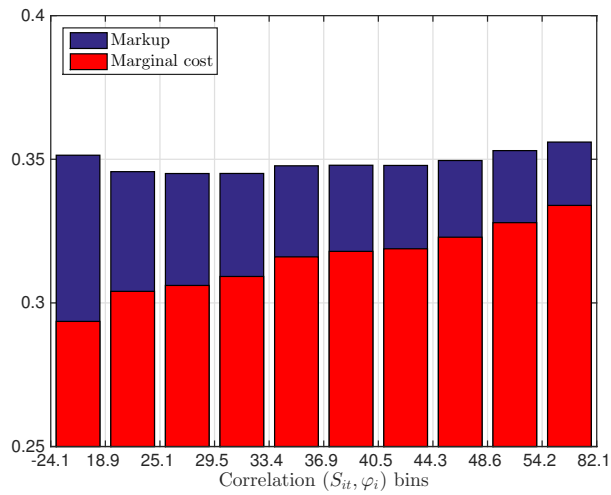


Figure 7: Heterogeneous response across industries

Note:

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.⁴¹ 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 (34) 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 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 (34)). The circumstances 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

⁴¹Strictly 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.

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 Belgium 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: First Stage Regressions from Table 1

Dep. var.:	Column (3)		Column (4)	
	Δmc_{it}	$\Delta p_{-i,t}$	Δmc_{it}	$\Delta p_{-i,t}$
Δmc_{it}^*	0.614*** (0.111)	0.173*** (0.039)	0.597*** (0.014)	0.174*** (0.033)
Δe_{st}	-0.222 (0.230)	0.270** (0.120)	-0.169 (0.258)	0.343** (0.144)
$\Delta mc_{-i,t}^*$	0.392*** (0.098)	0.468** (0.148)	0.379*** (0.124)	0.580*** (0.106)
Δp_{st}^{EU}	0.194*** (0.054)	0.304*** (0.053)	0.215*** (0.049)	0.274*** (0.053)
<i>F</i> -test	46.92	22.39	41.24	33.53
[<i>p</i> -value]	[0.00]	[0.00]	[0.00]	[0.00]
Industry F.E.s	no	no	yes	yes
Year F.E.s	yes	yes	yes	yes

Notes: The first two columns present the first stage regressions corresponding to column 3 of Table 1. The last two columns present the first stage regressions corresponding to column 4 of Table 1.

Table A2: Exchange Rate Projections

Dep. var.:	Firm-level regressions				Industry-level regressions		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Δp_{it}	Δmc_{it}	Δmc_{it}^*	Δv_{it}	Δp_{st}	Δp_{st}^D	Δp_{st}^F
Δe_{st}	0.279 (0.187)	0.395** (0.187)	0.246*** (0.040)	0.651*** (0.122)	0.489*** (0.061)	0.311*** (0.085)	0.642*** (0.059)
# obs.	64,815	64,815	64,815	64,815	1,921	1,921	1,921
Adj. R^2	0.001	0.002	0.015	0.010	0.032	0.006	0.058

Notes: Regressions do not include fixed effects. Δe_{st} is the log change in industry import-weighted exchange rate. Δp_{it} is the log change in firm-product price. Δmc_{it} is the log change in firm marginal cost. Δmc_{it}^* is the log change in the imported component of the firm marginal cost. Δp_{st} is the log change in the industry price index. Δp_{st}^F (Δp_{st}^D) 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.

Table A3: Robustness Instruments Check

Dep. var.: Δp_{it}	Δe_{ft} (1)	both ER (2)	no ER (3)	drop ER, add wage (4)	drop Δmc_{it}^* (5)
Δmc_{it}	0.718*** (0.174)	0.719*** (0.144)	0.777*** (0.195)	0.670*** (0.157)	0.748*** (0.136)
$\Delta p_{-i,t}$	0.354** (0.174)	0.353** (0.145)	0.291 (0.196)	0.402** (0.161)	0.330* (0.173)
# obs.	64,813	64,813	64,815	64,815	64,815

Notes: All regressions have industry fixed effects and year fixed effects. Robust standard errors are clustered at the industry level. Observations are weighted with lagged domestic firm sales. Alternative Instrument Sets: Column 1 : $\Delta mc_{-i,t}^*$, Δe_{ft} , Δmc_{it}^* , p_{st}^{EU} . Column 2 : $\Delta mc_{-i,t}^*$, Δe_{st} , Δe_{ft} , Δmc_{it}^* , p_{st}^{EU} . Column 3 : $\Delta mc_{-i,t}^*$, Δmc_{it}^* , p_{st}^{EU} . Column 4 : $\Delta mc_{-i,t}^*$, Δmc_{it}^* , p_{st}^{EU} , $\Delta wage$. Column 5 : $\Delta mc_{-i,t}^*$, Δe_{st} , p_{st}^{EU} .

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 A4 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 A4 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%.

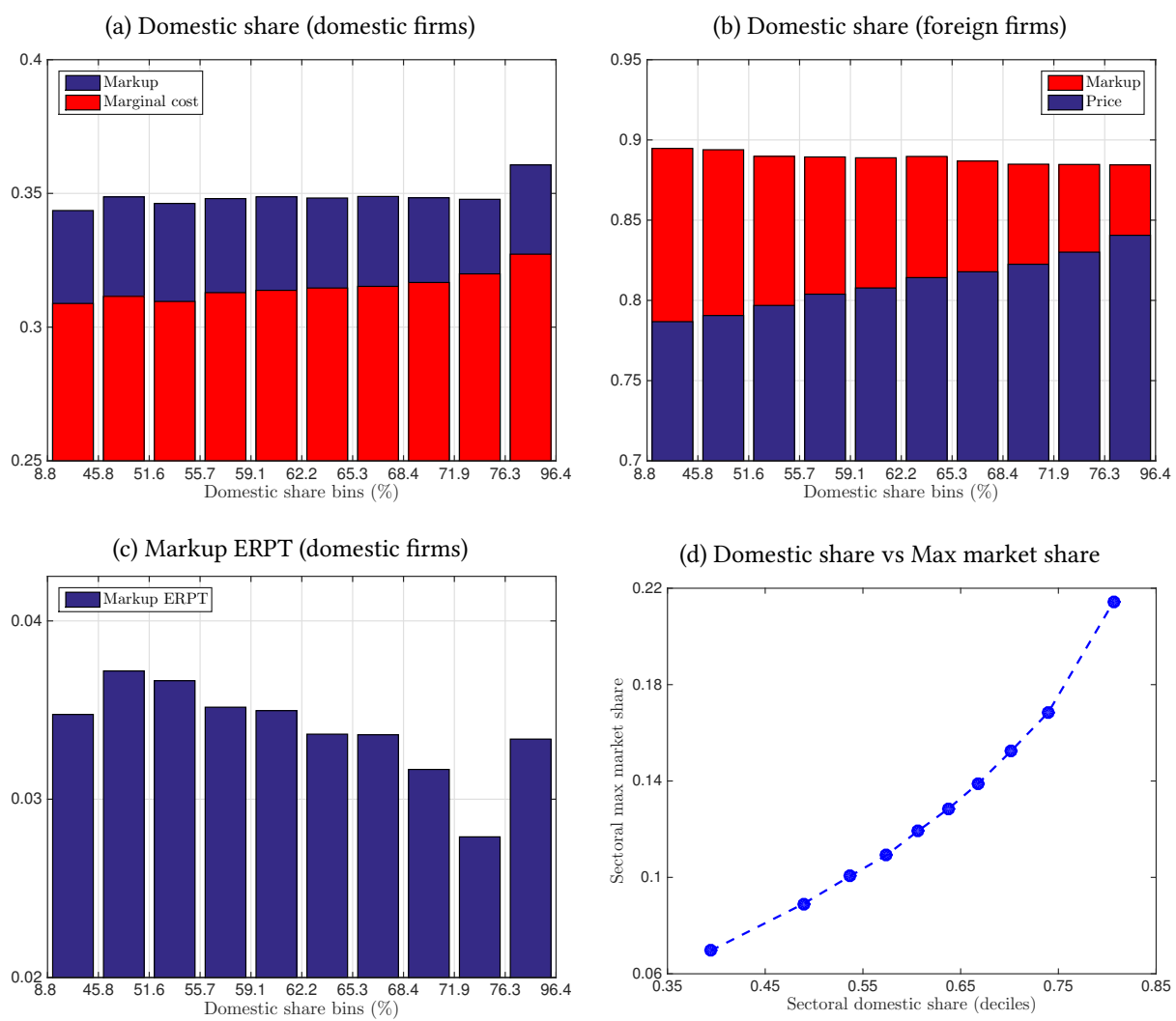
Table A4: Market share, exchange rate exposure, and markup distributions in the model

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

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.



Note:

Figure A1: Heterogenous response across sectors: Domestic share

C Data Appendix

Data Sources We draw on the three main data sources for the period 1995 to 2007. One, the production data at the firm-product level (PRODCOM) is from the National Bank of Belgium, collected by Statistic Belgium (part of the Federal Government Department of Economics). These data 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.

Two, the international data are from the National Bank of Belgium, with the 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.

Three, data on firm characteristics are from the Belgian Business Registry, covering all incorporated firms. These data are used to construct measures of total costs and total factor productivity. They are available on an annual frequency at the firm level. Each firm reports 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 Ilke, et al. 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 data sets are comparable. So we drop observations where the units that match in the two data sets 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 Marginal Cost under Decreasing Returns to Scale

D.3 Reduced-form of the model

D.4 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 (4), ψ_{it} and γ_{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, Δe_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 φ_{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 ε_{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:⁴²

$$\Psi_{it} = \psi_{it}\varphi_{it} + \gamma_{it}\Psi_{-i,t}, \quad (\text{A1})$$

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 Ψ_{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:

$$\Psi_{st} = \frac{1}{1 - \sum_i S_{it}\gamma_{it}} \sum_i S_{it}\psi_{it}\varphi_{it}. \quad (\text{A2})$$

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.

⁴²Alternatively, one can define Ψ_{it} , φ_{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 (4):

$$\begin{aligned}
\Delta p_{it} &= \frac{1}{1 + \Gamma_{it}} \Delta mc_{it} + \frac{\Gamma_{-i,t}}{1 - \omega_{i,t}} [(1 - \omega_{i,t}) \Delta P_{-i,t} \pm \omega_{i,t} \Delta p_{it}] + \varepsilon_{it} \\
\Rightarrow \left[1 + \frac{\omega_{it} \Gamma_{-i,t}}{1 - \omega_{it}} \right] \Delta p_{it} &= \frac{1}{1 + \Gamma_{it}} \Delta mc_{it} + \frac{\Gamma_{-i,t} / (1 - \omega_{it})}{1 + \Gamma_{it}} \Delta P_t + \varepsilon_{it} \\
\Rightarrow \Delta p_{it} &= \frac{1}{1 + \Gamma_{it} + \frac{\omega_{it} \Gamma_{-i,t}}{1 - \omega_{it}}} \Delta mc_{it} + \frac{\frac{\Gamma_{-i,t}}{1 - \omega_{it}}}{1 + \Gamma_{it} + \frac{\omega_{it} \Gamma_{-i,t}}{1 - \omega_{it}}} \Delta P_t + \tilde{\varepsilon}_{it}, \tag{A3}
\end{aligned}$$

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 $\tilde{\Gamma}_{it} \equiv \Gamma_{it} + \frac{\omega_{it} \Gamma_{-i,t}}{1 - \omega_{it}}$ and $\tilde{\Gamma}_{-i,t} \equiv \frac{\Gamma_{-i,t}}{1 - \omega_{it}}$. Then we can aggregate (A3) in the following way:

$$\begin{aligned}
\Delta P_t &= \sum_i \left\{ \frac{\omega_{it}}{1 + \tilde{\Gamma}_{it}} \Delta mc_{it} + \frac{\tilde{\Gamma}_{-i,t}}{1 + \tilde{\Gamma}_{it}} \Delta P_t + \omega_{it} \tilde{\varepsilon}_{it} \right\} \\
\Rightarrow \Delta P_t &= \frac{1}{1 - \sum_i \frac{\omega_{it} \tilde{\Gamma}_{-i,t}}{1 + \tilde{\Gamma}_{it}}} \sum_i \left\{ \frac{\omega_{it}}{1 + \tilde{\Gamma}_{it}} \Delta mc_{it} + \omega_{it} \tilde{\varepsilon}_{it} \right\} \\
\Rightarrow \Delta p_{it} &= \frac{1}{1 + \tilde{\Gamma}_{it}} \Delta mc_{it} + \frac{\frac{\tilde{\Gamma}_{-i,t}}{1 + \tilde{\Gamma}_{it}}}{1 - \sum_i \frac{\omega_{it} \tilde{\Gamma}_{-i,t}}{1 + \tilde{\Gamma}_{it}}} \sum_j \left\{ \frac{\omega_{jt}}{1 + \tilde{\Gamma}_{jt}} \Delta mc_{jt} + \omega_{jt} \tilde{\varepsilon}_{jt} \right\} + \tilde{\varepsilon}_{it}.
\end{aligned}$$

We also define

$$\begin{aligned}
\Delta MC_t &= \sum_i \omega_{it} \Delta mc_{it}, \\
\Delta \mathcal{M}_t &= \sum_i \omega_{it} \Delta \mu_{it} = \sum_i \omega_{it} (\Delta p_{it} - \Delta mc_{it}) = \Delta P_t - \Delta MC_t \\
&= -\frac{1}{1 - \sum_i \frac{\omega_{it} \tilde{\Gamma}_{-i,t}}{1 + \tilde{\Gamma}_{it}}} \sum_i \left[\frac{\tilde{\Gamma}_{it}}{1 + \tilde{\Gamma}_{it}} - \sum_j \frac{\omega_{jt} \tilde{\Gamma}_{-j,t}}{1 + \tilde{\Gamma}_{jt}} \right] \omega_{it} \Delta mc_{it} + \frac{\sum_i \omega_{it} \tilde{\varepsilon}_{it}}{1 - \sum_i \frac{\omega_{it} \tilde{\Gamma}_{-i,t}}{1 + \tilde{\Gamma}_{it}}}
\end{aligned}$$

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

prices, and markups:

$$\begin{aligned}
\Psi_{MC} &= \sum_i \omega_{it} \phi_{it}, \\
\Psi_P &= \frac{1}{1 - \sum_i \frac{\omega_{it} \tilde{\Gamma}_{-i,t}}{1 + \tilde{\Gamma}_{it}}} \sum_i \frac{\omega_{it} \phi_{it}}{1 + \tilde{\Gamma}_{it}}, \\
\Psi_{\mathcal{M}} &= -\frac{1}{1 - \sum_i \frac{\omega_{it} \tilde{\Gamma}_{-i,t}}{1 + \tilde{\Gamma}_{it}}} \sum_i \left[\frac{\tilde{\Gamma}_{it}}{1 + \tilde{\Gamma}_{it}} - \sum_j \frac{\omega_{jt} \tilde{\Gamma}_{-j,t}}{1 + \tilde{\Gamma}_{jt}} \right] \omega_{it} \phi_{it} \\
&= -\frac{\text{cov}\left(\frac{\tilde{\Gamma}_{it}}{1 + \tilde{\Gamma}_{it}}, \phi_{it}\right)}{1 - \sum_i \frac{\omega_{it} \tilde{\Gamma}_{-i,t}}{1 + \tilde{\Gamma}_{it}}} - \frac{\sum_i \frac{\omega_{it} (\tilde{\Gamma}_{it} - \tilde{\Gamma}_{-i,t})}{1 + \tilde{\Gamma}_{it}}}{1 - \sum_i \frac{\omega_{it} \tilde{\Gamma}_{-i,t}}{1 + \tilde{\Gamma}_{it}}} \sum_i \omega_{it} \phi_{it}
\end{aligned}$$

where we assume that $\tilde{\varepsilon}_{it}$ 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:

$$\Delta P_{Dt} = \frac{1}{1 - \sum_{i \in \mathcal{I}_D} \frac{\omega_{it}^D \tilde{\Gamma}_{-i,t} (1 - S_{Ft})}{1 + \tilde{\Gamma}_{it}}} \sum_{i \in \mathcal{I}_D} \omega_{it}^D \left[\frac{\Delta mc_{it}}{1 + \tilde{\Gamma}_{it}} + \tilde{\varepsilon}_{it} + \frac{\tilde{\Gamma}_{-i,t} S_{Ft}}{1 + \tilde{\Gamma}_{it}} \Delta P_{Ft} \right]$$

where \mathcal{I}_D is the subset of domestic firm-products and $\omega_{it}^D = \omega_{it} / (\sum_{i \in \mathcal{I}_D} \omega_{it})$, and $S_{Ft} = \sum_{i \notin \mathcal{I}_D} \omega_{it}$ is the foreign share of sales.

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

$$\begin{aligned}
\Psi_{MC}^D &= \sum_{i \in \mathcal{I}_D} \omega_{it}^D \phi_{it}, \\
\Psi_P^D &= \frac{1}{1 - \sum_{i \in \mathcal{I}_D} \frac{\omega_{it}^D \tilde{\Gamma}_{-i,t} (1 - S_{Ft})}{1 + \tilde{\Gamma}_{it}}} \sum_{i \in \mathcal{I}_D} \left[\frac{\omega_{it}^D \phi_{it}}{1 + \tilde{\Gamma}_{it}} + \frac{\omega_{it}^D \tilde{\Gamma}_{-i,t} S_{Ft}}{1 + \tilde{\Gamma}_{it}} \Psi_P^F \right], \\
\Psi_{\mathcal{M}}^D &= \Psi_P^D - \Psi_{MC}^D
\end{aligned}$$

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 :

$$\frac{1}{N} \sum_{i \in \Omega} A_i \Upsilon \left(\frac{N C_i}{\xi_i C} \right) = 1, \quad (\text{A4})$$

where Ω is the set of products i in the sector with $N = |\Omega|$ denoting the number of goods, and C_i is the consumption of product i ; A_i and ξ_i denote the two shifters (a quality parameter and a demand parameter, respectively, 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 $N \rightarrow \infty$, the demand aggregator becomes:

$$\frac{1}{|\Omega|} \int_{i \in \Omega} A_i \Upsilon \left(\frac{|\Omega| C_i}{\xi_i C} \right) di = 1, \quad (\text{A5})$$

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:

$$C = \left[N^{-1/\sigma} \sum_{i \in \Omega} \left(A_i \xi_i^{-\frac{\sigma-1}{\sigma}} \right) C_i^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \quad (\text{A6})$$

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 η 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:

$$\sum_{i \in \Omega} P_i C_i = E. \quad (\text{A7})$$

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 :

$$\max_{\{C_i\}_{i \in \Omega}} \left\{ C \mid \text{s.t. (A4) and (A7)} \right\}. \quad (\text{A8})$$

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

$$C_i = \frac{\xi_i C}{N} \cdot \psi(x_i), \quad \text{where } x_i \equiv \frac{P_i / \gamma_i}{P / D}. \quad (\text{A9})$$

In this expression, $\gamma_i \equiv A_i/\xi_i$ is the quality parameter and $\psi(\cdot) \equiv \Upsilon'^{-1}(\cdot)$ is the demand curve, while $\xi_i C/N$ is the normalized demand shifter, 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.⁴³ Note that an increase in γ_i directly reduces the effective price for the good in the eyes of the consumers, which corresponds to a shift along the demand curve. At the same time, an increase in ξ_i (holding γ_i constant), shifts out the demand curve holding the effective price unchanged. This is why we refer to ξ_i as the demand shifter, and γ_i as the quality parameter.

We show in the appendix that P and D are defined by:⁴⁴

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

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

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

$$s_i \equiv \frac{P_i C_i}{P C} = \frac{\xi_i P_i}{N P} \psi \left(\frac{P_i/\gamma_i}{P/D} \right), \quad (\text{A12})$$

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 $\psi(\cdot)$:

$$\sigma_i \equiv \sigma(x_i) = - \frac{d \log \psi(x_i)}{d \log x_i}, \quad (\text{A13})$$

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

⁴³Note 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).

⁴⁴In the limiting case of CES, we have $\Upsilon(z) = z^{\frac{\sigma-1}{\sigma}}$, and hence $\Upsilon'(z) = \frac{\sigma-1}{\sigma} z^{-1/\sigma}$ and $\psi(x) = \left(\frac{\sigma}{\sigma-1} x \right)^{-\sigma}$. Substituting this into (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:

$$P = \left[\frac{1}{N} \sum_{j \in \Omega} (A_j^\sigma \xi_j^{1-\sigma}) P_j^{1-\sigma} \right]^{\frac{1}{1-\sigma}}.$$

The case of CES is a knife-edge case in which the demand system can be described with only the price index P , which summarizes all information contained in micro-level prices needed to describe aggregate allocation. More generally, the second auxiliary variable D is needed to characterize the aggregate effects of micro-level heterogeneity. 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 :

$$\begin{aligned} d \log P &= \sum_{i \in \Omega} s_i d \log P_i, \\ d \log \frac{P}{D} &= \sum_{i \in \Omega} \frac{s_i \sigma_i}{\sum_{j \in \Omega} s_j \sigma_j} d \log P_i. \end{aligned}$$

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:

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

where σ_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 $s_i \rightarrow 0$ 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:

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

and is increasing in the market share s_i . Therefore, for that case we can write:⁴⁵

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

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 Γ_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

⁴⁵An 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 $P = [(\xi_i \gamma_i^\sigma) P_i^{1-\sigma} + (1 - \xi_i \gamma_i^\sigma) P_{-i}^{1-\sigma}]^{1/(1-\sigma)}$.

from $d \log P$, and $d \log D$ is not necessarily orthogonal with $d \log P$. Nonetheless, if variation in P_i is dominated by firm-idiosyncratic shocks, then $d \log D$ would indeed be close to orthogonal to $d \log P$, 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 general 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).⁴⁶ These auxiliary variables summarize all relevant information contained in the distribution 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:

$$\psi(x_i) = \left[1 - \bar{\varepsilon} \log \left(\frac{\bar{\sigma}}{\bar{\sigma} - 1} x_i \right) \right]^{\bar{\sigma}/\bar{\varepsilon}}, \quad (\text{A15})$$

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 ($N \rightarrow \infty$ and $s_i \rightarrow 0$ for all $i \in \Omega$), and briefly discuss the cross-sectional properties of this demand. The demand elasticity

⁴⁶These two auxiliary variables corresponds to the the Lagrange multipliers in the consumer optimization, corresponding to constraints (A7) and (A4) respectively (see the appendix).

and super-elasticity functions are given by:⁴⁷

$$\sigma_i \equiv \sigma(x_i) = -\frac{\partial \log \psi(x_i)}{\partial \log P_i} = \frac{\bar{\sigma}}{1 - \bar{\varepsilon} \log \left(\frac{\bar{\sigma}}{\bar{\sigma}-1} x_i \right)}, \quad (\text{A16})$$

$$\varepsilon_i \equiv \varepsilon(x_i) = \frac{\partial \log \sigma(x_i)}{\partial \log x_i} = \frac{\bar{\varepsilon}}{1 - \bar{\varepsilon} \log \left(\frac{\bar{\sigma}}{\bar{\sigma}-1} x_i \right)}. \quad (\text{A17})$$

Under this demand, the optimal markup is given by:

$$\mathcal{M}_i \equiv \frac{\sigma(x_i)}{\sigma(x_i) - 1} = \frac{\frac{\bar{\sigma}}{\bar{\sigma}-1}}{1 + \frac{\bar{\varepsilon}}{\bar{\sigma}-1} \log \left(\frac{\bar{\sigma}}{\bar{\sigma}-1} x_i \right)}, \quad (\text{A18})$$

and therefore the elasticity of markup is:

$$\Gamma_i \equiv \Gamma(x_i) = -\frac{\partial \log \mathcal{M}_i}{\partial \log P_i} = \frac{\varepsilon(x_i)}{\sigma(x_i) - 1} = \frac{\frac{\bar{\varepsilon}}{\bar{\sigma}-1}}{1 + \frac{\bar{\varepsilon}}{\bar{\sigma}-1} \log \left(\frac{\bar{\sigma}}{\bar{\sigma}-1} x_i \right)}. \quad (\text{A19})$$

Therefore, both markups \mathcal{M}_i and markup elasticity Γ_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 $\bar{\varepsilon} > 0$ has a few notable properties, whereas the limit of $\bar{\varepsilon} \rightarrow 0$ 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 $\hat{x} = \frac{\bar{\sigma}-1}{\bar{\sigma}} e^{1/\bar{\varepsilon}}$. Third, there is a least price below which the elasticity demand is below one (and hence inconsistent with profit maximization), as defined by $\sigma(\underline{x}) = 1$ and given by $\underline{x} = \frac{\bar{\sigma}-1}{\bar{\sigma}} e^{-(\bar{\sigma}-1)/\bar{\varepsilon}} < 1$. Note that at this price the markup becomes infinite, $\mathcal{M}(\underline{x}) = \infty$, 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 \underline{x} to a maximum of $\hat{\Psi} = \frac{1}{1+\bar{\varepsilon}/\bar{\sigma}}$ 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 $P_i = \mathcal{M}(x_i)MC_i$, where $x_i = \frac{P_i/\gamma_i}{P/D}$ 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:

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

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

⁴⁷Note that with this demand, the elasticity of elasticity with respect to quantity is constant: $d \log \sigma_i / d \log C_i = \bar{\varepsilon} / \bar{\sigma}$. Furthermore, the markup elasticity Γ_i is proportional to the level of markup \mathcal{M}_i (we introduce both below): $\Gamma_i / \mathcal{M}_i = \bar{\varepsilon} / \bar{\sigma}$.

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:

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

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

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 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 λ and μ the Lagrange multipliers on demand aggregator (A4) and the expenditure constraint (A7) respectively. The 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

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

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

$$C_j = \frac{\xi_j C}{N} \cdot \psi \left(\frac{P_j / \gamma_j}{P/D} \right), \quad \gamma_j \equiv A_j / \xi_j, \quad \psi(\cdot) \equiv \Upsilon'^{-1}(\cdot).$$

Given $P = E/C$, P and D are determined from the two constraints on the problem (A4) and (A7), which can be rewritten as:

$$\begin{aligned}\frac{1}{N} \sum_{j \in \Omega} A_j \Upsilon \left(\psi \left(\frac{P_j / \gamma_j}{P/D} \right) \right) &= 1, \\ \frac{1}{N} \sum_{j \in \Omega} \frac{\xi_j P_j}{P} \psi \left(\frac{P_j / \gamma_j}{P/D} \right) &= 1,\end{aligned}$$

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:

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

where P is defined in (??).

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

$$\begin{aligned}\tilde{\sigma}_j = \tilde{\sigma}(x_j) &\equiv - \frac{d \log \psi(x_j)}{d \log x} = - \frac{x_j \psi'(x_j)}{\psi(x_j)}, \\ \tilde{\varepsilon}_j = \tilde{\varepsilon}(x_j) &\equiv\end{aligned}$$

F.3 Large firms

Denote by $Z \equiv D/P$ 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:

$$\begin{aligned}\frac{d \log Z}{d \log P_i} &= - \frac{\frac{A_i}{N} \left(\frac{Z P_i}{\gamma_i} \right)^2 \psi' \left(\frac{Z P_i}{\gamma_i} \right)}{\sum_{j \in \Omega} \frac{A_j}{N} \left(\frac{Z P_j}{\gamma_j} \right)^2 \psi' \left(\frac{Z P_j}{\gamma_j} \right)}, \\ \frac{d \log P}{d \log P_i} &= \frac{\xi_i P_i}{NP} \left[\psi \left(\frac{Z P_i}{\gamma_i} \right) + \frac{Z P_i}{\gamma_i} \psi' \left(\frac{Z P_i}{\gamma_i} \right) \right] + \frac{d \log Z}{d \log P_i} \cdot \sum_{j \in \Omega} \frac{\xi_j P_j}{NP} \frac{Z P_j}{\gamma_j} \psi' \left(\frac{Z P_j}{\gamma_j} \right),\end{aligned}$$

where in manipulating the differential of (A10) we used the fact that $\Upsilon'(\psi(x)) \equiv x$ 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:

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

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

Profit maximization:

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

where

$$C_j = \frac{\xi_j E}{NP \eta} \cdot \psi (Z P_j / \gamma_j).$$

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:

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

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

$$\mathcal{M}_j = \frac{\sigma(1 - s_j) + \eta s_j}{\sigma(1 - s_j) + \eta s_j - 1}.$$

We need to derive:

$$\Gamma_j \equiv - \frac{d \log \mathcal{M}_j}{d \log P_j} =,$$

$$\Gamma_P \equiv \frac{d \log \mathcal{M}_j}{d \log P} =,$$

$$\Gamma_D \equiv \frac{d \log \mathcal{M}_j}{d \log D} =$$

F.4 Klenow and Willis demand

Figure A2 plots these cross-sectional relationships (for $\sigma = 4$ and various values of ε), 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, $\sigma(\underline{x}) = 1$ —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 ε is large (below 60% for $\varepsilon = 3$ and below 45% for $\varepsilon = 6$); when ε 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 $\bar{\varepsilon} = \bar{\sigma}$

With $\bar{\sigma} = \bar{\varepsilon} > 1$, 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:

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

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

and thus

$$\Upsilon(\psi(x_i)) = \sigma(1 - x_i).$$

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

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

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

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:

$$P = \mathbb{E}\{\xi_i P_i\} \cdot \left[1 - \sigma \mathbb{E} \left\{ \frac{\xi_i P_i}{\mathbb{E}\{\xi_i P_i\}} \cdot \log \left(\frac{\xi_i P_i}{\mathbb{E}\{\xi_i P_i\}} \frac{1}{A_i} \frac{\sigma \cdot \mathbb{E}\{A_i\} - 1}{\sigma - 1} \right) \right\} \right].$$

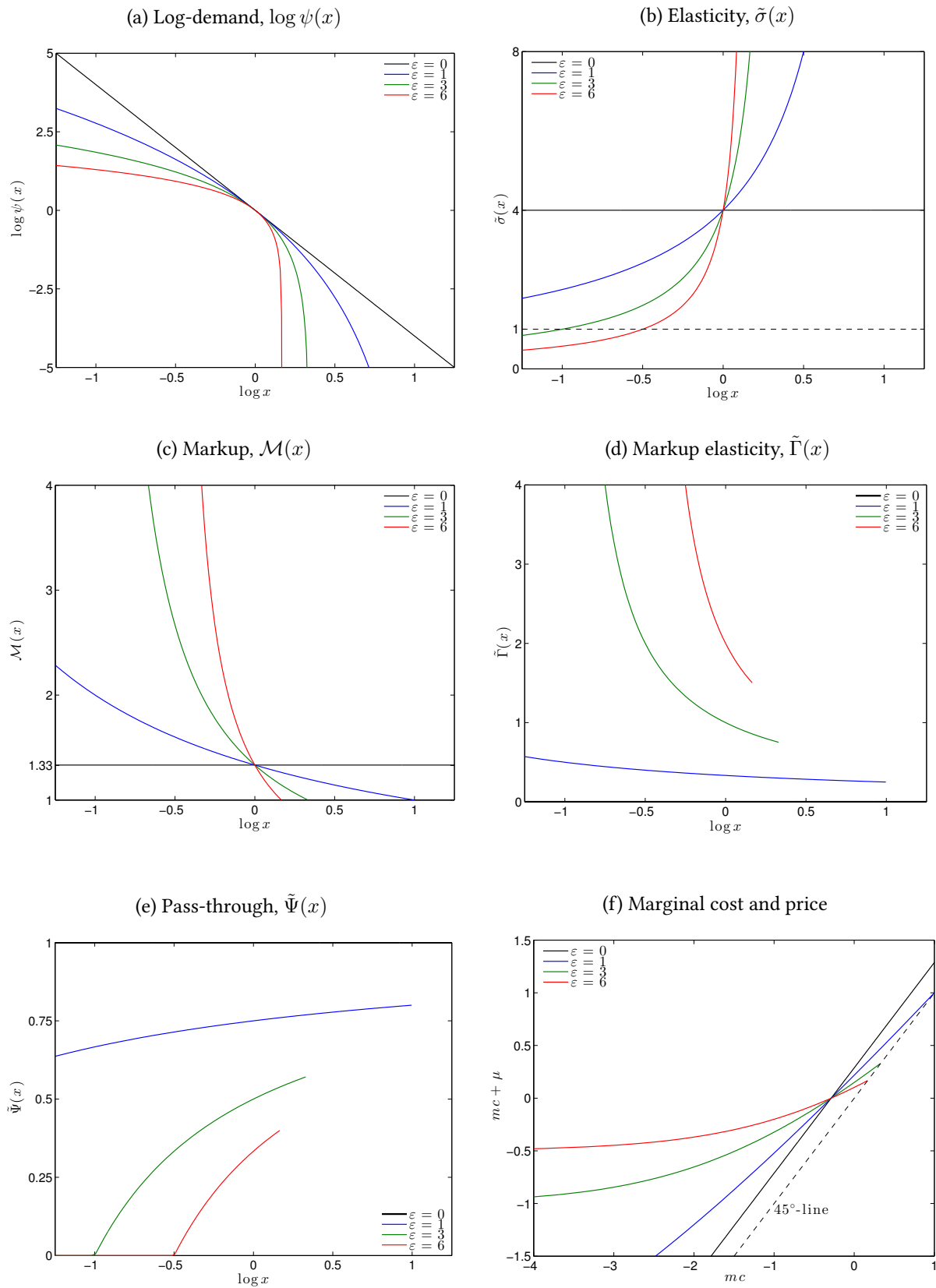


Figure A2: Klenow-Willis specification of Kimball demand

It is natural to impose the following normalization: $\mathbb{E}\{A_i\} = \frac{1}{|\Omega|} \int_{i \in \Omega} A_i di = 1$. In that case, the expression simplify to:

$$\begin{aligned} \frac{P}{D} &= \frac{\sigma}{\sigma - 1} \mathbb{E}\{\xi_i P_i\}, \\ P &= \mathbb{E}\{\xi_i P_i\} \cdot \left[1 - \sigma \mathbb{T}\{\xi_i P_i\} + \sigma \frac{\mathbb{E}\{\xi_i P_i \log A_i\}}{\mathbb{E}\{\xi_i P_i\}} \right], \end{aligned}$$

where $\mathbb{T}\{\xi_i P_i\}$ is the Theil inequality index for $\{\xi_i P_i\}$ defined as

$$\mathbb{T}\{\xi_i P_i\} = \frac{1}{|\Omega|} \int_{i \in \Omega} \frac{\xi_i P_i}{\mathbb{E}\{\xi_i P_i\}} \log \left(\frac{\xi_i P_i}{\mathbb{E}\{\xi_i P_i\}} \right) di.$$

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