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


Mary Amiti
Mary.Amiti@NY.FRB.ORG

Oleg Itskhoki
Itskhoki@Princeton.EDU

Jozef Konings
Joep.Konings@KULeuven.BE


May 28, 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 variables markups to match the salient features we identify in the data. We use the calibrated model to study counterfactual scenarios for the response of costs, markups and prices to an exchange rate devaluation across firms and industries.



*Amiti: Federal Reserve Bank of New York, 33 Liberty Street, New York, NY 10045 (email: Mary.Amiti@ny.frb.org); Itskhoki: Princeton University, Department of Economics, Princeton, NJ 08544 (email: itskhoki@princeton.edu); Konings: Katholieke Universiteit Leuven, Department of Economics, Naamsestraat 69, 3000 Leuven, Belgium, National Bank of Belgium (email: joep.konings@kuleuven.be).


We thank the National Belgium Bank for providing the data, and Ilke Van Beveren for all her help with the concordances. We thank Ariel Burstein, Linda Goldberg, Anna Kovner, Ben Mandel, Dmitry Mukhin, David Weinstein, and seminar participants at the NY Fed, Boston College, UBC, Columbia and University of Oslo for insightful comments. Sungki Hong and Preston Mui provided an excellent research assistance. The views expressed in this paper are those of the authors and do not necessarily represent those of the Federal Reserve Bank of New York or the National Bank of Belgium.

# 1 Introduction

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

In this paper, we construct a new micro-level dataset for Belgium containing 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 intermediate inputs purchased by Belgian firms at a very high level of disaggregation (over 10,000 products by source country). We use the changes in the unit values of the imported inputs as measures of the exogenous cost shocks to the firms, which allows us to instrument for both the prices of the competitors (with their respective cost shocks) and for the usual noisy proxy for the overall marginal cost of the firm measured as the ratio of total variable costs to output. We check our identification strategy by validating that our instruments are both strong and pass the over-identification tests.

Our results provide strong evidence of strategic complementarities. We estimate that, on average, a domestic firm changes its price in response to competitors' price changes with an elasticity of about

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

[2]We use the word *idiosyncratic* to emphasize that this cost pass-through elasticity is a counterfactual object which holds constant the prices of the firm's competitors. Also note that the strategic complementarity elasticity could, in principle, be negative if the prices of the firms were strategic substitutes.

35–40 percent.[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

[3] In our baseline estimation, the set of a firm's competitors consists of all firms within its 4-digit manufacturing industry, and our estimate averages the elasticity both across firms within industry and across all Belgian manufacturing industries. We calculate the competitor price index as the average weighted by sales of the competitor-firms.

[4] Our 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.

[5] More 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

[6] In 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 Itskhoki (2011) provide indirect evidence that is consistent with the presence of strategic complementarities in pricing, yet as the authors acknowledge, this evidence could also be consistent with the correlated cost shocks across the firms.[8] Amiti, Itskhoki, and Konings (2014) develop an identification strategy to decompose the variation across exporters in the exchange rates pass-through into the markup and marginal cost channels in the absence of direct data on prices of local competitors, which excludes the possibility of a counterfactual analysis. By constructing a more comprehensive dataset of firm prices and costs, this paper overcomes many of the limitations of the previous studies.

Although the main international shock we consider is an exchange rate shock, our analysis applies more broadly to other international shocks such as trade reforms or commodity price shocks. Studies that analyze the effects of tariff liberalizations on domestic prices mostly focus on developing countries,

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

[8] Gopinath and Itskhoki (2011) and Burstein and Gopinath (2012) survey a broader *pricing-to-market* (PTM) literature, which documents that firms charge different markups and prices in different destinations, and actively use markup variation to smooth the effects of exchange rate shocks across markets.

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 empirically the strength of strategic complementarities in price setting and understand the channels through which international shocks feed into domestic prices, we start with a general accounting framework following Gopinath, Itskhoki, and Rigobon (2010) and Burstein and Gopinath (2012). We use this framework to derive our empirical specifications estimated later in Section 3. In Section 2.2, we describe a popular model of variable markups based on oligopolistic competition under CES demand, introduced by Krugman (1987) and further developed by Atkeson and Burstein (2008). This model offers an example that fits our more general accounting framework, which we later adopt for calibration and quantitative analysis in Section 4.

## 2.1 General Accounting Framework

We start with the definition of log markup of firm $i$ in period $t$:

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

where $p_{it} \equiv \log P_{it}$ is the log price of the firm and $mc_{it} \equiv \log MC_{it}$ is the log marginal cost of the firm.[10] We further denote by $\Gamma_{it}$ and $\Gamma_{-i,t}$ the markup elasticity with respect to the own price of the firm and its competitors' price index:

$$\Gamma_{it} \equiv -\frac{\mathrm{d}\mu_{it}}{\mathrm{d}p_{it}} \qquad \text{and} \qquad \Gamma_{-i,t} \equiv \frac{\mathrm{d}\mu_{it}}{\mathrm{d}p_{-i,t}}, \tag{2}$$

[9] The second part of our analysis, in which we calibrate a model of variable markups to the Belgian micro-level data, is most directly related to the exercise in Edmond, Midrigan, and Xu (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.

[10] This markup may or may not be optimally set by the firm. For the structural interpretation of our estimates we adopt a flexible-price model, in which case $\mu_{it}$ is the static optimal oligopolistic markup. However, in a world with dynamic price setting, as for example under sticky prices, the realized markup $\mu_{it}$ is not necessarily statically optimal for the firm, in which case our estimates do not admit a simple structural interpretation, but can instead 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).

where $p_{-i,t} \equiv \log P_{-i,t}$ is the log price index of firms' competitors within an industry, which we define formally below. The elasticities in (2) can be thought of as structural objects in models of optimal price setting, in which markups are functions of the prices and demand parameters, as we show in Section 2.2. However, more generally, $\Gamma_{it}$ and $\Gamma_{-i,t}$ can be simply viewed as (logarithmic) projection coefficients of a firm's realized markup on its own price and the price index of its competitors. We expect both $\Gamma_{it}$ and $\Gamma_{-i,t}$ to be positive, reflecting that firms tend to increase their markups as they gain competitiveness (market share) as a result of either an increase in competitors prices or a reduction in own price. Furthermore, many models of variable markups, including the one in the next section, imply that the two elasticities are equal, $\Gamma_{-i,t} = \Gamma_{it}$, and that the markup elasticity is a function of firm characteristics, $\Gamma_{it} \equiv \Gamma(z_{it})$, where $z_{it}$ may include firm size, market share, price and/or quality of its product.[11]

Using the definitions in (2), we can write the change in markup of the firm as:

$$\Delta\mu_{it} = -\Gamma_{it}\Delta p_{it} + \Gamma_{-i,t}\Delta p_{-i,t} + \tilde{\varepsilon}_{it}, \tag{3}$$

where $\tilde{\varepsilon}_{it}$ is a residual shock to markup. In Section 2.2 we provide a structural interpretation to this shock, but more generally equation (3) can be viewed as a non-structural definition of the residual $\tilde{\varepsilon}_{it}$, which holds as a matter of accounting. Intuitively, this equation is a first-order Taylor expansion for the change in markup (based on the model of the markup outlined in footnote 11). The residual $\tilde{\varepsilon}_{it}$ contains terms of markup variation that are unrelated to the changes in prices, such as exogenous product demand shifts.[12]

Combining expression (3) with the markup identity (1) in changes, we can express the change in firm's price as:

$$\Delta p_{it} = \frac{1}{1+\Gamma_{it}}\Delta mc_{it} + \frac{\Gamma_{-i,t}}{1+\Gamma_{it}}\Delta p_{-i,t} + \varepsilon_{it}, \tag{4}$$

where $\varepsilon_{it} \equiv \frac{\tilde{\varepsilon}_{it}}{1+\Gamma_{it}}$. We use the following definition for the change in the log competitor price index:

$$\Delta p_{-i,t} = \sum_{j\in s, j\neq i} \omega_{jt}^{-i}\Delta p_{j,t}, \tag{5}$$

where $s$ denotes the industry in which the firm competes, $\omega_{jt}^{-i} = S_{jt}/(1-S_{it})$ are the sales weights of the competitors, where $S_{it}$ is the market share of firm $i$ within its industry.

[11] Formally, a general structural model of the markup can be written as $\mu_{it} \equiv \log\mathcal{M}(P_{it}, P_{-i,t}; X_{it}; \Theta)$, where $X_{it}$ is a vector of other characteristics of the firm including quality, market share and costs, and $\Theta$ is a vector of primitive parameters of demand, market structure and cost structure. The markup elasticity is then $\Gamma_{it} \equiv -\mathrm{d}\log\mathcal{M}/\mathrm{d}\log P_{it} = -\big[\partial\log\mathcal{M}/\partial\log P_{it} + \partial\log\mathcal{M}/\partial\log X_{it}\cdot\partial\log X_{it}/\partial\log P_{it}\big]|_{P_{it},P_{-i,t},X_{it}}$, and analogously for $P_{-i,t}$. Note that we allow markup elasticities to vary both across firms and over time. A specific example is discussed in Section 2.2. A necessary and sufficient condition for $\Gamma_{it} = \Gamma_{-i,t}$ is that the markup $\mu_{it}$ depends only on the relative price of the firm, $P_{it}/P_{-i,t}$, which for example is the case under a homothetic demand system.

[12] When $\Gamma_{it}$ and $\Gamma_{-i,t}$ are interpreted as *arc* (rather than point) elasticities of the markup, the expansion in (3) has no higher-order remainder, according to the intermediate value theorem.

Equation (4) is the focus of our empirical analysis in Section 3. The two coefficients of interest are:

$$\psi_{it} \equiv \frac{1}{1+\Gamma_{it}} \qquad \text{and} \qquad \gamma_{it} \equiv \frac{\Gamma_{-i,t}}{1+\Gamma_{it}}. \tag{6}$$

The coefficient $\psi_{it}$ measures the (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. Coefficient $\gamma_{it}$ measures the strength of *strategic complementarities* in price setting, as it is the elasticity of the firm's price with respect to the prices of its competitors. We expect the value of $\psi_{it}$ to be between zero and one, and the value of $\gamma_{it}$ to be either zero or positive in the presence of strategic complementarities in pricing.[13] The two coefficient are generally related. In particular, in models where $\Gamma_{-i,t} = \Gamma_{it}$, the two coefficients sum to one,

$$\psi_{it} + \gamma_{it} = 1, \tag{7}$$

a restriction that we will be able to evaluate in the data without imposing it in estimation. Furthermore, we expect coefficients $\psi_{it}$ and $\gamma_{it}$ to vary across firms in a systematic way, as we discuss below. Therefore, we are also interested in estimating the contribution of firm observable characteristics to explaining (a part of) this cross-sectional variation.

Estimation of equation (4) 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, as are the measures of competitors' prices that comprise all domestically-produced and imported products. Secondly, competitors' prices are endogenous to the firm's price, since all prices are set simultaneously as an outcome of the oligopolistic competition game. Therefore, estimating (4) requires finding valid instruments for the competitor price changes. We also need to make ensure that the instruments are orthogonal with the residual source of changes in markups captured by $\varepsilon_{it}$ in (4). Finally, the cross-sectional heterogeneity in the responsiveness of firms' prices to marginal costs and competitors' prices, emphasized by subindex $i$ in the coefficients $\psi_{it}$ and $\gamma_{it}$, needs to be taken care of. We address all of these issues in Section 3.

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

[13] The coefficient $\gamma_{it}$ could, in principle, be negative, if firms prices were strategic substitutes.

as:[14]

$$\Psi_{it} = \psi_{it}\varphi_{it} + \gamma_{it}\Psi_{-i,t}, \tag{8}$$

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

Equation (8) illustrates the rich set of determinants of the exchange rate pass-through into the prices of individual firms. Next consider what shapes the industry-level pass-through, which aggregates the responses $\Psi_{it}$ across firms within the industry. In Appendix D, we show that the response of the industry $s$ price index to an exchange rate shock is given by:

$$\Psi_{st} = \frac{1}{1 - \sum_i S_{it}\gamma_{it}} \sum_i S_{it}\psi_{it}\varphi_{it}. \tag{9}$$

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.

## 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 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). In the following Section 3 we provide direct evidence on the magnitudes of $\psi_{it}$ and $\gamma_{it}$, both of which we find to lie strictly between zero and one.

In order to capture these empirical patterns in a model, one needs to depart from either the CES assumption or the monopolistic competition assumption. 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.[15] 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

[14] Alternatively, one can define $\Psi_{it}$, $\varphi_{it}$ and $\Psi_{-i,t}$ as the regression coefficients of the log change in firm's price, marginal cost and competitors price index on the log change in the exchange rate.

[15] The common alternatives in the literature maintain the monopolistic competition assumption and consider non-CES demand: for example, Melitz and Ottaviano (2008) use quadratic demand, 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).

industry is $\rho \geq \eta$. Under these circumstances, the demand faced by a firm is:

$$Q_{it} = \xi_{it} D_{st} P_{st}^{\rho-\eta} P_{it}^{-\rho}, \tag{10}$$

where $\xi_{it}$ 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. In what follows we omit the industry identifier $s$ when it causes no confusion.

The industry price index is defined according to:

$$P_{st} = \left[\sum_{i=1}^{N} \xi_{it} P_{it}^{1-\rho}\right]^{\frac{1}{1-\rho}}, \tag{11}$$

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.[16] Further, we can write the firm's market share as:

$$S_{it} \equiv \frac{P_{it} Q_{it}}{\sum_{j=1}^{N} P_{jt} Q_{jt}} = \xi_{it} \left(\frac{P_{it}}{P_{st}}\right)^{1-\rho}, \tag{12}$$

where the second equality follows from the functional form of firm demand in (10). A firm has a large market share when it charges a low relative price $P_{it}/P_{st}$ (since $\rho > 1$) and/or when its product has a strong appeal in the eyes of the customers (i.e., a large demand shifter $\xi_{it}$).

We assume that firms have constant marginal costs $MC_{it}$, an assumption that we relax in Section 2.4. 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:[17]

$$P_{it} = \mathcal{M}_{it} MC_{it}, \qquad \text{where} \qquad \mathcal{M}_{it} \equiv \frac{\sigma_{it}}{\sigma_{it} - 1} \tag{13}$$

and

$$\sigma_{it} = \left[\frac{1}{\eta} S_{it} + \frac{1}{\rho}(1 - S_{it})\right]^{-1}. \tag{14}$$

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

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

[17] The only difference in setting prices under Bertrand competition is that $\sigma_{it} = \eta S_{it} + \rho(1 - S_{it})$, as opposed to (14), and all the qualitative results remain unchanged. Derivations for both cases are provided in Appendix E.

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

$$\Gamma_{it} = -\frac{\mathrm{d}\log \mathcal{M}_{it}}{\mathrm{d}\log P_{it}} = \frac{(\rho-\eta)(\rho-1)\sigma_{it}s_{it}(1-s_{it})}{\eta\rho(\sigma_{it}-1)}, \tag{15}$$

$$\Gamma_{-i,t} = \frac{\mathrm{d}\log \mathcal{M}_{it}}{\mathrm{d}\log P_{-i,t}} = \Gamma_{it}, \tag{16}$$

where $P_{-i,t}$ is the competitor price index defined as:[18]

$$P_{-i,t} = \Big[\textstyle\sum_{j\neq i} \frac{\xi_{jt}}{1-\xi_{it}} P_{jt}^{1-\rho}\Big]^{\frac{1}{1-\rho}}, \tag{17}$$

so that, according to (11), the following decomposition is satisfied: $P_{st} = \big[\xi_{it}P_{it}^{1-\rho} + (1-\xi_{it})P_{-i,t}^{1-\rho}\big]^{1/(1-\rho)}$. 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. Furthermore, the own and the competitor price elasticities are equal, $\Gamma_{-i,t} = \Gamma_{it}$, and therefore the parameter restriction (7) is satisfied.[19]

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

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

Therefore, $S_{it} < 1/2$ is a sufficient (but not a necessary) condition for the markup elasticity $\Gamma_{it}$ to increase with market share. In our data, market shares in excess of 50% are nearly non-existent. Further, note from equation (15) 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.

[18] Note that the expression for the change in the competitor's price index introduced in (5) is a first order approximation to the expression in (17).

[19] Indeed, in the notation of footnote 11, the model of markup in (12)–(14) results in $\mathcal{M}_{it} = \mathcal{M}(X_{it};\Theta)$, where $X_{it} = S_{it}$ and $\Theta = (\rho,\eta)'$. The market share, in turn, depends on the relative price of the firm $P_{it}/P_{-i,t}$. Therefore, the sufficient condition for $\Gamma_{-i,t} = \Gamma_{it}$ that the markup depends only on the relative price is satisfied.

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

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

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 prices do not impact the exogenous demand shifter, $\xi_{it}$, however alternative scenarios can also be considered (we return to the discussion of identification in Section 3).

### 2.3 A model of marginal costs

We assume that a firm has the following total cost function:

$$TC_{it} = AVC_{it} \cdot Y_{it} + F_{it},$$

where $F_{it}$ is the production fixed cost of firm $i$, $AVC_{it}$ is a constant average variable cost, and $Y_{it}$ is production (note the difference with $Q_{it}$, which is domestic demand). The marginal cost in this case equals the average variable cost, and hence can be measured as a ratio of the total variable cost to quantity produced:

$$MC_{it} = AVC_{it} = \frac{TVC_{it}}{Y_{it}}, \tag{19}$$

where $TVC_{it} = TC_{it} - F_{it}$.[20] This structure with constant marginal cost arises under constant returns to scale (CRS) in production upon paying a fixed cost, and is standard in both the theoretical and quantitative literature. We abuse the language somewhat by referring to this case as CRS, despite the possible presence of the fixed costs. The following subsection offers an extension with decreasing returns to scale and increasing marginal costs of production.

We assume the following structure for the firm's marginal cost in period $t$:

$$MC_{it} = \frac{W_{it}^{1-\phi_{it}}\left(V_{it}^{*}\mathcal{E}_t\right)^{\phi_{it}}}{\tilde{\Omega}_{it}}, \tag{20}$$

where $W_{it}$ is the cost index of domestic variable inputs (including wages and intermediates inputs), $V_{it}^{*}$ is the cost index of the foreign inputs in foreign currency (as emphasized by the asterisk), $\mathcal{E}_t$ is the nominal exchange rate (units of domestic currency for one unit of foreign currency), $\phi_{it}$ is the firm's *import intensity*, and $\tilde{\Omega}_{it}$ is the firm's productivity.

Note that we allow the cost indexes of domestic and foreign inputs to be firm-specific, which gives us the major source of identification in the empirical Section 3. Denote with $V_{it} = V_{it}^{*}\mathcal{E}_t$ the domestic-currency cost index of the imported inputs, which we assume comes from a CES aggregator of individual

[20] Garcia-Marin and Voigtländer (2013) provide empirical evidence that this measure of average variable costs provides a reasonable, albeit noisy, approximation to the marginal cost in the data.

imported varieties:

$$V_{it} = \left[ \int_{m \in M_{it}} V_{imt}^{\zeta} \mathrm{d}m \right]^{1/\zeta}, \tag{21}$$

where $m$ indexes imported varieties, $V_{imt}$ are firm-specific prices of these varieties, and $M_{it}$ is the firm-specific set of imported varieties. In the data we can directly measure the unit costs of the imported inputs at the firm level, $\{V_{imt}\}_{m \in M_{it}}$, along with the respective expenditure shares. This allows us to construct a precise measure of a component of the marginal cost, which is sufficient for our empirical implementation, as we discuss in more detail below. Our measures of the domestic component of the marginal cost $W_{it}$, which includes both firm-specific wages and domestic input costs, are less precise, and we choose not to rely on it in our identification. In Amiti, Itskhoki, and Konings (2014), we provided a microfoundation for the marginal cost in (20)–(21), where import intensity $\phi_{it}$ and the set of imported inputs $M_{it}$ are endogenously chosen by firms in a way that is consistent with the data. In this paper, we instead discipline the distribution of $\phi_{it}$ directly from the data, as we discuss in the following sections.

Taking log changes in (20), we have:[21]

$$\Delta mc_{it} = (1 - \phi_{it})\Delta w_{it} + \phi_{it}\Delta v_{it} + (v_{i,t-1} - w_{i,t-1})\Delta\phi_{it} - \Delta\tilde{\omega}_{it}, \tag{22}$$

where the small letters denote logs, $v_{it} = v_{it}^{*} + e_t$ and $e_t = \log \mathcal{E}_t$. We denote the imported component of the marginal cost with:

$$\Delta mc_{it}^{*} = \phi_{it}\Delta v_{it}. \tag{23}$$

This defines all the objects that will be relevant for our empirical analysis in Section 3.

### 2.4 Decreasing returns to scale

The analysis above was carried out under the assumption of constant marginal cost curves. We now show how the analysis extends to the case of increasing marginal cost schedules in firm's output (i.e., decreasing return to scale in production net of fixed costs). In particular, we assume that the marginal cost of the firm is increasing in its output, and instead of (20) is given by:

$$MC_{it} = C_{it} \cdot Q_{it}^{\alpha}, \qquad \alpha > 0, \tag{24}$$

where in turn $C_{it}$ satisfies equation (20). We show in Appendix D.2, that our main accounting decomposition of Section 2 still applies, but the coefficients are now given by

$$\psi_{it} = \frac{1}{1 + \Gamma_{it} + \alpha\tilde{\sigma}_{it}} \qquad \text{and} \qquad \gamma_{it} = \frac{\Gamma_{-i,t} + \alpha\tilde{\sigma}_{-i,t}}{1 + \Gamma_{it} + \alpha\tilde{\sigma}_{it}},$$

where $\tilde{\sigma}_{it}$ and $\tilde{\sigma}_{-i,t}$ are elasticities of demand with respect to firms's own price and its competitor price index. The decreasing returns to scale mechanism acts in the same way as the variable markup mechanism, reducing the response to own cost shocks and increasing the response to the changes in

[21] The changes in firm import intensity, $\Delta\phi_{it}$, in the data year-to-year are small, and can be approximately considered zeros. However, we do not need to make this assumption in our analysis.

the competitor's prices (i.e., the effect of positive $\alpha$ is equivalent to the effect of larger $\Gamma_{it}$ and $\Gamma_{-i,t}$). Intuitively, the decreasing returns to scale limit the firms' flexibility in adjusting to shocks by changing their output, and hence the firms respond more by adjusting their prices (and markups).

An important testable implication of the increasing marginal costs is that the sum of the coefficients is less than one, $\psi_{it} + \gamma_{it} < 1$. This is intuitive: a proportional increase in the costs for all firms in this case results in a smaller-than-proportional increase in prices by all firms, as decreased production (due to lower demand in response to higher prices) partly pushes back down the costs of the firms. We illustrate this for the special case of CES demand from Section 2.2, where $\tilde{\sigma}_{it} - \tilde{\sigma}_{-i,t} = \eta$ (see Appendix D.2), and hence:

$$\psi_{it} + \gamma_{it} = 1 - \alpha\eta\psi_{it} < 1.$$

In Section 3, we test the constant marginal cost benchmark, which implies the parameter restriction (7), against the alternative $\psi_{it} + \gamma_{it} < 1$ under increasing marginal costs.

# 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 2008 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 (1,700 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 (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.

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 2008 to construct the key variables for our analysis. As in Section 2, we use index $i$ for firm-products and index $s$ for industries.

**Domestic Prices** The main variable of interest is the price of the domestically sold goods, which we proxy using the log change in the domestic unit value, denoted $\Delta p_{it}$, where $i$ corresponds to a firm-product at the PC-8-digit level. The domestic unit values are calculated as the ratio of production sold domestically to quantity sold domestically:[22]

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

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 the 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 the firm $i$ as follows:

$$\Delta mc_{it} = \Delta \log \frac{\text{Total Variable Cost}_{it}}{Y_{it}} \tag{26}$$

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

$$\Delta mc^*_{it} = \sum_m \omega_{imt} \Delta v_{imt} \tag{27}$$

where $m$ indexes a firm's imported inputs at the country of origin and CN-8-digit product level, $\Delta v_{imt}$ 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

[22]In 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).

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

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:

$$\Delta p^F_{st} = \sum_{j \in F_s} \omega_j \Delta p_{jt}, \tag{28}$$

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:

$$\Delta p^D_{-i,t} = \sum_{j \in D_s, j \neq i} \omega^{-i}_{jt} \Delta p_{jt}, \tag{29}$$

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:

$$\Delta p_{-i,t} = (1 - \theta_{-i,t}) \Delta p^D_{-i,t} + \theta_{-i,t} \Delta p^F_{st} \tag{30}$$

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 175 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 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):

$$\Delta mc^*_{-i,t} = \sum_{j\in D_s, j\neq i} \omega^{-i}_{jt} \Delta mc^*_{jt}.$$

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:

$$\Delta e_{st} = \sum_k \theta^s_{kt} \Delta e_{kt},$$

where $k$ indexes countries and $\theta^s_{kt}$ is the share of competitors from country $k$ in industry $s$.[24] 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 Belgian. 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 PC 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 the import weights 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 $\Delta p^{EU}_{st}$.

## 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 its competitors' price index, as in equation (4). The coefficient on the marginal cost variable, which we denote $\psi_{it}$ in (6), 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 $\gamma_{it}$ in (6), 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.[25] If the markup elasticity, $\Gamma_{it}$ were symmetric for both own price and competitor price, the two coefficients

[24] The 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.

[25] In principle, prices could be strategic substitutes in which case the coefficient on the competitor price index would be negative.

in equation (4) would sum to one as in equation (7). 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. Recall from Section 2.4 that this is also a test of constant returns to scale in production.

**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 the endogeneity bias due to simultaneity of price setting by the firm and its competitors, as well as from the 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.[26] 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 $\varepsilon_{it}$ in (4). The structural model of Section 2.2 suggests that $\varepsilon_{it}$ 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 the Hansen overidentification $J$-tests in Table 1 with very large $p$-values. Additionally, we show that our results are robust to alternative instrument sets in the appendix table. 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.[27]

From column 3–4 in Table 1, where equation (4) is estimated using instrumental variables, we

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

[27] 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.

Table 1: Strategic complementarities: baseline estimates

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

Notes: All regressions are weighted by lagged domestic sales and include year fixed effects. The instrument set comprises $\Delta mc^*_{it}$, $\Delta e_{st}$, $\Delta mc^*_{-i,t}$, $p^{EU}_{st}$, 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.

see that the coefficient on the firm's marginal cost almost doubles in size, while the coefficient on the competitors' price index also slightly increases, compared to the OLS results in columns 1–2. Now, the coefficients on the firm marginal cost and competitor price index sum to one, consistent with restriction (7) implied by many theoretical models of variable markups, as discussed in Section 2. Additionally, we cannot reject the hypothesis of constant returns to scale in production, which also implies that the two coefficients sum to one, as discussed in Section 2.4.[28]

We find that firms exhibit incomplete pass-through of their own cost shocks with an average elasticity of 65–75% (i.e., $\bar{\psi}$ =0.65–0.75), 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., $\bar{\gamma}$ =0.3–0.45). 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. The standard errors for our estimates of $\bar{\psi}$ and $\bar{\gamma}$ are 0.12–0.15, and thus the estimated elasticities are significant both economically and statistically.

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 (6), we can recover the more primitive objects, namely the average elasticity of the markups with respect to the price of the firm

[28] The 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, easily rejecting the decreasing returns to scale hypothesis (in which case the sum must be less than 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.

Table 2: Strategic complementarities: robustness

| Dep. var.: $\Delta p_{it}$ | Two-period differences (1) | Alternative input definition (2) | Major product (3) | 5-digit industry (4) | 6-digit industry (5) |
|---|---|---|---|---|---|
| $\Delta mc_{it}$ | 0.642*** | 0.684*** | 0.658*** | 0.750*** | 0.494*** |
| | (0.245) | (0.148) | (0.173) | (0.167) | (0.139) |
| $\Delta p_{-i,t}$ | 0.434* | 0.388* | 0.374* | 0.410*** | 0.654*** |
| | (0.234) | (0.200) | (0.200) | (0.147) | (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 sales and include firm 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 (a total of 145 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 (a total of 230 industries). Column 6 defines all competition variables relative to 6-digit industries (a total of 340 industries).

(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.[29]

**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. 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 any sales. There is no clear way of determining whether a firm is importing a final good or an intermediate input. The definition we use in column 2 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

[29] Gopinath and Itskhoki (2011) further discuss the relationship of these estimates with the calibrations of the strategic complementarities in the 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. This, however, does 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 of Basu 1995).

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.[30] 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 largest domestic sales share). 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 2,514 8-digit product codes into 175 industries. In columns 4 and 5, we experiment with defining the competition variables at the 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 coefficient 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 competitors price. In contrast, large firms have a smaller coefficient on marginal cost and a larger coefficient on competitors' price index, both significant and both roughly equal to 0.5. In column 3, we use the full sample of firms and interact both coefficients with a $\text{Large}_{it}$ 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.

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

Table 3: Strategic complementarities: heterogeneity

| Large defined as: | Employment $\geq 100$ | | | Top 20% market share | | |
|---|---|---|---|---|---|---|
| Sample: | Small | Large | All | Small | Large | All |
| Dep. var.: $\Delta p_{it}$ | (1) | (2) | (3) | (4) | (5) | (6) |
| $\Delta mc_{it}$ | 0.929*** | 0.599** | 0.949*** | 0.947*** | 0.662*** | 0.947*** |
| | (0.152) | (0.237) | (0.201) | (0.200) | (0.204) | (0.226) |
| $\Delta mc_{it} \times \text{Large}_{it}$ | | | -0.315 | | | -0.270 |
| | | | (0.351) | | | (0.356) |
| $\Delta p_{-i,t}$ | 0.078 | 0.469** | 0.142 | 0.003 | 0.432** | 0.063 |
| | (0.189) | (0.202) | (0.225) | (0.177) | (0.210) | (0.180) |
| $\Delta p_{-i,t} \times \text{Large}_{it}$ | | | 0.279 | | | 0.355 |
| | | | (0.319) | | | (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 |
| [$\chi^2$ $p$-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 domestic sales. Instrument set: $\Delta e_{st}$, $\Delta mc^*_{it}$, $\Delta mc^*_{-i,t}$, $p^{EU}_{st}$.

The results in columns 4–6 replicate those in columns 1–3.[31]

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 less than 60%. Since these largest firms account for the majority of market sales, their behavior drives the average patterns across firms we documented 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.

[31] An 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.

# 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 2.2–2.3, 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 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 our representative industry to a typical industry in the Belgian data, focusing on the domestic market in which both domestic and foreign firms compete. 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 was 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 was greater than 32% or less than 2%. After this process, we end up with 38 industries (out of a total of 146), 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 $\bar{N}_B$, $\bar{N}_E$ and $\bar{N}_X$, respectively. We calibrate $\bar{N}_B = 48$, equal to the mean number of Belgian firms across typical Belgian industries.[32] 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 matches 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 modelled in the same way as in Section 2.3, with

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

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 $\Omega_{it}$ is the effective idiosyncratic productivity of the firm. Note that even though the input prices do not have an $i$ subscript this specification does not rule out the idiosyncratic heterogeneity in input prices present in Section 2.3). Here, the variation in input prices across firms is rolled into the effective idiosyncratic productivity term $\Omega_{it}$, which in logs can be written as $\omega_{it} = \tilde{\omega}_{it} - (1-\phi_{it})\tilde{w}_{it} - \phi_{it}\tilde{v}_{it}$, 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 $\varphi_i$ in (31) is firm-specific and constant over time.[33] Note that the exchange rate exposure $\varphi_i$ differs from import intensity $\phi_i$ in (20) by the factor of exchange rate pass-through into imported input prices. This can be seen as as a type of normalization since we will assume that $V_t^*$ does not move with 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 $\sigma_e$ is the standard deviation of the log change in the exchange rate. The initial value of the exchange rate is equal to one, that is $e_0 = 0$. We set the standard deviation of the exchange rate to $\sigma_e = 0.06$. Overall, this process closely approximates the Belgian trade-weighted exchange rate in the data. In some of our simulations we use the specific realizations of the exchange rate from the data. For simplicity, we normalize $W_t \equiv V_t^* \equiv 1$, which reflects the

[32] In the data, the number of Belgian firms varies across industries from 22 to 87 at the 10th and 90th percentiles, while in the model-simulated industries it varies less, from 40 to 57 (see Table 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.

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

Table 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 | $\sigma_\omega = 0.034$ | $\mathrm{std}(\Delta s_{it}) = 0.0042$ |
| — Drift | $\mu = -k\sigma_\omega^2/2$ | Distribution stationarity |
| — Reflecting barrier | $\underline{\omega} = 0$ | Normalization |
| St.dev. of $\Delta e_t$ | $\sigma_e = 0.06$ | 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 | $\phi_E, \phi_X \sim Beta$ | 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%] |
| $\mathrm{std}(\Delta S_{it})$ | 0.0042 | 0.0042 | $\mathrm{corr}(S_{it}, \phi_i^B)$ | 0.26 (0.24) [0.00,0.44] | 0.28 |
| $\mathrm{corr}(S_{it}, S_{i,t+12})$ | 0.90 (0.85) [0.69, 0.98] | 0.88 | $\mathrm{corr}\big(S_{it}, \phi_i^X/\phi_i^B\big)$ | 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.

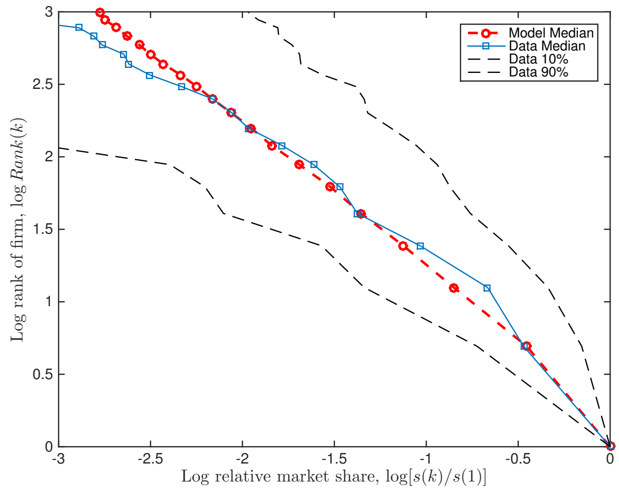



Figure 1: Market share distribution

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 $\Omega_{it}$ are assumed to follow a random growth process:

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

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

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

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 $\Omega_{i0}$ is given by $G_0(\Omega) = 1 - \big(\Omega/e^{\underline{\omega}}\big)^{-k}$ 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 $\Omega_{it}$ stays unchanged at $G_0(\cdot)$, as discussed e.g. in Gabaix (2009).

In our calibration, we set $k = 6.6$ and $\sigma_\omega = 0.034$, which given the other parameters of the model (in particular the demand elasticity $\rho$, see below), allows us to match the market share distribution across firms, and its dynamics. In particular, we match the standard deviation of changes in market shares over time, and the cross-sectional correlation in firm market shares over the 13 years of the data (see Table 5). The largest domestic firm in a typical industry has a market share of about 11%, while

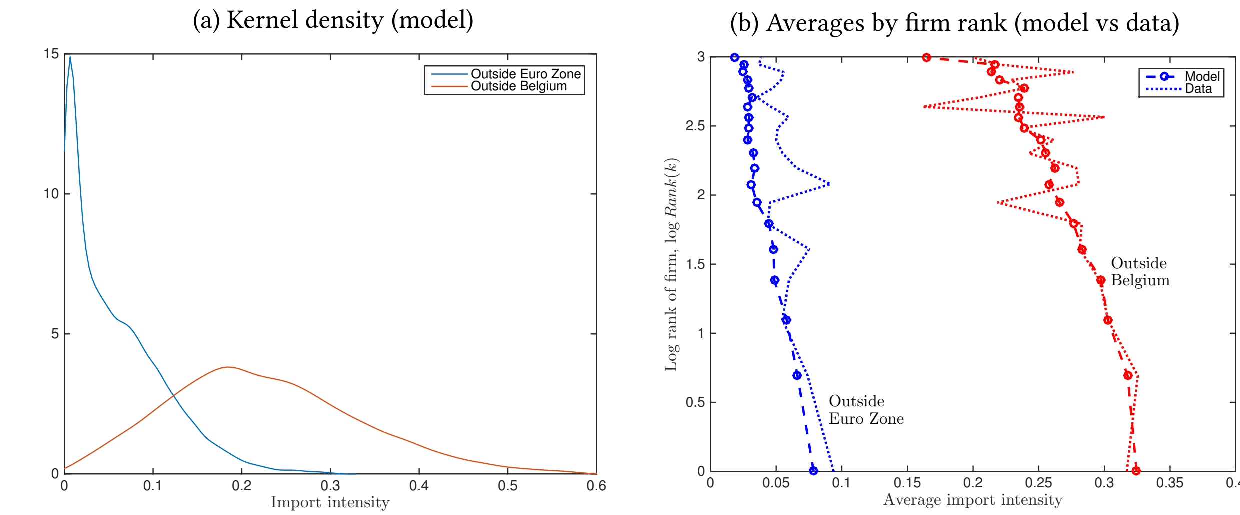



Figure 2: Import intensity

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, $\varphi_i$, across firms. For foreign firms we set $\varphi_i = \chi_E = 0.8$ for European non-Belgian firms and $\varphi_i = \chi_X = 1$ for non-EU firms. Since we do not observe this information directly in the data, this calibration allows us to match the aggregate pass-through into the prices of these two types of firms, as we discuss below. In contrast, the information on the import intensity of the Belgian firms can be read off the data. As shown in Amiti, Itskhoki, and Konings (2014), larger firms are more import intensive than small firms. We make sure to capture this feature of the data in our calibration.[34] 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

[34]In Amiti, Itskhoki, and Konings (2014) we motivated this regularity using a model of selection into importing due to Halpern, Koren, and Szeidl (2011). Here we opt instead in favor of calibrating the import intensity directly as we want to capture the available data as close as possible. This would have been also possible in the model using a very flexible specification of import fixed costs, but then the two approaches become virtually identical.

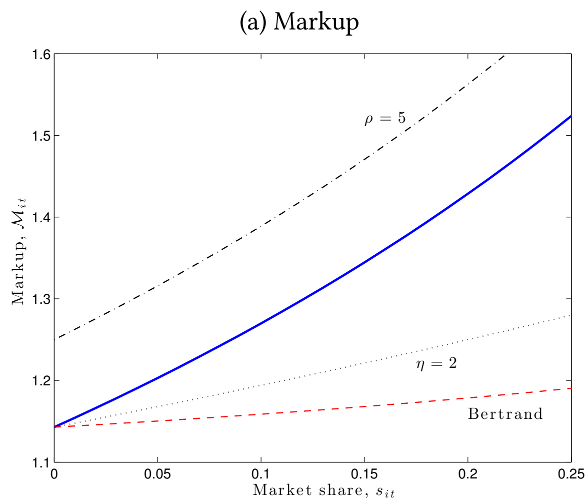



Figure 3: Markups and pass-through in a calibrated model

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, $\varphi_i$, for the Belgian firms is related to their import intensities according to:

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

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

This specifies the distribution of costs for the firms in each period $t$, $\{MC_{it}\}$. Given the costs, we calculate the equilibrium prices $\{P_{it}\}$ according to (13), which involves solving a fixed point using (12) and (14), and then find the equilibrium industry price index $P_{st}$ according to (11). We also calculate the market shares $\{S_{it}\}$ according to (12).[35] 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),

[35] We shut down the heterogeneity in $\xi_{it}$ and focus on productivity $\Omega_{it}$ 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 $\rho$ and $\eta$ in order to generate significant markup variability as in the data (see (15)). 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,[36] 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 $\eta$ or reducing $\rho$ 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 in the empirical Section 3. 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 a sector-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 (6), (7) and (8) of Table A2 in the appendix: the sectoral pass-through

[36] Note 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).

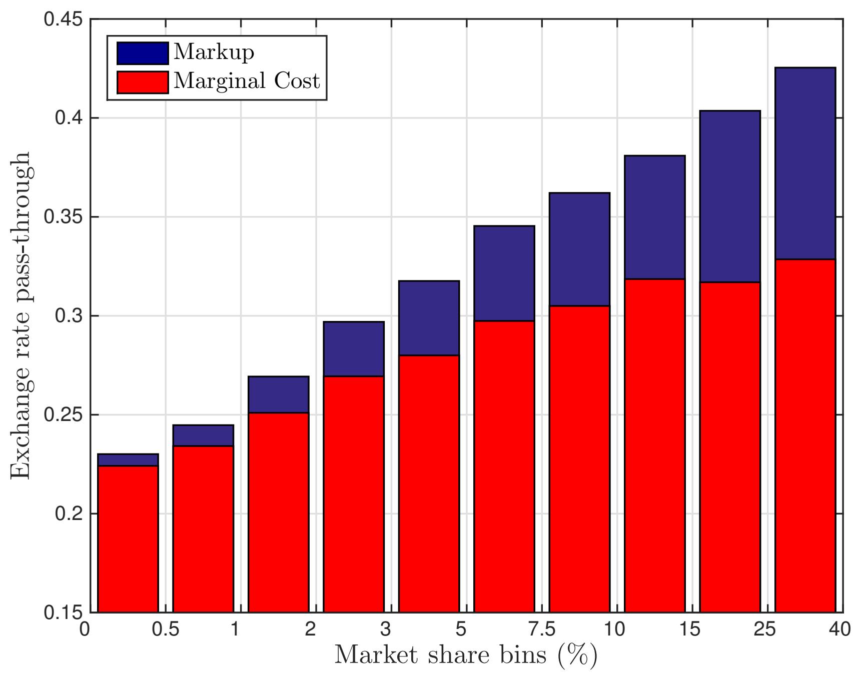



Figure 4: Exchange rate pass-through into marginal costs and prices, by market share bins

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 A3): 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 the model (compare the coefficient in column 4 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 A3 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, maintain 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: $\text{Large}_{it}$ is a dummy for top 20th quintile of firms within each sector according to market shares. Observations are weighted by firm sales (market shares).

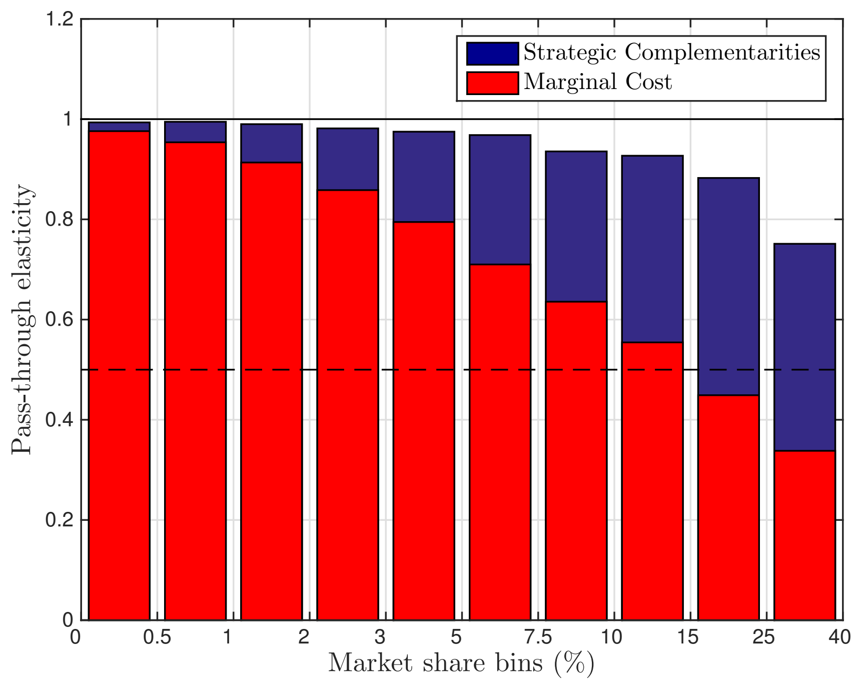



Figure 5: Marginal costs vs strategic complementarities: pass-through into firm prices, by market share bins

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 columns (3) of Tables 1 and 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%.[37]

### 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 A3), 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

[37]The 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 change in markup equation (3), which we rewrite projecting on the exchange rate movement as:

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

Therefore, for markups to move, it is not only necessary to have strong strategic complementarities in price setting (large $\Gamma_{it}$), but also to not be exposed to the same shock as your competitors, i.e. $\frac{\Delta P_{-i,t}}{\Delta e_t} \gg \frac{\Delta mc_{it}}{\Delta e_t}$. This latter condition often fails in the cross section of firms: from Table A3 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.

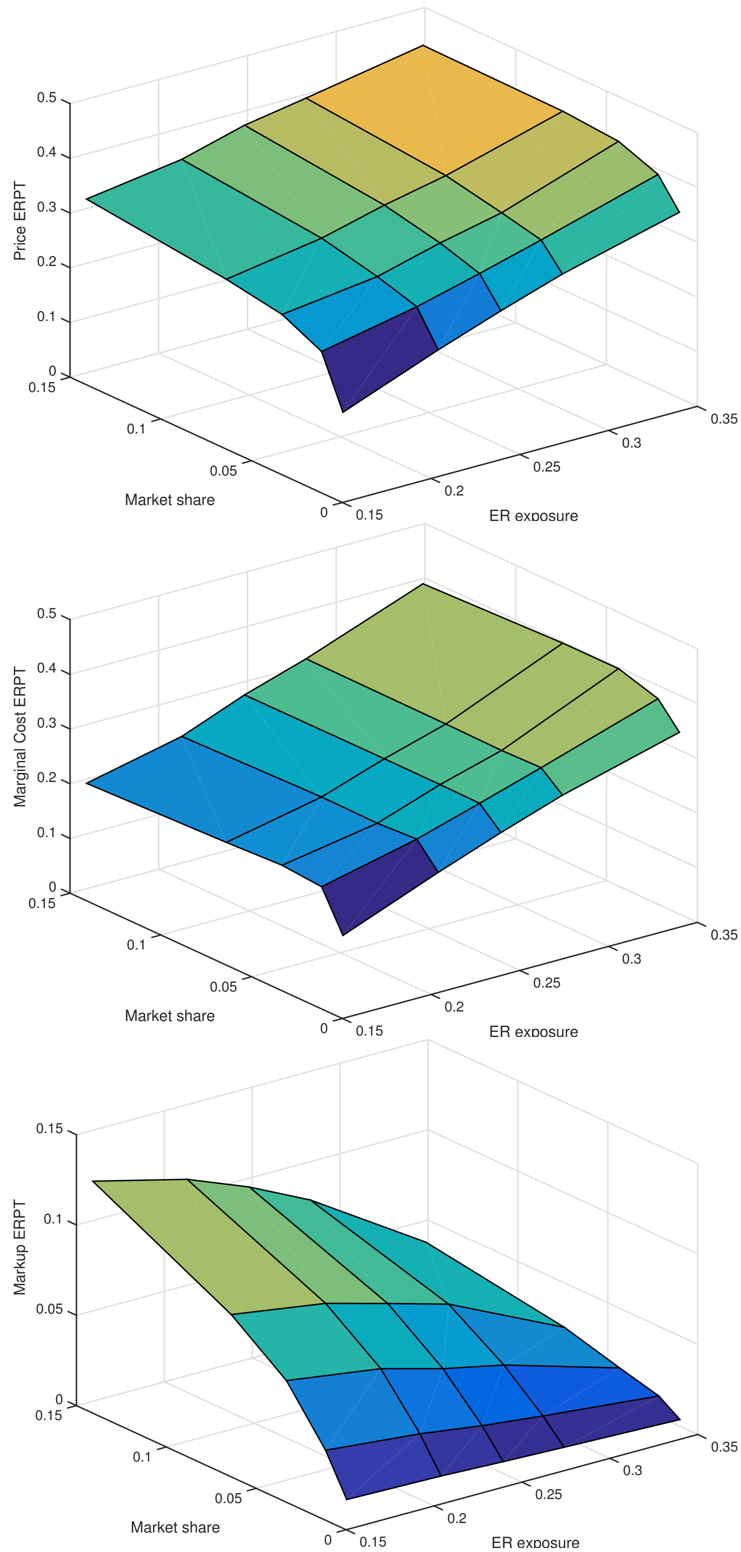
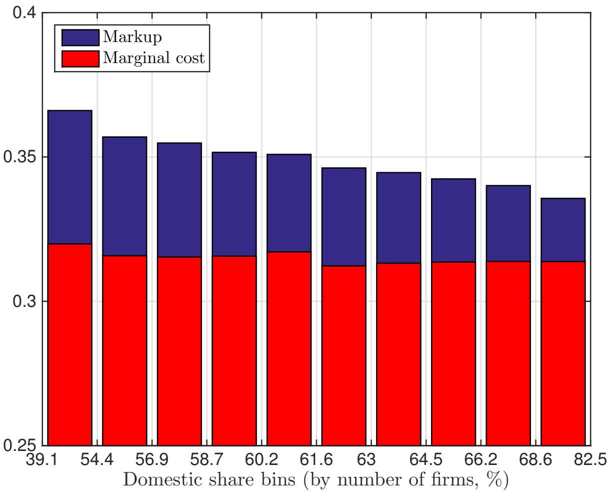


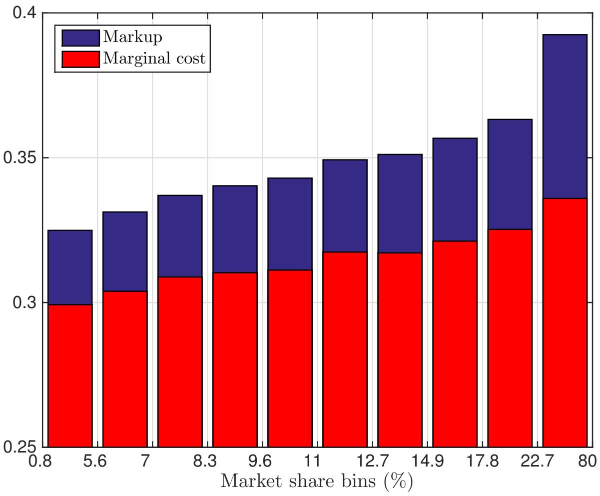

Figure 6: Exchange rate pass-through into firm markup

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 $\varphi_i$

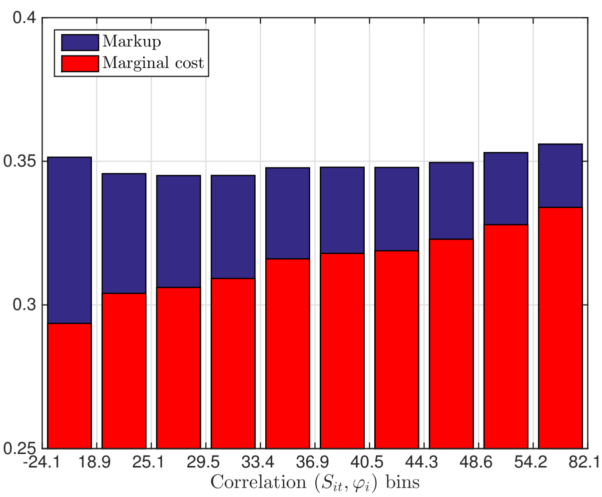



Figure 7: Heterogeneous response across sectors

Note:

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

First, in panel (a) of Figure 7 we explore the difference across sectors 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.[38] 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 sectors, 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 sectors 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-thrids 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 sectors 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 sectors 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 sectors is interesting because it allows us to compare sectors where large firms are heavily exposed to exchange rates directly versus sectors 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 sectors. This however masks a lot of offsetting heterogeneity. Indeed, in sectors 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 circumstance are different in the sectors with little correlation between market shares and import intensity. There, the largest firms are not exchange rate exposed, which limits the pass-through

[38] Strictly speaking, in this exercise we rank sectors 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, sectors 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 sectors); 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 sectors we should expect to have greater exchange rate pass-through into the sectoral price of the domestic products. The direction of the effects across sectors 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 sectors, 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 AB model.

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 the 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, in the 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 to about 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

| | Column (3) | | Column (4) | |
|---|---|---|---|---|
| Dep. var.: | $\Delta mc_{it}$ | $\Delta p_{-i,t}$ | $\Delta mc_{it}$ | $\Delta p_{-i,t}$ |
| $\Delta mc^*_{it}$ | 0.614*** | 0.173*** | 0.597*** | 0.174*** |
| | (0.111) | (0.039) | (0.014) | (0.033) |
| $\Delta e_{st}$ | -0.222 | 0.270** | -0.169 | 0.343** |
| | (0.230) | (0.120) | (0.258) | (0.144) |
| $\Delta mc^*_{-i,t}$ | 0.392*** | 0.468** | 0.379*** | 0.580*** |
| | (0.098) | (0.148) | (0.124) | (0.106) |
| $\Delta p^{EU}_{st}$ | 0.194*** | 0.304*** | 0.215*** | 0.274*** |
| | (0.054) | (0.053) | (0.049) | (0.053) |
| $F$-test | 46.92 | 22.39 | 41.24 | 33.53 |
| [$p$-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

| | Firm-level regressions | | | | Industry-level regressions | | |
|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Dep. var.: | $\Delta p_{it}$ | $\Delta mc_{it}$ | $\Delta mc^*_{it}$ | $\Delta v_{it}$ | $\Delta p_{st}$ | $\Delta p^D_{st}$ | $\Delta p^F_{st}$ |
| $\Delta e_{st}$ | 0.279 | 0.395** | 0.246*** | 0.651*** | 0.489*** | 0.311*** | 0.642*** |
| | (0.187) | (0.187) | (0.040) | (0.122) | (0.061) | (0.085) | (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. $\Delta e_{st}$ is the log change in industry import-weighted exchange rate. $\Delta p_{it}$ is the log change in firm-product price. $\Delta mc_{it}$ is the log change in firm marginal cost. $\Delta mc^*_{it}$ is the log change in the imported component of the firm marginal cost. $\Delta p_{st}$ is the log change in the industry price index. $\Delta p^F_{st}$ ($\Delta p^D_{st}$) is the log change in the industry price index of imported (domestic) goods. Firm-level regressions (columns 1-4) are weighted by lagged domestic value. Industry-level regressions (columns 5-7) are weighted by number of observations within each industry.

# B Additional Quantitative Results

We first describe briefly the properties of the calibrated model, which help better understand the transmission mechanism in the model, and then proceed with our counterfactual—a response to a 10% devaluation of the euro. Table A3 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 150 industries). The last two columns of Table A3 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 A3: 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.

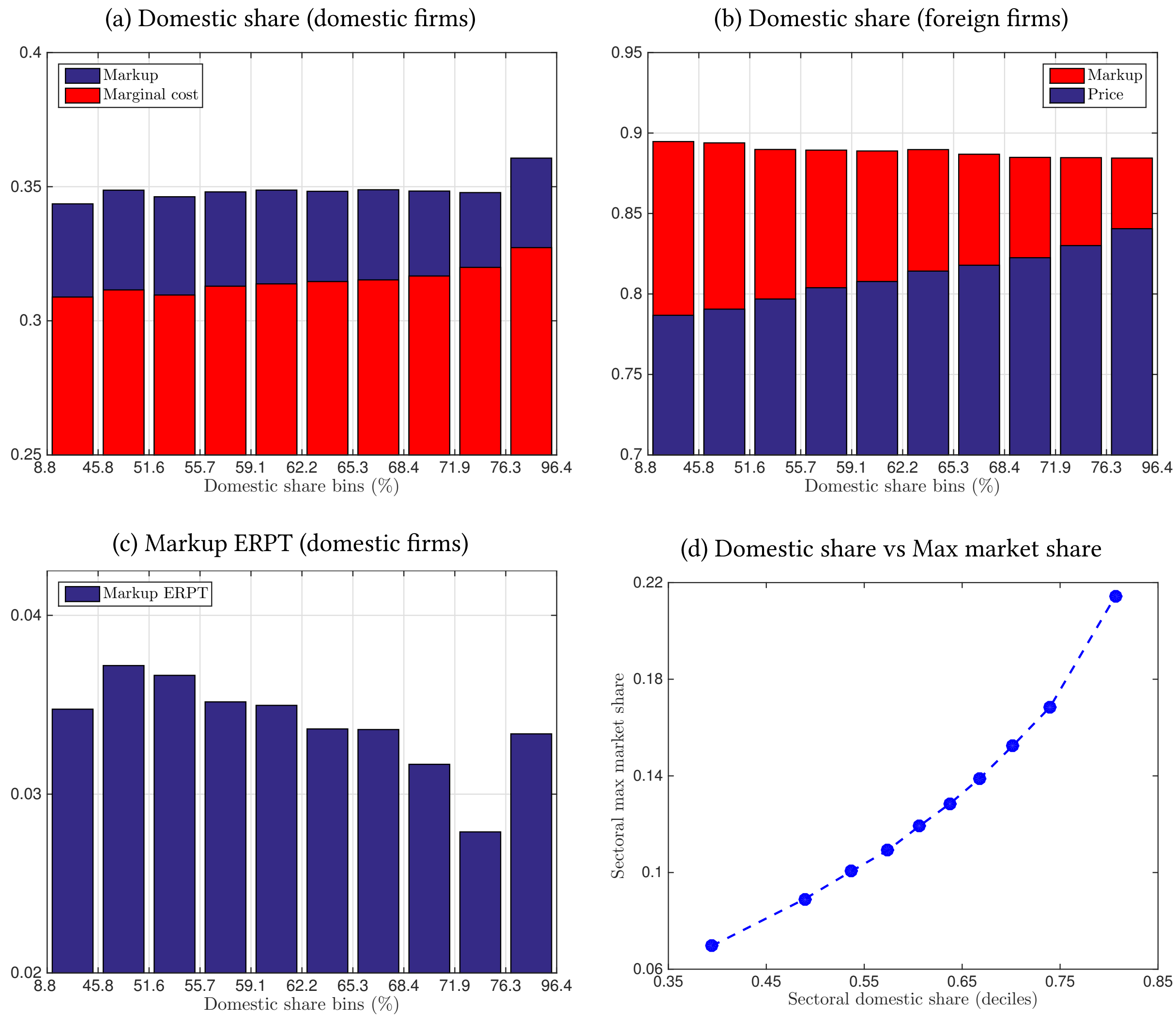



Figure A1: Heterogenous response across sectors: Domestic share

Note:

## C Data Appendix

**Data Sources** We draw on the three main data sources for the period 1995 to 2008. 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 firmï£¡s observation in period $t$ 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 Accounting derivations for Section 2

## D.1 Heterogeneity and Aggregation

We can transform (4):

$$\begin{aligned}
& \Delta p_{it} = \frac{1}{1+\Gamma_{it}}\Delta mc_{it} + \frac{\frac{\Gamma_{-i,t}}{1-\omega_{i,t}}}{1+\Gamma_{it}}\big[(1-\omega_{it})\Delta P_{-i,t} \pm \omega_{i,t}\Delta p_{it}\big] + \varepsilon_{it} \\
\Rightarrow \quad & \left[1+\frac{\frac{\omega_{it}\Gamma_{-i,t}}{1-\omega_{it}}}{1+\Gamma_{it}}\right]\Delta p_{it} = \frac{1}{1+\Gamma_{it}}\Delta mc_{it} + \frac{\Gamma_{-i,t}/(1-\omega_{it})}{1+\Gamma_{it}}\Delta P_t + \varepsilon_{it} \\
\Rightarrow \quad & \Delta p_{it} = \frac{1}{1+\Gamma_{it}+\frac{\omega_{it}\Gamma_{-i,t}}{1-\omega_{it}}}\Delta mc_{it} + \frac{\frac{\Gamma_{-i,t}}{1-\omega_{it}}}{1+\Gamma_{it}+\frac{\omega_{it}\Gamma_{-i,t}}{1-\omega_{it}}}\Delta P_t + \tilde{\varepsilon}_{it}, \qquad \text{(A1)}
\end{aligned}$$

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 (A1) in the following way:

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

We also define

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

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

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

where we assume that $\tilde{\varepsilon}_{it}$ is orthogonal with exchange rate shocks, $\phi_{it} \equiv \operatorname{cov}(\Delta p_{it}, \Delta e_t)/\operatorname{var}(\Delta e_t)$, $\Psi_P = \operatorname{cov}(\Delta P_t, \Delta e_t)/\operatorname{var}(\Delta e_t)$, 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:

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

where $\mathcal{I}_D$ is the subset of domestic firm-products and $\omega^D_{it} = \omega_{it}/\big(\sum_{i\in\mathcal{I}_D}\omega_{it}\big)$, 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:

$$
\begin{aligned}
\Psi^D_{MC} &= \sum_{i\in\mathcal{I}_D} \omega^D_{it}\phi_{it}, \\
\Psi^D_P &= \frac{1}{1-\sum_{i\in\mathcal{I}_D} \frac{\omega^D_{it}\tilde{\Gamma}_{-i,t}(1-S_{Ft})}{1+\tilde{\Gamma}_{it}}} \sum_{i\in\mathcal{I}_D}\left[\frac{\omega^D_{it}\phi_{it}}{1+\tilde{\Gamma}_{it}} + \frac{\omega^D_{it}\tilde{\Gamma}_{-i,t}S_{Ft}}{1+\tilde{\Gamma}_{it}}\Psi^F_P\right], \\
\Psi^D_{\mathcal{M}} &= \Psi^D_P - \Psi^D_{MC}
\end{aligned}
$$

### D.2 Decreasing Returns to Scale (Subsection 2.4)

In this case the log-linearized model contains the following additional equations:

$$
\begin{aligned}
\mathrm{d}mc_{it} &= \mathrm{d}c_{it} + \alpha\mathrm{d}q_{it}, \\
\mathrm{d}q_{it} &= -\tilde{\sigma}_{it}\mathrm{d}p_{it} + \tilde{\sigma}_{-i,t}\mathrm{d}p_{-i,t},
\end{aligned}
$$

where the first equation is log-linearization of (24) and the second equation is log-linearization of demand, where $\tilde{\sigma}_{it}$ and $\tilde{\sigma}_{-i,t}$ are the demand elasticities with respect to own and competitor prices. Combining it with the expression for the change in markup (3), we can solve for the change in price (in parallel with (4)):

$$\mathrm{d}p_{it} = \frac{1}{1+\Gamma_{it}+\alpha\tilde{\sigma}_{it}}\mathrm{d}mc_{it} + \frac{\Gamma_{-i,t}+\alpha\tilde{\sigma}_{-i,t}}{1+\Gamma_{it}+\alpha\tilde{\sigma}_{it}}\mathrm{d}p_{-i,t} + \varepsilon_{it}.$$

Note that decreasing returns act in the same way as additional strategic complementarities ($\alpha > 0$ is the same as larger $\Gamma_{it}$ and $\Gamma_{-i,t}$).

In the special case of Atkeson-Burstein demand, $\Gamma_{-i,t} = \Gamma_{it}$ and both are given by (15), while the elasticities of demand are:

$$\begin{aligned}\tilde{\sigma}_{it} &= \rho(1-S_{it}) + \eta S_{it} = (\rho-\eta)(1-S_{it}) + \eta,\\ \tilde{\sigma}_{-i,t} &= (\rho-\eta)(1-S_{it}).\end{aligned}$$

Therefore, the coefficients in the decomposition are in this case given by:

$$\psi_{it} = \frac{1}{1+\Gamma_{it}+\alpha\tilde{\sigma}_{it}} \qquad \text{and} \qquad \gamma_{it} = \frac{\Gamma_{it}+\alpha\tilde{\sigma}_{-i,t}}{1+\Gamma_{it}+\alpha\tilde{\sigma}_{it}} = 1-(1+\alpha\eta)\psi_{it}.$$

Therefore, the sum of the two coefficients is given by $\psi_{it}+\gamma_{it} = 1-\alpha\eta\psi_{it} \leq 1$.

# 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 $C$:

$$\frac{1}{N}\sum_{i\in\Omega} A_i \Upsilon\left(\frac{NC_i}{\xi_i C}\right) = 1, \tag{A2}$$

where $\Omega$ is the set of products $i$ in the sector with $N = |\Omega|$ denoting the number of goods, and $C_i$ is the consumption of product $i$; $A_i$ and $\xi_i$ denote the two shifters (a quality parameter and a demand parameter, respectively, as will become clear later); $\Upsilon(\cdot)$ is the demand function such that $\Upsilon(\cdot) > 0, \Upsilon'(\cdot) > 0, \Upsilon''(\cdot) < 0$ and $\Upsilon(1) = 1$.

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

$$\frac{1}{|\Omega|}\int_{i\in\Omega} A_i \Upsilon\left(\frac{|\Omega|C_i}{\xi_i C}\right)\mathrm{d}i = 1, \tag{A3}$$

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:

$$C = \left[ N^{-1/\sigma} \sum_{i\in\Omega} \left( A_i \xi_i^{-\frac{\sigma-1}{\sigma}} \right) C_i^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \tag{A4}$$

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

Consumers allocate expenditure $E$ to the purchase of products in the sector, and we assume that $E = \alpha P^{1-\eta}$, where $P$ is the sectoral price index and $\eta$ is the elasticity of substitution across sectors. This assumption corresponds to the case of the CES aggregator of sectoral outputs, when each sector is too small to affect economy-wide price index. Formally, we write the sectoral expenditure (budget) constraint as:

$$\sum_{i\in\Omega} P_i C_i = E. \tag{A5}$$

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

$$\max_{\{C_i\}_{i\in\Omega}} \left\{ C \middle| \text{ s.t. (A2) and (A5)} \right\}. \tag{A6}$$

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

$$C_i = \frac{\xi_i C}{N} \cdot \psi(x_i), \qquad \text{where} \quad x_i \equiv \frac{P_i/\gamma_i}{P/D}. \tag{A7}$$

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

[39]Note that the ideal price index $P$ exists since the demand defined by (A2) 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 (A6) subject to the expenditure constraint (A5).

We show in the appendix that $P$ and $D$ are defined by:[40]

$$\frac{1}{N}\sum_{i\in\Omega} A_i \Upsilon\left(\psi\left(\frac{P_i/\gamma_i}{P/D}\right)\right) = 1, \tag{A8}$$

$$\frac{1}{N}\sum_{i\in\Omega} \frac{\xi_i P_i}{P}\psi\left(\frac{P_i/\gamma_i}{P/D}\right) = 1. \tag{A9}$$

Equation (A8) ensures that (A2) is satisfied given the demand (A7), i.e. that $C$ is indeed attained given the consumption allocation $\{C_i\}$. Equation (A9) ensures that the expenditure constraint (A5) is satisfied given the allocation (A7). Note that condition (A9) simply states that the sum of market shares in the sector equals one, with the market share given by

$$s_i \equiv \frac{P_i C_i}{PC} = \frac{\xi_i P_i}{NP}\psi\left(\frac{P_i/\gamma_i}{P/D}\right), \tag{A10}$$

where we substituted in for $C_i$ from the demand equation (A7). In addition, we introduce the demand elasticity as a characteristic of the slope of the demand curve $\psi(\cdot)$:

$$\sigma_i \equiv \sigma(x_i) = -\frac{\mathrm{d}\log\psi(x_i)}{\mathrm{d}\log x_i}, \tag{A11}$$

where $x_i$ is the effective price of the firm as defined in (A7). Outside the CES case, the demand elasticity is non-constant and is a function of the effective price of the firm. We further show in the appendix the following results for the effects of changes in the individual firm prices on aggregate variables $P$ and $D$:

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

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

Given this, we can calculate the full elasticity of demand, which takes into account the effects of $P_i$ on

[40] In the limiting case of CES, we have $\Upsilon(z) = z^{\frac{\sigma-1}{\sigma}}$, and hence $\Upsilon'(z) = \frac{\sigma-1}{\sigma}z^{-1/\sigma}$ and $\psi(x) = \left(\frac{\sigma}{\sigma-1}x\right)^{-\sigma}$. Substituting this into (A8)–(A9) and taking their ratio immediately pins down the value of $D$. We have, $D \equiv (\sigma-1)/\sigma$ and is independent of $\{P_j\}$ and other parameters, and hence this auxiliary variable is indeed redundant in the CES case. Given this $D$, the price index can be recovered from either condition in its usual form:

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

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.

$P$ and $D$. Substituting $C = E/P = \alpha P^{-\eta}$ into (A7), we have:

$$\Sigma_i \equiv -\frac{\mathrm{d}\log C_i}{\mathrm{d}\log P_i} = \eta s_i + \sigma_i\left(1 - \frac{s_i\sigma_i}{\sum_{j\in\Omega} s_j\sigma_j}\right), \tag{A12}$$

where $\sigma_i$ is given in (A11). 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:

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

The two analytically tractable cases are: (1) monopolistic competition with $s_i \to 0$ for all $i \in \Omega$, and (2) CES demand with $\sigma_i \equiv \sigma$ for all $i$. Indeed in those two cases, the formula in (A12) 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:

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

and is increasing in the market share $s_i$. Therefore, for that case we can write:[41]

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

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

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

where $\Gamma_i$ is defined in the same way, but now does not depend on $s_i$, but rather depends on the relative effective price of the firm $x_i$, as we discuss further below. Also note that $\mathrm{d}\log(P/D)$ is different from $\mathrm{d}\log P$, and $\mathrm{d}\log D$ is not necessarily orthogonal with $\mathrm{d}\log P$. Nonetheless, if variation in $P_i$ is dominated by firm-idiosyncratic shocks, then $\mathrm{d}\log D$ would indeed be close to orthogonal to $\mathrm{d}\log P$, 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

[41] An alternative expression is

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

where $\Gamma_i' \equiv (1-s_i)\Gamma_i$ and $P_{-i}$ is the competitor price index such that $P = \left[(\xi_i\gamma_i^\sigma)P_i^{1-\sigma} + (1-\xi_i\gamma_i^\sigma)P_{-i}^{1-\sigma}\right]^{1/(1-\sigma)}$.

of the translog demand, see Feenstra ??). Second, Kimball demand nests CES as a special case. Third, Kimball demand (given in (A7)) 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 (A8)–(A9).[42] 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:

$$\psi(x_i) = \left[1 - \bar{\varepsilon} \log\left(\frac{\bar{\sigma}}{\bar{\sigma}-1} x_i\right)\right]^{\bar{\sigma}/\bar{\varepsilon}}, \tag{A13}$$

where $x_i$ is the effective price of the firm, as defined in (A7). 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 (A13) 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 (A13).

For concreteness, we specialize to the case of the monopolistic competition ($N \to \infty$ and $s_i \to 0$ for all $i \in \Omega$), and briefly discuss the cross-sectional properties of this demand. The demand elasticity and super-elasticity functions are given by:[43]

$$\sigma_i \equiv \sigma(x_i) = -\frac{\partial \log \psi(x_i)}{\partial \log P_i} = \frac{\bar{\sigma}}{1 - \bar{\varepsilon} \log\left(\frac{\bar{\sigma}}{\bar{\sigma}-1} x_i\right)}, \tag{A14}$$

$$\varepsilon_i \equiv \varepsilon(x_i) = \frac{\partial \log \sigma(x_i)}{\partial \log x_i} = \frac{\bar{\varepsilon}}{1 - \bar{\varepsilon} \log\left(\frac{\bar{\sigma}}{\bar{\sigma}-1} x_i\right)}. \tag{A15}$$

Under this demand, the optimal markup is given by:

$$\mathcal{M}_i \equiv \frac{\sigma(x_i)}{\sigma(x_i) - 1} = \frac{\frac{\bar{\sigma}}{\bar{\sigma}-1}}{1 + \frac{\bar{\varepsilon}}{\bar{\sigma}-1} \log\left(\frac{\bar{\sigma}}{\bar{\sigma}-1} x_i\right)}, \tag{A16}$$

[42] These two auxiliary variables corresponds to the the Lagrange multipliers in the consumer optimization, corresponding to constraints (A5) and (A2) respectively (see the appendix).

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

and therefore the elasticity of markup is:

$$\Gamma_i \equiv \Gamma(x_i) = -\frac{\partial \log \mathcal{M}_i}{\partial \log P_i} = \frac{\varepsilon(x_i)}{\sigma(x_i)-1} = \frac{\frac{\bar{\varepsilon}}{\bar{\sigma}-1}}{1+\frac{\bar{\varepsilon}}{\bar{\sigma}-1}\log\left(\frac{\bar{\sigma}}{\bar{\sigma}-1}x_i\right)}. \tag{A17}$$

Therefore, both markups $\mathcal{M}_i$ and markup elasticity $\Gamma_i$ are decreasing in the effective relative price $x_i$, and hence the idiosyncratic pass-through rate $\Psi_i \equiv 1/(1+\Gamma_i)$ is increasing in $x_i$.

The Klenow-Willis demand with $\bar{\varepsilon} > 0$ has a few notable properties, whereas the limit of $\bar{\varepsilon} \to 0$ correspond to the CES demand. First, it is log-concave (as can be immediately observed from (A13)), 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 be 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 (A8)–(A9). 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:

$$P_i = \underline{P} \cdot W\left(\exp\left\{\frac{\bar{\sigma}}{\bar{\varepsilon}}\frac{MC_i}{\underline{P}}\right\}\right), \qquad \text{where} \quad \underline{P} \equiv \frac{\bar{\sigma}-1}{\bar{\sigma}}e^{-\frac{\bar{\sigma}-1}{\bar{\varepsilon}}} \cdot \frac{P}{D} \tag{A18}$$

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

There exists no closed-form solution for $P$ and $D$ in general. We provide the implicit equations defining $P$ and $D$—the counterparts of (A8)–(A9)—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 $\Upsilon(z_i) = 1 + (\sigma-1)\big(1-\exp\{(1-z_i)/\sigma\}\big)$. Using this expression, we can simplify and manipulate the sector equilibrium conditions (A8)–(A9) to yield the following results:

$$P = \bar{P} \cdot [1-\bar{\sigma}T], \tag{A19}$$

$$D = \frac{\bar{\sigma}-1}{\bar{\sigma}}\frac{P}{\bar{P}} = \frac{\bar{\sigma}-1}{\bar{\sigma}}\big(1-\bar{\sigma}T\big), \tag{A20}$$

where $\bar{P} \equiv \frac{1}{|\Omega|}\int_{i\in\Omega} P_i \mathrm{d}i$ is the average price and $T \equiv \frac{1}{|\Omega|}\int_{i\in\Omega}\frac{P_i}{\bar{P}}\log\frac{P_i}{\bar{P}}\mathrm{d}i$ 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 $\lambda$ and $\mu$ the Lagrange multipliers on demand aggregator (A2) and the expenditure constraint (A5) respectively. The the first order conditions for $C$ and $C_j$ are respectively:

$$\begin{aligned} 1 &= \lambda \sum_{j\in\Omega} A_j \Upsilon'\left(\frac{NC_j}{\xi_j C}\right)\frac{C_j}{\xi_j C^2}, \\ \mu P_j &= \lambda A_j \Upsilon'\left(\frac{NC_j}{\xi_j C}\right)\frac{1}{\xi_j C}. \end{aligned}$$

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:

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

Given $P = E/C$, $P$ and $D$ are determined from the two constraints on the problem (A2) and (A5), 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 (A8) and (A9). This fully characterizes the solution to the consumer's problem and hence the demand schedule. Note that equation (A9) 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 (A7) for $C_j$ and expressed $P$ out using (A9). 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:

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

### F.3 Large firms

Denote by $Z \equiv D/P$ and take a full log differential of (A8)–(A9) with respect to $(P_i, P, Z)$ for some $i \in \Omega$ and holding $P_j$ for all $j \neq i$ constant:

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

where in manipulating the differential of (A8) 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:

$$\begin{aligned}\frac{\mathrm{d}\log Z}{\mathrm{d}\log P_i} &= -\frac{D\frac{\xi_i P_i}{NP}\psi\left(\frac{ZP_i}{\gamma_i}\right)\tilde{\sigma}_i}{\sum_{j\in\Omega} D\frac{\xi_j P_j}{NP}\psi\left(\frac{ZP_j}{\gamma_j}\right)\tilde{\sigma}_j} = -\frac{s_i\tilde{\sigma}_i}{\sum_{j\in\Omega} s_j\tilde{\sigma}_j},\\ \frac{\mathrm{d}\log P}{\mathrm{d}\log P_i} &= s_i\big(1-\tilde{\sigma}_i\big) - \frac{\mathrm{d}\log Z}{\mathrm{d}\log P_i}\cdot\sum_{j\in\Omega} s_j\tilde{\sigma}_j = s_i.\end{aligned}$$

Profit maximization:

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

where

$$C_j = \frac{\xi_j E}{NP^\eta}\cdot\psi\left(ZP_j/\gamma_j\right).$$

FOC:

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

where we have:

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

and therefore price-setting satisfies:

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

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

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

We need to derive:

$$\Gamma_j \equiv -\frac{\mathrm{d}\log \mathcal{M}_j}{\mathrm{d}\log P_j} =,$$
$$\Gamma_P \equiv \frac{\mathrm{d}\log \mathcal{M}_j}{\mathrm{d}\log P} =,$$
$$\Gamma_D \equiv \frac{\mathrm{d}\log \mathcal{M}_j}{\mathrm{d}\log D} =$$

### F.4 Klenow and Willis demand

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

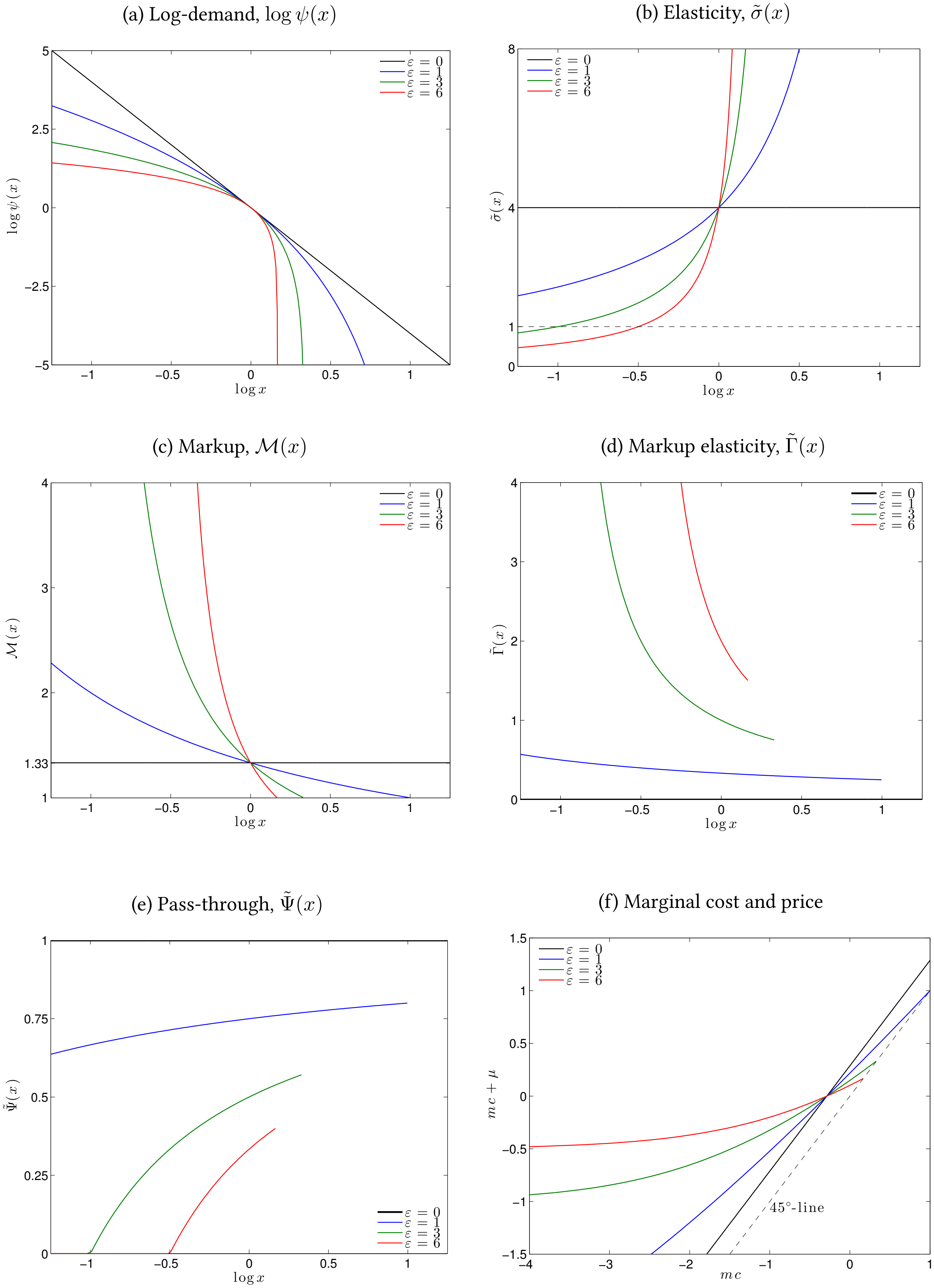



Figure A2: Klenow-Willis specification of Kimball demand

### 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 $\Gamma(1, y) = \int_y^\infty e^{-t}\mathrm{d}t = e^{-y}$. Therefore, in this case, we have:

$$
\begin{aligned}
y_i = \psi(x_i) = 1 - \sigma \log\left(\frac{\sigma}{\sigma-1}x_i\right), \qquad x_i = \frac{P_i/\gamma_i}{P/D},\\
\Upsilon(y_i) = 1 + (\sigma-1)\Big[1 - \exp\big\{(1-y_i)/\sigma\big\}\Big]
\end{aligned}
$$

and thus

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

Substituting this into (A8)–(A9), we have (in the monopolistic competition limit):

$$
\begin{aligned}
\frac{\sigma}{|\Omega|}\int_{i\in\Omega} A_i\left(1 - \frac{P_i/\gamma_i}{P/D}\right)\mathrm{d}i = 1,\\
\frac{1}{|\Omega|}\int_{i\in\Omega}\frac{\xi_i P_i}{P}\left[1 - \sigma\log\left(\frac{\sigma}{\sigma-1}\frac{P_i/\gamma_i}{P/D}\right)\right]\mathrm{d}i = 1.
\end{aligned}
$$

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:

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

It is natural to impose the following normalization: $\mathbb{E}\{A_i\} = \frac{1}{|\Omega|}\int_{i\in\Omega} A_i\mathrm{d}i = 1$. 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

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

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