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

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Abstract

How do international shocks affect domestic prices? In this paper, we estimate the effect of exchange rate changes on the prices that firms charge in their domestic market. These prices can be affected directly through the marginal cost channel for firms that import their intermediate inputs and indirectly through the markup channel as firms respond to changes in their competitors’ prices. The contribution of this paper is to examine, theoretically and empirically, the impact of exchange rate shocks on domestic prices, isolating the role of both the marginal cost and the markup channels, while taking explicit account that all prices in the economy are set simultaneously. We find that strategic complementarities play an important role in transmitting international shocks into domestic prices. We show that about a half of exchange rate movements is transmitted into the average domestic prices, with the marginal cost and the markup channels playing nearly equal roles. Firm heterogeneity plays a central role in this transmission mechanism, with small firms reacting mostly through the marginal cost channel and large firms adjusting more through the markup channel. Large firms exhibit substantially stronger strategic complementarities than small firms. Lastly, we provide a calibrated model of variable markups able to match a number of salient features of our data, and then use it to undertake a number of counterfactuals.

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1 Introduction

How do international shocks affect domestic prices? Although this question is at the heart of international economics the answers have remained unclear. In this paper, we estimate the effect of exchange rate changes on the prices that firms charge in their domestic market. These prices can be affected directly through the marginal cost channel for firms that import their intermediate inputs and indirectly through the markup channel as firms respond to changes in their competitors’ prices. The contribution of this paper is to examine, theoretically and empirically, the impact of exchange rate shocks on domestic prices, isolating the role of both the marginal cost and markup channels, while taking explicit account that all prices in the economy are set simultaneously. We find that strategic complementarities, as well as firm heterogeneity, play an important role in transmitting international shocks into prices of domestic goods.

There have been two major challenges that have made it difficult for researchers to address this question. The first challenge is being able to find data that allows you to measure firm-product-level domestic prices, marginal costs and markups. We use highly disaggregated Belgium firm-product level data combined with trade data to proxy for all these variables. One distinguishing feature of this data set is the availability of information on imported inputs at the firm level, making it possible to measure the component of marginal costs that is most directly affected by exchange rate movements. In addition, we proxy for the markup channel by constructing a comprehensive competitors price index at the industry level. With the matched industrial and trade data at the firm-product level, we can include all components of the competitors’ price index - price changes of both domestic and foreign competitors. There are few data sets that provide all these necessary ingredients.

To estimate the size of the strategic complementarities, we need to take into account that all prices in the economy are set simultaneously. We use instrumental variables estimation, instrumenting for the competitor’s price index with their marginal costs of importing inputs and sector-level exchange rates.

The second challenge is how to map the firm-product level results into movements in the aggregate price indexes. An important policy question in international macroeconomics is how much exchange rate movements matter for inflation. We develop a general equilibrium model, where we can construct counterfactuals using the firm-level results as inputs into the calibration.

Our results show that half of exchange rate movements are transmitted into domestic prices. On average, the contributions of the marginal cost and markup channels to price changes are roughly equal. We show that firm heterogeneity matters for these results. Small firms react to shocks relatively more through the marginal cost channel and large firms adjust more through the markup channel. Large firms have much stronger strategic complementarities than small firms.

There is a dearth of evidence on the effects of exchange rates on domestic prices and its components. Previous studies have either relied on aggregate industry level data (Goldberg and Campa 2010, Auer and Schoenle 2013). The more disaggregated empirical studies that use product-level data (Cao, Dong, and Tomlin 2012, Pennings 2012) have not been able to match the product level price movements with firm characteristics. These studies have generally found very low pass-through rates into domes-
tic prices. In contrast, we show that aggregate pass-through is much higher than previous studies have found, once you weight the observations by domestic sales of the firms. Without data on firm characteristics, you cannot distinguish between the marginal cost channel or strategic complementarities. The lack of data on domestic product prices at the firm-level matched with international data has meant that researchers have turned to looking at pass-through into import or export prices. Gopinath and Itskhoki (2011) regressed import prices on trade-weighted sector level exchange rates to try to identify the strategic complementarity channel, but the sector-level exchange rate can affect firm’s prices via its marginal costs if it imports its intermediate inputs, and/or through the markup channel if firms have variable markups and respond to changes in their competitors price index. Amiti, Konings, and Itskhoki (2014) decomposed the pass-through of exchange rates to export prices into the markup and marginal cost channels, but in that study the industry price index was held constant and the focus was on export prices. In this paper, we explicitly account for changes in the industry price index to estimate the size of the firms’ strategic complementarities in setting domestic prices. With firm-level data matched to trade data, we can estimate the relative magnitude of these channels.

Another closely related literature is the research on the pass-through of tariff liberalization on domestic prices. Although this literature is limited to studying developing countries because import tariffs have been low in developed countries for a long time, the mechanisms for which tariffs affect prices are analogous to exchange rate shocks. De Loecker, Goldberg, Khandelwal, and Pavcnik (2012) find that falls in output tariffs have procompetitive effects in India and Edmond, Midrigan, and Xu (2012) find procompetitive effects in Taiwan. Both of these studies have detailed firm-product domestic level data but neither has matched import data, thus making it difficult to measure the marginal cost component that is most directly affected by the international shock. As such, each has taken a distinct path in identifying markups, with De Loecker, Goldberg, Khandelwal, and Pavcnik (2012) using production function estimation to back out markups but not imposing any demand or market structure, which prevents them from performing any counterfactuals. In contrast, Edmond, Midrigan, and Xu (2012) rely on the structure of the Atkeson and Burstein (2008) model to back out the distribution of markups. Our paper falls in the middle of these two, where we rely more on the actual data to infer markup distributions and our industry equilibrium model enables us to perform counterfactuals, and thus make statements about the aggregate effects of international shocks on domestic prices.

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 develops the general equilibrium model and performs counterfactuals. Section 5 concludes.
2 Theoretical Framework

In order to quantify 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). In the following Subsection 2.1, we discuss a popular model of variable markups adopted by Krugman (1987) and Atkeson and Burstein (2008), which both provides an example that fits our more general accounting framework and which we later use for our quantitative analysis in Section 4. We use this general accounting framework to motivate our empirical specifications in Section 3.

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

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

where $p_{it}$ is the log price of the firm and $mc_{it}$ is the log marginal cost of the firm. We further denote by $\Gamma_{it}$ and $\Gamma_{-i,t}$ the markup elasticity with respect to the own price of the firm and the price of its competitors:

$$
\Gamma_{it} \equiv -\frac{\partial \mu_{it}}{\partial p_{it}} \quad \text{and} \quad \Gamma_{-i,t} \equiv \frac{\partial \mu_{it}}{\partial P_{-i,t}},
$$

where $P_{-i,t}$ is a price index of firm’s competitors within an industry, which we define formally below. We expect both $\Gamma_{it}$ and $\Gamma_{-i,t}$ to be positive, reflecting that firms tend to increase their markups when they gain competitiveness as a result of either increase in competitors prices or a reduction in own price. Furthermore, many models of variable markups, including the one adopted below, 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.

Using the definitions in (2), the approximation for the change in markup of the firm can be written as follows:

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

where $\tilde{\varepsilon}_{it}$ is a residual shock to markup, directly unrelated to changes in prices of the firm and its competitors. Combining this approximation with the markup identity (1) in changes, we can express the change in firm’s price as:

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

where $\varepsilon_{it} \equiv \tilde{\varepsilon}_{it}/(1 + \Gamma_{it})$. [Maybe define $\Delta P_{-i,t}$, $\Delta P_{t}$, $S_{it}$ and industry/sector...]

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

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

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. The two coefficients are generally related. In particular, in models where \( \Gamma_{-i,t} = \Gamma_{it} \), the two coefficients sum to one,

\[
\psi_{it} + \gamma_{it} = 1, \tag{6}
\]
a restriction that we will be able to evaluate in the data.

The magnitudes of the two coefficients, \( \psi_{it} \) 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). Denote with \( \varphi_{it} \) the elasticity of the marginal cost of the firm and with \( \Psi_{-i,t} \) the elasticity of the competitors prices of the firm, both with respect to the exchange rate. We sometimes refer to \( \varphi_{it} \) as the exchange rate exposure of the firm. For the sake of this example, we assume that other changes in markup \( \varepsilon_{it} \) are unrelated to changes in the exchange rate, and therefore we can express the full elasticity of the firm’s price to the exchange rate shock as:

\[
\Psi_{it} = \psi_{it} \varphi_{it} + \gamma_{it} \Psi_{-i,t}, \tag{7}
\]
where the first term is the marginal cost channel and the second term is the markup (or strategic complementarities) channel.

Estimation of equation (4) is associated with a number of identification challenges. First of all, it requires obtaining direct measures of firm’s marginal costs and competitors prices. Good firm-level measures of marginal costs are notoriously hard to come by, so are the measures of competitors prices which take into account 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 a price competition game. Therefore, estimating (4) requires finding a valid instrument for the competitors prices variable. We also need to make sure that the admissible 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 in (4) by subindex \( i \), needs to be taken care of. We address all of these issues in Section 3, and in what follows here we briefly discuss the implications of the cross-sectional heterogeneity.

Indeed, we expect pass-through and strategic complementarity elasticities \( \psi_{it} \) and \( \gamma_{it} \) to vary across firms within sectors, as will be reflected in our estimation and quantitative analysis in Sections 3 and 4.

[Add aggregation and example...]

\[
\Delta P_t = \frac{1}{1 - \sum_i S_{it} \gamma_{it}} \sum_i S_{it} \psi_{it} \Delta mc_{it},
\]

\(^{1}\)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.
where $S_{it}$ is the firm’s within-industry market share.

We next outline one specific model of demand and market structure, which gives rise to the markup and price decompositions above, and which we later use in our quantitative analysis of Section 4.

### 2.1 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, which 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 e.g. 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. Specifically, consumers (or customers) are assumed to have a CES demand aggregator over a continuum of sectors, while each sector’s output is a CES aggregator over a finite number of products, each produced by a separate firm. The elasticity of substitution across sectors is $\eta \geq 1$, while the elasticity of substitution across products within a sectors is $\rho \geq \eta$. Under these circumstances, the demand faced by a firm is:

$$Q_{it} = \xi_{it}D_{t}P_{it}^{\rho - \eta}P_{t}^{\eta},$$

where $\xi_{it}$ is the product-specific preference shock, $D_{t}$ is the aggregate demand shifter, $P_{it}$ is the firm’s price and $P_{t}$ is the sectoral price index, and we omitted the sectoral identifier for brevity.

The price index is defined according to:

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

where $N$ is the number of firms in the sector. The firms are large enough to affect the price index, but not large enough to affect the economy-wide aggregates, in particular $D_{t}$. Further, we can write the firm’s market share as:

$$S_{it} \equiv \frac{P_{it}Q_{it}}{\sum_{j=1}^{N} P_{jt}Q_{jt}} = \xi_{it} \left( \frac{P_{it}}{P_{t}} \right)^{1 - \rho}.$$
We assume that firms have constant marginal costs $MC_{it}$. As in much of the quantitative literature following Atkeson and Burstein (2008), for example Edmond, Midrigan, and Xu (2012), we assume oligopolistic competition in quantities (i.e., Cournot-Nash equilibrium). While the qualitative implications are the same as in the model with price competition (i.e., Bertrand-Nash), quantitatively Cournot competition allows for greater variation in markups across firms, which better matches the data, as we discuss further in Section 4. Under this market structure, the firms set prices according to the following markup rule:

$$P_{it} = \mathcal{M}_{it}MC_{it},$$  \hspace{1cm} \text{where} \hspace{1cm} \mathcal{M}_{it} \equiv \frac{\sigma_{it}}{\sigma_{it} - 1} \tag{11}$$

and

$$\sigma_{it} = \left(\frac{1}{\eta} S_{it} + \frac{1}{\rho} (1 - S_{it})\right)^{-1}. \tag{12}$$

Substituting equation (12) into (11), we see that the markup is an increasing function of the firm’s market share:

$$\mathcal{M}_{it} = \frac{1}{1 - 1/\sigma_{it}} = \frac{1}{1 - \frac{1}{\rho} - \frac{1}{\eta} S_{it}},$$

since our parameter restriction on $\rho$ and $\eta$ is equivalent to $1/\rho < 1/\eta \leq 1$.

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

$$\Gamma_{it} = -\frac{\partial \log \mathcal{M}_{it}}{\partial \log P_{it}} = \frac{(\rho - \eta)(\rho - 1)\sigma_{it} S_{it}(1 - S_{it})}{\eta \rho (\sigma_{it} - 1)}, \tag{13}$$

$$\Gamma_{-i,t} = \frac{\partial \log \mathcal{M}_{it}}{\partial \log P_{-i,t}} = \Gamma_{it}, \tag{14}$$

where $P_{-i,t}$ is the competitor price index which satisfies:

$$P_{it} = \left[\xi_{it} P_{-i,t}^{1-\rho} + (1 - \xi_{it}) P_{-i,t}^{1-\rho}\right]^{\frac{1}{1-\rho}} \quad \text{and} \quad P_{-i,t} = \left[\sum_{j \neq i} \frac{\xi_{jt}}{1 - \xi_{it}} P_{jt}^{1-\rho}\right]^{\frac{1}{1-\rho}}. \tag{15}$$

Note that in this model, the effect of the price of any of the competitors of the firm on the firm’s markup is fully mediated by its effect on the competitor price index. Furthermore, the own and the competitor price elasticities are equal, $\Gamma_{-i,t} = \Gamma_{it}$, and therefore the parameter restriction (6) is satisfied.

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

$$\frac{\partial \log \Gamma_{it}}{\partial \log S_{it}} = \frac{1 - 2S_{it}}{1 - S_{it}} + \frac{\Gamma_{it}}{\rho - 1}. \tag{16}$$

Therefore, $S_{it} < 1/2$ is a sufficient (but not necessary) condition for markup elasticity $\Gamma_{it}$ to increase with market share. In our data, market shares in excess of 50% are rare. Further, note from equation (13) 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

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5The only difference in setting prices under Bertrand competition is that $\sigma_{it} = \eta S_{it} + \rho (1 - S_{it})$, as opposed to (12), and all the qualitative results remain unchanged. Derivations for both cases are provided in Appendix C.
hence have incomplete pass-through of idiosyncratic shocks and positive strategic complementarities in price setting vis-à-vis their competitors, $\psi_{it}, \gamma_{it} \in (0, 1)$.

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

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

that is the source of the residual in (4) are the demand (preference, or quality) shocks.

### 2.2 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. This structure arises under constant returns to scale in production technology upon paying a fixed cost, and is standard in both theoretical and quantitative literature. Under these circumstances, the marginal cost of a firm equals the average variable cost, and hence can be measured as a ratio of the total variable cost to quantity produced:

$$MC_{it} = AVC_{it} = \frac{TVC_{it}}{Y_{it}}, \quad (16)$$

where $TVC_{it} = TC_{it} - F_{it}$. Garcia-Marin and Voigtländer (2013) provide empirical evidence that this measure of average variable costs provide a reasonable, albeit noisy, approximation to the marginal cost in the data.

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

$$MC_{it} = W_{it}^{1 - \phi_{it}} (V_{it}^* E_t)^{\phi_{it}} \tilde{\Omega}_{it}, \quad (17)$$

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), $E_t$ 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 $V_{it} = V_{it}^* E_t$ the domestic-currency cost index of the imported inputs, which we assume comes from a CES aggregator of individual imported varieties:

$$V_{it} = \left[ \int_{m \in M_{it}} V_{int}^\zeta \, dm \right]^{1/\zeta}, \quad (18)$$

where $m$ indexes imported varieties, $V_{int}$ 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, \( \{V_{int}\}_{m \in M_{it}} \), along with the respective expenditure shares. This allows us to construct a precise measure of a component of the marginal cost, as we discuss in more detail below. The same is true for the domestic component of the marginal cost, \( W_{it} \), but our measures of firm-specific wages and domestic input costs are less precise, and hence we do not focus on this component in our discussion. In Amiti, Konings, and Itskhoki (2014), we provided a microfoundation for the marginal cost in (17)–(18), 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 (17), we have:

\[
\Delta m_{it} = (1 - \phi_{it}) \Delta w_{it} + \phi_{it} \Delta v_{it} + (v_{i,t-1} - w_{i,t-1}) \Delta \phi_{it} - \Delta \tilde{\omega}_{it},
\]

(19)

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

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

(20)

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

Finally, in the quantitative analysis of Section 4, we combine all the idiosyncratic components of the firm’s marginal cost into a generalized measure of productivity, \( \omega_{it} = \tilde{\omega}_{it} - (1 - \phi_{it}) \tilde{w}_{it} - \phi_{it} \tilde{v}_{it} \), where \( \tilde{w}_{it} \) and \( \tilde{v}_{it} \) measure the idiosyncratic log deviations of firm’s respective costs from industry averages, \( w_t \) and \( v_t \). Under these circumstances, we can rewrite the log marginal cost as:

\[
m_{it} = (1 - \phi_{it}) w_t + \phi_{it} v_t - \omega_{it},
\]

(21)

so that the only two firm-specific terms in (21) are the generalized productivity \( \omega_{it} \) and the import intensity \( \phi_{it} \).

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4The 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.

5In Section 4, we further assume that the firm’s import intensity is constant over time and equal \( \phi_{it} \). As we showed in Amiti, Konings, and Itskhoki (2014), this assumption is justified in the data, where over 85% of variation in \( \phi_{it} \) is cross-sectional, and within a firm \( \phi_{it} \) is not responsive to exchange rate movements over horizons of 3–5 years.
3 Empirical Analysis

3.1 Data Description

To empirically implement this general accounting framework, we need to be able to measure each variable in equation (??). 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 firm’s 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 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. To be precise about levels of aggregation, each of these variables are indexed by firms \( f \), products \( h \) for CN product codes and \( g \) for PC product codes, and years \( t \). Every good (whether denoted by an \( h \) or a \( g \)) belongs to one industry \( N \). Foreign variables are denoted by superscript \( * \).

**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 \( \Delta p_{fgt} \). The domestic unit values are
calculated as the ratio of production sold domestically to quantity sold domestically.  

\[ \Delta p_{fgt} = \frac{Domestic\ Value_{fgt}}{Domestic\ Quantity_{fgt}} \]  

(22)

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 intermediate inputs. 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, which we construct as follows:

\[ \Delta mc_f = (\Delta Total\ Variable\ Cost_f - \Delta Q_f) \]  

(23)

with \( \Delta Q_f = \Delta Revenue_f - \Delta P_f \) and total variable costs is the sum of the total material cost and the total wage bill. This is likely to be a noisy measure of a firm’s marginal cost so we also utilize the foreign component of a firm’s marginal cost, defined as follows:

\[ \Delta mc^*_f = \left( \sum_{h,k} \omega_{fhk} \Delta v^*_{fhk} \right) \]  

(24)

where \( \Delta v^*_{fhk} \) is the change in the log unit value of the firm’s imported intermediate inputs, at the CN 8-digit level, \( h \), from all source countries \( k \), and the weights are the average of \( t \) and \( t - 1 \) import shares. We drop any change in import unit values greater than 200% and less than 66%. We also take into account that not all imports are intermediate inputs. In our baseline case, we define an import to be a final good for a firm if it also reports positive production of that good. To illustrate, suppose a firm imports cocoa and chocolate, and it also produces chocolate. In that case we would classify the imported cocoa as an intermediate input and the imported chocolate as a final good, and hence only the imported cocoa would enter in the calculation of the marginal cost variable.

**Competition Variables**  When selling goods in the Belgium market, Belgium firms in the PRODCOM sample face competition from other Belgium firms in the PRODCOM sample that produce their goods in Belgium and sell in the domestic market (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 variable faced
by each firm-product in industry $N$ is the weighted average log change in the import price of goods imported by its competitors, $f'_{h}$:

$$\Delta P^*_N = \left( \sum_{h \in N, k} \omega_{f'_{h}k} \Delta p^*_{f'_{h}k} \right)$$  \hspace{1cm} (25)$$

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-product in sector $s$ is constructed as the weighted average log change in the domestic price of goods sold by its competitors:

$$\Delta P^d_{f,N} = \left( \sum_{g \in N} \omega_{f'_{g}} \Delta p^d_{f'_{g}} \right)$$  \hspace{1cm} (26)$$

An overall competitors price index is constructed as the weighted average of the foreign and domestic indexes.

$$\Delta P_{-f,N} = (1 - \theta_N) \Delta P^d_{-f,N} + \theta_N \Delta P^*_N$$  \hspace{1cm} (27)$$

where $\theta$ is the foreign market share in industry $N$. A firm $f'$'s market share of product $g$ in industry $N$ 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 (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.

3.2 Empirical Results

In this section, we estimate the impact of international shocks on Belgian domestic prices. Our measure of international shocks is the import-weighted exchange rate at the industry level. We proceed in two steps. First, we project the firm-product level domestic price on exchange rates to get an average pass-through coefficient. To understand the channels through which exchange rates feed into domestic prices, we project each of the components of domestic prices on exchange rates. Second, we estimate equation (2) to assess the relative magnitudes of the marginal cost and markup channels, for the average firm. We then explore whether these coefficients differ across firms in a systematic way, as in equation (2).

---

7The 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.
Table 1: Exchange Rate Projections

<table>
<thead>
<tr>
<th>Dep. var.</th>
<th>(\Delta p_{fg})</th>
<th>(\Delta p_{fg})</th>
<th>(\Delta mc_f)</th>
<th>(\Delta mc_f^*)</th>
<th>(\Delta P_N)</th>
<th>(\Delta P_N^{D})</th>
<th>(\Delta P_N^{N})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Delta e_s)</td>
<td>0.108*</td>
<td>0.525***</td>
<td>0.463**</td>
<td>0.265***</td>
<td>0.484***</td>
<td>0.322***</td>
<td>0.631***</td>
</tr>
<tr>
<td># obs.</td>
<td>63,882</td>
<td>63,882</td>
<td>63,882</td>
<td>63,882</td>
<td>1,714</td>
<td>1,714</td>
<td>1,714</td>
</tr>
<tr>
<td>Adj. (R^2)</td>
<td>0.000</td>
<td>0.003</td>
<td>0.003</td>
<td>0.014</td>
<td>0.033</td>
<td>0.007</td>
<td>0.058</td>
</tr>
<tr>
<td>Weighted</td>
<td>none</td>
<td>value</td>
<td>value</td>
<td>value</td>
<td>nobs</td>
<td>nobs</td>
<td>nobs</td>
</tr>
</tbody>
</table>

Regressions do not include fixed effects. \(\Delta e_N\) is the (log change in) industry import-weighted exchange rate. \(\Delta p_{fg}\) is the (log change in) firm-product price. \(\Delta mc_f\) is the (log change in) firm marginal cost. \(\Delta mc_f^*\) is the (log change in the) imported component of the firm marginal cost. \(\Delta P_N\) is the (log change in) the industry price index. \(\Delta P_N^{D}\) (\(\Delta P_N^{N}\)) is the (log change in) the industry price index of imported (domestic) goods.

**Exchange rate projections** Projecting \(\Delta p_{fg}\) on \(\Delta e_s\) provides us with an estimate of the overall effect for the average firm. In column 1 of Table 1, we regress \(\Delta p_{fg}\) on \(\Delta e_s\) using ordinary least squares estimation, and find a small positive coefficient that is barely significant at 0.1. If instead we weight each observation by the firm’s domestic sales of that product, as in column 2, the coefficient increases in magnitude to 0.5 and becomes significant at the 1% level. This implies a 10% euro depreciation against its trading partners is associated with a 5% increase in domestic prices. Going forward, all of the firm-level regressions are weighted by firm-product level domestic sales in order to give more weight to larger sales where unit values are likely to be measured with more precision. Columns 1 and 2 illustrate the importance of weighting for the results. The unweighted regression implies a 10% pass-through from exchange rates to domestic prices compared with a 50% pass-through in the weighted regression. These differences could help explain the larger coefficients we find in this study compared with the previous literature.

In the next three columns we project measures of marginal cost on exchange rates. In column 3, the dependent variable is the firm’s change in its overall marginal cost \(\Delta mc_f\), and the coefficient on \(\Delta e_s\) is also positive and close to 0.5. Because this overall measure of marginal cost is likely to be noisy, we also project the foreign component of the firm’s marginal cost on exchange rates. This foreign component is the part that is most likely to be affected by exchange rates through imported intermediate inputs and it is very well measured in the Belgian data. From column 4, we see that the coefficient is also positive and estimated with a much smaller standard error. Note that the coefficient is nearly half the size of that of the overall marginal cost measure in column 2. This simply reflects the fact that the weights in the construction of the foreign component of the marginal cost sum to the share of imports in total costs, which average 20%. In column 5, where the dependent variable is just the weighted average of the firm’s import prices (with the weights summing to one), the coefficient is much higher at 0.7. These highly significant coefficients in the marginal cost projections indicate there is a sizeable role for exchange rate shocks transmitting through a firm’s marginal cost. They tell us how much the firm’s

---

8 Note that errors in all the firm-product level regressions are clustered at the 4-digit industry level to take into account that the exchange rate is an industry-level measure (Moulton (1990)).
marginal cost is affected by exchange rates. The question of how much of this shock to marginal costs is then passed on to the domestic price the firm charges will become clear below when we estimate equation (??). A firm could decide to pass on as much as 100% of the marginal cost shock to domestic prices or it could decide to adjust its markup instead.

Strategic complementarities in equation (??) will be estimated by the size of the coefficient on the competitor price index, calculated as a weighted sum of the change in all prices in the industry, excluding the firm’s own price. In column 6, we run an industry-level regression, where we project the aggregate industry price index on the exchange rate. As well as providing an estimate of the correlation of exchange rates with industry price indices, we start to make some progress in understanding the potential size of strategic complementarities. The industry-level regressions are weighted by the number of firm-product-level observations that were used to construct each sector-level price index, in order to give more weight to the indexes that are measured with the most precision. In column 6, where the dependent variable is the sector-level overall price index $\Delta P_s$, the coefficient is 0.5, and when we split this price index into the foreign $\Delta P_s^F$ and domestic $\Delta P_s^D$ component in columns 7 and 8, respectively, we see that the magnitude is much higher for the foreign price index and lower for the domestic price index, as expected. The size of the coefficient on exchange rates for the foreign price index is twice the size of that for the domestic price index. Nonetheless, we find even the domestic component of the price index is significantly responsive to the exchange rate movements. These numbers indicate that the markup channel is potentially large, however we cannot tell from these aggregate industry price regressions how much of the effect could be coming through changes in firm’s marginal costs.

One way to isolate the role of strategic complementarities is to restrict the sample to the set of firms that source all of their intermediate inputs domestically or from within the Euro area in order to switch off the marginal cost channel. However, one might argue that this subsample of firms’ marginal costs may still be indirectly affected by exchange rates as the domestic price of intermediate inputs

<table>
<thead>
<tr>
<th>Dep. var.:</th>
<th>$\Delta mc_f$</th>
<th>$\Delta p_{fg}$</th>
<th>$\Delta p_{fg}$</th>
<th>$\Delta p_{fg}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>$\Delta e_s$</td>
<td>0.064</td>
<td>0.350**</td>
<td>0.026</td>
<td>0.232*</td>
</tr>
<tr>
<td></td>
<td>(0.129)</td>
<td>(0.154)</td>
<td>(0.138)</td>
<td>(0.138)</td>
</tr>
<tr>
<td>$\Delta e_s \times Large_f$</td>
<td>0.651**</td>
<td>(0.327)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta e_s \times S_f$</td>
<td>4.361**</td>
<td>(1.929)</td>
<td></td>
<td></td>
</tr>
<tr>
<td># obs.</td>
<td>22,762</td>
<td>22,762</td>
<td>22,762</td>
<td>22,762</td>
</tr>
<tr>
<td>Adj. $R^2$</td>
<td>value</td>
<td>value</td>
<td>value</td>
<td>value</td>
</tr>
<tr>
<td>Weighted</td>
<td>value</td>
<td>value</td>
<td>value</td>
<td>value</td>
</tr>
</tbody>
</table>

Sample of firms that do not import from outside the EU. Notation as in Table 1. In column 3, $Large_f$ is defined as average marketshare at the firm-product level with 4-digit industry > 1%. In column 4, the market share $S_f$ interaction is linear.
responds to competing imports. To check for this, we regress the firm’s change in its overall marginal
cost on the sector level exchange rates for the subsample of firms that do not import anything from
outside the euro area. We find no evidence of this indirect channel, at least for this subsample of firms,
with the coefficient insignificantly different from zero in column 1 of Table 2. Given this result, we
can interpret the positive significant coefficient of 0.35 in column 2, from the regression of the change
in domestic prices on the change in exchange rates, as evidence of exchange rates impacting domestic
prices through strategic complementarities.

A large class of models suggests that strategic complementarities should be stronger for larger firms.
Even though many of the firms in this subsample are smaller than those that import their inputs from
outside the euro area, we can still check for this heterogeneity within this sample in a couple of ways.
In column 3, we interact the exchange rate with a Large dummy equal to one for firms with average
market shares of greater than 1%, and we see that the coefficient on this interaction term is high and
statistically significant. Since these firm’s marginal costs are not affected by exchange rates, the only
mechanism through which exchange rates can feed into their domestic prices is through variation in
markups in response to competitors’ price changes. The zero coefficient on the linear term in column
3 implies that small firms only adjust prices in response to marginal costs. In contrast large firms
respond through variations in markups. We see this same pattern of heterogeneity in column 4 where
we interact the exchange rate with the market share measure itself ($S_f$). Again we find a significant
and large coefficient on the interaction term. These results are suggestive of heterogenous responses
to exchange rate shocks, with large market share firms responding more strongly through variations
in markups. We will explore this more systematically for the full sample of firms below.

**Accounting framework**  Now that we have established that exchange rates affect both marginal
costs and industry-level price indices, we draw on the accounting framework developed in section ??
to identify through which channel these exchange rate shocks are transmitted into domestic prices for
the average firm. To do this, we estimate the change in firm-product prices on changes in marginal
cost and competitors price index, as in equation (??). We expect that both coefficients will lie between
zero and one. If the markup elasticity were symmetric for both own price and competitor price as
in equation (2), the two coefficients would sum to one. Effectively, this implies the equation is over-
identified. That is, if we know the coefficient on the marginal cost variable, we can infer the value of
the coefficient on the markup variable. 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.

Table 3 reports the results. In the first two columns we estimate equation (??) using weighted least
squares, without industry effects in column 1 and with industry fixed effects in column 2. The coeffi-
cients on the firm’s marginal cost and on the competitors price index are of similar magnitude in both
columns and the size of the coefficients are largely unaffected by the inclusion of industry fixed effects.
These similar sized coefficients on the two right-hand-side variables indicate equal contributions to
price changes through both channels. However, the sum of the two coefficients is clearly less than one.
These small coefficients could be driven by measurement error in the construction of marginal cost.
While our proxy for marginal cost has the benefit of encompassing all of the components of marginal
Table 3: Domestic Prices, Marginal Costs, and Competitors’ Price Index

<table>
<thead>
<tr>
<th>Dep. var.:</th>
<th>( \Delta p_{fg} )</th>
<th>( \Delta p_{fg} )</th>
<th>( \Delta p_{fg} )</th>
<th>( \Delta p_{fg} )</th>
<th>( \Delta p_{fg} )</th>
<th>( \Delta p_{fg} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta mc_f )</td>
<td>0.346*** (0.041)</td>
<td>0.345*** (0.042)</td>
<td>0.701*** (0.166)</td>
<td>0.704*** (0.162)</td>
<td>0.530*** (0.192)</td>
<td>0.561*** (0.179)</td>
</tr>
<tr>
<td>( \Delta P_{-f,N} )</td>
<td>0.477*** (0.081)</td>
<td>0.380*** (0.091)</td>
<td>0.355* (0.197)</td>
<td>0.337* (0.198)</td>
<td>0.574** (0.265)</td>
<td>0.549** (0.242)</td>
</tr>
<tr>
<td># obs.</td>
<td>63,882</td>
<td>63,882</td>
<td>63,882</td>
<td>63,882</td>
<td>63,399</td>
<td>47,850</td>
</tr>
<tr>
<td>Adj. ( R^2 )</td>
<td>0.181</td>
<td>0.193</td>
<td>0.064</td>
<td>0.035</td>
<td>0.119</td>
<td>0.146</td>
</tr>
<tr>
<td>Industry F.E.s</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Instrumental Vars</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Weak Instrument Test (F-stat)</td>
<td>127.86</td>
<td>130.39</td>
<td>139.84</td>
<td>159.44</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Overidentification

Hansen-J Test: 4.6, 3.97, 1.80, 4.18
\( \chi^2 \) p-value: 0.1, 0.14, 0.12

\( H_0: \beta_{mc_f} + \beta_{P_{-f}} = 1 \) 0.824*** (0.083) 0.725*** (0.089) 1.06*** (0.075) 1.04*** (0.098) 1.103*** (0.098) 1.094*** (0.082)

Notes: all regressions include year fixed effects. Standard errors are clustered at the industry level. Notation as in Table 1. \( \Delta P_{-f,s} \) denotes the firm’s competitors price index. Instrument set: \( \Delta e_s, \Delta MC_{-f,s} \) (firm’s competitors marginal cost), \( \Delta mc_f, (1 - \phi) \Delta w_f \) (change in firm wages). The IV regressions pass the weak instrument test with Cragg-Donald F-stats over 100. Column 5 uses a stricter definition of inputs, excluding any import in a 4-digit industry that the firm produces. Column 6 limits the sample to the products in the firm’s major industry.

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, which is the part of overall marginal cost that is most likely affected by exchange rate movements and which is more precisely measured than the other components of the firm’s marginal cost. We also include the firm’s average wage cost in the instrument set, but we do not have a measure of the domestic prices of intermediate inputs, which we expect would be much less affected by exchange rates than the foreign component given the evidence we presented in Table 2.

Another potential problem with the estimates in columns 1 and 2 is the endogeneity of the competitors’ price index, which arises because all prices are set simultaneously. As well as preventing us from inferring a causal relationship between shocks to marginal costs and domestic prices, the endogeneity may also be causing a downward bias in the estimated coefficients. To address this endogeneity, we instrument the price index using the weighted average of the competitors’ marginal cost of imported inputs and the sector-level exchange rate. With this instrument set in hand, we reestimate equation 1 in columns 3 and 4, with and without industry fixed effects respectively, using instrumental variables estimation. From column 3, we see that the coefficient on the firm’s marginal cost increases in size and the two coefficients now sum to one, consistent with predictions in a wide class of models. The
Table 4: Firm Heterogeneity

<table>
<thead>
<tr>
<th>Dep. var.:</th>
<th>Δpf_N</th>
<th>Δpf_N</th>
<th>Δpf_N</th>
<th>Δpf_N</th>
<th>Δpf_N</th>
<th>Δpf_N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
</tr>
<tr>
<td>Δmc_f</td>
<td>0.864***</td>
<td>0.930***</td>
<td>0.870***</td>
<td>0.955***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.143)</td>
<td>(0.193)</td>
<td>(0.147)</td>
<td>(0.200)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δmc_f × Large_f</td>
<td>-0.357</td>
<td>0.533**</td>
<td>-0.388</td>
<td>0.533**</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.260)</td>
<td>(0.346)</td>
<td>(0.261)</td>
<td>(0.351)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δpf -f,N</td>
<td>0.157</td>
<td>0.142</td>
<td>0.142</td>
<td>0.142</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.173)</td>
<td>(0.230)</td>
<td>(0.230)</td>
<td>(0.230)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δpf -f,N × Large_f</td>
<td>0.305</td>
<td>0.305</td>
<td>0.305</td>
<td>0.305</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.286)</td>
<td>(0.386)</td>
<td>(0.386)</td>
<td>(0.386)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

# obs.     48,939  14,993  63,932  48,939  14,993  63,932
Adj. R^2   0.037  0.072  0.038  0.030  0.048  0.013

All regressions have industry fixed effects and year fixed effects. Standard errors are clustered at the industry level. Observations are weighted with domestic sales. Notation as in Tables 1–3. Large_f is the dummy for employment>100. Instrument set: Δe_f, ΔMC^*_f,N, Δmc_f, (1−φ)Δw_f.

results are almost identical with industry fixed effects in column 4. In both regressions the instruments provide a good fit in the first stage and pass the overidentification tests with p values greater than 0.05. If we constrain the coefficients to sum to one, the coefficient on the firm’s marginal cost is unaffected, equal to 0.7 (not reported), consistent with the unconstrained results.

We check the robustness of these results in subsequent columns. In column 5, 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 that the firm has any sales. There is no clear way if determining whether a firm is importing a final good or an intermediate input. The definition we use in column 5 is very conservative and significantly reduces the share of imports in the construction of the foreign marginal cost variable. Nevertheless, we see from column 5 that although the size of the coefficient on the marginal cost variable is a bit smaller than in column 4, which utilizes our baseline definition of intermediate inputs, we cannot reject that the two coefficients are of the same magnitude. Another 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 (see De Loecker, Goldberg, Khandelwal, and Pavcnik (2012) for one approach). To check that this multiproduct issue is not muddying our results, we reestimate column 4 with a subsample limited to only including each firm’s main industry. We see that the coefficients on both the firm’s marginal cost and competitors price index in columns 5 and 6 are around 0.5 and we cannot reject that the sum of the two coefficients equals one. The first-stage regressions are reported in the appendix.

The results in Table 3 provide us with average coefficient for how shocks are transmitted through marginal costs and strategic complementarities. Our preferred specification in column 4 suggests that on average a third of the response comes through strategic complementarities. However, fom equa-
tion (2), we see there could be heterogeneity in responses, that is, the markup elasticity and hence the coefficients on marginal cost and competitor price index may vary with firm-product characteristics. In Table 4, we explore whether there is heterogeneity in firms’ responses, by allowing the coefficients on the marginal cost and competitors price index to vary with the firm’s size, which we measure in terms of the firm’s employment and its market share. We define a large firm as any firm that has more than 100 workers on average over the sample period. In column 1 we estimate equation (??) for the sample of small firms and in column 2 for the 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 zero on the competitors price. In contrast, large firms have a smaller coefficient on marginal cost of 0.6 and an larger coefficient of around 0.4 (though insignificant) on competitors’ price index. In column 3, we use the full sample of firms and interact both coefficients with a large dummy and we find a similar pattern. Constraining the coefficients to sum to one in columns 1 to 3 yields the same results (unreported). We reestimate column 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 produces. We find the results are robust to using different market share cutoffs to define a large firm. For example, we see similar results across different specifications in column 4 with large comprising observations in the top twenty percentile within a 4-digit industry, in column 5 the top ten percentile, and in column 6 we use a 3% market share cutoff. All of these results suggest a lot of heterogeneity in firm’s responses, with small firms having the largest pass-through from marginal costs of around 100% and large firms having lower pass-through of around 60%.
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 2.1–2.2, with the core mechanism being the oligopolistic (quantity) competition under CES demand structure, following Atkeson and Burstein (2008). We focus on an industry equilibrium in the domestic market, in which domestic firms compete with importing firms, 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, which ensures that the model fits the salient features of the data including the joint distribution of market share and import intensity across the 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 devaluations, to study the aggregate exchange rate pass-through across sectors that differ in the extent of foreign competition, in the reliance of firms on imported inputs and in the 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 our Belgian data, focusing on the domestic market in which both domestic and foreign firms compete. We calibrate the model using data on 4-digit sectors in the Belgian economy. We focus on industries that are important to the Belgium economy in terms of their overall size and in terms of their share of domestic firms. To capture a "representative" Belgian industry, we selected industries based on the following criteria: (i) we started 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 dropped industries that are dominated by foreign firms and hence domestic firms have tiny market shares. We dropped industries where the foreign share was greater than 75% in any one year; (iii) we dropped industries with less than 10 domestic firms in any one year; and (iv) we dropped industries if the largest market share was greater than 32% or less than 2%. This process resulted in 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 5 and 6 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. This assumption allows us 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.\textsuperscript{9} We do not directly observe the numbers of European and non-European firms in the Belgian market, and we set $\bar{N}_E = 21$ and $\bar{N}_X = 9$ to match the average sales shares of all products from these regions equal to 27% and 11% respectively. Upon entry, all firms are symmetric in terms of their cost draws, and therefore the market share distributions are the same for all three types of firms, as modeled in greater detail in Eaton, Kortum, and Sotelo (2012). Therefore, the expected number of entrants directly pins down the expected sales shares of the three types of firms. Our calibrations allows us not only to capture the average sales shares of the three types of firms across sectors, but also the variation across sectors in these shares (see Table 6), which we use in our counterfactuals in Section 4.3.

The marginal cost of each firm is described by (21), as in Section 2.2, which we write in levels as:

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

(28)

where again $W_t$ is the price index of domestic inputs, $V_t^*$ is the foreign-currency price index of foreign (imported) inputs, $E_t$ is the nominal exchange rate, and $\Omega_{it}$ is the effective idiosyncratic productivity of the firm. We assume that exchange rate exposure $\phi_i$ is firm-specific and constant over time.\textsuperscript{10} Note that this specification does not rule out the idiosyncratic heterogeneity in input prices ($W_{it}/W_t$ and $V_{it}/V_t$, as in Section 2.2), variation in which are rolled into the effective idiosyncratic productivity term $\Omega_{it}$.

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

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

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

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

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

(29)

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

\textsuperscript{9}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 6.

\textsuperscript{10}Exchange rate exposure $\phi_i$ differs from import intensity $\phi_i$ by the factor of exchange rate pass-through into imported input prices, as we explain below.
Table 5: Calibrated parameters

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

Note:

Table 6: Moments

<table>
<thead>
<tr>
<th>Moment</th>
<th>Data</th>
<th>Model</th>
<th>Moment</th>
<th>Data</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of firms:</td>
<td></td>
<td></td>
<td>Sales share:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Belgian</td>
<td>41 (48)</td>
<td>48</td>
<td>– Belgian</td>
<td>0.64 (0.62)</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>[22,87]</td>
<td>[40,57]</td>
<td></td>
<td>[0.39,0.86]</td>
<td>[0.46,0.77]</td>
</tr>
<tr>
<td>– EU</td>
<td>21</td>
<td>21</td>
<td>– EU</td>
<td>0.26 (0.27)</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>[16,27]</td>
<td></td>
<td></td>
<td>[0.12,0.42]</td>
<td>[0.14,0.41]</td>
</tr>
<tr>
<td>– Non-EU</td>
<td>9</td>
<td>9</td>
<td>– Non-EU</td>
<td>0.08 (0.11)</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>[5,13]</td>
<td></td>
<td></td>
<td>[0.01,0.25]</td>
<td>[0.04,0.22]</td>
</tr>
<tr>
<td>Inverse Herfindahl Index for Belgian firms</td>
<td>16.4 (20.8)</td>
<td>13.7</td>
<td>Top Belgian market share</td>
<td>10.0% (11.7%)</td>
<td>11.2%</td>
</tr>
<tr>
<td></td>
<td>[7.1,138.4]</td>
<td>[6.5,24.3]</td>
<td></td>
<td>[4.9%,20.9%]</td>
<td>[5.6%,23.2%]</td>
</tr>
<tr>
<td>std($\Delta S_{it}$)</td>
<td>0.0042</td>
<td>0.0042</td>
<td>corr($S_{it}, \phi_t^B$)</td>
<td>0.26 (0.24)</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[0.00,0.44]</td>
<td></td>
</tr>
<tr>
<td>corr($S_{it}, S_{i,t+12}$)</td>
<td>0.90 (0.85)</td>
<td>0.88</td>
<td>corr($S_{it}, \phi_t^X/\phi_t^B$)</td>
<td>0.05 (0.08)</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>[0.69, 0.98]</td>
<td></td>
<td></td>
<td>[-0.03, 0.37]</td>
<td></td>
</tr>
</tbody>
</table>

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

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

process becomes:

$$\omega_{it} = \begin{cases} 
\mu + \omega_{i,t-1} + \sigma \omega v_{it}, & \text{if } \omega > \omega, \\
\omega - (\mu + \omega_{i,t-1} + \sigma \omega v_{it} - \omega), & \text{otherwise.}
\end{cases} \quad (30)$$

That is, the process follows (29) as long as it stays above the lower bound $\omega$, and otherwise it reflects from the lower bound by the amount the process in equation (29) would undershoot $\omega$ without the reflection. The initial productivities are drawn from a Pareto distribution, $\Omega_{i0} \sim iid\text{Pareto}(k, e^{\omega})$, where $k$ is the shape parameter and $\omega$ is the lower bound for $\omega_{i0} = \log \Omega_{i0}$ (which acts as a normalization in our model). That is, the cumulative distribution function for $\Omega_{i0}$ is given by $G_{0}(\Omega) = 1 - \left(\Omega/e^{\omega}\right)^{-k}$ for $\Omega \geq e^{\omega}$. When $\mu = -k \sigma^2 \omega / 2 < 0$, the reflecting barrier in (30) 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 6). The largest domestic firm in a typical industry has a market share of about 11%, while the second-largest firm is about 38% smaller, both in the simulated model and in the data (see Table 6 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 aggregated 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 we discussed in Amiti, Konings, and Itskhoki (2014), larger firms are more import intensive. We make sure to capture this feature of the data in our calibration.\(^{11}\) We assume the import intensity is given to a firm 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 import intensity of the firms tends to stay stable over a horizon of 3–5 years and does 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, market shares are very persistent with a correlation between market share in the first and in the last (thirteenth) year of the sample above 0.85, as in the data. For Belgian firms, we match the intensity of both imports from within the EU and outside the EU, by fitting a four-parameter Beta distribution to these import intensities in the data separately for each of the first 40 firms in the industry by market share. For other firms we assign the values of the 40th firm. The four parameters of the distribution correspond to the lower and upper bounds, as well as the mean and the median. Further details of this calibration are provided in 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

\(^{11}\)In Amiti, Konings, and Itskhoki (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.
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 input prices. 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 (11), which involves solving a fixed point using (10) and (12), and then find the equilibrium price index $P_t$ according to (9). We also calculate the market shares $\{s_{it}\}$ according to (10).\footnote{For now, we shut down the heterogeneity in $\xi_{it}$, and focus on the only source of heterogeneity across firms in productivity $\Omega_{it}$.} We then calculate the measured log change in the price index according to:

$$\Delta \log P_t = \sum_{i=1}^{N+N^*} s_{it} + s_{it-1} \frac{1}{2} \left( \log P_{it} - \log P_{i,t-1} \right),$$

(31)

as we did in the data. We calculate similar price indexes for domestic and foreign subsets of firms. Additionally, we calculate the change in the competitor price index for each firm as:

$$\Delta \log P_{-i,t} = \sum_{j \neq i} s_{jt}^{-i} + s_{jt-1}^{-i} \frac{1}{2} \left( \log P_{jt} - \log P_{j,t-1} \right),$$

(32)

where $s_{jt}^{-i} \equiv s_{jt} / (1 - s_{it})$ so that $\sum_{j \neq i} s_{jt}^{-i} = 1$.

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), and we also experiment with an arguably more realistic larger elasticities (e.g., $\eta = 2$). The model requires a log elasticity, or more precisely a large gap between $\rho$ and $\eta$ in order to generate variable markups (see (13)), as in the data. We set the elasticity of substitution within sectors to $\rho = 8$. This is larger than the conventional estimates for 4-digit industries (see e.g. Broda and Weinstein 2006), but in line with the literature following Atkeson and Burstein (2008) (see, for example, Edmond, Midrigan, and Xu 2012). Given this parameters, Figures 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 a realistic range $[0, 0.25]$. The same picture also contrasts the alternative specifications with the same parameters but under price competition (‘Bertrand’), and under quantity competition but for two alternative sets of parameters ($\eta = 2$ in one, and $\rho = 5$ in the other). It is immediate that Bertrand does not work quantitatively as it predicts pass-through for firms with 10% market share of around 90%. In our data, this is more like 50-60%, much more in line with the Cournot model under our parameterization. Also note that increasing $\eta$ or reducing $\rho$ also makes it harder to fit the data quantitatively.
Figure 3: Markups and pass-through in a calibrated model

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

4.2 Simulation results

Using the calibrated model, we simulate a panel of firm-product prices across 20 industries and 11 times periods, roughly corresponding to the structure of our dataset. Given the calibrated exogenous marginal cost process in (17), we use the model to solve for the (Bertrand-Nash) equilibrium of the simultaneous price setting game. In addition to firm market shares and prices, we calculate the evolution of sectoral price indexes according to (31), the way it is done by statistical agencies. Provided this simulated panel dataset, we run the same regression specifications as in Tables 1–4.

In Table 7 we report the results from two regression specification. In the first row, we report the sector-level specification in which we run the log change in the price index \( \Delta \log P_t \) calculated according to (31), as well as a similarly constructed index of the change in the log marginal cost of all firms \( \Delta \log MC_t \),\(^{13}\) on the change in the log exchange rate \( \Delta \log E_t \). We do it for the full sample of all firms, as well as for the subsamples of domestic and foreign firms separately. Columns (2), (4), (6) of Table 7 correspond to columns (5), (7) and (6) of Table 1: the model sectoral pass-through rates are 0.34, 0.21 and 0.53 for all, domestic and foreign respectively, in parallel with 0.48, 0.32 and 0.63 pass-through estimated in our Belgian dataset. The marginal cost regressions for the domestic and foreign firms recover closely the respective average exposures to foreign inputs, \( \varphi^H = 0.1 \) and \( \varphi^F = 0.7 \) respectively, as well as for the sample of all firms, equal to \( S^H \varphi^H + S^F \varphi^F = 0.6 \cdot 0.1 + 0.4 \cdot 0.7 = 0.34 \), where \( S^F = (1 - S^H) \) is the sectoral sales share of foreign firms. Note the similarity in the sectoral-level coefficients for marginal costs and prices for the sample of all firms (both equal to 34%), reflecting that at the aggregate there is a complete pass-through. At the same time, the price of domestic firms move substantially more that the marginal costs (21% versus 7%), reflecting the role of strategic complemen-

\[^{13}\] \( \Delta \log MC_t = \sum_i s_{it} + s_{it-1} \left( \log MC_{it} - \log MC_{i,t-1} \right) \).
Table 7: Sectoral pass-through regressions

<table>
<thead>
<tr>
<th></th>
<th>All firms</th>
<th>Domestic firms</th>
<th>Foreign firms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MC</td>
<td>Price</td>
<td>MC</td>
</tr>
<tr>
<td>Sector-level</td>
<td>0.494</td>
<td>0.488</td>
<td>0.286</td>
</tr>
<tr>
<td>Firm-level pooled</td>
<td>0.460</td>
<td>0.460</td>
<td>0.233</td>
</tr>
<tr>
<td>— sales-weighted</td>
<td>0.473</td>
<td>0.464</td>
<td>0.268</td>
</tr>
</tbody>
</table>

Note: Data generated from 1000 symmetric industries. Sector-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. The weighted regression uses firm market shares squared as weights. MATLAB cannot do this with 1000 sectors, so we pool 50 sectors at a time and report the median estimates across 20 such simulations (1000 sectors in total).

![Figure 4: Exchange rate pass-through into marginal costs and prices, by market share bins](image)

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.
tarities in competition with foreign firms (which, in their turn, pass-through only 53% of the exchange rate movement while their costs move by 70%). This implies that 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.

The second row of Table 7 report the results from the pooled firm-product-level regressions of changes in log marginal costs ($\Delta \log MC_{it}$) and prices ($\Delta \log P_{it}$) on the change in the log exchange rate ($\Delta \log E_t$). The results closely replicate those form the sector-level regressions, with column (4) corresponding to columns (1)–(2) of Table 1 in the empirical section.

Table 8 reports the results from firm-level regressions of change in log firm prices ($\Delta \log P_{it}$) on the change in log firm marginal cost ($\Delta \log MC_{it}$) and the change in the firm’s log competitor price index ($\Delta \log P_{-i,t}$, calculated according to 32). The second column adds two additional interaction terms of the right-hand side variables with the ‘large’ dummy ($L_{it}$) for the firm belonging to the top quartile (20%) in terms of the market share to capture the heterogeneity in the markup elasticity across firms. The two columns of the table correspond to column (3) of Tables 3 and 4 respectively. We find very similar results in the first column, with coefficients on own marginal cost and competitors prices equal to 0.57 and 0.42 in the simulated dataset versus 0.70 and 0.36 in the Belgian dataset. In the second column, we see that the respective coefficients change to 0.65 and 0.35 for the smallest 75% of firms in terms of market share, while they equal 0.36 ($= 0.64 - 0.28$) and 0.64 ($= 0.35 + 0.29$) for the largest 25% of firms. This corresponds to somewhat smaller variations than in our Belgian dataset, where the smallest firms have about 90–95% pass-through of idiosyncratic marginal cost shocks, while for the largest firms it is lower by 35–40%.

4.3 Counterfactuals
Table 8: Pass-through heterogeneity across firms

<table>
<thead>
<tr>
<th>Dep. var.: $\Delta \log P_{it}$ interaction</th>
<th>Without size interaction</th>
<th>With size interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta \log MC_{it}$</td>
<td>UW 0.929 0.775</td>
<td>UW 0.960 0.951</td>
</tr>
<tr>
<td></td>
<td>W 0.960 0.951</td>
<td>W -0.163 -0.259</td>
</tr>
<tr>
<td>$\Delta \log P_{-i,t}$</td>
<td>UW 0.069 0.201</td>
<td>UW 0.040 0.047</td>
</tr>
<tr>
<td></td>
<td>W 0.040 0.047</td>
<td>W 0.156 0.248</td>
</tr>
</tbody>
</table>

Note: $L_{it}$ is a dummy for top 20th quintile of firms within each sector according to market shares. UW stands for unweighted and W stands for sales-weighted.

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 (as in (??)), 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 $\Gamma_{-i,t}/(1+\Gamma_{it})$).
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.
Figure 7: Heterogenous response across sectors: Domestic share

Note:
Figure 8: Heterogeneous response across sectors

Note:
Table 9: Pass-through decomposition

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

Table 10: Market share, exchange rate exposure, and markup distributions in the model

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

Note: Domestic firms only. Note that $\frac{\rho}{(\rho - 1)} = 1.143$ and corresponds to the markup of a zero-market-share firm.

A 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 firm'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.
B Accounting derivations for Section ??

We can transform (??):

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

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

\[
\Rightarrow \Delta p_{it} = \frac{1}{1+\Gamma_{it}} \Delta mc_{it} + \frac{\Gamma_{-i,t}}{1-\omega_{it}} \left[ (1-\omega_{it})\Delta P_{-i,t} \pm \omega_{it}\Delta p_{it} \right] + \varepsilon_{it},
\]  \hspace{1cm} (A1)

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:

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

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:

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

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

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

We also define

\[
\Delta MC_t = \sum_i \omega_{it}\Delta mc_{it},
\]

\[
\Delta M_t = \sum_i \omega_{it}\Delta \mu_{it} = \sum_i \omega_{it} \left( \Delta p_{it} - \Delta mc_{it} \right) = \Delta P_t - \Delta MC_t
\]

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

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

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

\[
\Psi_P = \frac{1}{1 - \sum_i \omega_t \tilde{\Gamma}_{-i,t}} \sum_i \frac{\omega_t \phi_{it}}{1 + \tilde{\Gamma}_{it}},
\]

\[
\Psi_M = -\frac{1}{1 - \sum_i \omega_t \tilde{\Gamma}_{-i,t}} \sum_i \left[ \tilde{\Gamma}_{it} \frac{\omega_t \phi_{it}}{1 + \tilde{\Gamma}_{it}} - \sum_j \omega_{jt} \tilde{\Gamma}_{-j,t} \right] \omega_t \phi_{it}
\]

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

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

\[
\Delta P_{Dt} = \frac{1}{1 - \sum_{i \in I_D} \omega_{it} \tilde{\Gamma}_{-i,t}} \sum_{i \in I_D} \omega_{it} \left[ \frac{\Delta m_{c_it}}{1 + \tilde{\Gamma}_{it}} + \tilde{\varepsilon}_{it} + \tilde{\Gamma}_{-i,t} S_{Ft} \Delta P_{Ft} \right]
\]

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

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

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

\[
\Psi_P^D = \frac{1}{1 - \sum_{i \in I_D} \omega_{it}^D (1 - S_{Ft})} \sum_{i \in I_D} \left[ \omega_{it}^D \phi_{it} + \omega_{it}^D \tilde{\Gamma}_{-i,t} S_{Ft} \Psi_P^F \right],
\]

\[
\Psi_M^D = \Psi_P^D - \Psi_{MC}^D
\]
C Derivations for Atkeson-Burstein model

D 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 $C$:

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

$$\frac{1}{|\Omega|} \int_{i \in \Omega} A_i \Upsilon \left( \frac{|\Omega|C_i}{\xi_i C} \right) \, di = 1,$$  \hspace{1cm} (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:

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

$$\sum_{i \in \Omega} P_i C_i = E.$$  \hspace{1cm} (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 \(C\):

\[
\max_{\{C_i\}_{i \in \Omega}} \left\{ C \mid \text{s.t. (A2) and (A5)} \right\}.
\] (A6)

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

\[
C_i = \frac{\xi_i C}{N} \cdot \psi(x_i), \quad \text{where } x_i \equiv \frac{P_i/\gamma_i}{P/D}.
\] (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.\(^{14}\) Note that an increase in \(\gamma_i\) directly reduces the effective price for the good in the eyes of the consumers, which corresponds to a shift along the demand curve. At the same time, an increase in \(\xi_i\) (holding \(\gamma_i\) constant), shifts out the demand curve holding the effective price unchanged. This is why we refer to \(\xi_i\) as the demand shifter, and \(\gamma_i\) as the quality parameter.

We show in the appendix that \(P\) and \(D\) are defined by:\(^{15}\)

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

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

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

\(^{14}\)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).

\(^{15}\)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 \(\{P_i\}\) and other parameters, and hence this auxiliary variable is indeed redundant in the CES case. Given this \(D\), the price index can be recovered from either condition in its usual form:

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

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.
sector equals one, with the market share given by

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

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 \( \psi(\cdot) \):

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

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 \( D \):

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

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

Given this, we can calculate the full elasticity of demand, which takes into account the effects of \( P_i \) on \( P \) and \( D \). Substituting \( C = E/P = \alpha P^{-\eta} \) into (A7), we have:

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

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:

\[ P_i = M_i MC_i, \quad M_i \equiv \frac{\Sigma_i}{\Sigma_i - 1}. \]

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, Konings, and Itskhoki (2014), where we showed that the markup elasticity is symmetric:

\[ \Gamma_i \equiv -\frac{\partial \log M_i}{\partial \log P_i} = \frac{d \log M_i}{d \log P} = \frac{(\rho - 1)(\rho - \eta) s_i}{\Sigma_i (\Sigma_i - 1)}, \]
and is increasing in the market share $s_i$. Therefore, for that case we can write:\footnote{An alternative expression is}

$$d \log P_i = \frac{1}{1 + \Gamma_i} d \log MC_i + \frac{\Gamma_i}{1 + \Gamma_i} d \log P + \epsilon_i.$$\footnote{An alternative expression is}

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

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

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

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

Before turning to a more special case of the Kimball demand, we discuss briefly some of its general properties. First, Kimball demand is homothetic and separable in the sense that the cross-partial elasticities are symmetric for all varieties (as is also the case for the most common parameterization of the translog demand, see Feenstra ?). Second, Kimball demand nests CES as a special case. Third, Kimball demand (given in (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).\footnote{These two auxiliary variables corresponds to the the Lagrange multipliers in the consumer optimization, corresponding to constraints (A5) and (A2) respectively (see the appendix).} 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.

### D.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:

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

where $\Gamma_i' \equiv (1 - s_i) \Gamma_i$ and $P_{-i}$ is the competitor price index such that $P = \left[(\xi_i \gamma_i^\sigma) P_i^{1-\sigma} + (1 - \xi_i \gamma_i^\sigma) P_{-i}^{1-\sigma}\right]^{1/(1-\sigma)}$.\footnote{These two auxiliary variables corresponds to the the Lagrange multipliers in the consumer optimization, corresponding to constraints (A5) and (A2) respectively (see the appendix).}
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:

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

(A14)

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

(A15)

Under this demand, the optimal markup is given by:

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

(A16)

and therefore the elasticity of markup is:

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

(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 $\sigma(\bar{x}) = 1$ and given by $\bar{x} = \frac{\bar{\sigma} - 1}{\bar{\sigma}} e^{-(\bar{\sigma} - 1)/\bar{\varepsilon}} < 1$. Note that at this price the markup becomes infinite, $\mathcal{M}(\bar{x}) = \infty$, and therefore in equilibrium this price can be charged only by firms with zero marginal costs, and in the absence of such firms, every firm charges an effective price strictly above $\bar{x}$. Lastly, the idiosyncratic pass-through $\Psi(x_i)$ varies from zero for the firm with a least price $\bar{x}$ to a maximum of $\bar{\Psi} = \frac{1}{1 + \bar{\varepsilon} / \bar{\sigma}}$ for the firm with the choke-off price $\bar{x}$. We illustrate these properties in Figure A1 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 $x_i = \frac{P_i / \gamma_i}{P / \gamma D}$ 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 $P$

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18Note that with this demand, the elasticity of elasticity with respect to quantity is constant: $d \log \sigma_i / d \log C_i = \bar{\varepsilon} / \bar{\sigma}$. Furthermore, the markup elasticity $\Gamma_i$ is proportional to the level of markup $\mathcal{M}_i$ (we introduce both below): $\Gamma_i / \mathcal{M}_i = \bar{\varepsilon} / \bar{\sigma}$. 

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and $D$, as well as for the individual prices $\{P_i\}$. The firm fixed point problem has an implicit closed form solution given by:

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

is the least price (corresponding to $z$), 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 $\bar{\sigma} = \bar{\epsilon} > 1$ and $\xi_i = A_i \equiv 1$ for illustration purposes, while the appendix offers derivations and general expressions. When $\bar{\sigma} = \bar{\epsilon}$, the utility aggregator has a simple closed form given by $\Upsilon(z_i) = 1 + (\sigma - 1)(1 - \exp\{(1 - z_i)/\bar{\sigma})\)$. Using this expression, we can simplify and manipulate the sector equilibrium conditions (A8)–(A9) to yield the following results:

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

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

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

### D.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:

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

$$\mu P_j = \lambda A_j \Upsilon'\left(\frac{NC_j}{\xi_j C}\right) \frac{1}{\xi_j C}.$$
Denote by $P \equiv 1/\mu$, which is the ideal price index such that $PC = E$ under the optimal consumption allocation, and by

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

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

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

Given $P = E/C$, $P$ and $D$ are determined from the two constraints on the problem (A2) and (A5), which can be rewritten as:

$$\frac{1}{N} \sum_{j \in \Omega} A_j \gamma \left( \psi \left( \frac{P_j / \gamma_j}{P/D} \right) \right) = 1,$n$$\frac{1}{N} \sum_{j \in \Omega} \xi_j P_j \psi \left( \frac{P_j / \gamma_j}{P/D} \right) = 1,$

which we reproduce in the main text as (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:

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

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

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

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

$$\tilde{\varepsilon}_j = \tilde{\varepsilon}(x_j) \equiv$$
D.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:

\[
\frac{d \log Z}{d \log P_i} = -\frac{\frac{A_i}{N} \left( \frac{ZP_i}{\gamma_i} \right)^2 \psi' \left( \frac{ZP_i}{\gamma_i} \right)}{\sum_{j \in \Omega} \frac{A_j}{N} \left( \frac{ZP_j}{\gamma_j} \right)^2 \psi' \left( \frac{ZP_j}{\gamma_j} \right)}
\]

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

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 $\bar{\sigma}_j$, we can rewrite:

\[
\frac{d \log Z}{d \log P_i} = -\frac{D \xi_i P_i}{NP} \psi \left( \frac{ZP_i}{\gamma_i} \right) \bar{\sigma}_i = -\frac{s_i \bar{\sigma}_i}{\sum_{j \in \Omega} s_j \bar{\sigma}_j},
\]

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

Profit maximization:

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

where

\[
C_j = \frac{\xi_j E}{NP} \cdot \psi \left( \frac{ZP_j}{\gamma_j} \right).
\]

FOC:

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

where we have:

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

and therefore price-setting satisfies:

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

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

\[
M_j = \frac{\sigma (1 - s_j) + \eta s_j}{\sigma (1 - s_j) + \eta s_j - 1}.
\]
We need to derive:

\[ \Gamma_j \equiv -\frac{d \log M_j}{d \log P_j} =, \]
\[ \Gamma_P \equiv \frac{d \log M_j}{d \log P} =, \]
\[ \Gamma_D \equiv \frac{d \log M_j}{d \log D} = \]

### D.4 Klenow and Willis demand

Figure A1 plots these cross-sectional relationships (for \( \sigma = 4 \) and various values of \( \varepsilon \)), from which we can draw a number of useful lessons. Figure A1a 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 A1c and, consequently, the price is equal to marginal cost (intersects 45°-line) in Figure A1f. Figure A1b illustrates that for low enough prices the elasticity of demand is less than unity, \( \sigma_i < 1 \), which is inconsistent with firm optimization; therefore, optimizing firms always choose a price at least to ensure demand with unit-elasticity, \( \sigma(x) = 1 \)—this can be seen in Figure A1c as the markup goes to infinity, in Figure A1e as the pass-through goes to zero, and in Figure A1f as the price asymptotes (on the left) and becomes insensitive to the marginal cost. Finally, Figure A1e 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.

### D.5 Special case of \( \bar{\varepsilon} = \bar{\sigma} \)

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

Therefore, in this case, we have:

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

and thus

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

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

\[ \frac{\sigma}{|\Omega|} \int_{i \in \Omega} A_i \left( 1 - \frac{P_i}{\gamma_i} \frac{P}{D} \right) di = 1, \]
\[ \frac{1}{|\Omega|} \int_{i \in \Omega} \frac{\xi_i P_i}{P} \left[ 1 - \sigma \log \left( \frac{\sigma}{\sigma - 1} \frac{P_i}{\gamma_i} \frac{P}{D} \right) \right] di = 1. \]
Figure A1: Klenow-Willis specification of Kimball demand
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:

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

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

$$\frac{P}{D} = \frac{\sigma}{\sigma - 1} \mathbb{E}\{\xi_i P_i\},$$

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

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

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

### E  Additional results

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Note: All entries are in %.
References


