**Can Sticky Quantities Explain Export Insensitivity to Exchange Rates?**

(with Doireann Fitzgerald and Stefanie Haller)

**14 December 2017, 11:15-12:30, bld. 72, room 465**

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# Can Sticky Quantities Explain Export Insensitivity to Exchange Rates?*

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**Abstract**

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# 1 Introduction

There is ample evidence from both macro and firm-level data that exports are insensitive to movements in real exchange rates, a fact which is key to explaining the disconnect between real exchange rates and other macroeconomic aggregates. A very large literature explores the possibility that price stickiness and pricing-to-market are responsible for this insensitivity. A much smaller literature explores the possibility that this insensitivity is due to what we call sticky quantities. The contribution of this paper is to provide both reduced form and quantitative evidence that sticky quantities play an important role in explaining why firm-level exports (and hence aggregate exports) are insensitive to movements in exchange rates.

We first use firm and customs micro data for Ireland to estimate the sensitivity of export prices, quantities, and revenue to real exchange rates, after conditioning on marginal cost. Prices invoiced in domestic currency do respond to movements in real exchange rates, but the extent of pricing-to-market is relatively modest. Domestic currency prices respond to real exchange rate movements with an elasticity of 0.17, implying relatively large movements in destination currency prices in response to real exchange rates (passthrough is 0.83). However export quantities are very insensitive to movements in real exchange rates: the elasticity of export quantities with respect to real exchange rates is 0.26. The elasticity of export revenue with respect to real exchange rates is 0.44, the sum of price and quantity responses.

Under standard assumptions about demand, and ignoring a possible role for customer base, these estimated elasticities with respect to real exchange rates imply a price elasticity of demand of 0.31. This is well below reasonable values for the price elasticity of demand, which should be above 1 for a monopolist to be profit-maximizing. This suggests that sticky prices and markup adjustment alone cannot explain why exports are so insensitive to real exchange rates. However we show that if demand does in fact depend on customer base, and if firms reduce investment in foreign customer base precisely when the home currency depreciates against the foreign currency, this could potentially reconcile our estimated elasticities with respect to real exchange rates with a price elasticity of demand that is greater than 1. Intuitively, this is most likely to happen if the costs of investment in customer base are incurred in the foreign currency.

The rest of the paper is devoted to a quantitative assessment of this scenario. In order to focus on exporter responses, we take a partial equilibrium approach, which does not require us to take a stand on other features of the international economy, such as the nature of asset markets. We take a model of the firm's export decision problem, estimated by Fitzgerald, Haller and Yedid-Levi (2016) to match facts about steady state exporter dynamics. We confront it with a joint process for real exchange rates foreign demand estimated from data. We simulate a panel of synthetic data based on the shock process and optimal firm responses based on the model under two scenarios: where the costs of investment in customer base are incurred in the home market, and where the costs of investment in customer base are incurred in the destination market. We use this data to estimate the same regressions we estimate in the actual data.

We find that customer base can play a role in driving the elasticity of export quantities (and hence revenues) with respect to real exchange rates. If the costs of investing in customer base are incurred in the home market, this elasticity is greater than the price elasticity of demand. If costs are incurred in the foreign market, this elasticity is less than the price elasticity of demand. At the same time, our model is consistent with an elasticity of export quantities with respect to tariffs that is substantially greater than the price elasticity of demand.

Our paper is most closely related to Drozd and Nosal (2012) who show that a quantitative two-country model with sticky quantities can account for several pricing puzzles in international macroeconomics, and to Corsetti and Dedola (2005) who argue that distribution costs may be important in explaining exchange rate disconnect. Our paper is related to a vast literature in macroeconomics and international macroeconomics on price stickiness, ably surveyed by Burstein and Gopinath (2014). We find that although price adjustment may indeed be infrequent, costs of adjustment of quantities alone can do a good job of rationalizing comovements of prices and quantities at a business cycle frequency. It is also related to papers in the macro and trade literatures which incorporate customer base (e.g. Arkolakis (2010), Eaton, Kortum and Kramarz (2011), Foster, Haltiwanter and Syverson (2016) and Gourio and Rudanko (2014)). Our empirical analysis is closely related to Berman, Martin and Mayer (2012).

The second section of the paper describes our micro data from Ireland. The third section presents evidence from this data on how export revenue, quantities and prices respond to shocks to real exchange rates and foreign demand. The fourth section describes our model of frictions in adjusting customer base. The fifth section describes how we estimate the joint process for real exchange rates and foreign demand, and parameterize and simulate the model. The sixth section describes our model-based estimates of responses of export revenue, prices and quantities to shocks, as well as a number of robustness checks. The final section concludes.

# 2 Data

## 2.1 Micro data

We make use of two sources of confidential micro data made available to us by the Central Statistics Office (CSO) in Ireland: the Irish Census of Industrial Production (CIP), and Irish customs records. The data are described in detail in the appendix to Fitzgerald and Haller (2017).

### 2.1.1 Census of Industrial Production

The CIP, which covers manufacturing, mining, and utilities, takes place annually. Firms with three or more persons engaged are required to file returns.[1] We make use of data for the years 1996-2009 and for NACE Revision 1.1 sectors 10-40 (manufacturing, mining, and utilities). Of the variables collected in the CIP, those we make use of in this paper are the country of ownership, total revenue, employment, and an indicator for whether the firm has multiple plants in Ireland.

In constructing our sample for analysis, we drop firms with a zero value for total revenue or zero employees in more than half of their years in the sample. We perform some recoding of firm identifiers to maintain the panel dimension of the data, for example, in cases in which ownership changes.

### 2.1.2 Customs records

Our second source of data is customs records of Irish merchandise exports for the years 1996-2014. The value (euros) and quantity (tonnes)[2] of exports are available at the level of the VAT number, the Combined Nomenclature (CN) eight-digit product, and the destination market (country), aggregated to an annual frequency. These data are matched by the CSO to CIP firms using a correspondence between VAT numbers and CIP firm identifiers, along with other confidential information. The appendix to Fitzgerald and Haller (2017) provides summary statistics on this match.

In the European Union, data for intra-EU and extra-EU trade are collected separately, using two different systems called Intrastat and Extrastat. The reporting threshold for intra-EU exports (635,000 euro per year in total shipments within the EU) is different from that for

[1] Multiplant firms also fill in returns at the level of individual plants, but we work with the firm-level data, since this is the level at which the match with customs records can be performed.

[2] The value is always available, but the quantity is missing for about 10% of export records.

extra-EU exports (254 euro per transaction).[3] The high threshold for intra-EU exports likely leads to censoring of exports by small exporters to the EU. However, since the threshold is not applied at the market level but to exports to the EU as a whole, we observe many firms exporting amounts below the 635,000 euro threshold to individual EU markets.

An important feature of the customs data is that the eight-digit CN classification system changes every year. We concord the product-level data over time at the most disaggregated level possible following the approach of Pierce and Schott (2012) and Van Beveren, Bernard, and Vandenbussche (2012). For our baseline analysis, we restrict attention to the period 1996-2009, for which we have CIP data in addition to customs data, and we make use only of customs data that matches to a CIP firm. In some robustness checks, we make use of the full sample period, 1996-2014, and all of the customs data irrespective of a CIP match. We perform the product concordance separately for the two different sample periods, as dictated by the Pierce and Schott approach.

As a result, we have annual data on value and quantity of exports at the firm-product-market level, where the product is defined at the eight-digit (concorded) level, and the market refers to the destination country. We use this to construct a price (unit value) by dividing value by quantity, where available. In aggregate trade statistics, unit value data at the product level are notoriously noisy. However, conditioning on the exporting firm as well as the product considerably reduces this noise.

We restrict attention to 40 export markets which account for at least 95% of exports over the sample period. The markets are: Australia, Austria, Belgium, Brazil, Bulgaria, Canada, China, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hong Kong, Hungary, India, Italy, Japan, Latvia, Lithuania, Malaysia, Mexico, Netherlands, New Zealand, Norway, Portugal, Romania, Saudi Arabia, Slovakia, Slovenia, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, U.A.E., U.K., and the U.S.

## 2.2 Macro data

We make use of data on two macro variables in our empirical analysis. The first is the real consumption exchange rate between Ireland and the relevant destination market. The second is a measure of real local currency demand in the relevant destination market. Real exchange rates are constructed using data on annual average nominal exchange rates and CPIs from the IMF's *International Financial Statistics* (IFS). The bulk of the variation in

[3]Intra-EU exports below the threshold are recovered based on VAT returns. The destination market within the EU is not recorded for these returns.

real exchange rates is driven by variation in nominal exchange rates. Real demand in the target market is calculated as GDP less exports plus imports, all measured in current local currency, with this aggregate deflated by the relevant country's CPI. The National Accounts data are taken from the OECD's *National Accounts Statistics* where available, and otherwise from the World Bank's *World Development Indicators*. The CPIs are taken from IFS. We collect these variables for the markets described above. More details are provided in the appendix to Fitzgerald and Haller (2017).

In order to estimate the joint process for real exchange rates and foreign demand for our quantitative exercise, we require data at a higher frequency, as a period in the model correponds to six months in the data. We collect quarterly data on all of the above variables from IFS, and construct biannual real exchange rates and foreign real demand based on this data.

# 3 Firm responses to real exchange rates and foreign demand

We now use these data to estimate the elasticity of firm-product-market-level export revenue, quantity and price to real exchange rates and foreign demand. We focus on the intensive margin of responses.[4] Our baseline estimating equation is:

$$w_t^{ijk} = c_t^{ij} + \gamma^{jk} + \boldsymbol{\alpha}'\mathbf{x}_t^{ijk} + \boldsymbol{\beta}'\mathbf{z}_t^k + \boldsymbol{\phi}'\left(\mathbf{z}_t^k * low_t^{ijk}\right) + \eta_t^{ijk} \quad (1)$$

$w_t^{ijk}$ is, in turn, the log of revenue, quantity and price for firm $i$ selling product $j$ in market $k$ at time $t$. $c_t^{ij}$ is a firm-product-year fixed effect, which controls for marginal cost. $\gamma^{jk}$ is a product-market fixed effect. $\mathbf{x}_t^{ijk}$ is a vector of variables including indicator variables for firm $i$'s tenure with product $j$ in market $k$ as well as interactions with these variables with indicators for the length of the completed export spell.[5] The purpose of these variables is to control for systematic dynamics related to market tenure. $\mathbf{z}_t^k$ is a vector containing the log of the consumption real exchange rate with market $k$ and the log of real demand in market $k$. $low_t^{ijk}$ is an indicator variable, set equal to 1 if the firm-product-market-year has low exit

[4]Fitzgerald and Haller (2017) estimate participation responses, and find that both entry and exit are unresponsive to real exchange rates.

[5]A detailed description of these variables is provided in Fitzgerald, Haller and Yedid-Levi (2016).

probability,[6] equal to zero otherwise. The purpose of this variable is to focus on elasticities for the observations least likely to be subject to selection bias. The coefficients of interest are therefore $\boldsymbol{\beta}' + \boldsymbol{\phi}'$.

The results from estimating these equations are reported in Table 1.

Table 1: Revenue, price and quantity sensitivity to macro shocks

| | | (1) | | (2) | | (3) | |
|---|---|---|---|---|---|---|---|
| | | Revenue | | Quantity | | Price | |
| | | coeff | s.e. | coeff | s.e. | coeff | s.e. |
| Low exit prob | $rer_t^k$ | 0.44 | (0.06)** | 0.26 | (0.06)** | 0.17 | (0.04)** |
| | $dem_t^k$ | 0.45 | (0.07)** | 0.37 | (0.07)** | 0.08 | (0.04)** |
| High exit prob | $rer_t^k$ | 0.40 | (0.06)** | 0.22 | (0.06)** | 0.17 | (0.03)** |
| | $dem_t^k$ | 0.39 | (0.07)** | 0.32 | (0.07)** | 0.08 | (0.04)** |
| Export history controls | | yes | | yes | | yes | |
| Firm-product-year f.e. | | yes | | yes | | yes | |
| Product-market f.e. | | yes | | yes | | yes | |
| N | | 235,229 | | 235,229 | | 235,229 | |
| $R^2$ | | 0.75 | | 0.82 | | 0.89 | |
| $R^2$-adj | | 0.66 | | 0.75 | | 0.85 | |

Notes: Estimation method is OLS. Dependent variable is in turn log Euro revenue, log tonnes and log unit value at the level of the firm-product-market. Robust standard errors are calculated. ** indicates significance at the 5% level. * indicates significance at the 10% level.

The first point to note about these results is that the elasticity of export revenue (in domestic) currency with respect to the real exchange rate is significantly different from zero, but less than one in absolute value. This is in line with estimates based on macro data. The second point to note is that there is pricing-to-market in response to real exchange rates, because the elasticity of price in domestic currency with respect to the real exchange rate is significantly greater than zero (the elasticity of quantity with respect to the real exchange rate is equal to the revenue elasticity less the price elasticity).

These results are robust to estimation in differences, to dropping the interaction with the low exit probability indicator, to dropping controls for export histories ($\mathbf{x}_t^{ik}$), and to restricting the sample to non-Eurozone countries only. There is some heterogeneity in behavior across firms of different sizes, domestic vs foreign-owned, and across different sectors, but in the main, these differences are not statistically significant. Moreover, our estimates are in line with those reported by Berman, Martin and Mayer (2012) based on French export data.

[6] If market tenure is greater than or equal to 6 years, or if the firm-product-market triplet is present in the sample in 1996, we code it as a low exit probability observation. See Fitzgerald and Haller (2017) for the associated exit equation.

## 3.1 Interpretation

Can pricing-to-market account for the low elasticity of revenue with respect to real exchange rates? To shed some light on this, consider the following. Suppose that demand faced by firm $i$ in market $k$ at time $t$ can be written:

$$Q_t^{ik} = Q_t^k d\left(\frac{P_t^{ik*}}{P_t^{k*}}\right)\Phi_t^{ik} = Q_t^k d\left(\frac{P_t^{ik}/E_t^k}{P_t^{k*}}\right)\Phi_t^{ik}$$

where $Q_t^k$ is aggregate demand in market $k$, $P_t^{ik}$ is the price charged by firm $i$ to buyers from market $k$ expressed in home currency, $E_t^k$ is the nominal exchange rate between the home market and market $k$, $P_t^{k*}$ is the aggregate price level in market $k$ expressed in the currency of market $k$, and $\Phi_t^{ik}$ is a demand shifter idiosyncratic to firm $i$ and market $k$. Assuming that firm $i$ faces the same marginal cost $C_t^i$ for sales to buyers from all markets $k$, we can write $P_t^{ik}$ as follows:

$$P_t^{ik} = \mu_t^{ik} C_t^i$$

$\mu_t^{ik}$ is the gross markup over marginal cost. Normalizing the aggregate price level in the home market to one, we can define the real exchange rate as

$$RER_t^k = E_t^k P_t^{k*}$$

and write

$$Q_t^{ik} = Q_t^k d\left(\frac{\mu_t^{ik} C_t^i}{RER_t^k}\right)\Phi_t^{ik}$$

If we assume that the markup $\mu_t^{ik}$ may depend on the real exchange rate $RER_t^k$, but that idiosyncratic demand $\Phi_t^{ik}$ does not, we can take the partial derivative with respect to the real exchange rate to yield[7]:

$$\eta_{Q_t^{ik},RER_t^k} = \theta_t^{ik}\left(\eta_{\mu_t^{ik},RER_t^k} - 1\right)$$

where $\theta_t^{ik}$ is the price elasticity of demand, and $\eta_{Q_t^{ik},RER_t^k}$ and $\eta_{\mu_t^{ik},RER_t^k}$ denote the elasticities of quantity and markup with respect to the real exchange rate, respectively.

Now, rearranging this expression, and substituting in our estimates of the quantity and

[7] Appendix B contains the detailed derivations

markup elasticities from Table 1, we obtain

$$\theta_t^{ik} = \frac{\eta_{Q_t^{ik},RER_t^k}}{\eta_{\mu_t^{ik},RER_t^k} - 1} = \frac{0.26}{0.17 - 1} = -0.31$$

The results reported in Appendix A indicate that the implied price elasticity of demand is less than 1 for all of the cuts of the data we have tried (firm size, ownership, sector). This is not driven by our use of Irish data. If we use instead the quantity and markup elasticities in Berman, Martin and Mayer (2012), we obtain values for the price elasticity of demand in the range $[0.25, 0.55]$. A price elasticity of demand which is less than 1 is inconsistent with optimizing behavior by monopolistically competitive firms. It is also inconsistent with the price elasticity of demand implied by quantity and price elasticities with respect to tariffs (see Fitzgerald and Haller (2017) for details).

However if $\Phi_t^{ik}$ is not exogenous idiosyncratic demand, but is the outcome of optimizing behavior by firms (as in the case of customer base), then we can write:

$$\theta_t^{ik} = \frac{\eta_{Q_t^{ik},RER_t^k} - \eta_{\Phi_t^{ik},RER_t^k}}{\eta_{\mu_t^{ik},RER_t^k} - 1}$$

Therefore, as long as the elasticity of $\Phi$ with respect the real exchange rate is sufficiently negative, our estimates of quantity and markup elasticities may be consistent with a value for the price elasticity of demand that is greater than 1. Is it plausible that customer base would be decreasing in the real exchange rate? If a real exchange rate depreciation makes it more expensive to acquire customers, this could potentially be the case.

# 4 Model

We now outline a model of exporting with customer base. The basic exporter problem is introduced in Fitzgerald, Haller and Yedid-Levi (2016), where it is structurally estimated to match moments of exporter dynamics. Here we augment the model by introducing stochastic real exchange rates and foreign demand.

The key elements of the model are as follows. Firms face the same cost of production irrespective of the market they are serving. They face sunk costs of export entry at the market level and a fixed cost of participation each period. In addition, they are uncertain about their idiosyncratic demand in each market, and must participate in a market in order to learn whether their demand is high or low. Once in a market, firms can attract customers in two ways: by charging low prices, and by investing in market-specific customer base through expenditures on marketing and advertising. These investments are subject to adjustment costs. We present two versions of the model, one where expenditures on marketing and advertising are incurred in the home market, and another version where these expenditures are incurred in the foreign market.

In what follows, $i$ indexes firms, and $k$ indexes markets. Firm $i$ faces marginal cost of production $C_t^i$ units of home consumption ($P_t$ is the numeraire), and expressed in home currency. This is the same for all markets the firm serves. $C_t^i$ follows an exogenous process known to the firm and may be autocorrelated. We treat the set of firms in existence as exogenous, and focus purely on decisions related to exporting.

## 4.1 Demand

A firm's demand in market $k$ has four components. It depends on aggregate demand in market $k$, and on the consumer price of its good relative to the aggregate price level in market $k$. In addition, it depends on the fraction of customers it reaches, which is a function of its "customer base."[8] Finally, there is an idiosyncratic component to demand. To learn about this component of demand, firms must actually sell in the market. Fitzgerald, Haller and Yedid-Levi (2016) show that when own-price elasticity of demand is constant, these assumptions are consistent with stylized facts about the post-entry behavior of export quantities and prices. Based on their formulation we write demand faced by firm $i$ in market $k$ as follows:

$$Q_t^{ik} = Q_t^k \left( \frac{P_t^{ik}}{E_t^k P_t^{k*}} \right)^{-\theta} \left( D_t^{ik} \right)^{\alpha} \exp\left( \varepsilon_t^{ik} \right). \tag{2}$$

Here, $Q_t^k$ is aggregate real demand in market $k$, $E_t^k$ is the nominal exchange rate between the home market and market $k$, $P_t^{k*}$ is the aggregate price level in market $k$, expressed in country $k$'s currency, and $P_t^{ik}$ is the price the firm charges to customers from market $k$, expressed in home currency.

## 4.2 Accumulation of customer base

The general demand shifter $\Phi_t^{ik}$ is split into an exogenous idiosyncratic demand $\varepsilon_t^{ik}$ component and and endogenous state variable $D_t^{ik}$. We refer to $D_t^{ik}$ as a market specific customer base that is chosen by the firm. The assumption that $0 < \alpha < 1$ guarantees that the optimal

[8]This follows Arkolakis (2010) and Eaton, Kortum and Kramarz (2011).

customer base conditional on export participation is finite and positive. Customer base accumulates as follows:[9]

$$D_t^{ik} = (1-\delta)X_{t-1}^{ik}D_{t-1}^{ik} + A_t^{ik}, \tag{3}$$

where $X_t^{ik} \in \{0,1\}$ is an indicator for participation in market $k$ by firm $i$ at date $t$, and $A_t^{ik}$ is the increment to customer base due to marketing and advertising activities undertaken by the firm. The rate of depreciation may depend on whether or not the firm actually sells in the market in the current period. Expenditure on investment in customer base is given by $c\left(A_t^{ik}, D_t^{ik}\right)$ if costs are incurred in the home market, or $E_t^k P_t^{k*} c\left(A_t^{ik}, D_t^{ik}\right)$ if costs are incurred in the foreign market. In either case, $c(\cdot,\cdot)$ is increasing in its first argument. This formulation allows for the possibility of irreversibility and other costs of adjustment. For example, if the cost function includes irreversibility and a convex adjustment cost, then

$$c\left(D_t^{ik}, A_t^{ik}\right) = \begin{cases} A_t^{ik} + \phi\left(\frac{A_t^{ik}}{D_t^{ik}} - \delta\right)^2 D_t^{ik} & \text{if } A_t^{ik} > 0 \\ 0 & \text{otherwise.} \end{cases}$$

## 4.3 Sunk and fixed costs

In order to sell in market $k$, firm $i$ must first pay a sunk cost of entry, $S_t^{ik}$ units of home consumption. $S_t^{ik}$ is drawn i.i.d. from a fixed distribution, the same for all firms. Modeling sunk cost in this way is consistent with the fact that entry is rare, synchronization of entry across firms within a market or across markets within a firm is limited, and there is considerable overlap in the size distribution of exporters and non-exporters. There is also a per-period fixed cost of participating in a market, $F_t^{ik}$, expressed in home currency. $F_t^{ik}$ is also drawn i.i.d. from a fixed distribution, the same for all firms. It is this cost which generates export exit in the model. Specifically, we assume that both the sunk and the fixed cost follow a two-state iid process:

$$S_t^{ik} = \begin{cases} 0 & \text{with probability } \lambda \\ \infty & \text{with probability } 1-\lambda \end{cases}$$

$$F_t^{ik} = \begin{cases} F & \text{with probability } 1-\omega \\ \infty & \text{with probability } \omega \end{cases}$$

[9] This is a dynamic extension of Arkolakis (2010).

## 4.4 Information

When making choices about participation, investment, and prices or quantities, firms observe the current values of individual state variables $\left\{C_t^i, F_t^{ik}, S_t^{ik}\right\}$ and aggregate state variables $\left\{E_t^k P_t^{k*}, Q_t^k\right\}$, as well as knowing the processes from which these are drawn. They do not observe current idiosyncratic demand $\varepsilon_t^{ik}$ at the time choices are made. They know the process for $\varepsilon_t^{ik}$, and may have some additional information, $\mathbf{I}_t^{ik}$, that they use to form conditional expectations of $\varepsilon_t^{ik}$. Specifically, we assume that idiosyncratic demand has two components:

$$\varepsilon_t^{ik} = \nu^{ik} + \eta_t^{ik}$$

with $\nu^{ik} \sim N\left(0, \sigma_\nu^2\right)$, $\eta_t^{ik} = \rho \eta_{t-1}^{ik} + \zeta_t^{ik}$, and $\zeta_t^{ik} \sim N\left(0, \sigma_\eta^2\right)$. Information evolves as follows. Let $N_{t-1}^{ik}$ be an indicator variable that takes the value 0 if the firm is uninformed in market $k$ entering period $t$, and 1 if it is informed. The firm's information set $I_t^{ik}$ evolves as follows:

$$I_t^{ik} = \begin{cases} \left\{\nu^{ik}, \eta_{t-1}^{ik}\right\} & \text{if } \left\{X_{t-1}^{ik} = 1, N_{t-1}^{ik} = 1\right\} \\ \\ \emptyset & \text{if } \left\{X_{t-1}^{ik} = 0\right\} \text{ or } \left\{X_{t-1}^{ik} = 1, N_{t-1}^{ik} = 0\right\}. \end{cases} \tag{4}$$

Meanwhile, uninformed incumbents ($X_{t-1}^{ik} = 1$) become informed at the beginning of a period with probability $\gamma$. Being informed is an absorbing state, as long as the firm participates. On exit, the firm returns to an uninformed state, and loses it draws of $\nu^{ik}$ and $\eta_t^{ik}$. [10]

## 4.5 Firm's optimal program

Firms set prices rather than quantities in the face of uncertainty about the idiosyncratic component of current demand.[11] As long as the aggregate state is known at the time prices are set, it does not matter whether they are set in home or foreign currency. Because demand is CES and there are no strategic interactions with other firms, the optimal price is equal to the statically optimal markup $\left(\frac{\theta}{\theta-1}\right)$ over the marginal cost of delivery in home currency, independent of the firm's participation history, information set for idiosyncratic demand, or customer base.

Let $\tilde{\theta} = (\theta - 1)^{\theta-1} / \theta^\theta$ and let $\mathbf{Z}_t^k = \left\{E_t^k P_t^{k*}, Q_t^k\right\}$ be the vector of relevant aggregate state

[10] Fitzgerald, Haller and Yedid-Levi (2016) examine the performance of specific assumptions about how this information evolves in matching the behavior of exports.

[11] This assumption allows the model to match quantity and price as well as revenue dynamics.

variables, which follows a joint process known to all firms. We interpret $E_t^k P_t^{k*}$ as the real exchange rate between the home market and market $k$. If costs of accumulating customer base are incurred at home, assuming discounting at rate $\beta$, the intertemporal optimization problem for firm $i$ in market $k$ can be written:

$$V\left(X_{t-1}^{ik}, D_{t-1}^{ik}, \mathbf{I}_t^{ik}, F_t^{ik}, S_t^{ik}, C_t^i, \mathbf{Z}_t^k\right) =$$

$$\max_{\substack{X_t^{ik} \in \{0,1\} \\ A_t^{ik}}} \left\{ \begin{array}{c} X_t^{ik}\tilde{\theta}Q_t^k \left(E_t^k P_t^{k*}\right)^{\theta} \left(C_t^i\right)^{1-\theta} \Phi\left(D_t^{ik}\right) \mathbb{E}\left(\exp\left(\varepsilon_t^{ik}\right)|\mathbf{I}_t^{ik}\right) \\ \\ -X_t^{ik}\left(F_t^{ik} + \left(1 - X_{t-1}^{ik}\right) S_t^{ik}\right) - c\left(A_t^{ik}, D_t^{ik}\right) \\ \\ +\beta\mathbb{E}\left(V\left(X_t^{ik}, D_t^{ik}, \mathbf{I}_{t+1}^{ik}, F_{t+1}^{ik}, S_{t+1}^{ik}, C_{t+1}^i, \mathbf{Z}_{t+1}^k\right)|\mathbf{I}_t^{ik}\right) \end{array} \right\} \tag{5}$$

subject to (a) the accumulation of customer base $D_t^{ijk}$ and (b) the evolution of information $\mathbf{I}_t^{ik}$ about idiosyncratic demand. If costs are incurred in the destination market, the problem is:

$$V\left(X_{t-1}^{ik}, D_{t-1}^{ik}, \mathbf{I}_t^{ik}, F_t^{ik}, S_t^{ik}, C_t^i, \mathbf{Z}_t^k\right) =$$

$$\max_{\substack{X_t^{ik} \in \{0,1\} \\ A_t^{ik}}} \left\{ \begin{array}{c} X_t^{ijk}\tilde{\theta}Q_t^k \left(E_t^k P_t^{k*}\right)^{\theta} \left(C_t^{ij}\right)^{1-\theta} \Phi\left(D_t^{ijk}\right) \mathbb{E}\left(\exp\left(\varepsilon_t^{ijk}\right)|\mathbf{I}_t^{ijk}\right) \\ \\ -X_t^{ik}\left(F_t^{ik} + \left(1 - X_{t-1}^{ik}\right) S_t^{ik}\right) - \left(E_t^k P_t^{k*}\right) c\left(A_t^{ik}, D_t^{ik}\right) \\ \\ +\beta\mathbb{E}\left(V\left(X_t^{ik}, D_t^{ik}, \mathbf{I}_{t+1}^{ik}, F_{t+1}^{ik}, S_{t+1}^{ik}, C_{t+1}^i, \mathbf{Z}_{t+1}^k\right)|\mathbf{I}_t^{ik}\right) \end{array} \right\} \tag{6}$$

# 5 Calibration and simulation of the model

## 5.1 Functional forms and firm-level stochastic processes

Fitzgerald, Haller and Yedid-Levi (2016) fix $\{\beta, \theta, \lambda\}$ and estimate $\left\{\alpha, \delta, \phi, \sigma_\nu^2, \rho, \sigma_\eta^2, F, \omega, \gamma\right\}$ to match moments of the post-entry dynamics of export participation, export quantities and export prices. They use a bi-annual model. We use their parameter estimates, setting $\theta = 1.5$. Parameter values are reported in Table 2.

## 5.2 Aggregate shock process

The aggregate shocks that enter the firm's dynamic problem are the real exchange rate ($RER_t^k = E_t^k P_t^{k*}$) and foreign aggregate demand, $Q_t^k$. Using bi-annual data on consumption

Table 2: Parameters for simulation

| Parameter | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $\theta$ | $\beta$ | $\lambda$ | $\alpha$ | $\delta$ | $\phi$ | $\gamma$ | $\rho$ | $\sigma_\nu$ | $\sigma_\eta$ | $\frac{F}{E(R_1)}$ | $\omega$ |
| 1.5 | $1.05^{0.5}$ | 0.01 | 0.43 | 0.49 | 7.35 | 0.56 | 0.44 | 0.51 | 0.43 | 0.57 | 0.03 |

Notes: Parameters $\theta$, $\beta$ and $\lambda$ are fixed. The remaining parameters are estimated by Simulated Method of Moments to match moments of the post-entry dynamics of export participation, quantity and prices, as described in Fitzgerald, Haller and Yedid-Levi (2016).

real exchange rates and real demand relative to Irish real demand, we estimate the following vector autoregression, pooling across partner countries (indexed by $k$):

$$Y_t^k = A_k + BY_{t-1}^k + \varepsilon_t^k$$

Here, $A_k$ is a $2 \times 1$ vector of partner-specific constants, and $B$ is a $2 \times 2$ matrix of coefficients, restricted to be the same for all partner countries. The variance-covariance matrix of the fitted residuals, $\Sigma$ is also calculated. The point estimates yield

$$\begin{bmatrix} \ln\left(Q_t^k/Q_t^{IRL}\right) \\ \ln\left(E_t^{k,IRL} P_t^{k*}/P_t^{IRL}\right) \end{bmatrix} = A_k + \begin{bmatrix} 0.8419 & -0.0111 \\ 0.0230 & 0.9055 \end{bmatrix} \begin{bmatrix} \ln\left(Q_{t-1}^k/Q_{t-1}^{IRL}\right) \\ \ln\left(E_{t-1}^{k,IRL} P_{t-1}^{k*}/P_{t-1}^{IRL}\right) \end{bmatrix} + \varepsilon_t^k$$

and

$$\Sigma = \begin{bmatrix} 0.0151 & -0.0001 \\ -0.0001 & 0.0032 \end{bmatrix}$$

The point estimates of $B$ and $\Sigma$ are then used as inputs into the method proposed by Gospodinov and Lkhagvasuren (2014) for constructing a first-order Markov chain representation of a first-order vector autoregression.[12] This yields a transition matrix and corresponding vectors for relative demand and real exchange rates, $Q$ and $RER$.

## 5.3 Simulation

Given the parameters in Table 2 and the stochastic process for $\mathbf{Z}_t^k$ we can solve for the policy functions of the firm in the case where investment in customer base takes place in the home market, and in the case where investment in customer base takes place in the foreign market. We then take 100 sets of draws of the stochastic process for $\mathbf{Z}_t^k$, each of length 228,

[12] This method generalizes the Rouwenhorst approach to discretizing an AR(1) process. We use 5 states for each variable, and order relative demand first in the procedure.

corresponding to 114 "years" given that the model operates at a bi-annual frequency. We also take 5,000 draws of the processes governing idiosyncratic demand shocks, sunk and fixed costs, and the evolution of information, again with each draw of length 228.[13] We start all "firms" out of the market, and use the shock realizations combined with the policy functions to simulate their export choices. We assume that after 200 periods (100 "years") the ergodic distribution has been reached. Based on the last 28 periods, we aggregate the simulated data to an annual frequency, obtaining a 14-year panel of simulated data on firm-level exports to 100 markets.

# 6 Results

We now use the simulated data to estimate equation (1) with revenue as the dependent variable.[14] We do not include firm-year fixed effects, as there is neither cross-sectional nor time-series heterogeneity in costs. Table 3 reports the key elasticities with respect to the RER, along with the corresponding elasticities from the actual data. Note that the price elasticity of demand in the model is set equal to 1.5.

In the case where investment in customer base takes place in the home country, the elasticity of export revenue with respect to the real exchange rate is greater than the price elasticity of demand. This is because a real exchange rate depreciation increases the marginal return to investment in customer base, inducing greater investment. However, in the case where investment takes place in the foreign country, the elasticity of export revenue with respect to the real exchange rate is less than the price elasticity of demand. Although a real exchange rate depreciation increases the marginal return to investment in customer base, it also increases the cost of that investment. On balance, firms prefer to reduce investment so much that the inward shift in demand offsets the extent to which demand in the foreign market responds to lower prices. The last column of Table 3 illustrates this point: the estimated elasticity of customer base ($D$) with respect to RER is positive if investment takes place domestically, but turns negative when investment takes place in the foreign country.

It is worth noting that this model can generate much stronger responses to trade liberalizations than to movements in real exchange rates, as trade liberalizations are unlikely to drive up the cost of investing in foreign customer base.

[13] There are on average 5,000 firms in our Irish data in any given year.

[14] In our baseline model, there is no pricing-to-market by construction, so markup elasticities will be equal to zero, and revenue elasticities will equal quantity elasticities.

| Table 3: Baseline simulation results | | | | |
|---|---|---|---|---|
| | Revenue | Quantity | Price | Customer |
| Data | 0.44 | 0.26 | 0.17 | n/a |
| Inv Home | 1.76 | 1.76 | 0 | 0.26 |
| Inv Foreign | 1.37 | 1.37 | 0 | -0.13 |

Notes: Estimates of elasticities of variables with respect to the Real Exchange Rate. Coefficients from actual data are taken from Table 1. Inv Home refers to the model where investment in customer base takes place in the home markets. Inv Foreign refers to the case where investment in customer base takes place in the foreign market. $\theta = 1.5$ in all simulations.

## 6.1 Robustness: sticky prices

Our baseline analysis is unable to match the response of markups to real exchange rates. To investigate the potential contribution of price stickiness to markup adjustment and revenue responses, we modify the model. We assume that firms must choose prices and investment in customer base before they observe the current period's realization of the aggregate shocks, $\mathbf{Z}_t^k$. Under this assumption, it matters whether firms set prices in home or foreign currency.[15] We investigate what happens in both cases. Results are reported in Table 4 .

| Table 4: Simulation results: Sticky Prices | | | | |
|---|---|---|---|---|
| | Revenue | Quantity | Price | Customer |
| Data | 0.44 | 0.26 | 0.17 | n/a |
| Investment in Foreign Currency | | | | |
| Sticky Home P | 1.42 | 1.42 | 0 | -0.08 |
| Sticky Foreign P | 1.37 | 1.11 | 0.21 | -0.08 |
| Investment in Home Currency | | | | |
| Sticky Home P | 1.79 | 1.79 | 0 | 0.29 |
| Sticky Foreign P | 1.69 | 1.48 | 0.21 | 0.30 |

Notes: Estimates of elasticities of variables with respect to the Real Exchange Rate. Coefficients from actual data are taken from Table 1. Inv Home refers to the model where investment in customer base takes place in the home markets. Inv Foreign refers to the case where investment in customer base takes place in the foreign market. Sticky Home P refers to a model where the home currency price is set prior to the realization of shocks. Sticky Foreign P refers to models where the foreign currency price is set prior to the realization of shocks. $\theta = 1.5$ in all simulations.

When prices are sticky in home currency, by construction, markups do not move in response to real exchange rates. The fact that investment in customer base is chosen before the aggregate shocks are realized means that on net, there is no impact of customer base on the revenue and quantity elasticities. But when prices are sticky in foreign currency, markups adjust in response to real exchange rates as in the data. When home currency depreciates, for example, markups are higher and demand for the firm's product is lower. In cases where investment expenditure is in foreign currency, the elasticity of customer base to RER is also negative. As a result, the response of quantity is lower relative to the baseline. The results

[15]In the model, firms set real rather than nominal prices, as we do not have a separate process for the nominal exchange rate and the aggregate price level in the foreign relative to the home market.

reported at the bottom panel of Table 4 support the claim that investment expenditure in foreign currency is still key to mitigating the response of quantities.

## 7 Conclusion

In this paper, we argue that sticky prices and markup adjustment are not sufficient to account for the insensitivity of exports to real exchange rates. We show using micro data for Ireland that even conditional on the behavior of markups, export quantities are very insensitive to real exchange rates. Because these elasticities are estimated at the firm-product level, under standard assumptions about demand, they would imply a value for the price elasticity of demand inconsistent with profit maximization. We argue that this points to some kind of market-specific quantity stickiness as playing an important role in the insensitivity of exports.

We next perform a quantitative exploration of a particular model of quantity stickiness. In this model, firms invest in customer base which shifts their demand conditional on price. We show that under the assumption that investment in customer base takes place in the market in which it is accumulated, this investment falls in response to depreciations of the domestic currency against a foreign market, thus dampening the tendency of exports to increase in response to a depreciation, because costs (and prices) fall, and firms slide down their demand curve.

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# A Robustness

Table 5: Revenue, price and quantity sensitivity to macro shocks: estimation in differences

| | | (1) | | (2) | | (3) | |
|---|---|---|---|---|---|---|---|
| | | $\Delta$ ln Revenue | | $\Delta$ ln Quantity | | $\Delta$ ln Price | |
| | | coeff | s.e. | coeff | s.e. | coeff | s.e. |
| Low exit prob | $rer_t^k$ | 0.43 | (0.14)** | 0.10 | (0.14) | 0.31 | (0.08)** |
| | $dem_t^k$ | 0.39 | (0.20)* | 0.37 | (0.21)* | -0.01 | (0.11) |
| High exit prob | $rer_t^k$ | 0.25 | (0.14)* | 0.26 | (0.15)* | -0.02 | (0.08) |
| | $dem_t^k$ | 1.57 | (0.20)** | 1.49 | (0.20)** | 0.02 | (0.12) |
| Export history controls | | yes | | yes | | yes | |
| Firm-product-year f.e. | | yes | | yes | | yes | |
| Product-market f.e. | | no | | no | | no | |
| N | | 139,271 | | 138,877 | | 138,877 | |
| $R^2$ | | 0.34 | | 0.35 | | 0.31 | |
| $R^2$-adj | | 0.20 | | 0.21 | | 0.16 | |

Notes: Estimation method is OLS. Dependent variable is in turn change in log Euro revenue, log tonnes and log unit value at the level of the firm-product-market. Robust standard errors are calculated. ** indicates significance at the 5% level. * indicates significance at the 10% level.

Table 6: Revenue, price and quantity sensitivity to macro shocks: no interaction with spell length

| | (1) | | (2) | | (3) | |
|---|---|---|---|---|---|---|
| | Revenue | | Quantity | | Price | |
| | coeff | s.e. | coeff | s.e. | coeff | s.e. |
| $rer_t^k$ | 0.41 | (0.06)** | 0.24 | (0.06)** | 0.17 | (0.03)** |
| $dem_t^k$ | 0.41 | (0.07)** | 0.34 | (0.07)** | 0.08 | (0.04)** |
| Export history controls | yes | | yes | | yes | |
| Firm-product-year f.e. | yes | | yes | | yes | |
| Product-market f.e. | yes | | yes | | yes | |
| N | 235,229 | | 235,229 | | 235,229 | |
| $R^2$ | 0.75 | | 0.82 | | 0.89 | |
| $R^2$-adj | 0.66 | | 0.75 | | 0.85 | |

Notes: Estimation method is OLS. Dependent variable is in turn log Euro revenue, log tonnes and log unit value at the level of the firm-product-market. Robust standard errors are calculated. ** indicates significance at the 5% level. * indicates significance at the 10% level.

Table 7: Revenue, price and quantity sensitivity to macro shocks: no interaction with spell length, no trajectories

| | (1) | | (2) | | (3) | |
|---|---|---|---|---|---|---|
| | Revenue | | Quantity | | Price | |
| | coeff | s.e. | coeff | s.e. | coeff | s.e. |
| $rer_t^k$ | 0.54 | (0.07)** | 0.37 | (0.07)** | 0.17 | (0.03)** |
| $dem_t^k$ | 0.66 | (0.07)** | 0.58 | (0.07)** | 0.08 | (0.04)** |
| Export history controls | no | | no | | no | |
| Firm-product-year f.e. | yes | | yes | | yes | |
| Product-market f.e. | yes | | yes | | yes | |
| N | 235,229 | | 235,229 | | 235,229 | |
| $R^2$ | 0.73 | | 0.80 | | 0.89 | |
| $R^2$-adj | 0.63 | | 0.73 | | 0.85 | |

Notes: Estimation method is OLS. Dependent variable is in turn log Euro revenue, log tonnes and log unit value at the level of the firm-product-market. Robust standard errors are calculated. ** indicates significance at the 5% level. * indicates significance at the 10% level.

Table 8: Quantity sensitivity to macro shocks: Firm size

| | | (1) | | (2) | | (3) | |
|---|---|---|---|---|---|---|---|
| | | Small | | Medium | | Large | |
| | | coeff | s.e. | coeff | s.e. | coeff | s.e. |
| Low exit prob | $rer_t^k$ | 0.14 | (0.10) | 0.46 | (0.15)** | 0.20 | (0.11)* |
| | $dem_t^k$ | 0.13 | (0.12) | 0.39 | (0.16)** | 0.61 | (0.12)** |
| High exit prob | $rer_t^k$ | 0.10 | (0.10) | 0.45 | (0.15)** | 0.15 | (0.11) |
| | $dem_t^k$ | 0.10 | (0.12) | 0.33 | (0.16)** | 0.56 | (0.12)** |
| Export history controls | | yes | | yes | | yes | |
| Firm-product-year f.e. | | yes | | yes | | yes | |
| Product-market f.e. | | yes | | yes | | yes | |
| N | | 88,334 | | 53,617 | | 80,572 | |
| $R^2$ | | 0.85 | | 0.85 | | 0.80 | |
| $R^2$-adj | | 0.78 | | 0.78 | | 0.73 | |

Notes: Estimation method is OLS. Dependent variable is log tonnes at the level of the firm-product-market. Robust standard errors are calculated. ** indicates significance at the 5% level. * indicates significance at the 10% level.

Table 9: Price sensitivity to macro shocks: Firm size

| | | (1) | | (2) | | (3) | |
|---|---|---|---|---|---|---|---|
| | | Small | | Medium | | Large | |
| | | coeff | s.e. | coeff | s.e. | coeff | s.e. |
| Low exit prob | $rer_t^k$ | 0.11 | (0.05)** | 0.14 | (0.07)* | 0.23 | (0.05)** |
| | $dem_t^k$ | 0.09 | (0.06) | 0.12 | (0.07) | 0.07 | (0.06) |
| High exit prob | $rer_t^k$ | 0.12 | (0.05)** | 0.14 | (0.07)* | 0.22 | (0.05)** |
| | $dem_t^k$ | 0.09 | (0.06) | 0.12 | (0.07) | 0.07 | (0.06) |
| Export history controls | | yes | | yes | | yes | |
| Firm-product-year f.e. | | yes | | yes | | yes | |
| Product-market f.e. | | yes | | yes | | yes | |
| N | | 88,334 | | 53,617 | | 80,572 | |
| $R^2$ | | 0.92 | | 0.92 | | 0.87 | |
| $R^2$-adj | | 0.87 | | 0.88 | | 0.82 | |

Notes: Estimation method is OLS. Dependent variable is log unit value at the level of the firm-product-market. Robust standard errors are calculated. ** indicates significance at the 5% level. * indicates significance at the 10% level.

Table 10: Implied price elasticity of demand: Firm size

| | Small | Medium | Large |
|---|---|---|---|
| $\theta_t^{ik}$ | 0.16 | 0.53 | 0.26 |

Table 11: Quantity sensitivity to macro shocks: Ownership

| | | (1) Domestic | | (2) Foreign | |
|---|---|---|---|---|---|
| | | coeff | s.e. | coeff | s.e. |
| Low exit prob | $rer_t^k$ | 0.15 | (0.11) | 0.30 | (0.08)** |
| | $dem_t^k$ | 0.17 | (0.13) | 0.43 | (0.08)** |
| High exit prob | $rer_t^k$ | 0.13 | (0.11) | 0.26 | (0.08)** |
| | $dem_t^k$ | 0.14 | (0.13) | 0.38 | (0.09)** |
| Export history controls | | yes | | yes | |
| Firm-product-year f.e. | | yes | | yes | |
| Product-market f.e. | | yes | | yes | |
| N | | 82,694 | | 144,773 | |
| $R^2$ | | 0.88 | | 0.79 | |
| $R^2$-adj | | 0.82 | | 0.71 | |

Notes: Estimation method is OLS. Dependent variable is log tonnes at the level of the firm-product-market. Robust standard errors are calculated. ** indicates significance at the 5% level. * indicates significance at the 10% level.

Table 12: Price sensitivity to macro shocks: Ownership

| | | (1) Domestic | | (2) Foreign | |
|---|---|---|---|---|---|
| | | coeff | s.e. | coeff | s.e. |
| Low exit prob | $rer_t^k$ | 0.17 | (0.05)** | 0.19 | (0.04)** |
| | $dem_t^k$ | 0.15 | (0.06)** | 0.06 | (0.04) |
| High exit prob | $rer_t^k$ | 0.18 | (0.05)** | 0.18 | (0.04)** |
| | $dem_t^k$ | 0.14 | (0.06)** | 0.06 | (0.04) |
| Export history controls | | yes | | yes | |
| Firm-product-year f.e. | | yes | | yes | |
| Product-market f.e. | | yes | | yes | |
| N | | 82,694 | | 144,773 | |
| $R^2$ | | 0.94 | | 0.85 | |
| $R^2$-adj | | 0.90 | | 0.80 | |

Notes: Estimation method is OLS. Dependent variable is log unit value at the level of the firm-product-market. Robust standard errors are calculated. ** indicates significance at the 5% level. * indicates significance at the 10% level.

Table 13: Implied price elasticity of demand: Ownership

| | Domestic | Foreign |
|---|---|---|
| $\theta_t^{ik}$ | 0.18 | 0.37 |

Table 14: Quantity sensitivity to macro shocks: Industry

| | | (1) Cons food | | (2) Cons nonf nondur | | (3) Cons dur | | (4) Intermediates | | (5) Capital goods | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | coeff | s.e. | coeff | s.e. | coeff | s.e. | coeff | s.e. | coeff | s.e. |
| Low exit prob | $rer_t^k$ | 0.14 | (0.16) | 0.42 | (0.16)** | 0.13 | (0.53) | 0.30 | (0.13)** | 0.26 | (0.11)** |
| | $dem_t^k$ | 0.60 | (0.19)** | 0.11 | (0.20) | 1.50 | (0.57)** | 0.30 | (0.14)** | 0.37 | (0.11)** |
| High exit prob | $rer_t^k$ | 0.15 | (0.16) | 0.38 | (0.16)** | -0.00 | (0.53) | 0.28 | (0.13)** | 0.21 | (0.11)** |
| | $dem_t^k$ | 0.57 | (0.19)** | 0.07 | (0.20) | 1.48 | (0.57)** | 0.25 | (0.14)* | 0.31 | (0.11)** |
| Export history controls | | yes | | yes | | yes | | yes | | yes | |
| Firm-product-year f.e. | | yes | | yes | | yes | | yes | | yes | |
| Product-market f.e. | | yes | | yes | | yes | | yes | | yes | |
| N | | 41,975 | | 32,306 | | 6,753 | | 60,452 | | 84,736 | |
| $R^2$ | | 0.78 | | 0.78 | | 0.84 | | 0.84 | | 0.76 | |
| $R^2$-adj | | 0.68 | | 0.71 | | 0.73 | | 0.77 | | 0.67 | |

Notes: Estimation method is OLS. Dependent variable is log tonnes at the level of the firm-product-market. Robust standard errors are calculated. ** indicates significance at the 5% level. * indicates significance at the 10% level.

Table 15: Price sensitivity to macro shocks: Industry

| | | (1) | | (2) | | (3) | | (4) | | (5) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cons food | | Cons nonf nondur | | Cons dur | | Intermediates | | Capital goods | |
| | | coeff | s.e. | coeff | s.e. | coeff | s.e. | coeff | s.e. | coeff | s.e. |
| Low exit prob | $rer_t^k$ | 0.18 | (0.05)** | -0.01 | (0.10) | 0.26 | (0.21) | 0.19 | (0.06)** | 0.21 | (0.05)** |
| | $dem_t^k$ | 0.00 | (0.06) | 0.29 | (0.12)** | 0.14 | (0.24) | 0.22 | (0.08)** | -0.05 | (0.05) |
| High exit prob | $rer_t^k$ | 0.18 | (0.05)** | -0.02 | (0.09) | 0.28 | (0.21) | 0.18 | (0.06)** | 0.21 | (0.05)** |
| | $dem_t^k$ | 0.01 | (0.06) | 0.29 | (0.12)** | 0.15 | (0.24) | 0.21 | (0.08)** | -0.05 | (0.05) |
| Export history controls | | yes | | yes | | yes | | yes | | yes | |
| Firm-product-year f.e. | | yes | | yes | | yes | | yes | | yes | |
| Product-market f.e. | | yes | | yes | | yes | | yes | | yes | |
| N | | 41,975 | | 32,306 | | 6,753 | | 60,452 | | 84,736 | |
| $R^2$ | | 0.89 | | 0.79 | | 0.87 | | 0.91 | | 0.83 | |
| $R^2$-adj | | 0.83 | | 0.71 | | 0.79 | | 0.86 | | 0.77 | |

Notes: Estimation method is OLS. Dependent variable is log tonnes at the level of the firm-product-market. Robust standard errors are calculated. ** indicates significance at the 5% level. * indicates significance at the 10% level.

Table 16: Implied price elasticity of demand: Sector

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| $\theta_t^{ik}$ | 0.17 | 0.42 | 0.18 | 0.37 | 0.33 |

Table 17: Sensitivity to macro shocks: Split xrate

| | | (1) | | (2) | |
|---|---|---|---|---|---|
| | | Quantity | | Price | |
| | | coeff | s.e. | coeff | s.e. |
| Low exit prob | $x_t^k$ | 0.20 | (0.06)** | 0.21 | (0.03)** |
| | $p_t^k$ | 0.36 | (0.07)** | 0.12 | (0.03)** |
| | $dem_t^k$ | 0.35 | (0.07)** | 0.08 | (0.04)** |
| High exit prob | $x_t^k$ | 0.16 | (0.06)** | 0.21 | (0.03)** |
| | $p_t^k$ | 0.29 | (0.07)** | 0.14 | (0.04)** |
| | $dem_t^k$ | 0.31 | (0.07)** | 0.08 | (0.04)** |
| Export history controls | | yes | | yes | |
| Firm-product-year f.e. | | yes | | yes | |
| Product-market f.e. | | yes | | yes | |
| N | | 235,229 | | 235,229 | |
| $R^2$ | | 0.82 | | 0.89 | |
| $R^2$-adj | | 0.75 | | 0.85 | |

Notes: Estimation method is OLS. Dependent variable is log unit value at the level of the firm-product-market. Robust standard errors are calculated. ** indicates significance at the 5% level. * indicates significance at the 10% level.

Table 18: Sensitivity to macro shocks: Non-Euro countries

| | | (1) | | (2) | |
|---|---|---|---|---|---|
| | | Quantity | | Price | |
| | | coeff | s.e. | coeff | s.e. |
| Low exit prob | $rer_t^k$ | 0.30 | (0.07)** | 0.15 | (0.04)** |
| | $dem_t^k$ | 0.46 | (0.09)** | 0.10 | (0.04)** |
| High exit prob | $rer_t^k$ | 0.16 | (0.07)** | 0.14 | (0.04)** |
| | $dem_t^k$ | 0.40 | (0.09)** | 0.10 | (0.04)** |
| Export history controls | | yes | | yes | |
| Firm-product-year f.e. | | yes | | yes | |
| Product-market f.e. | | yes | | yes | |
| N | | 131,993 | | 131,993 | |
| $R^2$ | | 0.80 | | 0.86 | |
| $R^2$-adj | | 0.70 | | 0.80 | |

Notes: Estimation method is OLS. Dependent variable is log tonnes or log unit value at the level of the firm-product-market. Robust standard errors are calculated. ** indicates significance at the 5% level. * indicates significance at the 10% level.

# B Derivation of elasticities

## B.1 Implications of the estimates in a model without customer base

Start with a normalization of $P_t = 1$ so that the Real Exchange Rate is $RER_t^k = \frac{E_t^k P_t^{k*}}{P_t} = E_t^k P_t^{k*}$.

Ignoring aggregate shocks, the optimal pricing decition of a firm is a constant markup over cost:

$$Q_t^{ik} = Q_t^k d\left(\frac{P_t^{ik*}}{P_t^{k*}}\right)\Phi_t^{ik} = Q_t^k d\left(\frac{P_t^{ik}/E_t^k}{P_t^{k*}}\right)\Phi_t^{ik} = Q_t^k d\left(\frac{P_t^{ik}}{RER_t^k}\right)\Phi_t^{ik} = Q_t^k d\left(\frac{\mu_t^{ik}C_t^i}{RER_t^k}\right)\Phi_t^{ik}$$

where $\mu_t^{ik}$ is (potentially) a function of $RER_t^k$.

We want to derive the elasticity of $Q_t^{ik}$ with respect to $RER_t^k$.

$$\frac{\partial Q_t^{ik}}{\partial RER_t^k} = Q_t^k \Phi_t^{ik} d'\left(\frac{\mu_t^{ik}C_t^i}{RER_t^k}\right)\left[\frac{\frac{\partial \mu_t^{ik}}{\partial RER_t^k} C_t^i RER_t^k - \mu_t^{ik}C_t^i}{\left(RER_t^k\right)^2}\right] = Q_t^k \Phi_t^{ik} d'\left(\frac{\mu_t^{ik}C_t^i}{RER_t^k}\right)\mu_t^{ik}C_t^i\left[\frac{\frac{\partial \mu_t^{ik}}{\partial RER_t^k}\frac{RER_t^k}{\mu_t^{ik}} - 1}{\left(RER_t^k\right)^2}\right] =$$
$$Q_t^k \Phi_t^{ik} d'\left(\frac{\mu_t^{ik}C_t^i}{RER_t^k}\right)\frac{\mu_t^{ik}C_t^i}{RER_t^k}\left[\epsilon_{\mu,RER} - 1\right]\frac{1}{\left(RER_t^k\right)}$$

where $\epsilon_{\mu,RER}$ is the elasticity of the markup with respect to the real exchange rate.

Now note that the price elasticity of demand is defined as:

$$\theta_t^{ik} = \frac{\partial Q_t^{ik}}{\partial\left(\frac{P_t^{ik*}}{P_t^{k*}}\right)}\frac{\left(\frac{P_t^{ik*}}{P_t^{k*}}\right)}{Q_t^{ik}} = \frac{\partial Q_t^{ik}}{\partial\left(\frac{\mu_t^{ik}C_t^i}{RER_t^k}\right)}\frac{\left(\frac{\mu_t^{ik}C_t^i}{RER_t^k}\right)}{Q_t^{ik}}$$

implying that

$$Q_t^k \Phi_t^{ik} d'\left(\frac{\mu_t^{ik}C_t^i}{RER_t^k}\right)\frac{\mu_t^{ik}C_t^i}{RER_t^k} = \theta_t^{ik} Q_t^{ik}$$

and we can substitute:

$$\frac{\partial Q_t^{ik}}{\partial RER_t^k} = \left[\eta_{\mu,RER} - 1\right] \theta_t^{ik} \frac{Q_t^{ik}}{\left(RER_t^k\right)}$$

$$\Leftrightarrow$$

$$\eta_{Q,RER} = \frac{\partial Q_t^{ik}}{\partial RER_t^k} \frac{RER_t^k}{Q_t^{ik}} = \left[\eta_{\mu,RER} - 1\right] \theta_t^{ik}$$

where $\eta_{Q,RER}$ is the elasticity of quantitiy with respect to RER. As our point estimates are the qunatity and markup elasticities, we can infer the implied price elasticity of demand:

$$\theta_t^{ik} = \frac{\eta_{Q,RER}}{\eta_{\mu,RER} - 1} = \frac{0.26}{0.17 - 1} = -0.313$$

## B.2 Adding customer base

As before assume that demand is

$$Q_t^{ik} = Q_t^k d\left(\frac{\mu_t^{ik} C_t^i}{RER_t^k}\right) \Phi_t^{ik}$$

But now assume that $\Phi_t^{ik}$ is a function of $RER_t^k$.

In this case

$$\frac{\partial Q_t^{ik}}{\partial RER_t^k} = Q_t^k \left[ \Phi_t^{ik} d' \left( \frac{\mu_t^{ik} C_t^i}{RER_t^k} \right) \left[ \frac{\frac{\partial \mu_t^{ik}}{\partial RER_t^k} C_t^i RER_t^k - \mu_t^{ik} C_t^i}{\left( RER_t^k \right)^2} \right] + d \left( \frac{\mu_t^{ik} C_t^i}{RER_t^k} \right) \frac{\partial \Phi_t^{ik}}{\partial RER_t^k} \right]$$

$$= Q_t^k \left[ \Phi_t^{ik} d' \left( \frac{\mu_t^{ik} C_t^i}{RER_t^k} \right) \mu_t^{ik} C_t^i \left[ \frac{\frac{\partial \mu_t^{ik}}{\partial RER_t^k} \frac{RER_t^k}{\mu_t^{ik}} - 1}{\left( RER_t^k \right)^2} \right] + d \left( \frac{\mu_t^{ik} C_t^i}{RER_t^k} \right) \frac{\partial \Phi_t^{ik}}{\partial RER_t^k} \right]$$

$$= Q_t^k \left[ \Phi_t^{ik} d' \left( \frac{\mu_t^{ik} C_t^i}{RER_t^k} \right) \frac{\mu_t^{ik} C_t^i}{RER_t^k} \left[ \eta_{\mu,RER} - 1 \right] \frac{1}{\left( RER_t^k \right)} + d \left( \frac{\mu_t^{ik} C_t^i}{RER_t^k} \right) \frac{\partial \Phi_t^{ik}}{\partial RER_t^k} \right]$$

$$= Q_t^k \frac{\Phi_t^{ik}}{\left( RER_t^k \right)} \left[ d' \left( \frac{\mu_t^{ik} C_t^i}{RER_t^k} \right) \frac{\mu_t^{ik} C_t^i}{RER_t^k} \left[ \eta_{\mu,RER} - 1 \right] + d \left( \frac{\mu_t^{ik} C_t^i}{RER_t^k} \right) \frac{\partial \Phi_t^{ik}}{\partial RER_t^k} \frac{RER_t^k}{\Phi_t^{ik}} \right]$$

$$= Q_t^k \frac{\Phi_t^{ik}}{\left( RER_t^k \right)} \left[ d' \left( \frac{\mu_t^{ik} C_t^i}{RER_t^k} \right) \frac{\mu_t^{ik} C_t^i}{RER_t^k} \left[ \eta_{\mu,RER} - 1 \right] + d \left( \frac{\mu_t^{ik} C_t^i}{RER_t^k} \right) \eta_{\Phi,RER} \right]$$

$$= Q_t^k \frac{\Phi_t^{ik}}{\left( RER_t^k \right)} d \left( \frac{\mu_t^{ik} C_t^i}{RER_t^k} \right) \left[ \frac{d' \left( \frac{\mu_t^{ik} C_t^i}{RER_t^k} \right) \frac{\mu_t^{ik} C_t^i}{RER_t^k} \left[ \epsilon_{\mu,RER} - 1 \right]}{d \left( \frac{\mu_t^{ik} C_t^i}{RER_t^k} \right)} + \eta_{\Phi,RER} \right]$$

$$\Leftrightarrow$$

$$\frac{\partial Q_t^{ik}}{\partial RER_t^k} \frac{RER_t^k}{Q_t^{ik}} = \left[ \frac{d' \left( \frac{\mu_t^{ik} C_t^i}{RER_t^k} \right) \frac{\mu_t^{ik} C_t^i}{RER_t^k} \left[ \eta_{\mu,RER} - 1 \right]}{d \left( \frac{\mu_t^{ik} C_t^i}{RER_t^k} \right)} + \eta_{\Phi,RER} \right]$$

and note that the price elasticity of demand is

$$\theta_t^{ik} = \frac{d' \left( \frac{\mu_t^{ik} C_t^i}{RER_t^k} \right) \frac{\mu_t^{ik} C_t^i}{RER_t^k}}{d \left( \frac{\mu_t^{ik} C_t^i}{RER_t^k} \right)}$$

therefore we have:

$$\eta_{Q,RER} = \theta_t^{ik} \left[ \eta_{\mu,RER} - 1 \right] + \eta_{\Phi,RER}$$

$$\Leftrightarrow$$

$$\theta_t^{ik} = \frac{\eta_{Q,RER} - \eta_{\Phi,RER}}{\eta_{\mu,RER-1}}$$