Can Sticky Quantities Explain Export Insensitivity to Exchange Rates?*

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Abstract

Why are trade flows insensitive to movements in real exchange rates? We use micro data on exports for Ireland to show that this insensitivity persists at the firm level, and sticky prices and markup adjustment cannot explain it: some quantity stickiness is also necessary. We propose customer base as a potential source of quantity stickiness. We show using a quantitative model of customer base that if costs of accumulating customer base are incurred in the foreign market, firms will choose to cut back on foreign customer base just when the home currency depreciates. This explanation is consistent with the fact that exports are more responsive to tariffs than to real exchange rates, as tariff changes are unlikely to affect costs of accumulating customer base.

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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 and tariffs, after conditioning on marginal cost. Prices 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 0.18, implying relatively large movements in destination currency prices in response to real exchange rates (passthrough is 0.82). However export quantities are very insensitive to movements in real exchange rates: the elasticity of export quantities with respect to real exchange rates is 0.32. The elasticity of export revenue with respect to real exchange rates is 0.5, the sum of price and quantity responses. Interestingly, export responses to tariffs are quite different, although in principle, real exchange rates and tariffs should shift the relative prices faced by buyers in a similar way. Export quantities are quite sensitive to tariffs: the elasticity of export quantities with respect to tariff changes is -3.10, while there is no pricing-to-market in response to tariff changes, so revenue inherits this elasticity. This adds up to quite different elasticities of export revenue with respect to real exchange rates and tariffs.

Can differences in pricing-to-market explain differences in revenue responses, and in particular the insensitivity of exports to real exchange rates? Under standard assumptions about demand, and ignoring a possible role for customer base, the estimated elasticities with respect to real exchange rates imply a price elasticity of demand of 0.39. This is well below reasonable values for the price elasticity of demand, which should be above 1 for a monopolist to be profit-maximizing. In contrast, since there is no pricing-to-market in response to tariff changes, in the absence of changes in customer base the price elasticity of demand is equal to the absolute value of the quantity elasticity, i.e. 3.10. This suggests that sticky prices and markup adjustment alone cannot explain why exports are so insensitive to real exchange rates.

We argue, however, that customer base can generate quantity stickiness in response to real exchange rates, and potentially drive a substantial wedge between quantity responses to real exchange rates and tariffs. Suppose that demand does indeed depend on customer base, and that this customer base is accumulated through expenditures an marketing and advertising. 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. This will happen if the costs of investment in customer base are incurred in the foreign market. Of course in this case, a sufficiently broad-based episode of tariff reductions if anything reduces costs of accumulating customer base in the foreign market, which would magnify export responses to tariff changes. Meanwhile a more narrrow tariff reduction leaves this cost largely unaffected, still contrasting with the real exchange rate impact.

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 (2017) to match facts about steady state exporter dynamics. We confront it with a joint process for real exchange rates and foreign demand estimated from data. We also confront it with a tariff reduction that resembles the trade liberalization observed in our data. We simulate a panel of synthetic data based on the shock processes 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, under the assumption that costs of investing in customer base are insensitive to tariffs, 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, and also tariffs. The fourth section describes our model of frictions in adjusting customer base. The fifth section describes our shock processes, and how we 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

[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.

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 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.

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

[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.

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 30 export markets which account for 94% of Irish merchandise exports over the sample period. The markets are: Australia, Austria, Belgium, Brazil, Canada, China, Denmark, Finland, France, Germany, Hong Kong, India, Italy, Japan, Malaysia, Mexico, Netherlands, New Zealand, Norway, Portugal, Saudi Arabia, 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 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 (2018).

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.

2.3 Tariff data

We also make use of data on tariffs faced by Irish firms in the 30 markets of interest. These data are obtained from the WTO and other sources. Tariff data are reported by the WTO using the Harmonized System (HS) 6-digit classification. We restrict attention to HS6 product-market-years for which there are no non-ad-valorem tariffs,[4] and for which there is no sub-HS6 variation in ad valorem tariffs. The HS6 classification changes in 2002 and 2007. We concord the classification over the period 1996-2009 following the approach of Pierce and Schott (2012). When this implies joining multiple HS6 categories together in a given period, we take the simple average of tariffs to construct tariffs at the concorded product-market-year level. To make use of the tariff data, we must also concord it with our export data. At a 6-digit level, the CN (export) classification corresponds to the HS classification. In some cases, our concordance of the CN classification oveer time results in "products" that cover multiple HS6 categories. We use revenue at the firm-HS6-market-year level to construct a weighted average of tariffs across the relevant HS6 categories. Full details of the data sources and construction are provided in the appendix to Fitzgerald and Haller (2018).

3 Firm responses to real exchange rates, foreign demand and tariffs

We now use these data to estimate the elasticity of firm-product-market-level export revenue, quantity and price to real exchange rates, foreign demand and tariffs. We focus on the intensive margin of responses.[5] Our baseline estimating equation is:

$$w_t^{ijk} = c_t^{ij} + \gamma^{jk} + \boldsymbol{\lambda}'\mathbf{a}_t^{ijk} + \boldsymbol{\beta}'\left(\mathbf{z}_t^{jk} * long_t^{ijk}\right) + \boldsymbol{\phi}'\left(\mathbf{z}_t^{jk} * short_t^{ijk}\right) + \varepsilon_t^{ijk} \qquad (1)$$

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. γ^{jk} is a product-market fixed effect. $\mathbf{a}_t^{ijk}$ is a vector of indicator variables for export history, i.e. a set of indicator variables for the number of years since the most recent export entry (topcoded at 7 years), as well as an indicator for whether export entry is censored by the beginning of the sample. This vector captures not just the causal relationship between export histories

[4] Unlike ad-valorem tariffs, non-ad-valorem tariffs affect incentives to export differently depending on the firm's export price.

[5] Fitzgerald and Haller (2018) estimate participation responses, and find that both entry and exit are unresponsive to real exchange rates, while they are somewhat responsive to tariffs.

and revenue, but also the impact of persistent heterogeneity in idiosyncratic demand.[6] $\mathbf{z}_t^{jk}$ is a vector, the elements of which are rer_t^k, which is the log of an index of the real exchange rate between the home market and market k, dem_t^k, which is the log of an index of real aggregate demand in market k, and $\tau_t^{jk} = \ln\left(1 + T_t^{jk}\right)$, which is the log gross ad valorem tariff faced by a firm exporting product j to market k. Finally, $long_t^{ijk}$ (for long export tenure) is an indicator variable, set equal to 1 for observations where market tenure is at least 6 years as well as observations in export spells whose entry is censored, and equal to zero otherwise, while $short_t^{ijk}$ is equal to $1 - long_t^{ijk}$.[7] The purpose of this variable is to focus on elasticities for the observations least likely to be subject to selection bias by virtue of the fact that they have low exit probability.[8] The coefficients of interest are therefore $\boldsymbol{\beta}'$.

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

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

		(1)		(2)		(3)	
		Revenue		Quantity		Price	
		coeff	s.e.	coeff	s.e.	coeff	s.e.
Low exit prob	rer_t^k	0.50	(0.08)**	0.32	(0.09)**	0.18	(0.04)**
	dem_t^k	0.43	(0.09)**	0.35	(0.09)**	0.08	(0.05)*
	τ_t^{jk}	-3.13	(0.65)**	-3.10	(0.67)**	-0.02	(0.35)
High exit prob	rer_t^k	0.47	(0.08)**	0.29	(0.09)**	0.17	(0.04)**
	dem_t^k	0.34	(0.09)**	0.26	(0.09)**	0.08	(0.05)*
	τ_t^{jk}	0.81	(0.56)	0.62	(0.54)	0.19	(0.31)
Export history controls		yes		yes		yes	
Firm-product-year f.e.		yes		yes		yes	
Product-market f.e.		yes		yes		yes	
N		184,890		184,890		184,890	
R^2		0.77		0.83		0.91	
R^2-adj		0.68		0.76		0.87	

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). The third point to

[6] A detailed description of these variables is provided in Fitzgerald and Haller (2018).

[7] Since $long_t^{ijk}$ and $short_t^{ijk}$ are linear combinations of $\mathbf{a}_t^{ijk}$, their level effects are captured by the inclusion of $\mathbf{a}_t^{ijk}$ in the regression.

[8] Fitzgerald and Haller (2018) for the associated exit equation.

note is that the elasticity of export revenue with respect to tariffs is negative, significantly different from zero, and significantly greater than one in absolute value. However there is no pricing-to-market in response to tariffs.

Responses to exchange rates are broadly robust to estimation in differences, to dropping the interaction with the low exit probability indicator, and to dropping controls for export histories ($\mathbf{x}_t^{ik}$).[9] Responses to tariffs are sensitive to these changes, in the sense that under alternative specifications, responses are not significantly different from zero. This is not surprising given that selection bias is more likely for tariffs, and there is less underlying year-to-year variation in tariffs than in real exchange rates. 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 of coefficients on real exchange rates are in line with those reported by Berman, Martin and Mayer (2012) based on French export data.

3.1 Interpretation

Can pricing-to-market account for the low elasticity of revenue with respect to real exchange rates, which contrasts with the high elasticity of revenue with respect to tariffs? 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:

$$Q_t^{ik} = Q_t^k d\left(\frac{P_t^{ik*}}{P_t^{k*}}\right)\Phi_t^{ik} = Q_t^k d\left(\frac{\left(1+\tau_t^{ik}\right)P_t^{ik}/E_t^k}{P_t^{k*}}\right)\Phi_t^{ik}$$

where Q_t^k is aggregate demand in market k, τ_t^{ik} is the ad valorem tariff firm i faces in that market, 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 Φ_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:

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

[9] All of the robustness checks are reported in the Appendix.

where μ_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

$$Q_t^{ik} = Q_t^k d \left(\frac{\left(1+\tau_t^{ik}\right) \mu_t^{ik} C_t^i}{RER_t^k} \right) \Phi_t^{ik} \tag{2}$$

If we assume that the markup μ_t^{ik} may depend on the real exchange rate RER_t^k, but that idiosyncratic demand Φ_t^{ik} does not, we can take the partial derivative with respect to the real exchange rate to yield[10]:

$$\eta_{Q_t^{ik},RER_t^k} = \theta_t^{ik} \left(\eta_{\mu_t^{ik},RER_t^k} - 1 \right) \tag{3}$$

where θ_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 markup elasticities from Table 1, we obtain

$$\theta_t^{ik} = \frac{\eta_{Q_t^{ik},RER_t^k}}{\eta_{\mu_t^{ik},RER_t^k} - 1} = \frac{0.32}{0.18 - 1} = -0.39$$

This value is clearly less than one.[11] 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 $[0.25, 0.55]$. In contrast to research that makes use of macro data, these elasticities are based on firm-level data, so this low value cannot be an artifact of aggregation. Note that a price elasticity of demand which is less than 1 is inconsistent with optimizing behavior by monopolistically competitive firms.

Now a similar expression to (3) can be derived in the case of ad valorem tariffs:

$$\eta_{Q_t^{ik},1+\tau_t^{jk}} = \theta_t^{ik} \left(\eta_{\mu_t^{ik},1+\tau_t^{jk}} + 1 \right)$$

[10] Appendix B contains the detailed derivations

[11] Since quantity and revenue elasticities are estimated, and the price elasticity of demand is therefore a nonlinear function of random variables, strictly speaking we should use the Delta method. This yields a range of $[-0.39, 0.40]$, depending on the assumed correlation between the two random variables. The value is always significantly greater than zero and significantly less than one. Details are reported in the Appendix.

where $\eta_{Q_t^{ik},1+\tau_t^{jk}}$ and $\eta_{\mu_t^{ik},1+\tau_t^{jk}}$ denote the elasticities of quantity and markup with respect to the tariff, respectively. Again rearranging and substituting in our estimates of the relevant elasticities from Table 1, we obtain[12]

$$\theta_t^{ik} = \frac{\eta_{Q_t^{ik},1+\tau_t^{jk}}}{\eta_{\mu_t^{ik},1+\tau_t^{jk}} + 1} = \frac{-3.10}{-0.02+1} = -3.16$$

There is an order of magnitude in the difference between the elasticity of demand based on tariff variation and that based on real exchange rate variation. This is despite the fact that the underlying quantity and markup elasticities are obtained using the same firms, and shocks to real exchange rates and tariffs at the same frequency (i.e. annual). Clearly, the fact that there is pricing-to-market in response to real exchange rate shocks, but not in response to tariff shocks, is not sufficient to account for the difference in revenue elasticities.

We propose the following potential resolution of this puzzle. If Φ_t^{ik} is not exogenous idiosyncratic demand, but is the outcome of optimizing behavior by firms (as in the case of endogenously accumulated customer base), then we obtain:

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

Therefore, as long as the elasticity of Φ 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 (2017), 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 (and changes in tariffs).

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

[12] Values calculated using the delta method and associated standard errors are reported in the Appendix.

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. 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."[13] 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 (2017) 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:

$$Q_t^{ik} = Q_t^k \left(\frac{\left(1 + \tau_t^{ik}\right) P_t^{ik}}{E_t^k P_t^{k*}} \right)^{-\theta} \left(D_t^{ik}\right)^{\alpha} \exp\left(\varepsilon_t^{ik}\right). \tag{4}$$

Here, Q_t^k is aggregate real demand in market k, τ_t^{ik} is the ad valorem tariff firm i faces 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.

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

4.2 Accumulation of customer base

The general demand shifter Φ_t^{ik} is split into an exogenous idiosyncratic demand component, ε_t^{ik}, 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 customer base conditional on export participation is finite and positive. Customer base accumulates as follows:[14]

$$D_t^{ik} = (1-\delta) X_{t-1}^{ik} D_{t-1}^{ik} + A_t^{ik}, \tag{5}$$

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 of customer base depends on whether or not the firm actually sells in the market in the current period: there is full depreciation on exit. Expenditure on investment in customer base depends on the function $c\left(A_t^{ik}, D_t^{ik}\right)$:

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

This formulation includes irreversibility and a convex adjustment cost. If costs are incurred in the home market, expenditure on investment in customer base expressed in terms of the (home country) numeraire is given by $c\left(A_t^{ik}, D_t^{ik}\right)$. If costs are incurred in the foreign market, it is given by $E_t^k P_t^{k*} c\left(A_t^{ik}, D_t^{ik}\right)$. If implemented as part of a broad-based trade liberalization, lower tariffs might result in a slightly lower foreign price level P_t^{k*}. However we believe this effect is likely to be of second order importance.[15]

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

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

[15] If present, such an effect would magnify the difference in responses to real exchange rates and tariffs we obtain below.

exit in the model. Specifically, we assume that both the sunk and the fixed cost follow a two-state iid process:

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

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

4.4 Information

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

$$I_t^{ik} = \begin{cases} \left\{\nu^{ik}, \eta_{t-1}^{ik}\right\} & \text{if } \left\{X_{t-1}^{ik} = 1, N_{t-1}^{ik} = 1\right\} \\ \\ \emptyset & \text{if } \left\{X_{t-1}^{ik} = 0\right\} \text{ or } \left\{X_{t-1}^{ik} = 1, N_{t-1}^{ik} = 0\right\}. \end{cases} \tag{6}$$

Meanwhile, uninformed incumbents ($X_{t-1}^{ik} = 1$) become informed at the beginning of a period with probability γ. 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 ν^{ik} and η_t^{ik}. [16]

As regards the aggregate state variables $\left\{E_t^k P_t^{k*}, Q_t^k, \tau_t^{ik}\right\}$, we consider several cases, in particular for macro shocks. We consider the case where firms observe current realizations $\left\{E_t^k P_t^{k*}, Q_t^k\right\}$ before making choices, and the case where firms observe only the previous

[16] Fitzgerald, Haller and Yedid-Levi (2017) examine the performance of specific assumptions about how this information evolves in matching the behavior of exports.

period's realizations $\left\{E^k_{t-1}P^{k*}_{t-1}, Q^k_{t-1}\right\}$, and must use this information together with what they know about the joint process for these shocks in order to form expectations. With respect to tariffs, we describe our experiment in detail below, including what firms know, and when they know it.

4.5 Price setting

We assume that in the face of uncertainty (about idiosyncratic demand, and potentially also macro shocks), firms set prices rather than quantities. If the real exchange rate at time t is known at the time date-t prices are set, the optimal price (in terms of the numeraire) is the usual markup over marginal cost:

$$P^{ik}_t = \frac{\theta}{\theta - 1} C^i_t$$

On the other hand, if the real exchange rate at time t is not known at the time date-t prices are set, it matters whether firms set their relative price in the home market, or set their relative price in the foreign market.[17] If they set their relative price in the home market, they choose:

$$P^{ik}_t = \frac{\theta}{\theta - 1} C^i_t$$

If they set their relative price in the foreign market, they choose:

$$\frac{P^{ik*}_t}{P^{k*}_t} = \frac{\theta}{\theta - 1} \frac{C^i_t}{\mathbb{E}\left(E^k_t P^{k*}_t\right)}$$

5 Calibration and simulation of the model

5.1 Functional forms and firm-level stochastic processes

Fitzgerald, Haller and Yedid-Levi (2017) fix $\{\beta, \lambda\}$ and estimate $\left\{\alpha, \delta, \phi, \sigma^2_\nu, \rho, \sigma^2_\eta, F, \omega, \gamma\right\}$ to match moments of the post-entry dynamics of export participation, export quantities and export prices using a bi-annual model. They do not estimate a process for marginal cost, as their estimation approach relies on moments which are conditional on marginal cost, and they do not estimate θ as it is not identified in the model. We use their parameter estimates, setting $\theta = 1.5$. Parameter values are reported in Table 2.

[17] 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.

Table 2: Parameters for simulation

Parameter											
θ	β	λ	α	δ	ϕ	γ	ρ	σ_ν	σ_η	$\frac{F}{E(R_1)}$	ω
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 θ, β and λ 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 (2017).

5.2 Aggregate shock processes

The aggregate shocks that enter the firm's dynamic problem are the real exchange rate ($RER_t^k = E_t^k P_t^{k*}$), foreign aggregate demand, Q_t^k, and the tariff τ_t^{ik}. We consider macro shocks and tariff shocks in two separate exercises.

For macro shocks, we use bi-annual data on consumption real exchange rates and real demand relative to Irish real demand to 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 2×1 vector of partner-specific constants, and B is a 2×2 matrix of coefficients, restricted to be the same for all partner countries. The variance-covariance matrix of the fitted residuals, Σ is also calculated. The point estimates yield

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

and

$$\Sigma = \left[\begin{array}{cc} 0.0151 & -0.0001 \\ -0.0001 & 0.0032 \end{array} \right]$$

The point estimates of B and Σ 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.[18] This yields a transition matrix and corresponding vectors for relative demand and real exchange rates, Q and RER.

For tariff shocks, we consider the following exercise, designed to mimic the trade liberal-

[18]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.

ization associated with the Uruguay Round which we use to identify firm-level responses to tariffs. We assume that for some long period of time, ad valorem tariffs are 5% in all export markets, and are expected to remain constant at this level. At some date t, it is announced unexpectedly that the tariff will fall from 5% to 0, with this being phased in over a period of 10 years such that the tariff falls by 0.5% each year. At the end of this liberalization, firms believe that tariffs will remain at 0 forever.

5.3 Simulation

Given the parameters in Table 2, the process for the relevant shocks, the relevant assumptions about where investment in customer base takes place, what firms know when they make choices, and what choices they make, we can solve for the policy functions of the firm.

For the macro shocks, we then take 100 sets of draws of the stochastic process, each of length 240, corresponding to 120 "years" given that the model operates at a bi-annual frequency. Each of these 100 draws corresponds to a "market." 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 240.[19] We start all "firms" out of the relevant "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 40 periods, we aggregate the simulated data to an annual frequency, obtaining a 20-year panel of simulated data on firm-level exports to 100 markets.

For the tariff experiment, we take 100*5000 draws of the processes governing idiosyncratic demand shocks, sunk and fixed costs, and the evolution of information, again with each draw of length 240. We start all "firms" out of the export "market," and use the shock realizations combined with the policy functions to simulate their export choices. We assume that for the first 200 periods (100 "years") the tariff firms face is 5% and this is believed to last forever. At date 201, the tariff reduction is announced. Based on the last 40 periods, we aggregate the simulated data to an annual frequency, obtaining a 20-year panel of simulated data on firm-level exports.

6 Simulation results

We now use the simulated data from the various different models and the two sets of shocks to estimate equation (1) with revenue, quantity and price in turn as the dependent variable.

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

We do not include firm-year fixed effects, as there is neither cross-sectional nor time-series heterogeneity in costs. Table 3 reports the elasticities with respect to the RER for the range of models considered, along with the corresponding elasticities from the actual data. Table 4 reports the elasticities with resepect to the tariff. Note that the price elasticity of demand in each 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, under all models of pricing. 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, under all models of pricing. 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.

Responses also differ depending on the model of pricing. When prices are flexible, and when prices are pre-set in the home market, by construction, markups do not move in response to real exchange rates. When prices are pre-set in the foreign market, markups do move, and indeed, markup elasticities are quite close to those in the data. Revenue and quantity elasticities are lower in the case where there is markup adjustment than when there is not. However changing where investment in customer base takes place contributes more to reducing these elasticities than markup adjustment does.

Turning to the tariff elasticities in Table 4, we see that this model generates much stronger responses of quantities and revenues to the tariff shock than it does to real exchange rates. This is because the response of customer base is much stronger than it is in the case of the real exchange rate shock. This is partly due to the fact that the shock does not affect the cost of accumulating customer base and partly due to the very different process for tariffs compared to real exchange rates. Note that this arises out of the fact that investment in customer base is a dynamic rather than a static decision in our model.

Table 3: Simulation results: RER elasticities

	Revenue	Quantity	Price	Customer Base	θ
			Data		
	0.50	0.32	0.18	n/a	n/a
			Model		
Price sticky in	Investment in home market				
Foreign	1.69	1.48	0.21	0.30	1.5
Home	1.79	1.79	0.00	0.29	1.5
Flexible price	1.76	1.76	0.00	0.26	1.5
Price sticky in	Investment in foreign market				
Foreign	1.31	1.11	0.21	-0.08	1.5
Home	1.42	1.42	0.00	-0.08	1.5
Flexible price	1.37	1.37	0.00	-0.13	1.5

Notes: Estimates of elasticities of variables with respect to the real exchange rate. Elasticities with respect to demand are reported in the Appendix. Coefficients from actual data are taken from Table 1. $\theta = 1.5$ in all simulations.

Table 4: Simulation results: RER elasticities

	Revenue	Quantity	Price	Customer Base	θ
			Data		
	-3.12	-3.10	-0.02	n/a	n/a
			Model		
Flexible price	-2.37	-2.37	0.00	-0.87	1.5

Notes: Estimates of elasticities of variables with respect to the tariff. Coefficients from actual data are taken from Table 1. $\theta = 1.5$ in all simulations.

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. There is still a role for markup adjustment to play in explaining revenue and quantity insensitivity to real exchange rates. But this role is quantitatively small relative to the customer base channel. Moreover, the customer base channel does a good job of explaining different responses of exports to tariffs vs real exchange rates.

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A Robustness

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

		(1)		(2)		(3)	
		Δ ln Revenue		Δ ln Quantity		Δ ln Price	
		coeff	s.e.	coeff	s.e.	coeff	s.e.
Low exit prob	rer_t^k	0.48	(0.17)**	0.07	(0.17)	0.38	(0.09)**
	dem_t^k	0.65	(0.25)**	0.64	(0.26)**	-0.02	(0.14)
	τ_t^{jk}	-0.54	(1.60)	-0.71	(1.64)	-0.21	(0.86)
High exit prob	rer_t^k	0.19	(0.20)	0.14	(0.20)	0.04	(0.11)
	dem_t^k	1.07	(0.28)**	1.10	(0.27)**	-0.04	(0.16)
	τ_t^{jk}	0.80	(1.55)	0.74	(1.71)	-0.16	(1.09)
Export history controls		yes		yes		yes	
Firm-product-year f.e.		yes		yes		yes	
Product-market f.e.		no		no		no	
N		113,843		113,556		113,556	
R^2		0.38		0.39		0.35	
R^2-adj		0.22		0.24		0.19	

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	0.47	(0.08)**	0.30	(0.09)**	0.17	(0.04)**
dem_t^k	0.40	(0.09)**	0.32	(0.09)**	0.08	(0.05)*
τ_t^{jk}	-0.37	(0.53)	-0.50	(0.53)	0.12	(0.29)
Export history controls	yes		yes		yes	
Firm-product-year f.e.	yes		yes		yes	
Product-market f.e.	yes		yes		yes	
N	184,890		184,890		184,890	
R^2	0.77		0.83		0.91	
R^2-adj	0.68		0.76		0.87	

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	0.53	(0.09)**	0.35	(0.09)**	0.18	(0.04)**
dem_t^k	0.56	(0.09)**	0.48	(0.10)**	0.08	(0.05)*
τ_t^{jk}	-0.37	(0.55)	-0.49	(0.54)	0.12	(0.29)
Export history controls	no		no		no	
Firm-product-year f.e.	yes		yes		yes	
Product-market f.e.	yes		yes		yes	
N	184,890		184,890		184,890	
R^2	0.75		0.82		0.91	
R^2-adj	0.65		0.74		0.87	

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	0.17	(0.14)	0.44	(0.20)**	0.32	(0.15)**
	dem_t^k	0.08	(0.15)	0.37	(0.21)*	0.61	(0.17)**
	τ_t^{jk}	-0.18	(1.39)	-4.97	(1.50)**	-4.20	(1.10)**
High exit prob	rer_t^k	0.13	(0.14)	0.43	(0.20)**	0.29	(0.15)*
	dem_t^k	0.03	(0.15)	0.33	(0.16)**	0.54	(0.17)**
	τ_t^{jk}	1.08	(1.11)	-0.60	(1.22)	0.47	(0.91)
Export history controls		yes		yes		yes	
Firm-product-year f.e.		yes		yes		yes	
Product-market f.e.		yes		yes		yes	
N		70,357		43,428		61,752	
R^2		0.86		0.85		0.82	
R^2-adj		0.79		0.78		0.75	

Notes: Small: <100 employees. Medium: 100-249 employees. Large: 250+ employees. 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	0.14	(0.07)**	0.20	(0.09)**	0.19	(0.08)**
	dem_t^k	0.17	(0.07)**	0.06	(0.10)	0.05	(0.09)
	τ_t^{jk}	0.40	(0.74)	-0.24	(0.61)	0.16	(0.60)
High exit prob	rer_t^k	0.14	(0.07)**	0.21	(0.09)**	0.18	(0.08)**
	dem_t^k	0.17	(0.07)**	0.07	(0.10)	0.05	(0.09)
	τ_t^{jk}	0.13	(0.55)	0.75	(0.65)	-0.46	(0.54)
Export history controls		yes		yes		yes	
Firm-product-year f.e.		yes		yes		yes	
Product-market f.e.		yes		yes		yes	
N		70,357		43,428		61,752	
R^2		0.92		0.93		0.89	
R^2-adj		0.89		0.89		0.84	

Notes: Small: <100 employees. Medium: 100-249 employees. Large: 250+ employees. 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
rer_t^k	0.20	0.55	0.40
τ_t^{jk}	0.13	6.54	3.62

Table 11: Quantity sensitivity to macro shocks: Ownership

		(1)		(2)	
		Domestic		Foreign	
		coeff	s.e.	coeff	s.e.
Low exit prob	rer_t^k	0.05	(0.14)	0.42	(0.11)**
	dem_t^k	0.14	(0.16)	0.42	(0.12)**
	τ_t^{jk}	-0.72	(1.30)	-3.60	(0.78)**
High exit prob	rer_t^k	0.04	(0.14)	0.39	(0.11)**
	dem_t^k	0.07	(0.16)	0.34	(0.12)**
	τ_t^{jk}	1.64	(1.22)	0.52	(0.65)
Export history controls		yes		yes	
Firm-product-year f.e.		yes		yes	
Product-market f.e.		yes		yes	
N		68,595		110,572	
R^2		0.88		0.80	
R^2-adj		0.82		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 12: Price sensitivity to macro shocks: Ownership

		(1)		(2)	
		Domestic		Foreign	
		coeff	s.e.	coeff	s.e.
Low exit prob	rer_t^k	0.27	(0.06)**	0.16	(0.05)**
	dem_t^k	0.12	(0.07)**	0.08	(0.06)
	τ_t^{jk}	-0.17	(0.74)	-0.04	(0.40)
High exit prob	rer_t^k	0.28	(0.06)**	0.15	(0.05)**
	dem_t^k	0.13	(0.07)*	0.07	(0.06)
	τ_t^{jk}	-0.16	(0.65)	0.05	(0.38)
Export history controls		yes		yes	
Firm-product-year f.e.		yes		yes	
Product-market f.e.		yes		yes	
N		68,595		110,572	
R^2		0.94		0.87	
R^2-adj		0.91		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 13: Implied price elasticity of demand: Ownership

θ_t^{ik}	Domestic	Foreign
rer_t^k	0.07	0.50
τ_t^{jk}	0.87	3.75

Table 14: Quantity sensitivity to macro shocks: Industry

		(1)		(2)		(3)		(4)		(5)	
		Cons food		Cons nonf nondur		Cons durables		Intermediates		Capital goods	
		coeff	s.e.	coeff	s.e.	coeff	s.e.	coeff	s.e.	coeff	s.e.
Low exit prob	rer_t^k	-0.17	(0.19)	0.58	(0.23)**	-0.36	(0.78)	0.28	(0.17)*	0.48	(0.14)**
	dem_t^k	0.27	(0.23)	0.18	(0.25)	1.76	(0.80)**	0.32	(0.19)	0.36	(0.15)**
	τ_t^{jk}	-1.24	(1.54)	-3.11	(1.60)*	-1.89	(4.60)	-3.21	(1.27)**	-3.21	(1.46)**
High exit prob	rer_t^k	-0.15	(0.19)	0.55	(0.23)**	-0.51	(0.78)	0.25	(0.17)	0.44	(0.14)**
	dem_t^k	0.26	(0.23)	0.07	(0.25)	1.69	(0.80)**	0.08	(0.19)	0.30	(0.15)**
	τ_t^{jk}	0.27	(1.30)	-1.09	(1.32)	4.79	(3.68)	1.42	(1.14)	0.95	(0.92)
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		36,036		24,649		5,094		46,249		66,091	
R^2		0.78		0.80		0.83		0.85		0.77	
R^2-adj		0.67		0.73		0.72		0.78		0.69	

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 durables		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	(0.06)**	0.01	(0.13)	0.14	(0.29)	0.30	(0.08)**	0.16	(0.07)**
	dem_t^k	0.03	(0.07)	0.37	(0.15)**	-0.19	(0.33)	0.24	(0.10)**	-0.04	(0.07)
	τ_t^{jk}	-0.05	(0.71)	1.98	(1.18)*	2.07	(2.14)	-0.61	(0.64)	-0.62	(0.53)
High exit prob	rer_t^k	0.19	(0.06)**	0.01	(0.13)	0.16	(0.29)	0.29	(0.08)**	0.15	(0.07)**
	dem_t^k	0.05	(0.07)	0.37	(0.15)**	-0.18	(0.33)	0.22	(0.10)**	-0.04	(0.07)
	τ_t^{jk}	0.31	(0.95)	1.87	(0.93)**	-0.83	(1.91)	-0.19	(0.62)	-0.26	(0.46)
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		36,036		24,649		5,094		46,249		66,091	
R^2		0.89		0.81		0.86		0.92		0.85	
R^2-adj		0.84		0.74		0.77		0.88		0.79	

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

θ_t^{ik}	(1)	(2)	(3)	(4)	(5)
rer_t^k	-0.21	0.59	-0.42	0.40	0.57
τ_t^{jk}	1.30	1.04	0.62	8.23	8.44

Table 17: Sensitivity to macro shocks: Split exchange rate in nominal and price parts

		(1)		(2)	
		Quantity		Price	
		coeff	s.e.	coeff	s.e.
Low exit prob	x_t^k	0.30	(0.09)**	0.24	(0.04)**
	p_t^k	0.62	(0.10)**	0.11	(0.05)**
	dem_t^k	0.40	(0.09)**	0.08	(0.05)*
	τ_t^{jk}	-2.98	(0.67)**	-0.08	(0.35)
High exit prob	x_t^k	0.27	(0.09)**	0.24	(0.04)**
	p_t^k	0.04	(0.11)	0.14	(0.05)**
	dem_t^k	0.32	(0.09)**	0.08	(0.05)*
	τ_t^{jk}	0.59	(0.54)	0.15	(0.31)
Export history controls		yes		yes	
Firm-product-year f.e.		yes		yes	
Product-market f.e.		yes		yes	
N		184,890		184,890	
R^2		0.83		0.91	
R^2-adj		0.76		0.87	

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.

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 μ_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:

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

$$\Leftrightarrow$$

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

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 Φ_t^{ik} is a function of RER_t^k.

In this case

$$
\begin{aligned}
\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]
\end{aligned}
$$

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:

$$
\begin{aligned}
&\eta_{Q,RER} = \theta_t^{ik} \left[\eta_{\mu,RER} - 1 \right] + \eta_{\Phi,RER} \\
&\Leftrightarrow \\
&\theta_t^{ik} = \frac{\eta_{Q,RER} - \eta_{\Phi,RER}}{\eta_{\mu,RER-1}}
\end{aligned}
$$

C Price elasticity of demand estimates based on delta method

The price elasticity of demand is a nonlinear function of random variables:

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

and similarly for tariffs. To use the delta method to calculate the mean and standard deviation of θ_t^{ik}, we need to take a stand on the covariance of the two elasticities. We do not estimate this covariance, but based on the fact that the correlation must lie in the range $[-1, 1]$, we can calculate a range of different means and standard deviations. The table below reports the means and standard deviations for correlations equal to $\{-1, 0, 1\}$:

Table 18: Price elasticity of demand using Delta method

$\rho(\eta_Q, \eta_P)$	-1	0	1
Variation		rer_t^k	
$\mu(\theta_t^{ik})$	-0.39	-0.39	-0.40
$\sigma(\theta_t^{ik})$	0.09	0.11	0.13
Variation		τ_t^{jk}	
$\mu(\theta_t^{ik})$	-3.33	-3.57	-3.81
$\sigma(\theta_t^{ik})$	1.81	1.32	0.44