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**THE EFFECT OF EXCHANGE RATE  
SHOCKS ON FIRM-LEVEL EXPORTS:  
EVIDENCE FROM THE BREXIT VOTE**

L. Alan Winters and Ana Fernandes

**INTERNATIONAL TRADE AND  
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## Abstract

This paper exploits the abrupt and sharp depreciation of the British Pound after the Brexit referendum as a quasi-natural experiment to investigate the effect of exchange rate shocks on export quantity, price, entry and exit. We use transaction-level export data for the universe of exporters in Portugal. Using monthly observations on export quantity and price for the same firm exporting the same product to buyers in the UK and in other countries, allows us to cleanly identify the differential response to the shock for the UK market, relative to other markets. We find that exporters reduced their mark-up in the UK market after the referendum shock. Our estimates imply a large pricing-to-market coefficient and exchange rate pass-through. Exporters that are more productive adjust their mark-ups by more after the exchange rate shock, and have lower pass-through. There is more pricing-to-market for consumer goods than for intermediate inputs. Within the same firm-product, export quantity to the UK also decreased after the shock. The referendum shock reduced the rate of export entry to the UK market by Portuguese firms and the probability of their continuing to export in the UK.

JEL Classification: F14, F31, F32, F41

Keywords: Brexit vote, exchange rate pass-through, exchange rate shocks, exports, extensive margin of trade, intensive margin of trade, pricing-to-market

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# The effect of exchange rate shocks on firm-level exports: evidence from the Brexit vote \*

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## Abstract

This paper exploits the abrupt and sharp depreciation of the British Pound after the Brexit referendum as a quasi-natural experiment to investigate the effect of exchange rate shocks on export quantity, price, entry and exit. We use transaction-level export data for the universe of exporters in Portugal. Using monthly observations on export quantity and price for the same firm exporting the same product to buyers in the UK and in other countries, allows us to cleanly identify the differential response to the shock for the UK market, relative to other markets. We find that exporters reduced their markup in the UK market after the referendum shock. Our estimates imply a large pricing-to-market coefficient and exchange rate pass-through. More productive exporters adjust markups more after the exchange rate shock, and have lower pass-through. There is more pricing-to-market for consumer goods than for intermediate inputs. Within the same firm-product, export quantity to the UK also decreased after the shock. The referendum shock contributed to deter export entry to the UK market and reduce the probability of continuing to export in the UK.

**Key Words:** Brexit vote, Exchange rate pass-through, exchange rate shocks, exports, extensive margin of trade, intensive margin of trade, pricing-to-market.

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# 1 Introduction

Economists have long been interested in understanding the effect of exchange rate movements on economic activity. In particular, understanding the effect of exchange rate changes on international trade quantities and prices has attracted significant academic and policy attention. Recent economic shocks and their effects on the exchange rate have renewed interest in understanding the impact of exchange rate changes on economic outcomes.

Existing empirical evidence on the effects of exchange rate changes is inconclusive. A number of studies have focused on the aggregate effects of exchange rate depreciation, in particular the responses of import and export prices, consumer prices and the volume of imports and exports to exchange rate changes (Campa and Goldberg, 2005, 2010). Burstein and Gopinath (2014) provide a review of the literature on the relation between international prices and exchange rates. However, aggregate data does not allow estimation of microeconomic responses and heterogeneous effects across firms. Evidence based on firm-level studies is still relatively scarce and has produced a wide range of estimates of the exchange rate elasticity of export quantity and exchange rate pass-through (ERPT) to price. Recent studies include Pennings (2017), Li et al. (2015) and Amiti et al. (2014).

In this paper, we provide quasi-natural experimental evidence on the effects of exchange rate shocks on export prices, quantities and export participation, based on the large, sudden and unanticipated plunge in the British pound following the Brexit referendum. We use uniquely disaggregated export data, at the firm-product-country-month level for the universe of exporters in Portugal to provide novel evidence on the short-run ERPT and pricing to market, as well as on firm-level exports and extensive margin of exports. We have monthly observations on export quantity and prices charged by the same firm exporting the same product to buyers in the UK and in other countries. Assuming that relative marginal cost is constant across markets within the same firm and product, this allows us to cleanly identify the effect on the markup in the UK market relative to that on other countries, particularly other European Union (EU) countries, after the referendum shock. We are also able to estimate heterogeneous effects of the shock on the pricing strategies of exporters across the size distribution.

On June 23, 2016, 51.9% of the UK voted in a referendum to leave the European Union. Until the results of the referendum were announced, the outcome of the vote was unknown; the UK's most prominent polling firms, as well as exit poll results on the night of the vote predicted 52 percent for Remain, and 48 percent for Leave. The pound briefly appreciated following the prediction that remain would win. But once the referendum result became known on the night of the vote, the pound depreciated sharply against the Euro and the U.S. dollar, plunging 10% to its lowest level in 31 years, as shown in Figure 1 below. The depreciation of the pound proved to be persistent, and by the end of 2017 Sterling remained 10% below its pre-referendum

value. The sharp depreciation of the pound was sudden and unanticipated and as such offers a quasi-natural experiment to study the effect of exchange rate changes on economic activity.

The setting we analyze is exceptional to study the effects of exchange rate shocks on export quantity and price. The large and sudden depreciation of Sterling after the referendum occurred in an otherwise stable macroeconomic environment. The UK is the fourth largest destination market for Portuguese exports, following Spain, Germany and France, which are all Eurozone countries; that is, the UK is the largest non-Euro destination market. By using the sharp depreciation of the pound after the vote, we are able to cleanly identify the effect based on changes before and after the shock for the same firm-product-country triplet, for exports to the UK relative to exports to other countries. We identify the effects using a difference-in-differences strategy, estimating the differential response to the exchange rate shock for firms selling the same product in the UK market and in other countries, after accounting for countries' unobserved characteristics. Estimation is based on six months of data post-referendum. Existing studies have shown that firms adjust export prices very quickly to exchange rate shocks, with most of the adjustment occurring within the first six months or less (see e.g., Auer et al., 2018; Bonadio et al., 2018; Campa and Goldberg, 2005; Engle and Morley, 2001).

We find that, within the same firm-product, the export price to the UK decreases after the Brexit vote, relative to the export price for the same product exported by the same firm to a different foreign market. That is, within a product, Portuguese firms reduced the markup for their exports to the UK relative to other markets after the exchange rate shock. The reduction in the markup is observed also when we restrict the estimation sample to the EU, a more comparable group of countries, and thus exploit differences between exports to the UK and exports to the other 27 EU countries, for the same firm and product. Our estimates imply that the export price (denominated in Euro) to the UK decreased by 1% after the shock. Since the Sterling exchange rate depreciated by 10% after the referendum, which implied an appreciation of the Euro vis-a-vis the pound, this estimate represents a high ERPT in the short run.<sup>1</sup>

We also obtain heterogeneous pricing-to-market, with larger exporters absorbing more of the exchange rate shock on their markups. In particular, exporters in the top quartile of the size distribution reduce the export price in the UK by 1.3% on average, within a product, with no statistically significant effects found for smaller exporters. Our finding is consistent with previous papers that document heterogeneous pass-through responses to exchange rate changes (e.g., Amiti et al., 2014; Berman et al., 2012).<sup>2</sup>

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<sup>1</sup>Our estimates are consistent with significant pricing-to-market (PTM) following the exchange rate shock. PTM can arise in models with variable markups, where firms choose different prices for different destinations. Atkeson and Burstein (2008) provide a quantitative investigation of PTM. Gopinath and Itskhoki (2011) show that PTM is important in explaining incomplete ERPT. Fitzgerald and Haller (2014) provide evidence on PTM, estimating a significant price differential response to exchange rate movements for firms selling the same good in domestic and export markets.

<sup>2</sup>Heterogeneous response to exchange rate changes can arise in theoretical models such as the monopolistic competition model of Melitz and Ottaviano (2008), and the model of imperfect competition and variable markups

Given the cyclical nature of exports, in alternative specifications, we regress twelve-month log differences in prices or quantities, and estimate the effect of the shock on the percentage change in the price of a product relative to its price in the same month in 2015, for products that are exported in 2015 and continue to be exported in the same month, by the same firm in 2016. We continue to find a significant price differential response to the referendum shock for firms selling a good in the UK and in other markets. The estimates imply a differential reduction in export price in the UK of 2.8 percentage points. In those specifications, we find that export volume to the UK fell by 4 percentage points following the shock.

We investigate potential alternative mechanisms for the response to the exchange rate shock, in particular, the role of imported inputs, demand elasticity and frequency of exporters' price adjustment. We find that the effects of the referendum shock on export price to the UK, relative to other countries, persist after accounting for these factors. We also find that the effect of the exchange rate shock on export price is higher, with more pricing-to-market, for consumer goods than for intermediate inputs, consistent with existing literature (e.g. Campa and Goldberg, 2010).

Finally, we examine the impact of the exchange rate shock on European exporters' adjustment at the extensive margin of export participation. We investigate whether the Brexit shock contributed to deter entry to the UK export market for Portuguese firms or forced exits from the market. We find that the exchange rate shock reduces the probability of firm export entry to the UK, relative to other markets; the probability to continue exporting in the UK is also reduced after the vote.

Our paper is related to the literature that studies the extent of exchange rate pass-through. Recent research has analyzed imports or exports of individual countries, using micro data which allows estimation of the effects within particular products. Studies providing estimates for the exchange rate pass-through into import prices include Gopinath and Rigobon (2008), Gopinath et al. (2010), and Neiman (2010); they find a low ERPT using micro data for the US. Evidence for exchange rate pass-through and pricing to market based on micro-level export data for other countries includes Berman et al. (2012), for France, Fitzgerald and Haller (2014) for Ireland, Amiti et al. (2014) for Belgium and Li et al. (2015) for China. A branch of the literature has studied currency invoicing as a determinant of the exchange rate pass-through (see, e.g., Bonadio et al., 2018 and Gopinath et al., 2010).

Our results have important policy implications for the adjustment to exchange rate shocks in general, and in particular at a time when the UK and the EU are negotiating their future trade relationship. The fact that exporters lower their markups to the UK market following the referendum shock and reduce export volume, could imply a reduction in profits in the UK export market for European firms, from a combination of lower markups and lower sales. Also, of Atkeson and Burstein (2008), where more productive firms have larger market share.

given evidence that the Brexit vote led to an increase in aggregate inflation in the UK, our finding that European firms exporting to the UK reduce their markups suggests that if they had not lowered the export price to the UK, the effect on UK inflation from imported goods could have been higher.

The remaining of the paper is organized as follows. The next section describes the data used and the identification strategy. Section 3 presents and discusses the results on the effect of the quasi-natural experiment on export prices and quantities, alternative mechanisms, as well as entry and exit. The last section concludes.

## 2 Data description and identification strategy

### 2.1 Data description

Our empirical analysis is based on the Portuguese international trade customs data from the Foreign Trade Statistics, collected by the Portuguese Statistics Office (INE), covering virtually the entire universe of monthly export and import transactions at the firm-product-country level. For each transaction, the data contains information, among other, on free-on-board (FOB) prices and physical quantities of each exported and imported product (both at the CN 8-digit level, which we aggregate to the HS 6-digit level), from/ to each origin (destination) country (over 200 countries), and transport mode (road, plane, rail, ocean, among other). Data for transactions with countries outside the EU are collected by the Customs System (“Extrastat”), which covers the universe of international trade transactions. Due to the removal of physical customs barriers within the EU from 1993, data for trade transactions with other EU member states have been collected through the “Intrastat” system, under which firms are required to provide information on their trade transactions if the volume of exports or imports in the current year, in the previous year, or two years before were above a legally binding threshold, which for Portugal was set at 85,000 Euros for exports and 60,000 Euros for imports.<sup>3</sup> For this paper we use monthly data for 2015 and 2016, the last year the data is available.

The main dependent variables in our analysis are the quantity of exports and export price. The quantity is reported in mass (weight measured in kilo) and for some observations a "supplementary unit" is also reported (e.g. units, pairs, liters, meters, and other). We obtain unit values for a firm-product-country-month by dividing the export value of the transaction by the quantity in kilos, for consistency.

We complement the International Trade data with census data on firms’ balance-sheet information from the Enterprise Integrated Accounts System (SCIE) for the analysis of alternative mechanisms. The data contains information on firms’ sales, employment, industry, output, dif-

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<sup>3</sup>Eurostat regulation ensures harmonization of methods and definitions for collection of international trade data for both the Intrastat and the Extrastat for compilation of data under both systems.

ferent types of inputs, and location, among other. Since 2004, detailed balance-sheet information on the universe of all manufacturing firms is available.

Table A.1 in the Appendix reports statistics for the top export destinations of Portugal. As shown, the UK is the fourth destination for Portuguese exports, accounting for over 7% of export value, following Spain, Germany and France, all part of the Eurozone. Together these four countries account for 56% of Portugal’s exports. The UK is the largest non-Euro destination market for Portuguese exports. Table A.2 presents aggregate statistics. The number of exporting firms was 22519 in 2015 decreasing to 21206 in 2016. An exporter exports on average 13 products to 4 destinations. Table 1 reports summary statistics for firm-product-country exports in 2016.

Table 1: Summary statistics

	#obs.	Mean	Median	Std. dev.	p10	p90
Country-product level						
ln export quantity	460857	5.580	5.475	3.619	0.875	10.358
ln unit value	460857	2.452	2.442	1.850	0.105	4.679
Firm-product-country						
ln export quantity	1206355	4.839	4.698	3.317	0.693	9.333
ln unit value	1206355	2.466	2.444	1.836	0.140	4.691
$\Delta$ ln export quantity	498503	0.025	0.006	1.673	-1.805	1.866
$\Delta$ ln unit value	498503	0.000	0.000	0.747	-0.628	0.630
# firms per product-country	461226	2.617	1	4.974	1	5
# countries per firm-product	716807	1.684	1	2.315	1	3
# products per firm-country	383005	3.152	1	8.173	1	6

Own calculations based on Portuguese firm-level international trade data, from the National Statistics Office (INE).

## 2.2 Identification strategy

Our empirical analysis aims to estimate how sensitive export prices, quantity and export participation are to exchange rate shocks. We adopt a reduced form strategy, which has the advantage of producing estimates that can be used to rationalize a variety of structural models.

To identify the effects of exchange rate shocks on export volume, entry and exit, and particularly on export prices, we use the Brexit vote as a quasi-natural experiment. On June 23, 2016 the British people voted in a referendum to leave the European Union. Until the results were announced, the outcome of the referendum was unanticipated. In fact, at the close of the polls, predictions were that remain would win. The pound briefly appreciated as a result of the exit

polls, but when the results were announced and it became clear that Brexit won the referendum, the pound depreciated sharply against the Euro and the U.S. dollar, plunging 10% to its lowest level in 31 years, as shown in Figure 1. The pound exchange rate depreciation proved to be persistent, and by the end of 2017 the pound remained 10% below its pre-referendum value. The sharp depreciation of the pound following the referendum night was sudden and unanticipated, and as such offers an exogenous shock to study the effect of exchange rate changes on the economy.

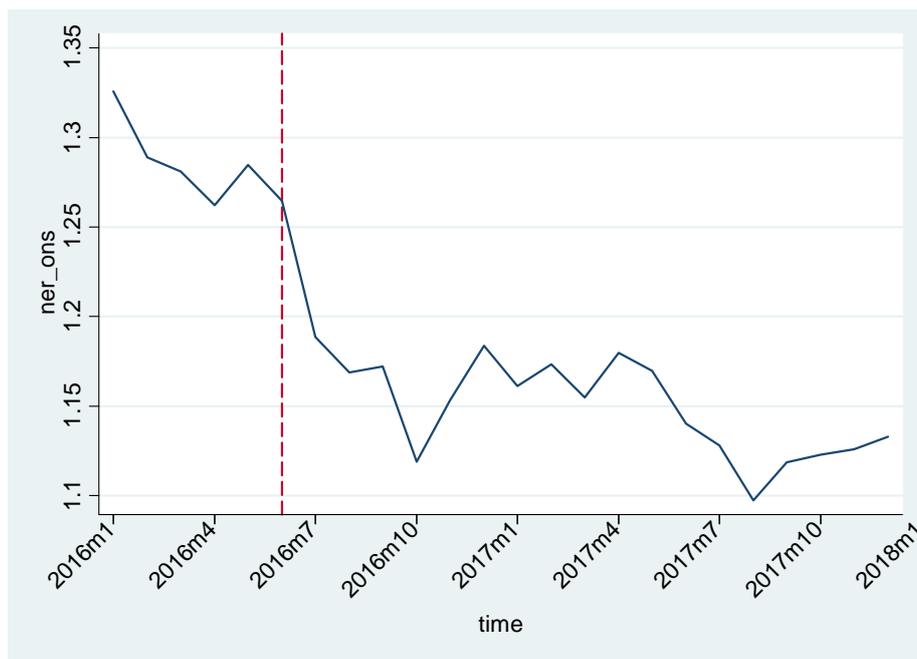


Figure 1: Sterling euro nominal exchange rate, ONS

Our identification is based on a difference-in-differences approach to estimate the differential effect of the referendum shock on exports to the UK relative to exports to other countries of the same product by the same firm, before and after the referendum. We use monthly observations on export quantity and prices charged by the same Portuguese firm exporting the same product to buyers in the UK and to buyers in other countries. Assuming that relative marginal cost is constant across markets within the same firm-product pair, this allows us to cleanly identify the effect of the exchange rate shock on the markup in the UK market relative to other countries. In some specifications we restrict the sample to European Union countries, which offer a cleaner comparison with the UK after the referendum shock. We estimate specifications in levels and in some cases also in twelve-month log differences, for prices or quantities, thus estimating the differential effect of the shock on the percentage change in the price of a product relative to its price in same month in 2015, for products that are exported in 2015 and continue to be exported in the same month, by the same firm in 2016.

Figure 2 below shows the Sterling Euro exchange rate and the percentage change in log unit

values relative to the same month in 2015. The Figure shows that the exchange rate and export price moved together, especially after the referendum.

The explanatory variable of interest in our empirical specifications in the following sections is the interaction term  $Post \times GB$ , where the variable  $Post$  is an indicator variable that takes the value 1 for all months after the referendum, and zero before.  $GB$  is a dummy variable for exports to Britain. Our regressions always control for firm-product and country or firm-product-country fixed effects and for time dummies. These account for unobserved firm, product and country characteristics and for general trends.

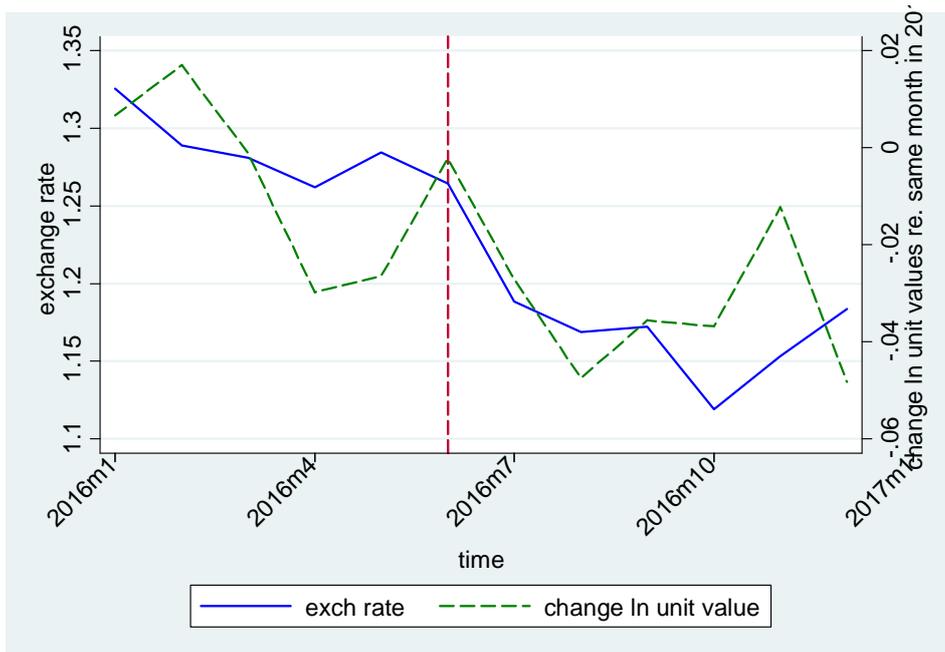


Figure 2: Sterling euro exchange rate and change in ln export unit value

### 3 Empirical results

#### 3.1 Aggregate country and country-product level results

Before we turn to our firm-level analysis, in this section we start by estimating the effects of the referendum shock at the country and country-product aggregate levels. We use monthly data for 2016, which includes six months before and six months after the referendum.<sup>4</sup> We first aggregate the export data to the country level and estimate specifications of export value, number of exporters and number of exported products on the  $Post \times GB$  interaction term, controlling for destination country fixed effects, to account for unobservable destination heterogeneity, and for month dummies. That is, we estimate the following specification

<sup>4</sup>Existing studies find that most of the responses to exchange rate shocks take place within the first 6 months after the shock (see e.g., Auer et al., 2018; Bonadio et al., 2018; Campa and Goldberg, 2005; Tang and Zhang, 2012 and Engle and Morley, 2001).

$$\ln X_{ct} = \beta(Post_t \times GB_c) + d_c + d_t + \epsilon_{ct}, \quad (1)$$

where  $X_{ct}$  is either export value from Portugal to country  $c$  in month  $t$ , number of firms exporting to  $c$  or number of exported products. As explained above,  $Post$  is a dummy variable that takes the value 1 for all months after the referendum and  $GB$  is an indicator taking the value 1 for exports to the UK and zero otherwise.  $d_c$  and  $d_t$  represent country and month fixed effects, respectively.  $\epsilon_{ct}$  it is the mean-zero disturbance term. Standard errors are clustered at the country level.  $\beta$  is the coefficient of interest, which captures the differential effect of the referendum shock on exports to the UK, relative to exports to other destinations.

Results from estimating Eq. (1) are reported in Table 2. We obtain negative and statistically significant coefficients on the  $Post \times GB$  interaction term showing that export value, number of exporters and number of products all decreased to the UK after the exchange rate shock following the referendum. The estimates suggest a 14% reduction in export value to the UK relative to other destinations; the number of exporters serving the UK market fell by 4%, while the number of HS6 products exported to the UK was reduced by 5.5%.

Table 2: Agreggate effects, country-level estimations

	(1)	(2)	(3)
Dependent variable:	ln export value	ln # exporters	ln # products
$Post \times GB$	-0.144*** (-3.24)	-0.0397*** (-2.83)	-0.0547** (-2.37)
Constant	13.36*** (203.25)	3.043*** (148.39)	3.603*** (101.33)
Fixed effects	Country fixed effects		
Month dummies	yes	yes	yes
Observations	2238	2238	2238
R <sup>2</sup>	0.0129	0.0421	0.0238

t-statistics based on robust standard errors clustered by country in parenthesis. \*p<0.1; \*\*p<0.05; \*\*\*p<0.01.

To examine the effect of the exchange rate shock on export price and quantity adjustments separately, we use data at the country-product level. We aggregate the firm-product-country level data to exports of each 6-digit HS product to each country. For each product-country we calculate the price, that is, the unit value, as the ratio between the export value and the export quantity (in kilograms). This results in a panel dataset with information of export quantities and prices for 4584 HS6 products to 212 countries in 2016.

We estimate an equation similar to Eq.(1) above but at the product-country-month level

for export quantity and unit value of exports. We control for country-product fixed effects and thus identify the effects within the same product exported to the same country before and after the referendum shock. We also include month dummies to capture trends common to all product-country pairs.

The results are presented in Table 3. We find that the coefficient on the interaction term of interest is negative and statistically significant for export price but it is statistically insignificant, although negative, for quantity. That is, as a result of the exchange rate shock, export prices to the UK fell, relative to other countries, within a product. The effect on quantity is statistically insignificant. The estimates imply that after the referendum, export price to the UK fell by 1.28% relative to the export price to other destinations. This entails a relatively large pricing-to-market coefficient since we are looking at the short run effects; and this also involves a large ERPT. These results suggest that Portuguese firms exporting to the UK adjusted their export price after the Brexit vote.

Table 3: Agreggate effects, country-product level estimations

	(1)	(2)
Dependent variable:	ln export quantity	ln unit value
<i>Post</i> × <i>GB</i>	-0.0114 (-0.48)	-0.0128*** (-3.60)
Constant	5.477*** (294.62)	2.457*** (545.63)
Fixed effects	Product-country fixed effects	
Month dummies	yes	yes
Observations	460857	460857
R <sup>2</sup>	0.00214	0.0001

A product is a hs6 category. t-statistics based on robust standard errors clustered by country in parenthesis. \*p<0.1; \*\* p<0.05; \*\*\*p<0.01.

## 3.2 Firm-product-country level results

### 3.2.1 Benchmark results

In the previous section we report that at the product-country level the exchange rate shock led to a reduction in export price to the UK. However, aggregate data hides substantial heterogeneity across firms. Moreover, export prices are more precisely defined at the firm-product-country level. At that level we can also assume that relative marginal cost is constant allowing us to identify more cleanly the effect on the markup in the UK market relative to other markets. Therefore, in this section we investigate the effect of the shock to the exchange rate on export

price and quantity at the firm-product-country level. The total number of monthly observations increases to over 1.2. million in 2016. We estimate specifications of the form:

$$\ln X_{fpct} = \beta(Post_t \times GB_c) + d_{fpc} + d_t + \epsilon_{fpct}, \quad (2)$$

here,  $X_{fpct}$  is either unit value ( $UV$ ), that is, the Euro producer price, or quantity ( $Q$ ) of exports of product  $p$  exported by firm  $f$  to destination country  $c$  in month  $t$ .  $Post$  takes the value 1 for periods after the referendum shock and  $GB$  takes the value 1 if the destination country is the UK. We include firm-product-destination country fixed effects ( $d_{fpc}$ ) which absorb any time-invariant unobservable characteristics specific to a firm, product and destination, as well as month dummies ( $d_t$ ) to control for common shocks across all exporters.

Table 4 reports the results from estimating Eq. (2). The results are consistent with the finding in Table 3 that Portuguese exporters adjusted export price to the UK after the exchange rate shock. We find a negative and statistically significant coefficient on the  $Post_t \times GB_c$  interaction term, showing that within the same firm-product, the export price to the UK falls after the Brexit vote, relative to the price of the same products exported by the same firm to a different destination. That is, within a product, Portuguese firms reduced the markup for their exports to the UK relative to other markets after the exchange rate shock.

Table 4: Firm-product-country level benchmark estimations

	(1)	(2)	(3)	(4)
Dependent variable:	ln(Q)	ln(UV)	ln(Q)	ln(UV)
$Post \times GB$	0.00575 (0.55)	-0.0117*** (-3.85)	0.00451 (0.36)	-0.0114*** (-4.66)
Constant	3.317*** (31.57)	2.538*** (165.72)	4.801*** (250.23)	2.462*** (404.89)
Fixed effects	Firm-product + country		Firm-product-country	
Month dummies	yes	yes	yes	yes
Observations	1206355	1206355	1206355	1206355
R <sup>2</sup>	0.0538	0.0068	0.00134	0.0001

Observations are by firm-product-country-month. A product is a hs6 category. Columns (1) and (2) include firm-product and country fixed effects, exploiting variation across countries within a firm-product. Columns (3) and (4) include firm-product-country fixed effects. t-statistics based on robust standard errors clustered by country in parenthesis. \*p<0.1; \*\* p<0.05; \*\*\*p<0.01.

The estimates in columns (1) and (2) imply that export price to the UK fell by 1.2% on average after the shock, relative to exports of the same product to other destinations, controlling for firm-product and for destination fixed effects. The results remain robust when we include firm-product-country fixed effects and thus identify the effect of the shock from changes within

the same firm-product-country triplet before and after the referendum (columns 3 and 4). That is, Portuguese exporters reduced their markup in the UK market relative to other markets. The estimates imply a large ERPT into destination prices in the short-run, since the depreciation of Sterling (and appreciation of the Euro) after the referendum was around 10%. The effects on export quantity are statistically insignificant.

Our finding of large ERPT to international prices is in contrast to a set of papers which found low ERPT; among others, Gopinath and Rigobon (2008), Gopinath et al. (2010), and Neiman (2010), provide estimates of incomplete pass-through. However, our results are consistent with a number of studies that document significant pass-through of exchange rates to international prices, e.g., Fitzgerald and Haller (2014), Amiti et al. (2014) and Berman et al. (2012).

In Table 5, we estimate the same specifications, with firm-product-country fixed effects, for different sub-samples. First, since the shock is particularly clean for the bilateral exchange rate between the Euro and Sterling, we restrict our sample to EU countries. This results in a cleaner comparison between exports to the UK and exports to the other 27 EU countries since they are a more similar group of countries. In columns (1) and (2), we continue to find a negative and statistically significant differential effect of the referendum shock on the price charged in the UK market. The estimate implies that the appreciation of the Euro against the pound resulted in a 0.7% reduction in export price charged in the UK, after the referendum, relative to other EU countries. In columns (3) and (4) we restrict the sample to multiproduct exporters to a country.<sup>5</sup> The results remain robust in sign, magnitude and statistical significance as those reported in Table 4, implying a reduction in the export price charged by Portuguese firms in the UK of 1.2%.

Table 5: Firm-product-country level, sub-samples

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:	ln(Q)	ln(UV)	ln(Q)	ln(UV)	ln(Q)	ln(UV)
Sample:	EU28		Multiproduct		w/o entry/exit	
<i>Post</i> × <i>GB</i>	0.0179* (1.76)	-0.00711*** (-2.81)	-0.00514 (-0.40)	-0.0116*** (-4.13)	0.0239* (1.70)	-0.00941*** (-5.30)
Constant	5.082*** (195.31)	2.494*** (404.41)	4.529*** (222.54)	2.498*** (354.29)	4.756*** (179.59)	2.462*** (1007.48)
Fixed effects	Firm-product-country fixed effects					
Time dummies	yes	yes	yes	yes	yes	yes
Observations	653257	653257	1072710	1072710	961646	961646
R <sup>2</sup>	0.00255	0.0001	0.00117	0.00007	0.00156	0.00003

Observations are by firm-product-country-month. A product is a hs6 category. t-statistics based on robust standard errors clustered by country in parenthesis. \*p<0.1; \*\* p<0.05; \*\*\*p<0.01.

<sup>5</sup>That is, more than one product for a firm-country.

To account for potential selection issues caused by entry and exit, in columns (5) and (6) we use a sample that excludes observations in entry and exit years. The results remain similar, with the differential price response to the shock in the UK estimated at a decrease of 0.9%. In sum, the results are robust to different samples. Our findings of high exchange rate pass-through are consistent with previous estimates that use exchange rate data. Berman et al. (2012) find that following a 10% exchange rate appreciation, the average exporter in France reduces its export price in Euro by 0.8%; this is a similar response to our estimate since the appreciation of the Euro was about 10% after the referendum shock. Other studies that find high ERPT include Freund et al. (2011) and Li et al. (2015).

We also estimate specifications with differenced dependent variables. To account for cyclical-ity of exports, we use data for 2015 and 2016 and obtain differences for each monthly observation, between the value in 2016 and the value in same month in 2015. That is, we estimate:

$$\Delta \ln X_{fpct} = \beta_1(Post_t \times GB_c) + d_{fpc} + d_t + \epsilon_{fpct}, \quad (3)$$

where  $\Delta \ln X_{fpct}$  is the log difference in export quantity or price between month  $t$  in 2016 and month  $t$  in 2015, for a firm-product-country ( $fpc$ ). The other variables are as defined above. We continue to include firm-product-country fixed effects and month dummies. This is a clean identification, based on products that are exported in 2015 and continue to be exported by the same firm to the same destination in the same month in 2016. The effects are obtained based on differences before and after the referendum shock.

The results from estimating Eq. (3) are presented in Table 6. We find that the export price to the UK is reduced on average by 2.8 percentage points after the exchange rate shock. That is, the depreciation of the pound, and consequent appreciation of the Euro, led to a reduction in the markup of Portuguese exporters in the UK market, consistent with the previous results. We also find a negative and statistically significant effect of the shock on export quantity. The estimates imply a 4 percentage point reduction in exports to the UK after the referendum shock.

The results are robust across the different samples, reported in the columns of Table 6, with a similar magnitude of the coefficients. The estimated volume elasticity is in line with other studies, e.g., Berman et al. (2012) estimate a 4% response of export volume to a 10% change in the exchange rate; Li et al. (2015) and Tang and Zhang (2012) report similar estimates for

Table 6: Firm-product-country level, differenced dependent variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dep. variable:	$\Delta\ln(Q)$	$\Delta\ln(UV)$	$\Delta\ln(Q)$	$\Delta\ln(UV)$	$\Delta\ln(Q)$	$\Delta\ln(UV)$	$\Delta\ln(Q)$	$\Delta\ln(UV)$
Sample:	All		EU28		Multiproduct		w/o entry/exit	
<i>Post</i> $\times$ <i>GB</i>	-0.0421*** (-3.19)	-0.0282*** (-7.73)	-0.0337** (-2.40)	-0.0243*** (-4.64)	-0.0429*** (-2.95)	-0.0263*** (-7.05)	-0.0345*** (-2.81)	-0.0227*** (-6.65)
Constant	0.0764*** (4.96)	-0.00186 (-0.42)	0.105*** (7.20)	-0.00686 (-1.23)	0.0763*** (4.55)	-0.00254 (-0.55)	0.0719*** (4.76)	-0.00302 (-0.72)
Fixed effects	Firm-product-country fixed effects							
Time dummies	yes	yes	yes	yes	yes	yes	yes	yes
Observations	498503	498503	359814	359814	439077	439077	456134	456134
R <sup>2</sup>	.00119	.0000836	.00142	.000117	.00114	.0000752	.00122	.0000642

This table uses data for 2015 and 2016 and the dependent variables are differences relative to the same month between 2016 and 2015 for a firm-product-country. A product is a hs6 category. Month dummies are included in all specifications. t-statistics based on robust standard errors clustered by country in parenthesis. \*p<0.1; \*\* p<0.05; \*\*\*p<0.01.

China. Fitzgerald and Haller (2018) report lower aggregate elasticities for real exchange rate changes using micro data for Ireland. In sum, the results in this section show that following the exchange rate shock Portuguese exporters reduce the export price in the UK market on average, and also the export volume to the UK, relative to other countries, in particular other EU countries.

Our estimates imply significant pricing-to-market (PTM) following the exchange rate shock. This is consistent with previous literature. PTM can arise in models with variable markups, where firms choose different prices for different destinations based on local market conditions. Atkeson and Burstein (2008) provide a quantitative investigation of PTM and its implication for aggregate international prices. Gopinath and Itskhoki (2011) show that PTM is important in matching aggregate and micro-level international price data. Fitzgerald and Haller (2014) provide direct evidence on this phenomenon. They find a significant price differential response to exchange rate movements for Irish firms selling the same good in domestic and export (UK) markets.

We interpret our findings as resulting from the exchange rate shock after the referendum. It could be argued that increased uncertainty after the Brexit vote could also affect exports. However, our results of a reduction in export price and quantity in the immediate months after the shock are consistent with other work on the effects of exchange rate movements (e.g., Auer et al., 2018; Bonadio et al., 2018). Moreover, we exploit variation within the same firm-product for exports to the UK relative to other EU countries.

### 3.2.2 Firm heterogeneity

In this section we investigate whether there is heterogeneity of pass-through response to the exchange rate shock across the firm size distribution. A large body of literature, following the work by (Melitz, 2003) has documented substantial heterogeneity across firms. Previous work has also shown that more productive firms have lower pass-through into their prices due to the fact that their markup elasticity is higher and thus they adjust markups more following an exchange rate shock. This was documented by Berman et al. (2012), and more recently by Amiti et al. (2014) and Chatterjee et al. (2013). We investigate the response to the exchange rate shock following the Brexit referendum vote for exporters across the size distribution. To that end we divide firms into quartiles of the export sales, and define quartile dummy variables,  $q_f^r$ , taking the value 1 if firm  $f$  is in quartile  $r$  of the export distribution.<sup>6</sup> To investigate how the effects differ across firms by quartiles of exports, we estimate the following specification for export quantity and price

$$\ln X_{fpct} = \sum_{r=1}^4 \beta^r (Post_t \times GB_c \times q_f^r) + d_{fpc} + d_t + \epsilon_{fpct}, \quad (4)$$

where  $q_f^r$  are the quartile dummies and the other variables are as defined above. In addition to the variables and controls described above, we also include quartile $\times$ month dummies to absorb any trends of the quartile. This specification allows us to estimate the response to the shock for exporters in each quartile separately.

Table 7 reports the results. We find that the negative differential effect of the shock on export price to the UK is obtained for the larger, more productive, exporters in the fourth quartile. The estimate in column (2) implies that export price to the UK falls by 1.33%, and suggests that the markup elasticity is higher for the more productive exporters. The coefficient on the quartile interactions is insignificant for the second and third quartiles.

We obtain a positive and significant coefficient for the first quartile interaction but this arises due to the low number of firm-product observations in this quartile to estimate the effects consistently, since identification is based on within firm-product changes for products that continue to be exported after the referendum. Therefore, in columns (3) and (4), we keep only observations where a product is exported by the same firm to the UK and also to other foreign markets; since our aim is to identify differences in exports to the UK relative to other

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<sup>6</sup>Quartile 1 is the lowest export quartile and quartile 4 the highest.

countries. We then construct the export quartiles for this sample. As shown, for this sample the coefficient on the interaction term is statistically insignificant for the smaller exporters, in the first quartile, and is negative and statistically significant for the other quartiles. The negative effect on prices is also larger for the more productive exporters, in the top two quartiles of the export distribution.<sup>7</sup> Table A.3 in the appendix reports results for a sample constructed in the same way but restricted to EU countries. We continue to find that the larger exporters, in the top quartiles, reduce export price to the UK relative to other EU destinations, for the same product; while the effect remains statistically insignificant for the smaller exporters.

Table 7: Firm-product-country level, firm heterogeneity

	(1)	(2)	(3)	(4)
Dependent variable:	ln(Q)	ln(UV)	ln(Q)	ln(UV)
<i>Post</i> × <i>GB</i> ×				
Quartile 1	-1.781*** (-14.44)	1.796*** (22.09)	0.0652** (2.00)	0.0232 (1.50)
Quartile 2	0.481*** (18.57)	0.0101 (0.64)	0.0223 (1.25)	-0.0147* (-1.69)
Quartile 3	-0.000651 (-0.05)	0.00592 (1.48)	0.0463** (2.52)	-0.0186*** (-3.66)
Quartile 4	0.00485 (0.36)	-0.0133*** (-5.18)	-0.0191 (-1.27)	-0.0154*** (-5.72)
Fixed effects		Firm-product-country		
Month dummies	yes	yes	yes	yes
Observations	1206355	1206355	431030	431030
R <sup>2</sup>	.00147	.00024	.00244	.000681

Quartile × month dummies included in all specifications along with the other fixed effects. A constant term is also included in all specifications. Columns (1) and (2) are for the full sample, while columns (3) and (4) keep only observations where a product is exported by a firm to the UK and also to other countries; the export quartiles are then defined for this sample. t-statistics based on robust standard errors clustered by country in parenthesis. \*p<0.1; \*\*p<0.05; \*\*\*p<0.01.

The results reported in Table 7 remain robust for different percentiles of the export distribution; in unreported results available upon request, we define dummy variables for exporters belonging to each percentile, based on the median, quintiles or deciles of exports and the results

<sup>7</sup>The previous results in the paper, for the average effects across exporters, remain robust and similar for this sample that keeps only observations where a product is exported by the same firm to the UK and to other countries.

remain similar. Firms at the top of the export distribution reduce their price in the UK by significantly more than smaller, less productive exporters.

The results in this section show that there is heterogeneous pricing-to-market, with larger exporters absorbing more of the exchange rate shock on their markups. Heterogeneous response to exchange rate changes can arise in theoretical models, such as the monopolistic competition model of Melitz and Ottaviano (2008), which generates a linear demand with endogenous markups across firms. In this framework, more productive firms face less elastic demand and charge higher markups, allowing them to price more to market following exchange rate movements. The model of imperfect competition and variable markups of Atkeson and Burstein (2008), where more productive firms have larger market share, can also generate heterogeneous pricing-to-market.

### 3.2.3 Alternative mechanisms

In this section we investigate potential alternative explanations for the differential response of export price and quantity of exports to the UK following the exchange rate shock. The first mechanism we analyze is the role of imported inputs. The share of imported inputs in production can affect the export price and quantity response to exchange rate shocks. If the share of imported inputs in production is high, an appreciation of the Euro may decrease firms' marginal cost of production through lower import costs. In our setting, if Portuguese exporters import inputs from the UK, which due to the depreciation of Sterling became cheaper, that could affect the response of export price. As discussed in Amiti et al. (2014), large exporters are often also large importers of intermediate inputs. For such firms, exchange rate shocks will also affect input costs by more; these firms set high markups and change them in response to changes in marginal costs. Therefore, more import-intensive exporters would have lower exchange rate pass-through.

To investigate whether imports from the UK affect the estimates of the impact of the shock on price and volume elasticity, columns (1) and (2) of Table 8 start by restricting the estimation sample to Portuguese exporters that do not import goods from the UK. We continue to find that after the shock, the markup they charge in the UK market decreases by 1.2% on average, relative to other countries. The magnitude is similar to the effect reported in Table 4. Therefore, the effect of the shock on export price is not arising through imports of intermediate goods from the UK. In columns (3) and (4), we interact the  $Post \times GB$  term with import intensity from the

Table 8: Alternative mechanisms

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent variable:	ln(Q)	ln(UV)	ln(Q)	ln(UV)	ln(Q)	ln(UV)	ln(UV)
Sample:	excl. importers from UK		importers from UK		All		
$\Phi$ :			UK imports/purchases		Demand elasticity		mean $\Delta$ ln(UV)
<i>Post</i> $\times$ <i>GB</i>	0.0232 (1.46)	-0.0116*** (-4.27)	-0.0562** (-2.49)	-0.0260*** (-2.86)	0.00629 (0.44)	0.00179 (0.34)	-0.00867*** (-4.24)
<i>Post</i> $\times$ <i>GB</i> $\times$ $\Phi$			-0.00659* (-1.85)	-0.00254* (-1.69)	-0.00150 (-0.40)	-0.0127*** (-4.07)	-0.0330 (-1.23)
<i>Post</i> $\times$ $\Phi$			-0.00617* (-1.73)	-0.00171 (-1.13)	0.00235 (0.62)	0.00231 (0.74)	0.0438 (1.63)
Fixed effects	Firm-product-country fixed effects						
Month dummies	yes	yes	yes	yes	yes	yes	yes
Observations	771639	771639	428650	428650	1198320	1198320	981754
R <sup>2</sup>	.00147	.0000833	.00146	.000234	.00134	.0000755	.0417

Columns (1) and (2) exclude firms that import from the UK during the period. Columns (3) and (4) interact the *Post* $\times$ *GB* term with the ratio of imports from the UK over purchases by the firm, and are thus based on the sample of exporters that import from the UK. Columns (5) and (6) interact with (the log of) Broda and Weinstein (2006) import demand elasticity for each HS good. Column (7) interacts with the average change in (log) unit values over the period for a firm, to proxy for the frequency of price adjustment. A constant term is included in all specifications. Column (7) includes lower-order terms; they are absorbed by the fixed effects included in the remaining columns. t-statistics based on robust standard errors clustered by country in parenthesis. \*p<0.1; \*\* p<0.05; \*\*\*p<0.01. \*p<0.1; \*\* p<0.05; \*\*\*p<0.01.

UK, computed as the share of imports from the UK on total purchases by the firm; the sample is thus restricted to exporters that also import goods from the UK. We continue to find a negative coefficient on the *Post*  $\times$  *GB* interaction and the estimate is of larger magnitude. The estimates imply a reduction in price of 2.9%. We also find that the effect is larger (more negative) for firms' with higher share of imports from the UK. In the sample of firms that import from the UK, we find a negative impact of the shock on export quantity to the UK, with an estimated volume elasticity of 5.6%.

Next, we investigate differences across goods with different import demand elasticity. In the model of Atkeson and Burstein (2008), the export price and volume elasticities to exchange rate changes depend on the elasticity of substitution between goods. To investigate this, we interact the *Post*  $\times$  *GB* term with (the log of) the elasticity of substitution estimated by Broda and Weinstein (2006). We match the elasticity of substitution at the HS 3-digit tariff provided by Broda and Weinstein (2006) with the product exported by Portuguese firms. The results in columns (5) and (6) show that the export price to the UK decreases by more after the exchange rate shock the higher the import demand elasticity of the good. For the mean elasticity (0.993), the estimates imply that the markup to the UK is reduced by 1%, similar to the baseline estimate reported above.

Finally, we investigate the role of frequency of price adjustment on exchange rate pass-

through, as emphasized in Gopinath and Itskhoki (2010). We follow Berman et al. (2012) and proxy for firms' frequency of price adjustment by the average change in the price of a firm-product-country over the period. We interact this proxy with the treatment interaction term,  $Post \times GB$ . The results in column (7) show that accounting for this does not significantly change the results: we continue to find that exporters decrease the price to the UK market by about 0.9% after the shock. Table A.4 in the appendix reports results for the dependent variables in differences relative to the same month in 2015. The same conclusions hold. In sum, we find that the differential effects of the referendum shock on export price to the UK persist after accounting for the role of imported inputs, demand elasticity and frequency of price adjustment.

### 3.2.4 Intermediates versus consumer goods

In this section, we investigate the effect of the exchange rate shock on export prices of intermediate inputs and consumer goods. As discussed in Berman et al. (2012), an implication from Corsetti and Dedola (2005) is that following a depreciation, export price should change by more for goods with higher distribution costs. Since distribution costs are higher for consumer goods than for intermediate inputs, we explore the role of distribution costs by estimating the effects of the shock on the price of inputs and consumer goods. To that end, we classify each HS 6-digit product exported by Portuguese firms as final consumer good or as input using the UN-BEC concordance.

Table 9 reports the results separately for inputs in column (1) and for consumption goods in column (2). As expected, the effect of the exchange rate shock on export price is larger for consumer goods, which have higher distribution costs, than for inputs. For consumer goods, we find that exporters reduced the markup to the UK market after the shock by 1.8%, within a product; while for inputs the effect is not statistically significant. In Appendix Table A.5, we report results with the dependent variable defined as the log difference in price relative to the same month in 2015. We find that the effect on export price is negative and statistically significant for both types of goods but consistently with Table 9, consumer goods respond more to the exchange rate shock. Studies that also find that pricing-to-market is higher for consumer goods include, e.g., Berman et al. (2012) and Li et al. (2015).

Table 9: Intermediates and consumer goods

	(1)	(2)
Dependent variable:		ln unit value
Goods type:	inputs	consumer goods
<i>Post</i> × <i>GB</i>	-0.00357 (-1.00)	-0.0184*** (-8.44)
Constant	2.187*** (352.46)	2.578*** (447.63)
Fixed effects	Firm-product-country fixed effects	
Month dummies	yes	yes
Observations	494734	610792
R <sup>2</sup>	.0000585	.000297

Each HS6 good is classified as intermediate input or consumer good using the UN-BEC concordance. We report estimation results for both types of goods separately in columns (1) and (2). t-statistics based on robust standard errors clustered by country in parenthesis. \*p<0.1; \*\* p<0.05; \*\*\*p<0.01.

### 3.3 Extensive margin

This section investigates the differential effect of the exchange rate shock on export participation in the UK market for Portuguese exporters, relative to other markets. Exchange rate fluctuations may affect firms' decision to enter or exit foreign markets. We estimate the effect of the referendum shock on the probability of firm  $f$  to export to destination  $c$  in period  $t$ . We estimate separately the effect of the exchange rate shock on entry decisions and on the decision to continue serving the export market. For this analysis we use data for 2015 and 2016, and due to potential seasonal trends in exporting, to consistently estimate the effect of the referendum shock, we aggregate the data on firm-country level exports to half-yearly observations, for January to June and July through December of each year. We want to assess whether the exchange rate shock deters entry to the UK market and forces exits, relative to other destinations.

We first define the entry dependent variable of the regression as follows:

$$Entry_{fct} = \begin{cases} 1 & \text{if } X_{fc,t-1} = 0, X_{fct} > 0 \\ 0 & \text{if } X_{fc,t-1} = 0, X_{fct} = 0 \end{cases}, \quad (5)$$

where  $X_{fct}$  is export value of firm  $f$  to country  $c$  in period  $t$ . That is,  $Entry_{fct} = 1$  if firm  $f$  was not exporting to country  $c$  in  $t - 1$ , but started exporting to  $c$  in  $t$ . To study the probability of entry, we set  $Entry_{fct} = 0$  for all potential destination markets that were not served by firm  $f$  before or in period  $t$ . Exporters that were already serving market  $c$  in  $t - 1$  are not included

in the estimation. The variable is not defined in the first period since we need information from the previous period's export status to define an entry.

We then estimate how the exchange rate shock affects the probability of entry with the following specification:

$$\Pr(Entry_{fct}) = \beta(Post_t \times GB_c) + \ln X_{ft} + d_c + d_t + \epsilon_{fpct}, \quad (6)$$

where  $Entry_{fct}$  is as defined above. We control for the firms' aggregate exports ( $\ln X_{ft}$ ), to account for the exporter's size, and include country fixed effects ( $d_c$ ) and time dummies ( $d_t$ ). Standard errors are clustered by country. As before, the coefficient of interest is  $\beta$ , which captures the differential effect of the referendum shock on the probability of firm export entry to the UK market, relative to other destinations. We also define a dependent variable for the decision to continue on the export market;  $Cont_{fct}$  takes the value 1 if the firm was exporting to market  $c$  in period  $t-1$  ( $X_{fc,t-1} > 0$ ) and continues to export in  $t$ . If the firm exports in period  $t-1$  but not in  $t$ ,  $Cont_{fct} = 0$ . We use an additional dependent variable for the probability of exporting to country  $c$  in  $t$ , which takes the value of 1 if the firm exports to  $c$  in period  $t$  and zero otherwise.

Table 10: Extensive margin

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:	Pr(exp)	Pr(enter)	Pr(cont)	Pr(exp)	Pr(enter)	Pr(cont)
Sample:	Full sample			EU28 sample		
PostxGB	-0.000456 (-0.06)	-0.0543*** (-4.72)	0.0149 (1.33)	-0.0103*** (-2.80)	-0.0522*** (-3.50)	-0.00742*** (-3.97)
ln firm exports	0.0464*** (20.38)	0.0347*** (13.15)	0.0473*** (29.87)	0.0556*** (36.54)	0.0355*** (18.43)	0.0559*** (45.71)
Fixed effects	Country fixed effects					
Time dummies	yes	yes	yes	yes	yes	yes
Observations	436716	135398	201435	168564	36529	98055
R2	.186	.118	.121	.153	.0933	.127

The dependent variable in columns (1) and (4) is the probability for a firm  $j$  to export to destination  $c$  in period  $t$ . In columns (2) and (5) the dependent variable takes the value 1 if firm  $f$  was not exporting to country  $c$  in  $t-1$ , but started exporting to  $c$  in  $t$  and is set to zero for all potential destination markets that were not served by the firm before or in period  $t$ . In columns (3) and (6) we study the probability of a firm continuing to export to a market, the dependent variable takes the value 1 if the firm was exporting to market  $c$  in period  $t-1$  and continues to export in  $t$ ; if the firm exports in period  $t-1$  but not in  $t$ ,  $cont=0$ . Observations are by firm-country. Monthly data for 2015 and 2016 are aggregated to half-yearly observations, for the first and second six-month periods in each year for a firm-product. Time dummies are always included along with the other fixed effects specified. A constant term is also included in all specifications. t-statistics based on robust standard errors clustered by country in parenthesis. \* $p < 0.1$ ; \*\*  $p < 0.05$ ; \*\*\* $p < 0.01$ .

The results are reported in Table 10. Our specification is a linear probability model, similar to Bernard and Jensen (2004), Alborno et al. (2012) and Fernandes and Tang (2014), so coefficient estimates can be interpreted as average marginal effects.<sup>8</sup> We find that the coefficient on the interaction term of interest is negative and statistically significant for entry; that is, after the shock Portuguese firms are less likely to start exporting to the UK relative to other markets. In particular, the estimates imply that the probability to start exporting in the UK is 5 percentage points lower after the Brexit vote. Columns (4) to (6) report results for the sample restricted to EU countries; they show that the coefficients are negative and statistically significant for all dependent variables, showing that after the shock firms are less likely to enter the UK market, relative to the other 27 countries of the European Union, and that existing exporters to the UK are less likely to continue exporting there. In sum, the shock contributed to deter export entry to the UK market and reduced the probability of surviving in the market. In a recent study, Crowley et al. (2018) using data for the UK, find that after the Brexit vote, UK firms are less likely to enter exports into EU countries and those exporting to the EU are more likely to exit.

## 4 Conclusion

In this paper, we provide quasi-natural experimental evidence on the effects of exchange rate shocks on export prices, quantities, entry and exit, using uniquely disaggregated export data, at the firm-product-country-month level for the universe of exporters in Portugal. We exploit the large, sudden, and unanticipated plunge in the British pound following the Brexit referendum as an exogenous exchange rate shock to provide novel evidence on the short-run ERPT and pricing-to-market, as well as on firm-level exports and extensive margin of exports. We have monthly observations on export quantity and prices charged by the same firm exporting the same product to buyers in the UK and in other countries. Assuming that relative marginal cost is constant across markets within the same firm and product, this allows us to cleanly identify the effect on the markup in the UK market relative to that on other countries, particularly other European Union countries, after the referendum shock.

The setting we analyze is exceptional to study the effects of exchange rate shocks on export quantity and ERPT. The large and sudden depreciation of Sterling after the referendum

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<sup>8</sup>It has been extensively shown (see, for example, Wooldridge, 2002 and Angrist and Pischke, 2009) that the average marginal effects from probit estimates are usually very close to the linear estimates.

occurred in an otherwise stable macroeconomic environment. The UK is the fourth largest destination market for Portuguese exports, following Spain, Germany and France, and the largest non-Euro destination market. By using the sharp depreciation of the pound after the vote, we are able to cleanly identify the effect based on changes before and after the referendum shock for the same firm-country-product triplet, for exports to the UK relative to exports to other countries.

We find that, within the same firm-product, the export price to the UK decreases after the Brexit vote, relative to the export price for the same product exported by the same firm but to a different country. That is, within a product, Portuguese firms reduced the markup for their exports to the UK relative to other markets after the exchange rate shock. The reduction in the markup is observed also when we restrict the estimation sample to the EU, which is a more comparable group of countries to the UK, and thus compare exports to the UK with exports to other 27 EU countries, for the same firm and product. Our estimates imply that the export price (denominated in Euro) to the UK decreased by 1% after the shock. Since the sterling exchange rate depreciated by 10% after the referendum, which implied an appreciation of the Euro vis-a-vis the pound, this estimate represents a high ERPT in the short run. We also obtain heterogeneous pricing-to-market, with larger exporters absorbing more of the exchange rate shock on their markups. In particular, exporters in the top quartile of the size distribution reduce the export price in the UK by 1.3% on average, with no statistically significant effects for smaller exporters.

In alternative specifications, we use dependent variables in differences relative to the same month in 2015, and thus estimate the effect of the shock on the percentage change in the price of a product relative to its price in same month in 2015, for products that are exported in 2015 and continue to be exported in the same month, by the same firm in 2016. We continue to find that in response to the depreciation of the pound exporters reduce their export price to the UK; the estimates imply a reduction in export price of 2.8 percentage points. In those specifications, we find that export volume also dropped to the UK following the shock, by 4 percentage points. We also confirm that the effects of the referendum shock on export price to the UK, relative to other countries, persist after accounting for the role of imported inputs, demand elasticity and frequency of price adjustment. We also find that there is more pricing-to-market for consumer goods than for intermediate inputs.

Finally, we examine the impact of the Brexit vote shock on Portuguese firms export parti-

icipation in the UK market. We find that the exchange rate shock reduces the probability of firm export entry to the UK, and the probability to continue exporting in the UK is also reduced after the vote.

Our results have important policy implications for the adjustment to exchange rate movements. The fact that firms lower their markups to the UK following the depreciation of the pound, and consequent appreciation of the Euro, could imply a reduction in profits in the export market for European firms, from a combination of lower markups and lower sales. Also, given evidence that the Brexit vote led to an increase in aggregate inflation in the UK, our finding that European firms exporting to the UK reduce their markups suggests that if they had not lowered the export price to the UK, the effect on UK inflation from imported goods could have been higher.

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## A Appendix

Table A.1: Top export destinations for Portugese firms

2015			
country	rank	exports (billion Euro)	export share
Spain	1	11.50	24.59
Germany	2	5.80	12.41
France	3	5.72	12.24
Great Britain	4	3.31	7.09
USA	5	2.29	4.90
Angola	6	1.97	4.21
Netherlands	7	1.94	4.14
Italy	8	1.55	3.32
Belgium	9	1.09	2.33
China	10	0.80	1.71

2016			
country	rank	exports (billion Euro)	export share
Spain	1	11.90	25.34
France	2	6.00	12.78
Germany	3	5.74	12.22
Great Britain	4	3.49	7.43
USA	5	2.20	4.69
Netherlands	6	1.82	3.88
Italy	7	1.69	3.60
Angola	8	1.45	3.08
Belgium	9	1.18	2.50
Morroco	10	0.66	1.41

Own calculations based on Portuguese firm-level international trade data, from the National Statistics Office.

Table A.2: Sumary statistics, agreggate exports

	total exports (million euros)	number of exporters	average export p/ firm	# products per firm mean	per firm median	# countries per firm mean	per firm median
2015	46730	22519	2.08	13.05	3	3.65	1
2016	46980	21206	2.22	12.16	3	3.91	1

Own calculations based on Portuguese firm-level international trade data, from the National Statistics Office.

Table A.3: Firm-product-country level, firm heterogeneity; EU28 sample

	(1)	(2)
Dependent variable:	ln(Q)	ln(UV)
Sample:	EU28	
<i>Post</i> × <i>GB</i> ×		
Quartile 1	0.0761** (2.21)	0.0212 (1.26)
Quartile 2	0.0288 (1.49)	-0.0136 (-1.38)
Quartile 3	0.0612*** (3.34)	-0.0173*** (-2.84)
Quartile 4	-0.0123 (-0.65)	-0.0106*** (-3.64)
Fixed effects		
Month dummies	yes	yes
Observations	326234	326234
R <sup>2</sup>	0.00341	0.000695

Quantile × month dummies are included in all specifications along with the other fixed effects. A constant term is also included in all specifications. t-statistics based on robust standard errors clustered by country in parenthesis. \*p<0.1; \*\*p<0.05; \*\*\*p<0.01.

Table A.4: Alternative mechanisms, differences relative to the same month in 2015

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent variable:	$\Delta \ln(Q)$	$\Delta \ln(UV)$	$\Delta \ln(Q)$	$\Delta \ln(UV)$	$\Delta \ln(Q)$	$\Delta \ln(UV)$	$\Delta \ln(UV)$
Sample:	excl. importers from UK		importers from UK		All		
$\Phi$ :			import UK/purchases		Demand elasticity		mean $\Delta$ unit val.
$Post \times GB$	-0.0242** (-2.00)	-0.0179*** (-5.32)	0.0938* (1.91)	-0.0714*** (-4.11)	-0.0255* (-1.70)	-0.0439*** (-9.56)	-0.0232*** (-6.68)
$Post \times GB \times \Phi$			0.0260*** (3.96)	-0.00515** (-2.33)	-0.0155** (-2.27)	0.0160*** (4.08)	-0.0583*** (-3.85)
$Post \times \Phi$			-0.0170** (-2.59)	0.00574*** (2.61)	0.00778 (1.14)	0.00418 (1.07)	0.0344** (2.25)
Fixed effects	Firm-product-country fixed effects						
Month dummies	yes	yes	yes	yes	yes	yes	yes
Observations	297818	297818	197545	197545	495358	495358	484224
R2	.00132	.0000932	.00156	.00045	.00118	.0000918	.0243

Columns (1) and (2) exclude firms that import from the UK during the period. Columns (3) and (4) interact the  $Post \times GB$  term with the ratio of imports from the UK over purchases by the firm, and are thus based on the sample of firms that import from the UK. Columns (5) and (6) interact with (the log of) Broda and Weinstein (2006) import demand elasticity for each HS good. Column (7) interact with the average change in (log of) unit values over the period for a firm, to proxy for the frequency of price adjustment. A constant term is included in all specifications. Column (7) includes lower-order terms; they are absorbed by the fixed effects included in the remaining columns. t-statistics based on robust standard errors clustered by country in parenthesis. \* $p < 0.1$ ; \*\*  $p < 0.05$ ; \*\*\* $p < 0.01$ .

Table A.5: Intermediates and consumer goods, differences relative to the same month in 2015

	(1)	(2)
Dependent variable	$\Delta \ln$ unit value	
Goods type	inputs	consumer goods
$Post \times GB$	-0.0292*** (-7.07)	-0.0331*** (-4.84)
Constant	0.0242*** (3.18)	0.00533 (0.54)
Fixed effects	Firm-product-country fixed effects	
Month dummies	yes	yes
N	204553	264186
R2	.000196	.000205

Each HS6 good is classified as intermediate input or consumer good using the UN-BEC concordance. We report estimation results for both types of goods separately in columns (1) and (2). t-statistics based on robust standard errors clustered by country in parenthesis. \* $p < 0.1$ ; \*\*  $p < 0.05$ ; \*\*\* $p < 0.01$ .