Invoicing and the Dynamics of Pricing-to-market

Evidence from UK Export Prices around the Brexit Referendum

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Abstract

We provide micro-econometric evidence that, following the large and persistent sterling depreciation after the Brexit referendum, on impact, exchange rate pass-through (ERPT) was complete for transactions invoiced in producer currency and low for sales invoiced either in a vehicle or in the destination market currency. Yet these differences strikingly narrowed within six quarters. A weaker currency did not translate into a persistent gain in price competitiveness for UK exports. At a granular level we find that UK exporters invoice in multiple currencies—even when shipping a product to the same destination—and switch currencies over time. Remarkably, we fail to detect significant changes in the relative shares of invoicing currencies in response to the Brexit shock. Last but not least, we find that UK firms price-to-market, i.e., adjust markups to bilateral exchange rate and CPI movements, only when they invoice sales in the destination-market currency.

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1 Introduction

International economists have long noted that aggregate exchange rate pass through (ERPT) is significantly correlated with the currency in which most international trade transactions are invoiced.[1] In recent years, the availability of large datasets has boosted this line of research; leading papers have identified empirical regularities that have propelled the frontier of open macro and trade theory forward (see, e.g., Gopinath, Itskhoki and Rigobon (2010); Goldberg and Tille (2016); Amiti, Itskhoki and Konings (2018); Gopinath et al. (2020); Auer, Burstein and Lein (2021)). Most notably, in light of the widespread use of the US dollar in invoicing, Gopinath (2015) put forward the view that the bulk of global trade operates under a dollar-dominated "international price system"—implying significant asymmetries in the international transmission of monetary and real shocks at odds with the received wisdom on the role of the exchange rate as a shock absorber.[2]

In this paper we provide novel evidence on how invoicing currencies influence the pricing of traded goods with an investigation into the dynamics of ERPT and pricing-to-market using granular administrative data—the universe of the UK's extra-EU trade transactions—spanning the years 2010 through 2017.[3] A relatively long sample with detailed information on invoicing at the firm, product, and destination level allows us both to offer a novel set of stylized facts utilizing cross-sectional and time variations in a firm's choice of currencies, and to carry out two econometric studies. In the first econometric study, we examine ERPT in response to the sharp fall in the sterling after the 2016 Brexit referendum, building on the approach pioneered by Bonadio, Fischer and Saure (2019).[4] In the second, we examine pricing-to-market by applying the panel data method we developed in related work, see Corsetti, Crowley, Han and Song (2018). UK data are particularly suitable for the purpose of our comparative study of pricing by invoicing currency because significant shares of foreign

[1] See the discussion in Burstein and Gopinath (2014).

[2] See Goldberg and Knetter (1997) and Corsetti and Pesenti (2005) for an early discussion.

[3] Our analysis also examines HMRC's EU dispatches (exports) and arrivals (imports) data over 2010-2017.

[4] Cravino (2017) and Auer, Burstein and Lein (2021) examine pricing and invoicing currency focusing on episodes of large unilateral currency movements.

sales are invoiced in pounds sterling, dollars, and euros as well as in the currencies of destination markets (see also Chen, Chung and Novy (2021)).

We articulate our analysis with three distinct but complementary questions. First, are there significant patterns of invoicing that can be identified using granular data at the firm, product, and destination level? For example, a firm may rely on a single currency or multiple currencies when exporting globally or to specific markets. A firm may vary its invoicing choice, switching currencies over time and/or in response to large shocks, such as the Brexit referendum. The second question concerns the way invoicing currencies correlate with the degree of exchange rate pass through. Using transaction-level export data, one can track the response to large currency movements both on impact and over time. An event study of the Brexit referendum enables us to identify and trace systematic differences in the evolution of ERPT by currency of invoicing in response to a large shock that caused the sterling to depreciate unilaterally and persistently against all currencies.

As for our final and most novel question, we ask whether pricing-to-market (PTM) varies systematically with the currency of invoicing. Evidence that the degree of ERPT correlates with the currency of invoicing does not necessarily imply that invoicing currency also correlates with the way a firm adjusts markups and prices according to destination-specific conditions. A firm that invoices in dollars or its own producer's currency might still adjust its prices differently across markets in response to asymmetric local shocks. Establishing whether firms adjust markups in response to *bilateral* exchange rate movements *conditional on invoicing in dollars* would provide insight into the extent to which Gopinath's "international price system" specifically impinges on markup adjustment.

Our main results are as follows. Through a detailed examination of the use of invoicing currencies by firms, we establish four new stylized facts. First, UK trade is dominated by firms invoicing in more than one currency; for extra-EU exports, these firms originate 99% of British export value. Strikingly, our second fact is that around 15% (50%) of extra-EU export transactions (value) originate from firms that use more than one currency to invoice sales of the same product in the same destination in a given year. These multi-currency exports at the firm, product and destination level

are broadly distributed across currencies, with the median trade share ranging from approximately 60% to 80% for the of the top-ranked currency, and about 20% for the second-ranked currency. Third, an aggregation of firm-level data to the country level reveals that the shares of different currencies are largely stable over time, but there is a slow-moving trend of invoicing in sterling being replaced by invoicing in the US dollar (or in a vehicle currency). Vis-à-vis this aggregate evidence, our fourth finding is that, at a granular level, a proportion of British exporters switch the invoicing currency for sales of the same product in the same destination between one year and the next. Remarkably, however, at both the aggregate and the granular level, we fail to detect significant changes in the relative shares of invoicing currencies in the aftermath of the Brexit referendum.

Our econometric analysis of ERPT in the wake of the Brexit depreciation documents significant differences in the dynamic responses of British export prices according to the currency in which UK firms invoiced their cross-border transactions.[5] We group our observations into three currency schemes: producer currency invoicing (PCI), i.e., invoicing in the currency of the country in which production occurs; local currency invoicing (LCI), i.e., invoicing in the currency of the destination country; and vehicle currency invoicing (VCI), i.e. using a major, third-country currency. We run the econometric model on a sample of 12 quarters centered around the date of the referendum. On impact, British export prices measured in foreign currency fell with the exchange rate rapidly and completely only for trade invoiced in pounds, implying close to 100% exchange rate pass through in the very short run for the majority of export transactions. In contrast, firms invoicing in vehicle (e.g., dollars) or destination currencies kept their prices in the destination market stable over a horizon of about six months, implying no gain in price competitiveness. This differential response remained significant but attenuated relatively quickly. In about six quar-

[5]Since the United States and the European Union are the homes of the two most important vehicle currencies used in the UK's trade, there is a possible ambiguity in the classification of sales as invoiced in vehicle or local currency. For this reason, we begin our analysis on a subsample that excludes the US and EU, comprising 40% of the UK's total export value. We then extend our sample to include first the US and then the EU. Because the UK government does not record the invoicing currency on transactions with the EU, the last extension requires some modifications to our methodology.

ters, differences in the price responses *measured in sterling* significantly narrowed across all invoicing schemes.

Finally, we provide new econometric evidence on the markup elasticity to the exchange rate, documenting a systematic relationship between a firm's pricing strategy and its choice of invoicing currency. We estimate the markup elasticity to the exchange rate by applying the *trade pattern sequential fixed effects* (TPSFE) estimator developed in Corsetti, Crowley, Han and Song (2018) to the 2010-2017 sample.[6] Beyond confirming the pattern of pass through found in our Brexit event study,[7] our econometric study shows that firms adjust markups to bilateral exchange rates—hence price-to-market—only when they invoice in local currency. For transactions invoiced in local currency, about one-half of a bilateral depreciation of the pound is absorbed by markup adjustments that are unique to a specific foreign destination; markup adjustments account for about one half of incomplete exchange rate pass through. Conversely, when invoicing in pounds or a vehicle currency, firms appear to price to the 'global' market, in that they do not adjust markups differently across destinations in line with differences in bilateral exchange rate movements.

We show that the evidence of pricing-to-market is stronger when we include trade with the large US or EU market in the analysis. Expanding the dataset to include UK exports with the US invoiced in US dollars, we find that markup adjustment becomes more pronounced, accounting for up to 70% of incomplete exchange rate pass through; this is consistent with evidence on the dollar price stability of US imports (Gopinath, Itskhoki and Rigobon (2010)). For trade with EU countries, although

[6]The key difference between the TPSFE and other leading fixed effects (FE) estimators in the literature is that the former explicitly controls for the realized set of foreign destinations where a firm's product is sold. By doing so, the TPSFE reduces estimation bias by reducing the variation associated with any unobserved and/or unobservable factors driving a firm's decision to export in a particular set of destination markets. The estimator takes advantage of multi-destination exporters to difference out, for each product, the common marginal cost and markup charged in all markets within a period. The remaining (residual) variation in prices can be used to identify changes in markups that are specific to particular destinations in reaction to exchange rate fluctuations. In Section OA6.3 of the Online Appendix, we provide estimates based on other FE estimators which confirm our main conclusions.

[7]In our dataset for 2010-2017, which omits US and EU exports, we find that exchange rate pass through is higher when trade is invoiced in sterling (around 80%) relative to when it is invoiced in a vehicle or in local currency (around 65% and 45%, respectively).

we have no data on the invoicing currency, we infer the importance of pricing-to-market in two ways. First, we estimate the price and markup elasticities to changes in individual EU countries' CPIs. We find these elasticities to be significantly higher than the average for extra-EU destinations, and close to the elasticities for extra-EU transactions invoiced in local currency. Second, we show that when we add exports to the EU to the sample of exports to extra-EU destinations, the share of incomplete ERPT accounted for by markup adjustments rises from 25 to 67 percent, regardless of the invoicing currency.

Our econometric results contribute important evidence to the recent literature exploring how invoicing currencies map into markup decisions by firms. Most notably, based on microdata on Irish firms, Fitzgerald and Haller (2014) find that, with a home currency depreciation, markups for sterling-invoiced exports rise one-to-one in proportion to the markups charged on domestic sales when conditioning on a price change. Because the Irish dataset does not systematically report the foreign destinations of firm-level exports, it is not possible to quantify differences in the elasticity of markups charged by Irish exporters across invoicing currencies and destinations at a global level, as we do in our study of UK firms. Yet Fitzgerald and Haller (2014) and our study together provide complementary evidence of price discrimination in different forms—these authors document relative markup adjustment across the domestic and the foreign market, while we document relative markup adjustment across different destination markets by currency of invoicing. In his study focused on productivity and quantity elasticities using data on Chilean firms over the years 2009-2011, Cravino (2017) shows that Chilean export prices are rigid in the currency in which they are invoiced, so that, in a given destination, the relative price of products invoiced in different currencies fluctuates with the nominal exchange rate.

As a contribution to the literature exploring the choice of invoicing currency (see e.g., Friberg (1998), Devereux, Engel and Storgaard (2004), Bacchetta and van Wincoop (2005), Engel (2006), Gopinath, Itskhoki and Rigobon (2010), Chung (2016), Mukhin (2017), Amiti, Itskhoki and Konings (2018), Gopinath et al. (2020), and Bahaj and Reis (2020)), our new facts and evidence suggest that currency choice is an active margin, leading to variation in pricing within and across foreign markets as

well as over time. Specifically, our results lend support to models in which firms build portfolios of invoicing currencies as an endogenous response to their profit optimization problem; pioneering work includes Corsetti and Pesenti (2002) and Goldberg and Tille (2008).

The rest of the paper is organized as follows. Section 2 describes our data. Section 3 presents new stylized facts for firm and transaction-level invoicing choices. Section 4 discusses our Brexit event study. Section 5 presents our econometric results on price and markup elasticities conditional on invoicing currency. Section 6 concludes.

2 Data

Our dataset includes the universe of UK trade transactions with countries outside of the EU. We additionally include all data reported in the EU overseas dispatches and arrivals dataset.[8] The length and coverage of our sample is dictated by data availability. HMRC holds information on the invoicing currency for extra-EU trade transactions since January 2010. Since this date, all importers must report their currency of invoicing for every extra-EU transaction. Exporters have to report the invoicing currency only when their annual exports outside the EU exceed £100,000 in value. While, because of data availability, the bulk of our analysis will focus on extra-EU trade, at the end of the paper we extend our empirical analysis to include trade with the EU.[9] In HMRC's extra-EU dataset, transactions are reported with the day, month, and year that goods enter (exports) or clear (imports) UK customs. Firms are identified by a firm-specific anonymised identifier and products are defined by an 8-digit Combined Nomenclature (CN) code. We observe one transaction (value in sterling and quantity) for each firm, product, destination, currency and

[8]The dataset on EU overseas dispatches and arrivals includes monthly data on firm-product-level trade between UK firms and EU member states for for UK firms whose total value of exports exceeds the Intrastat reporting threshold £250k of per annum (since 2009). Notably excluded are small value postal transactions and trade by firms that regularly export less than £250k per annum to the EU. Detailed statistics and data cleaning procedures are reported in Online Appendix OA6.1.

[9]Approximately 53% of UK exports were sent to extra-EU destinations over 2010-2017. Author's calculation from HMRC Overseas Trade in Goods Statistics: `https://www.uktradeinfo.com/trade-data/`.

day combination.[10] More information on the database and the construction of the estimation sample is provided in the accompanying Online Appendix.

Our analysis begins by classifying each transaction in the extra-EU dataset according to its invoicing currency and destination/origin. For UK *exports*, we group transactions into three invoicing schemes: producer currency invoicing (PCI) if the invoice is written in pounds sterling; local currency invoicing (LCI) if it is written in the currency of the destination country; and vehicle currency invoicing (VCI) if it is written in a third-country currency. Examples of LCI include UK exports to South Korea invoiced in won and UK exports to the US invoiced in US dollars; examples of VCI include UK exports to Mexico invoiced in US dollars or UK exports to Cote D'Ivoire invoiced in euros.

For UK *imports*, the same categories apply in a symmetric way. All imports into the UK invoiced in British pounds are classified as LCI. All UK imports invoiced in the currency of the country of the foreign exporter are classified as PCI. UK imports invoiced in neither of the above are VCI. Examples of PCI include imports from Japan invoiced in yen; examples of VCI include imports from Mexico invoiced in dollars.

When the currency of invoicing is not reported, we drop the corresponding observation. In 2015, extra-EU exports from the UK with no invoicing currency reported account for around 7.5% of total export value and 31.0% of the total number of transactions. For extra-EU imports, observations for which no invoicing currency is reported account for a much smaller fraction of transactions (less than 5%) and a trivial share of import value (0.1% or lower).[11]

[10] That is, for every day in our sampling period (1 January 2010 through 31 December 2017), we observe the set of firms which exported on that day. For each firm, we have detailed information on the set of products sold in each destination market along with the invoicing currencies used for each product in each destination.

[11] See Figure OA1-1 for additional information on the fraction of extra-EU exports for which no invoicing currency is reported.

3 Facts about invoicing currencies and their trade shares

In this section, we use firm-level transactions data from the UK to document a set of stylized facts about invoicing and the dynamics of invoicing shares. First, most exporters invoice in more than one currency. Second, a large share of exporters use multiple currencies for invoicing their transactions to the same destination and involving the same product within a calendar year. Third, a non-negligible share of firms switch the currency of invoicing from one year to the next. Together, these three facts suggest that exporters do not invoice in a single currency—neither by product, nor by destination market, nor both; and that, at the margin, firms switch currencies.[12] Last but not least, we show that these rich and complex patterns, unveiled by our granular analysis, are hidden beneath aggregate invoicing shares which remain relatively stable throughout our sample period.

3.1 The UK's trade is dominated by firms invoicing in more than one currency

Our analysis begins with the universe of the UK's extra-EU exports, including exports to the US, at the transaction level. In table 1, we report the joint distribution of the number of invoicing currencies and the number of destinations for extra-EU exports at the firm level. Specifically, for each firm, we calculate the total number of destinations reached and the total number of invoicing currencies used in all transactions across all years in which the firm is observed in our sampling period, and then allocate each firm into one of the destination and invoicing currency bins specified in table 1. As can be seen from the first column of the table, only 43.4% of

[12]These findings point to an extra degree of complexity in modelling endogenous currency choices, departing from the existing literature focusing on nominal rigidities (see, e.g., Devereux, Engel and Storgaard (2004), Engel (2006) and Gopinath, Itskhoki and Rigobon (2010)) and "strategic complementarities" in input costs and competition (see e.g., Goldberg and Tille (2008), Chung (2016), Mukhin (2017) and Amiti, Itskhoki and Konings (2018)). These patterns of invoicing differ substantially from those identified by Cravino (2017) in Chilean microdata. Crowley, Han and Son (2021) examine the complex firm-level invoicing patterns identified here and highlight the importance of the dynamics of a firm's currency choices both over time and across markets.

exporters sell their products using a single currency of invoicing. Among these, the overwhelming majority are single-destination firms—accounting for 35% of all firms. The bottom panel of the table shows that the economic importance of exporters invoicing in a single currency is actually very limited, accounting for less than 1% of export value. Remarkably, even firms that export to a single destination use more than one currency. About 15% (6.4/41.6) of single-destination exporters use multiple currencies, generating 60% (0.6/1.0) of the export value from all single-destination firms.[13]

Table 1: Distribution of the number of exporting destinations and invoicing currencies used at the firm level (extra-EU exports, 2010-2017)

	No. of Invoicing Currencies				
No. of Destinations	1	2-5	6-10	10+	Total
(a) by Share of Firms					
1	35.2	6.4	0.0	0.0	41.6
2-5	7.8	25.3	0.0	0.0	33.1
6-10	0.4	10.4	0.1	0.0	10.9
10+	0.1	12.7	1.5	0.2	14.4
Total	43.4	54.8	1.5	0.2	100.0
(b) by Share of Trade Values					
1	0.4	0.6	0.0	0.0	1.0
2-5	0.2	3.0	0.0	0.0	3.2
6-10	0.0	3.9	0.1	0.0	4.1
10+	0.0	30.4	26.7	34.5	91.7
Total	0.7	38.0	26.9	34.5	100.0

Note: The top panel shows the share of firms, the bottom panel shows results weighted by trade value. We calculate the trade-weighted statistics by weighting each firm by its total trade value (denominated in sterling) over all trading periods across all destinations and invoicing currencies. Data source: HMRC administrative datasets, UK's extra-EU exports, 2010-2017.

Turning to column 2 of table 1, we find that the use of more than one invoic-

[13]In Online Appendix OA1.1, we report statistics when the number of destinations and the number of invoicing currencies are calculated for firms in a particular year. Consistent with our findings at the firm level, we find 94% of the UK's extra-EU export value originates from firms invoicing in more than one currency at the firm-year level.

ing currency is the norm among multi-destination exporters (see rows indicating 2-5, 6-10 and 10+ destinations in the top panel). Only 14% of firm-year dyads ([7.8+0.4+0.1]/[33.1+10.9+14.4]) and 0.2% of export value (0.2/[3.2+4.1+91.7]) originate from multi-destination exporters that invoice in a single currency. The headline conclusion from this table is that over 99% of export value (38.0 + 25.9 + 34.5) originates from firms that invoice in multiple currencies.[14]

3.2 Firms use multiple currencies to invoice a single product within a single destination

We next exploit the highly disaggregated information in our dataset to explore the structure of invoicing patterns within a firm, product, destination, and year. Specifically, we calculate the total number of currencies used by the same firm selling the same CN08 product in the same destination in a calendar year; we refer to observations at this level of aggregation as "firm-product-destination-time" (FPDT) quartets.

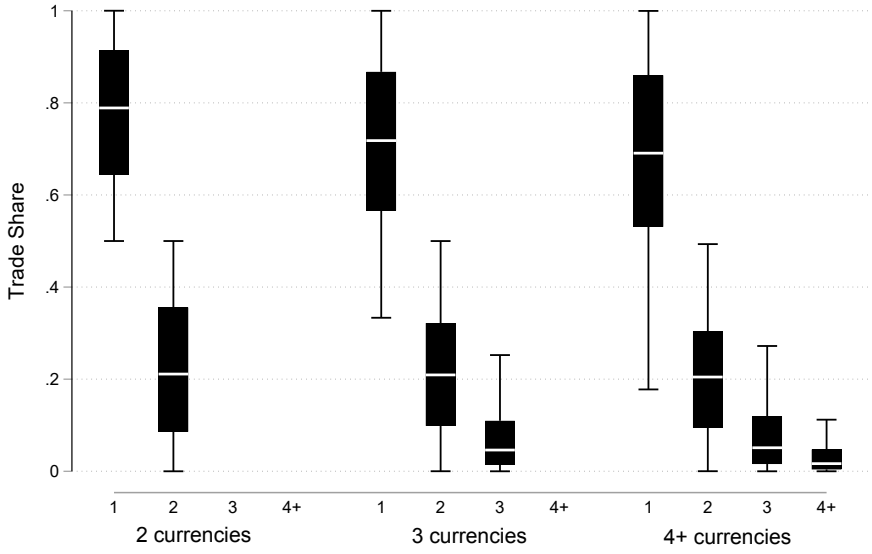
Table 2 reveals that multi-currency invoicing within a firm-product-destination-year quartet is high. Invoicing in two or more currencies accounts for 16% (14.3+1.5+0.2) of FPDT quartets and nearly 50% (41.1+8.0+1.5) of trade-weighted FPDT quartets. In other words, for a non-trivial share of trade in the same product, reaching the same destination, originating from a single firm, invoicing is done in more than one currency.

The evidence in table 2 naturally prompts the question of whether the shares of different currencies used in invoicing a firm's product in a particular destination are economically significant. Figure 1a documents that, for FPDT quartets in which more than one currency is used in a destination, the trade share of the second most important currency is substantial, with a median value of twenty percent. The top panel (figure 1a) shows the distributions of the trade shares for three distinct groups of FPDT quartets: the group in the top left panel includes FPDT quartets that use

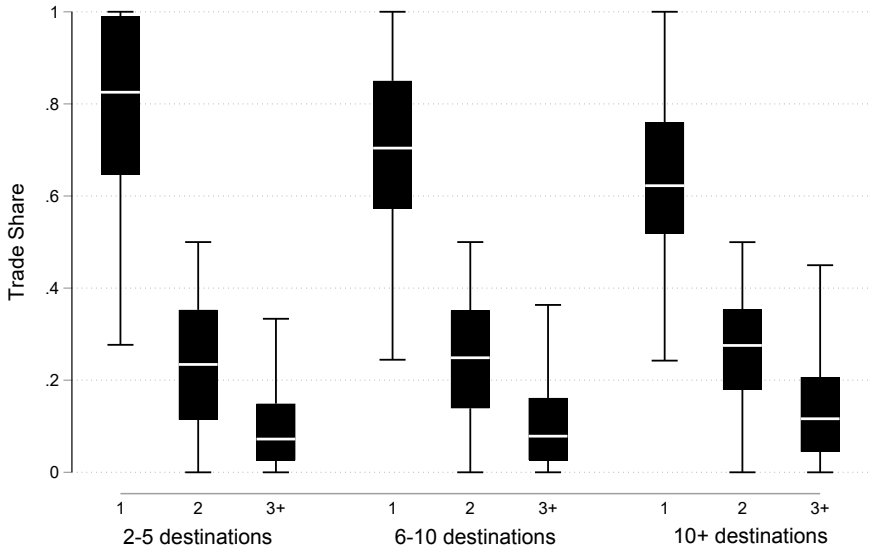
[14]We provide a decomposition of the firms' invoicing shares by destination following Amiti, Itskhoki and Konings (2018) in Online Appendix OA3.

Figure 1: The Value Share Distributions of Invoicing Currencies
(extra-EU exports, 2010-2017)

(a) Grouped by the number of currencies at the firm-product-destination-time level



(b) Grouped by the firm's total number of exporting destinations



Note on Box Plot Statistics

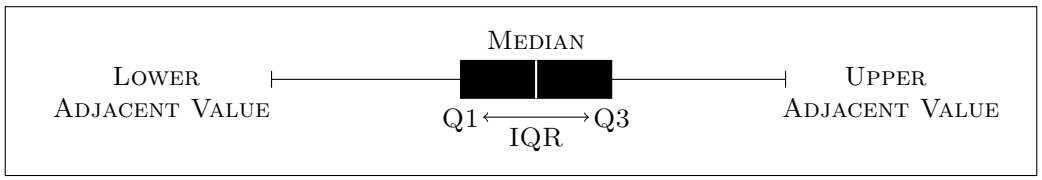


Table 2: Number of invoicing currencies for each firm-product-destination-year quartet (extra-EU exports, 2010-2017)

No. of Currencies	No. of FPDT quartets	Share (FPDT quartets %)	Share (Trade %)
1	5,134,053	84.0	49.4
2	872,124	14.3	41.1
3	92,631	1.5	8.0
4 plus	9,833	0.2	1.5
Total	6,108,641	100.0	100.0

Data source: HMRC administrative datasets, UK's extra-EU exports, 2010-2017.

two currencies in a destination (labelled "2 currencies"); the top middle group refers to FPDT quartets that use three currencies in a destination (labelled "3 currencies"); and the top right group (labelled "4+ currencies") consists of FPDT quartets that use four or more currencies in a destination. To construct the distributions in each panel, we begin by rank-ordering each FPDT quartet's currencies by trade value. Next, we construct a box plot of the distribution of the trade share of the first through the nth ranked currency for all FPDT quartets in each panel.[15] In the group of box plots to the left of the panel, depicting data from the FPDTs that use two currencies, the first currency accounts for nearly 80% (at the median) of the trade value—leaving a non-trivial trade share for the second-ranked currency of around 20% at the median. The value share of the first currency decreases for the FPDT quartets that invoice in more currencies (moving across to the middle and right groups of Figure 1a). For the FPDT quartets that use four or more currencies, the median trade share of the first currency drops below 70%, with most of this decline absorbed by the third and fourth (plus) currencies.

Figure 1b shows an alternative breakdown where we rank-order the trade value of the currencies at the firm level and group the firms into three bins according to

[15]For clarity, the 872,124 (92,631; 9,833) FPDT quartets in Table 2 that use two (three; four or more) currencies are used to construct the distributions in the left (middle; right) panel of Figure 1a. The box graphs are produced using the Stata's `graph box` command, where the upper and lower adjacent values are as defined by Tukey (1977). Let x represent a variable for which adjacent values are being calculated. Define $x_{(i)}$ as the i th ordered value of x, and define $x_{[25]}$ and $x_{[75]}$ as the 25th and 75th percentiles. Define U as $x_{[75]} + \frac{3}{2}\left(x_{[75]} - x_{[25]}\right)$. The upper adjacent value is defined as x_i, such that $x_{(i)} \leq U$ and $x_{(i+1)} > U$. Define L as $x_{[25]} - \frac{3}{2}\left(x_{[75]} - x_{[25]}\right)$. The lower adjacent value is defined as x_i, such that $x_{(i)} \geq L$ and $x_{(i-1)} < L$.

their total number of export destinations. The left, middle and right groups of box plots in figure 1b correspond to the second, third and fourth rows of the panels in table 1, respectively. Notably, the share of the most-used currency declines in the number of destination markets reached by a firm.

The median trade share of the most important currency is above 80% for firms that reach 2 to 5 destinations; it declines to about 60% for firms that reach 10+ destinations. Correspondingly, the value shares of the second and third most important currencies are non trivial; the median trade shares of these currencies rise as the firm reaches more destination markets. When the analysis is repeated at the more granular firm-product-destination-month level, the value share distributions are quite similar. We find similar patterns for the invoicing currency shares of UK imports from extra-EU origins. These additional results are shown in Online Appendix OA2.

These new facts on multi-currency invoicing at the firm, product, destination and time period level pose an important challenge to theoretical models which typically assume that a firm invoices in only a single currency to a given destination. These empirical findings call for more comprehensive models that allow firms to choose a combination of different currencies to implement their desired pricing strategies.

3.3 Firms switch the currency of invoicing over time

The evidence on the use of multiple currencies in invoicing raises a host of questions concerning an exporter's choice of invoicing currencies. When a UK exporter sells a product in a specific destination and we observe transactions in two or more invoicing currencies, it is possible that the firm uses different currencies for different customers. Alternatively, it might be that the firm is switching the invoicing currency over time. Since our dataset does not include information on the identity of the buyer, we cannot distinguish among these different cases. Yet, the highly granular nature of our data allows us to provide some evidence on the persistence of invoicing schemes—i.e. on the extent to which exporters stick to their choices over time.

To gain insight into the extent to which firms switch the currency of invoicing within any given time span, we focus on FPDT quartets (as defined in the previous

subsection) for which invoices are written in only one currency. Namely, starting from the universe of extra-EU exports aggregated to FPDT quartets which are presented in table 2, we drop all FPDT quartets associated with invoicing in more than one currency within a calendar year. This leaves us with the 5.1 million annual FPDT quartets in row 1 of table 2. For these single-currency FPDT quartets, we classify each quartet's invoicing scheme (PCI, VCI, or LCI) and estimate the probability that the scheme changes between years. Results are shown in table 3.

The main takeaway from the table is straightforward. Looking at firms that use only a single currency within a calendar year for a product and destination, the choice of invoicing scheme – PCI, LCI or VCI – tends to be highly persistent. As shown in the top panel of the table, the percentages on the diagonal of the table are between 76% and 93%. Yet, there is a fair amount of switching. For extra-EU exports, a switch in the invoicing currency is most likely for FPDT quartets invoiced in local and vehicle currencies. When there is a switch, the most likely switch is into producer currency invoicing. For around 7% of PCI FPDT quartets (row 2 of the top panel of table 3), we observe a switch into other currencies, with about 90% of these switches going into a vehicle currency.

The bottom panel of table 3 repeats the analysis for a restricted sample of large value transactions. To construct this sample, we rank all firm-level transactions by their trade values at the CN08-product level within each destination in each year. We then select those transactions in the top quarter of the distribution for each CN08-product in each destination in each year. The estimated transition matrix based on these large-value transactions is shown in the bottom panel of table 3. For these transactions, the probability of a switch in the currency of invoicing is slightly lower than for the whole sample—firms are more likely to stay with the same currency scheme used in the previous period. The difference between the two panels is most pronounced for local currency invoiced transactions. These estimates may lend some empirical support to the argument that the size of a transaction is a key determinant of the choice of an invoicing currency (e.g., Goldberg and Tille (2016)).

Table 3: Invoicing scheme transition matrix
(extra-EU exports, annual estimates 2010-2017)

		To		
		LCI	PCI	VCI
From	LCI	76.44	18.11	5.45
	PCI	0.53	93.32	6.14
	VCI	0.52	17.07	82.41
Conditional on large transactions (top quarter by trade value)				
		To		
		LCI	PCI	VCI
From	LCI	83.32	12.94	3.74
	PCI	0.59	94.19	5.23
	VCI	0.53	12.86	86.62

Note: This transition matrix is generated conditional on single invoicing currency transactions at the firm-product-destination-year level. Data source: HMRC administrative datasets, UK's extra-EU exports, 2010-2017.

Table 4: Monthly transition matrices at different points of time
(extra-EU exports, monthly estimates, 2010-2017)

			To		
			LCI	PCI	VCI
18 Months from the Start of the Sample (Jan2010-Jun2011)	From	LCI	83.50	12.53	3.96
		PCI	0.38	94.94	4.68
		VCI	0.40	13.80	85.80
			To		
			LCI	PCI	VCI
18 Months before the Brexit Referendum (Jan2015-Jun2016)	From	LCI	87.70	9.07	3.24
		PCI	0.54	94.50	4.95
		VCI	0.42	11.52	88.06
			To		
			LCI	PCI	VCI
18 Months after the Brexit Referendum (Jul2016-Dec2017)	From	LCI	89.18	7.78	3.03
		PCI	0.51	94.72	4.77
		VCI	0.49	10.65	88.85

Note: This transition matrix is generated conditional on single invoicing currency transactions at the firm-product-destination-month level. Data source: HMRC administrative datasets, UK's extra-EU exports, 2010-2017.

After seeing these statistics, a natural question is whether these transition probabilities vary over time, and whether they are affected by macroeconomic fluctuations such as the large devaluation of sterling after the Brexit referendum. Table 4 presents the monthly transition matrices of all firms calculated for three time periods: (1) the first 18 months of our estimation sample from January 2010 through July 2011; (2) the eighteen month window before the Brexit referendum in June 2016, and (3) the 18 month window after the Brexit referendum. Comparing the diagonal elements of the three panels in table 4, we find firms choosing LCI and VCI schemes become more likely to stick to their choices over time (LCI: 83.50 $\rightarrow$ 87.70 $\rightarrow$ 89.18; VCI: 85.80 $\rightarrow$ 88.06 $\rightarrow$ 88.85) while the transition probabilities of PCI remain almost the same. The off-diagonal elements of the three panels suggest the changing stickiness of LCI and VCI schemes are mainly driven by fewer firms switching from LCI and VCI schemes to the PCI scheme. Comparing the bottom two panels of Table 4, changes in the transition probabilities immediately after the Brexit referendum seem modest in magnitude; moreover, the small increase in the LCI and VCI invoicing probabilities are possibly part of a long-term trend that preceded the Brexit depreciation.[16] Our results thus suggest very persistent invoicing patterns of firms.[17]

3.4 Slow-moving trends in aggregate shares of invoicing currencies

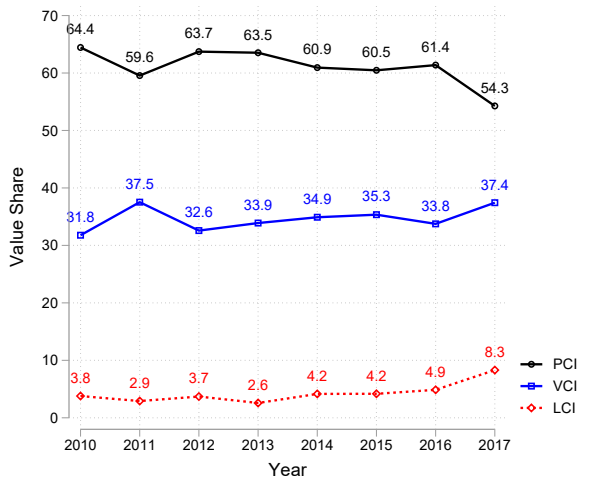
We conclude this section by examining the aggregate shares of invoicing schemes in British trade. To minimize confusion about the role of the US dollar as a vehicle

[16]In Online Appendix OA4, we repeat the analysis for big firms/transactions and do not find significant changes in the invoicing patterns. We report the monthly transaction matrices of UK extra-EU imports in tables OA4-3–OA4-5 of Online Appendix OA4. The patterns of imports are analogous to our findings on exports.

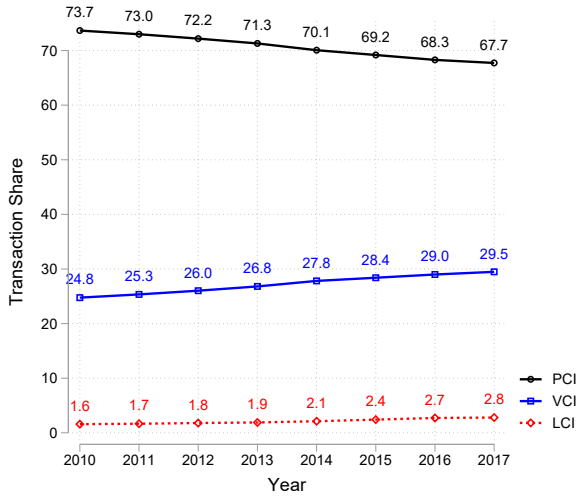
[17]Our evidence on the lack of changes in the invoicing patterns in the short-run do not preclude the possibility that a large sterling depreciation can have significant long-run effects on invoicing patterns. As new firms start exporting and existing firms add new destination markets, the effect of the sterling depreciation can gradually materialize and have a sizeable long-run impact on aggregate invoicing patterns of British firms. We provide a more comprehensive analysis of the dynamic aspects of invoicing currency choices in Crowley, Han and Son (2021).

Figure 2: Aggregate composition of invoicing schemes

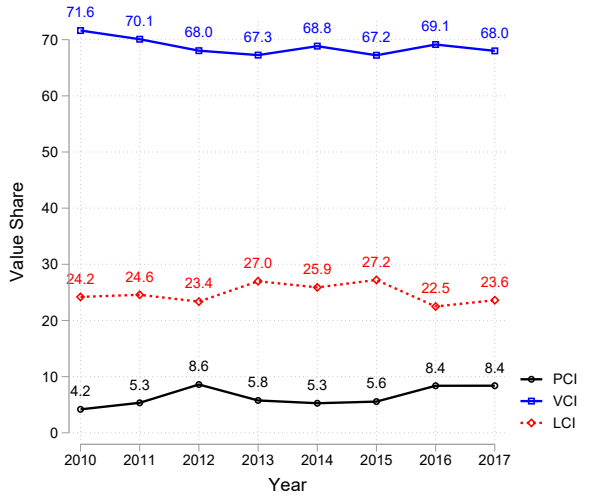
(a) UK exports to extra-EU destinations, value share



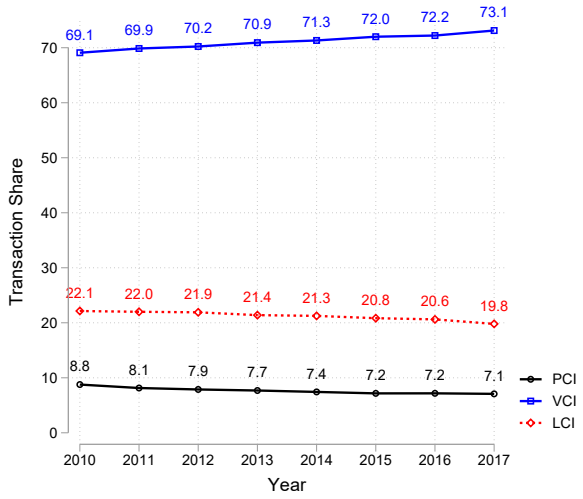
(b) UK exports to extra-EU destinations, transaction share



(c) UK imports from extra-EU sources, value share



(d) UK imports from extra-EU sources, transaction share



currency, we omit all trade with the US from the analysis.[18] Thus, the analysis below excludes the two leading destination markets for UK exporters, the US and the EU, for which we may expect a large share of LCI transactions in dollars and euros, respectively.

In each year, we define the unit of observation as the quintuplet comprised of a (1) firm, (2) product, (3) country of origin (imports) or destination (exports), (4) quantity measure, and (5) invoicing currency. We refer to these quintuplets as "transactions" and categorize them into the three currency schemes: PCI, VCI, and LCI. Figure 2 shows the aggregate value (left) and transaction (right) shares of the three invoicing schemes for each year in our sample, with exports presented in the top panels and imports presented in the bottom panels.

Three facts are noteworthy. First, the invoicing patterns differ across exports and imports; exports are dominated by PCI, while imports are dominated by VCI (i.e., by trade invoiced in dollars). Second, while granular information suggests that firms use multiple currencies by product and destination and sometimes switch invoicing currencies, when we aggregate individual transactions, changes in the share of each invoicing currency scheme are quite modest across the sample period.[19] Figures 2a and 2b show that UK exports are primarily invoiced in producer currency, the pound sterling; PCI accounts for around 70% of firm-product-destination-quantity measure-currency (FPDQC) transactions and about 60% of export value. The second-most important scheme for UK exporters is VCI; between 25-30% of FPDQC transactions are invoiced in vehicle currencies. The picture is rather different for UK imports (figures 2c and 2d). Here, invoicing is dominated by vehicle currencies, with over half of FPOQC transactions and import value invoiced in a vehicle currency in all years of the sample. The shares of LCI imports are smaller, but still about three times larger than those of PCI imports (21% vs. 7%).

Finally, there is a clear slow-moving trend of sterling transactions being replaced

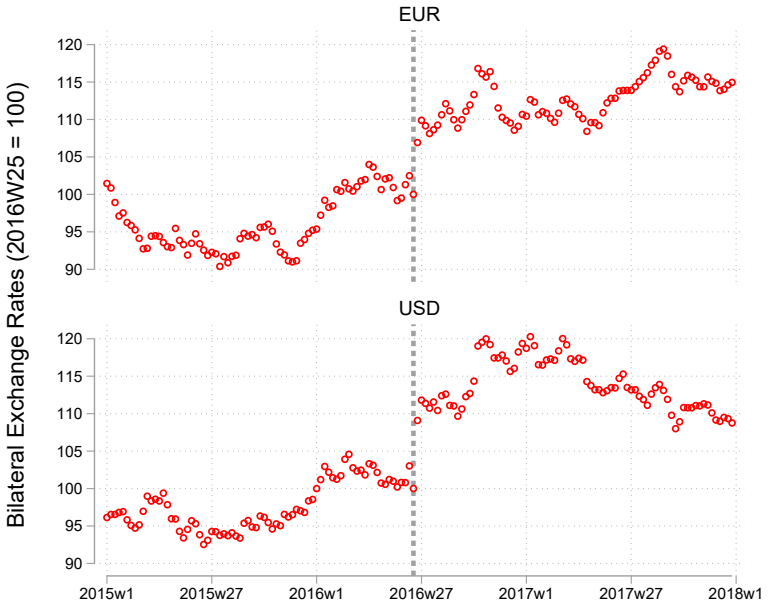
[18]Figure OA1-1 in Online Appendix OA1 presents statistics on the top invoicing currencies for British exports, including exports to the US.

[19]Consistent with table 4 discussed in the previous subsection, we find no significant change of the aggregate transaction share of different invoicing currencies immediately after the large sterling depreciation following the Brexit referendum. See figure OA1-2 in Online Appendix OA1 for more details.

by VCI transactions for both extra-EU imports and exports. From 2010 to 2017, the aggregate share of sterling-invoiced transactions decreased by 6.0 percentage points (73.7% → 67.7%) for extra-EU exports and by 2.3 percentage points (22.1% → 19.8%) for extra-EU imports. In contrast, the aggregate share of VCI transactions increased by 4.7 percentage points (24.8% → 29.5%) for extra-EU exports and by 4.0 percentage points (69.1% → 73.1%) for extra-EU imports. The evolution of the transaction share of the trade partner's currency diverges for extra-EU exports versus imports – its transaction share has almost doubled (1.6% → 2.8%) for extra-EU exports, but dropped by 1.7 percentage points (8.8% → 7.1%) for extra-EU imports.

4 Invoicing and the speed of export price adjustment: evidence from the Brexit depreciation

Figure 3: Movements of sterling bilateral exchange rates



The Brexit event study in this section allows us to study pricing and invoicing conditional on a specific, complex shock that resulted in an idiosyncratic, large and

persistent nominal depreciation of the sterling. Figure 3 plots the nominal exchange rate of the sterling over a three year window centered around the Brexit referendum.

While our previous findings suggest no significant switch across currencies following the large depreciation of the pound, the effect of the depreciation on export pricing differed markedly across invoicing schemes. To set the stage for our econometric analysis below, in the three panels of figure 4 we plot the empirical distribution of changes in export prices (in sterling), contrasting the price changes measured from prior years to 2016 (dashed blue line) with all price changes measured in the previous 6 years (solid red line). In the second and third panels of this figure, for the VCI and LCI transactions, respectively, there is a distinct shift to the right of the distribution of price changes in 2016, relative to those in the 2010-2015 period. This shift to the right suggests that UK export prices rose in sterling (and remained relatively stable in foreign currency) with the depreciation of the pound. In contrast, for UK trade invoiced in sterling, shown in the top panel, the two distributions of price changes overlap almost perfectly: there is no difference across the two subperiods. This suggests that UK exporters who were invoicing in sterling exploited the sterling's weakness to gain price competitiveness in foreign markets.

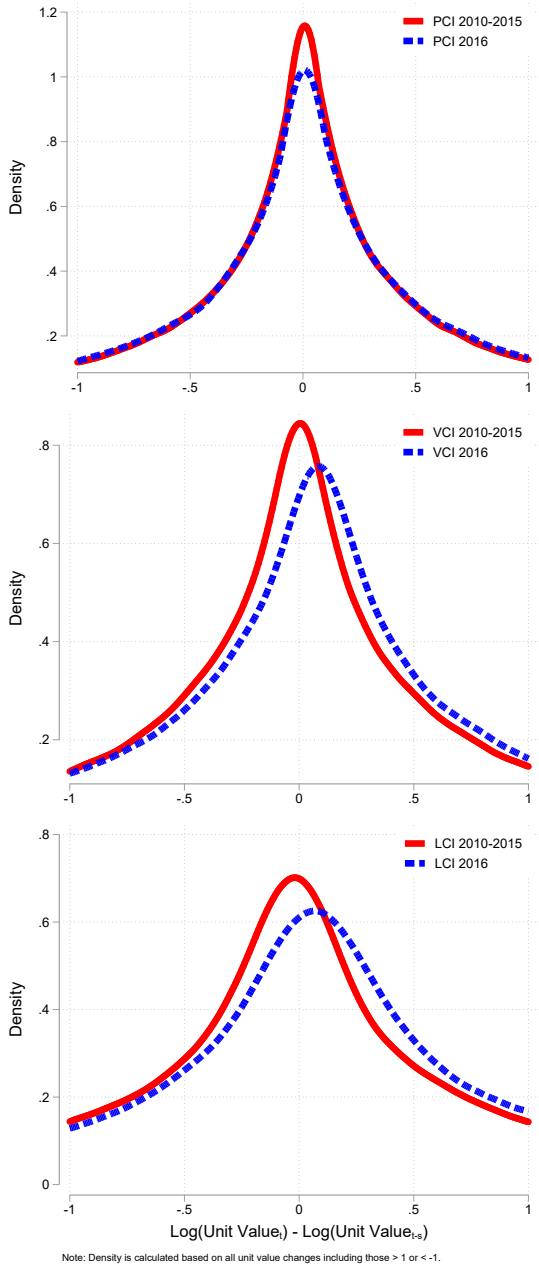
4.1 The empirical model for the event study

In our event study, we analyze the dynamics of export price changes in sterling before and after the Brexit referendum. adopting the methodology of Bonadio, Fischer and Saure (2019). Specifically, we use data from the first week of 2015 through the last week of 2017 to estimate:

$$y_{fidct} = \lambda_t + \delta_{fid} + v_{fidct} \quad y \in \{p_{fidct}, e_{dt}\} \tag{1}$$

where the subscripts f, i, d, c, and t stand for firm, product, destination country, invoicing currency, and time (*in weeks*), respectively; p_{fidct} represents the unit value *in sterling* from the transactions of product i sold by firm f to destination d and invoiced in currency c during week t; and e_{dt} is the sterling-destination currency bilat-

Figure 4: Distribution of annual price changes for extra-EU exports over 2010-2015 versus 2016 by invoicing currency schemes



Note: This graph shows the distribution of annual price changes of the UK's extra-EU exports over 2010-2015 versus 2016 by invoicing currency schemes: producer currency invoicing (PCI), vehicle currency invoicing (VCI), and local currency invoicing (LCI). Data source: HMRC administrative datasets, UK's extra-EU exports excluding the US, 2010-2016.

eral exchange rate, where an increase in e_{dt} means an appreciation of the destination country's currency.[20] All variables enter the estimating equation in logs.

Essentially, the empirical model (1) decomposes the variation of the dependent variable y_{fidct} into three terms: (i) a time-invariant fixed effect (δ_{fid}) capturing firm-product-destination specific features; (ii) a set of week dummies (λ_t for $t = 1, ..., 156$) capturing the average price changes over time; and (iii) a pure idiosyncratic term (v_{fidct}). We estimate (1) for each of the invoicing currency schemes, PCI, VCI, and LCI, over a three year window (156 weeks) around the Brexit referendum to ascertain the "completeness" of pass through over different time horizons.

4.2 Price responses to the Brexit depreciation

Our results are synthesized in figures 5 through 7, one for each invoicing currency scheme (PCI, LCI and VCI). Each figure plots our estimates of λ_t from (1) from the beginning of 2015 through the end of 2017. The x-axis indicates the number of weeks before and after the Brexit referendum, while the y-axis presents the percentage change in the pound sterling (red) or the UK export price measured in sterling (blue). For clarity, we normalize the bilateral exchange rates and the UK average export price in the week of the Brexit referendum to zero. The solid red line depicts the transaction-weighted changes in the sterling bilateral exchange rates based on the transactions invoicing in the specific currency (i.e., increases reflect a decline in the value of sterling).[21] The solid blue line shows our estimates of changes in the export price level (in logs) after absorbing factors specific to the firm, product, and destination. The dashed blue lines represent the 90% confidence intervals.

[20] We construct weekly unit values as our measure of prices. For every transaction in the HMRC dataset, we observe the date on which the goods enter customs. We aggregate the total quantity and value for a firm, CN08-product, currency, and destination at the weekly level. We then calculate the unit value as the total sterling value divided by the total reported quantity (i.e., units, pairs, etc. where reported and net mass in kilos when a unit-type measure is not available). We construct weekly average exchange rates from the official daily exchange rates reported by the Bank of England.

[21] More specifically, the solid red line plots the estimated λ_ts from (1) using the bilateral exchange rate as the dependent variable. Empirically, the sets of destinations to which firms export are different across the three invoicing schemes. In estimating the evolution of the pound sterling under each invoicing scheme, the use of a set of destination-specific bilateral exchange rates implies there will be small differences in the estimates of the λ_ts for each scheme.

Figure 5: Price responses of sterling invoiced transactions (extra-EU exports, 2015-2017)

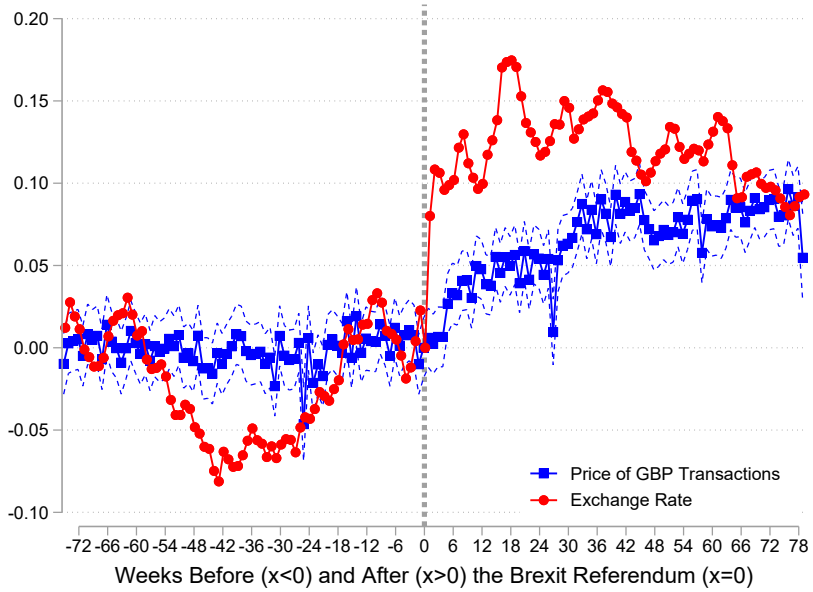


Figure 6: Price responses of local currency invoiced transactions (extra-EU exports, 2015-2017)

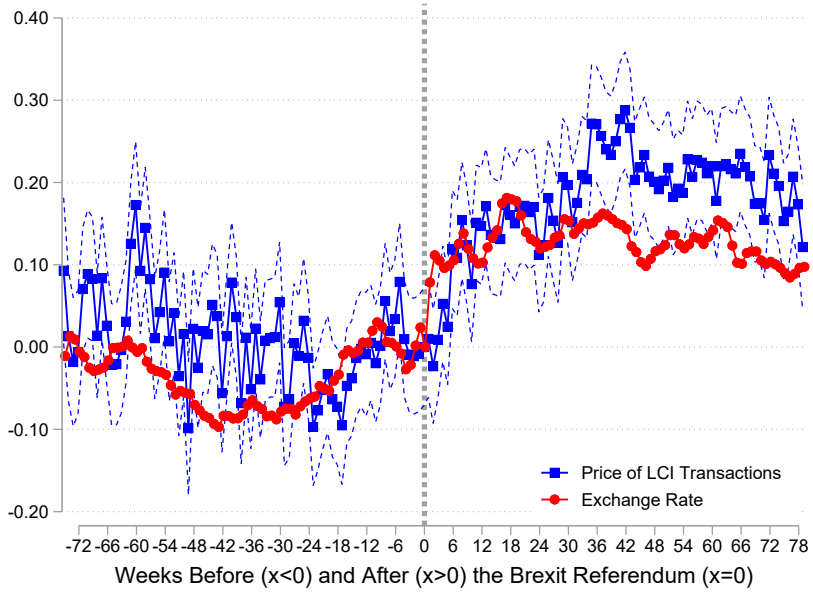
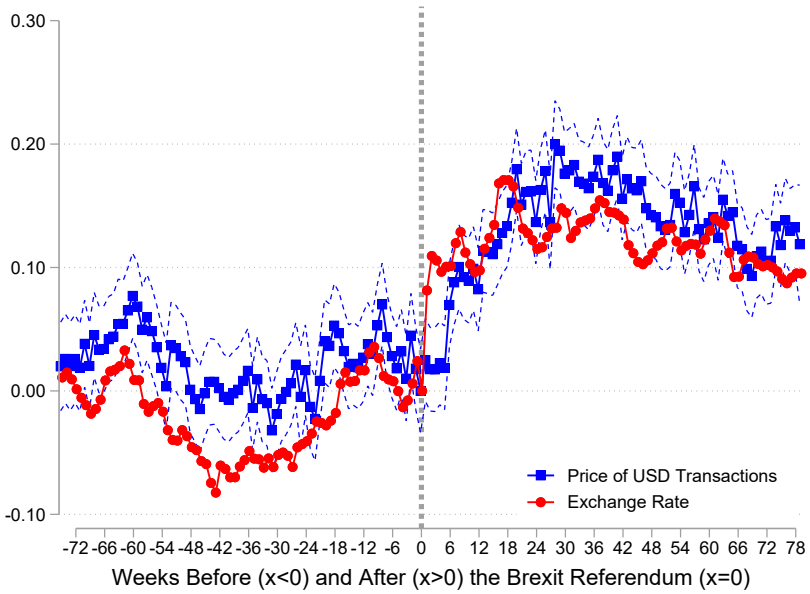


Figure 7: Price responses of dollar invoiced transactions (extra-EU exports, 2015-2017)



These figures highlight striking differences in the export price response to the Brexit depreciation by currency of invoicing. Export prices *measured in sterling* for LCI and VCI transactions, shown in figures 6 and 7, respectively, rose quickly and almost completely with the fall in the pound. Export prices *measured in sterling* for PCI transactions, shown in figure 5, hardly moved on impact, and only rose quite slowly thereafter. The relatively stable export prices for sterling invoiced transactions in the early months after the depreciation mean that, from the perspective of an importer, the prices measured in the local currency of the destination dropped almost one-to-one with the exchange rate—an "exchange rate pass through" of close to 100%.

Over time, figure 5 shows that export prices for sterling-invoiced transactions increased gradually and converged to the rate of the sterling depreciation after about 72 weeks. This pattern implies that the exchange rate pass through into *import prices* fell steadily from almost 100% on impact, to around 0% after a year and a half. In the interim period, for the first 66 weeks (15 months) after the depreciation, the magnitude of the export price change remained significantly smaller than the change

in the exchange rate. Increasing imported input costs likely played a non-negligible role in this evolution of sterling-invoiced export prices, as UK *import prices* also rose steadily with the weaker exchange rate. In the appendix, we document that, by week 36, UK import prices (invoiced in all currencies) had fully adjusted to the weaker pound (see the figures OA5-2–OA5-5 in the Online Appendix).[22]

In sharp contrast, for transactions invoiced in the local currencies of destination markets, the sterling price adjustment to exchange rate changes was much faster and larger. As shown in figure 6, the movements in the exchange rate and the sterling price of LCI transactions largely came to align with each other by six weeks after the referendum, implying a relatively stable price in local currency and suggesting a possibly substantial increase in the exported product's markup. Moreover, from week 36 on, the increase in the sterling price began to exceed the change in the value of the pound. That is, the UK export price *in the destination-market currency* actually rose, if only moderately, around six months after the Brexit Referendum. As already mentioned, by this time, the pass through of the weaker pound into UK import prices had become complete. Together, the evidence of higher import prices and the pricing pattern in the figure hint at the possibility that firms invoicing in local currency passed through the higher marginal costs due to more expensive imported inputs while stabilizing their markups by raising their prices in local currency. In the next section we will provide further evidence that export pricing for LCI transactions significantly differs from pricing for VCI and PCI transactions, specifically with respect to markup adjustment.

Sterling prices also rose quickly for trade invoiced in a vehicle currency. Figure 7 depicts results for US dollar-invoiced transactions to non-US destinations.[23] By week 6 after the referendum, dollar-invoiced export prices (measured in sterling) had risen with the exchange rate almost one to one. Sometime around week 20, the exchange rate pass through into foreign import prices became close to zero.

[22]In light of the point stressed by Goldberg and Tille (2008), Amiti, Itskhoki and Konings (2014), and Chung (2016) among others, one may expect that firms that select into PCI are likely to have a relatively low average share of imported inputs.

[23]Figure OA5-1 in the Online Appendix documents that the evolution of the sterling price of euro-invoiced exports to extra-EU destinations is similar to that of dollar-invoiced transactions to non-US destinations in figure 7.

By the end of the 2017, on average, UK export prices in the currencies of the destination markets had apparently lost the memory of the Brexit depreciation—the weaker currency did not translate into any persistent gain in price-competitiveness for UK exports. This is a remarkable headline conclusion. With UK import prices rising steadily over the post-referendum period, the evidence in this section raises questions about the extent to which adjustment in pricing was driven by costs reflecting rising imported input prices, as opposed to relative markup stabilization. In the interim period, between the referendum and the end of 2017, the time pattern of price adjustment shown in our figures suggests that by invoicing in local and vehicle currency, UK exporters captured temporary but possibly large markup increases (in sterling), which were not observed for trade invoiced in sterling.

5 Invoicing and markup adjustment

In this section, we investigate the extent to which the differences in price adjustment across invoicing schemes can be attributed to markup adjustment in response to destination specific conditions. Firms may price-to-market whether they invoice and price in sterling, local currency or a vehicle currency. Evidence that firms do not price-to-market when they invoice in a vehicle currency would suggest that, when invoicing in dollars, firms tend to adjust prices only to global, rather than destination-specific shocks.

We estimate price and markup elasticities over the entire timespan for which we have data on invoicing, 2010-2017. The longer sample includes movements in the sterling exchange rate that were less dramatic and more varied across countries than those in the aftermath of the Brexit referendum.

5.1 Econometric models

We assess pricing-to-market by following the Knetter (1989) approach of comparing the relative price and exchange rate movements across markets. In Corsetti, Crowley, Han and Song (2018) we show how the Knetter approach can be generalized for

use with highly disaggregated data on customs transactions, where firms may enter and exit destination markets. In this section we adopt the Trade Pattern Sequential Fixed Effect (TPSFE) estimator developed in our earlier contribution—where a *trade pattern* is defined as the set of active markets for a firm's product in each period. This method estimates the markup elasticity to the exchange rate (κ_1) and destination CPI (κ_2) in the following equation through a carefully constructed differencing procedure:[24]

$$p_{fidt} = \kappa_0 + \kappa_1 e_{dt} + \kappa_2 cpi_{dt} + \psi_{fidD} + \eta_{fit} + \upsilon_{fidt} \tag{2}$$

where p_{fidt} is the export price measured in pounds sterling; e_{dt} is the bilateral exchange rate defined as units of sterling per foreign currency; cpi_{dt} is the consumer price index in the destination market; ψ_{fidD} represents the firm-product-destination-trade pattern fixed effects; and η_{fit} represents the firm-product-time fixed effects. All variables are entered in logs. In econometric specifications that focus on sales using the same invoicing scheme, i.e., PCI, VCI or LCI, the trade pattern is restricted to active markets in which a firm uses the relevant currency.[25]

The key idea underlying the TPSFE estimator is to use, for each product, the trade patterns of firms as additional fixed effects to control for unobserved factors driving firms' pricing and market entry decisions. To appreciate the difference relative to a conventional model including firm-product-destination fixed effects, note that the latter restricts the comparison of prices (and exchange rates) to be within the same firm-product-destination triplets. In contrast, our specification with firm-product-destination-trade pattern fixed effects restricts the comparison of prices (and exchange rates) to be within firm-product-destination triplets *with the same trade pattern*.[26]

[24]We apply the estimator conditional on each of the identified invoicing schemes. We omit the invoicing currency subscript here for conciseness. See Online Appendix OA6.1 for details on implementing our method.

[25]Empirically, trade patterns vary considerably over time at the firm-product level. See Han (2018) for stylized facts on the extensive margin adjustments of British firms during our sampling period.

[26]For the sake of clarity, we abstract from the additional complexity caused by adding the firm-product-time η_{fit} fixed effects in the discussions here. See Section 3 of Corsetti, Crowley, Han and Song (2018) for a more comprehensive discussion of the benefits of adding trade patterns as fixed effects and Appendix C of Corsetti, Crowley, Han and Song (2018) for a full theoretical discussion.

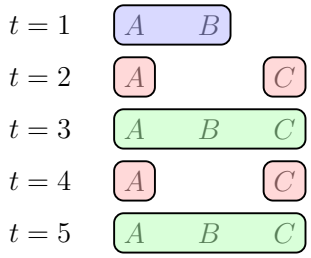


Figure 8: Example of an observed trade pattern

To illustrate how our estimator works, consider the following stylized example. Figure 8 shows the trading records of a firm exporting a specific product to three destinations, A, B, and C, over five years. Empty elements indicate that there is no trade in a period. According to our definition, the firm has three *unique* trade patterns, A-B, A-C, A-B-C over the course of its five-year trade in that product. Notably, two of these firm's product-level trade patterns repeat. The pattern A-C repeats in periods 2 and 4; A-B-C repeats in periods 3 and 5. Now, consider estimating a markup elasticity through the use of an empirical model which includes firm-product-destination fixed effects. In this case, the identification of the markup elasticity would come from variation in price and exchange rate observations across all time periods within the same firm-product-destination (e.g., $p_{A,1}, p_{A,2}, p_{A,3}, p_{A,4}, p_{A,5}$). A key problem for this approach is that changes in the trade patterns of firms may (and are likely to) be endogenous to observed (e.g, bilateral exchange rates) and unobserved (e.g., the marginal cost) variables affecting prices.[27] If market participation is endogenous, an estimator that directly compares prices within a firm-product-destination triplet can embody significant omitted variable and selection biases. As shown in Corsetti, Crowley, Han and Song (2018), including firm-product-destination-trade pattern fixed effects that force the estimator to compare prices (and exchange rates) *within* the same trade pattern (e.g., $p_{A,2}$ with $p_{A,4}$ and $p_{A,3}$ with $p_{A,5}$), can substan-

The latest draft of Corsetti, Crowley, Han and Song (2018) can be found here.

[27]See Han (2018) for direct empirical evidence on the endogeneity of trade patterns to the exchange rate for UK firms. Empirically, trade patterns vary considerably over time at the firm-product level.

tially reduce these biases.[28]

Essentially, the TPSFE builds on the idea that a firm's trade pattern contains valuable information about unobservable economic variables that, in addition to determining market participation, affect pricing in all the foreign markets where the firm is active. As in the control function approaches of Heckman (1979) and Kyriazidou (1997), by restricting the comparison of price observations to those sharing the same trade pattern, the TPSFE estimator reduces the variability of the unobserved variable(s) driving the selection of destination markets. Thus, identification of the markup elasticity is obtained from price observations with similar probabilities of being observed and any selection or omitted variable bias is reduced.[29]

We complement our estimates of the markup elasticity with a comparable esti-

[28]The TPSFE estimator shares important features with the estimator by Fitzgerald and Haller (2014). The analysis of these authors conditions on two matched records of prices, for the domestic Irish and foreign UK markets, at the firm-product level. Take the destinations A (their Irish market) and B (their UK market) of figure 8 as an example. Their approach would compare prices (and exchange rates) when both markets A and B are observed (i.e., $p_{A,1}$, $p_{A,3}$, $p_{A,5}$ and $p_{B,1}$, $p_{B,3}$, $p_{B,5}$)—a methodology that is intuitive and works well in the case of two markets. What the TPSFE accomplishes is a generalization of the differences-across-markets approach, which ultimately goes back to Knetter (1989), to the case of multiple destinations, where the set of active markets changes in response to observed and unobserved factors. Again looking at our example, the TPSFE drops observations corresponding to non-repeated trade patterns, such as $p_{A,1}$, from the pattern, AB. In light of our theoretical results in Corsetti, Crowley, Han and Song (2018), this significantly reduces omitted variable and selection biases. At the same time, the TPSFE utilizes the information of $p_{A,2}$ and $p_{A,4}$ (in addition to the information of $p_{A,3}$ and $p_{A,5}$) as useful variation to identify the price and markup elasticities in a multi-country context.

[29]In Corsetti, Crowley, Han and Song (2018), we prove that our TPSFE estimator and a conventional specification with firm-product-destination fixed effects will generate the same (unbiased) estimates when any underlying unobserved shocks driving pricing and selection can be broken down into additive firm-product-destination and firm-product-time shocks (e.g., when the marginal cost is not destination-specific). However, the TPSFE significantly reduces the omitted variable and selection biases under complex cases/shocks, e.g., when the unobserved marginal cost is firm-product-destination-time specific. In addition, we show that the TPSFE can be implemented by twice-demeaning the variables and then running a simple OLS regression. Alternative approaches, such as a specification adding firm-product-destination and firm-product-time fixed effects, would require iterative algorithms to partial out the fixed effects and solve for the correct parameter values (e.g., Guimaraes and Portugal (2011), and Correia (2017)). As discussed in Corsetti, Crowley, Han and Song (2018), the fact that our approach can be implemented by just twice-demeaning variables greatly enhances the clarity around the sources of variation used to identify the parameters of interest in a complex unbalanced panel with multi-level fixed effects. See Online Appendix OA6.1 for details. It is also worth stressing that our approach to estimating relative markups does not require an estimation of marginal costs based on detailed balance sheet data. See Corsetti, Crowley, Han and Song (2018) for a discussion of the differences and applicability of our methods and leading alternative methods such as De Loecker, Goldberg, Khandelwal and Pavcnik (2016).

mate of the export price elasticity to the exchange rate. Specifically, we remove from equation (2) the fixed effects controlling for the firm-product-time varying components, and run the model below:

$$p_{fidt} = \gamma_0 + \gamma_1 e_{dt} + \gamma_2 cpi_{dt} + \psi_{fidD} + u_{fidt} \tag{3}$$

where γ_1 measures the price elasticity to bilateral exchange rates and is the complement to 1 of the degree of exchange rate pass through (a higher γ_1 indicates a lower ERPT). To understand the difference between (3) and (2), consider the following three-term decomposition of the change in an export price following a change in the exchange rate; the total change consists of: (a) an unobservable change in marginal costs (e.g., due to imported input price changes), (b) an unobserved markup adjustment that is common across all export destinations, and (c) an unobserved markup adjustment that is specific to a particular destination. Our export price elasticity specification (3) estimates the combined response of these three unobserved terms (correcting for endogenous market participation). Our pricing-to-market specification (2) differences out the common components (a) and (b), and thus captures the markup adjustment to destination-specific exchange rate movements (c).

We proceed by constructing each firm's product-level time-varying trade pattern, at first across all extra-EU foreign sales (regardless of invoicing currency), then for each currency scheme, PCI, VCI, and LCI, separately.[30] By doing so we can contrast our estimates of price and markup elasticities averaged over "All" invoicing currencies, with the elasticities for each invoicing scheme—and investigate which invoicing scheme (if any) is associated with pricing-to-market. We carry out our analysis at different time frequencies, and, following Gopinath, Itskhoki and Rigobon (2010), conditional on a change in price.[31] We start by focusing our analysis on the dataset

[30] An important difference between this paper and our previous work using the TPSFE is that British transaction-level data allows us to control for trade patterns not only at the level of a product within a firm, but also by currency of invoicing.

[31] An important refinement is that, in our application, we condition on a price change *in the currency of invoicing*. Specifically, we filter out observations for firm-product-destination triplets (and invoicing currency when relevant) for which the absolute price change is less than 5%. See the accompanying Online Appendix for details. It is worth stressing that, because we condition our analysis on trade patterns *and* price changes, our estimates cumulate price and exchange rate

of exports to all destinations except the EU and US in subsection 5.2; we extend the sample to include the US in subsection 5.3; and, finally, extend to the whole world in subsection 5.3.2.[32]

5.2 Results excluding UK trade with the US

Our econometric results are shown in table 5, at annual, quarterly, and monthly frequencies.[33] At these frequencies, we have information on CPIs. Hence, the table includes estimates of price and markup elasticities not only to the exchange rate, but also to the CPI in the destination market. The first two columns are devoted to the export price elasticities from regression model (3), the next two columns present the markup elasticities from regression model (2). In each of the three panels in the table (one for each data frequency), the row under the headline "All" shows estimates for the full sample without conditioning on invoicing choices. In the following rows, under the headlines "PCI", "LCI", and "VCI", the estimation sample is restricted to firm-product-destination transactions that are invoiced in, respectively, British pounds, vehicle currencies and local currencies.

A first notable result is that the price elasticities with respect to the exchange rate and the CPI (columns (1) and (2)) are economically sizeable and significantly different from zero across all invoicing schemes, and roughly stable when estimated at different frequencies.[34] Conversely, the results on pricing-to-market show that

changes over variable but, typically, long time intervals. These long intervals and a control for the firm-product trade pattern mitigate concerns about potential bias in estimating pass through due to nominal rigidities.

[32]Because no data on invoicing currency is available for UK trade with EU countries, subsection 5.3.2 focuses on comparing estimates across different groups of export destinations rather than across invoicing currencies.

[33]As in our Brexit event study, results shown are conditional on a price change. See Online Appendix OA6.2 for results that do not condition on a price change.

[34]Recall that our estimation procedure cumulates price and exchange rate changes at long and variable intervals, dictated by the re-occurrence of the same trade pattern and/or a price change. Therefore, even though the data in the bottom panel of table 5 consists of monthly observations, the variation in prices and exchange rates used to identify the elasticity could be accumulated over a much longer time span, e.g., over a quarter or year. In general, we find that changing the time frequency of aggregation (and therefore the frequency at which the trade patterns are calculated) does not significantly impact our estimates. One exception is the annual frequency panel, in which the confidence intervals of the point estimates are very large due to a much smaller number of observations and therefore far less variation in prices after controlling for trade patterns.

Table 5: Price and markup elasticities conditional on invoicing currency
– extra-EU destinations excluding the US
– monthly, quarterly, and annual frequencies over 2010-2017

Freq.	Invoicing	Price		Markup		n. of obs
		NEX (1)	CPI (2)	NEX (3)	CPI (4)	
Annual	All	0.23***	0.43***	-0.03	0.07	2,407,326
	PCI	0.19***	0.40***	-0.04	0.02	1,719,388
	VCI	0.30***	0.48***	0.04	0.17	629,323
	LCI	0.51***	1.19***	-0.16	0.61	58,615
Quarterly	All	0.24***	0.43***	0.01	-0.05	4,577,505
	PCI	0.18***	0.37***	-0.01	-0.13	3,226,606
	VCI	0.35***	0.54***	-0.01	0.01	1,224,890
	LCI	0.60***	1.00***	0.39***	0.71*	126,009
Monthly	All	0.25***	0.41***	0.06**	0.00	6,154,892
	PCI	0.19***	0.36***	0.04	0.01	4,255,848
	VCI	0.35***	0.52***	0.06	-0.04	1,732,086
	LCI	0.53***	0.68***	0.30***	-0.04	166,958

Note: This table presents price and markup elasticities by invoicing currency schemes at different time frequencies. Transactions are aggregated at the monthly/quarterly/annual frequency and the trade pattern is calculated at the frequency of aggregation. The dependent variable is the unit value denominated in pounds sterling. The bilateral exchange rate is defined as units of sterling per destination currency; an increase in the bilateral exchange rate is a depreciation of sterling. Statistical significance, based on robust standard errors, is reported at the 1, 5 or 10 percent level which is indicated by ***, **, or * respectively. Data source: HMRC administrative datasets, UK's extra-EU exports, 2010-2017.

the markup elasticity is economically sizeable and significant with respect to the exchange rate (column (3)) only for LCI transactions at the monthly and quarterly frequencies.

A second notable result is that the price elasticities with respect to both the exchange rate and the CPI in the first two columns differ by invoicing scheme.[35] In the first column of table 5, the estimated sterling price elasticity with respect to the exchange rate for vehicle and local currency invoiced transactions are both significantly higher than those for sterling invoiced transactions. Recall that the sterling price elasticities shown in this column are equivalent to one minus the exchange rate pass through into import prices. For example, the price elasticity of 0.19 for sterling invoiced transactions means that, against a 1% bilateral depreciation of sterling, the sterling price of exports increases by 0.19% – this corresponds to an exchange rate pass through into foreign import prices of 81%. Altogether, the econometric results over the longer sample of 2010–2017 are broadly in line with the results of the Brexit event study where we found that the pass through into *import prices* was higher for PCI relative to LCI and VCI transactions. However, the estimates in table 5 also show that the degree of pass through is significantly lower for LCI than for VCI transactions.

But while exchange rate pass through is relatively low in both vehicle and local currency invoiced transactions, markup adjustment is different. Turn to the third column of table 5, which reports estimates from the TPSFE pricing-to-market model (2). Here, the markup elasticity is significantly different from zero only for LCI transactions. Furthermore, the magnitudes of the estimates are substantial; markup adjustments act as a serious brake to the transmission of currency movements across countries. Namely, they account for 56% and 65% of the incomplete pass through, at the quarterly and monthly frequencies (0.39/0.60 and 0.53/0.68), respectively.

In sum, for the bulk of UK exports that are invoiced in sterling or a vehicle currency and sold outside the US or EU, UK firms do not respond to destination-

[35]Out of the firm-product-destination-year combinations in our regression sample that are classified as vehicle currency invoicing, 68% are invoiced in dollars and 29% are invoiced in euros. In the sample, the number of transactions that use other vehicle currencies like the Swiss franc or Japanese yen is small.

specific exchange rates or local inflation by adjusting their markups differentially across different foreign markets. This is a key novel result from our analysis. Our evidence suggests that, for PCI and VCI transactions, price adjustments are driven by either changes in marginal costs or changes in the component of the markup that is common across destinations. Conversely, the choice to invoice trade in local currency appears to reflect (and is associated with) a firm's decision to tailor its prices to destination market-specific conditions (in addition to changes in marginal costs and global market conditions).[36]

It is worth stressing that in our study of pricing-to-market we investigate whether firms change the destination-specific component of their markups vis-à-vis changes in the bilateral exchange rates. Our results that markup differences across markets do not move systemically with differences in bilateral exchange rate movements for transactions invoiced in either producer or vehicle currency do not preclude pricing-to-market *in levels*. That is, it is possible (and plausible) that firms invoicing in producer and vehicle currencies do price discriminate across markets, e.g., by charging a higher markup in rich countries.

5.3 Results extending the analysis to UK trade with the US and the EU

Thus far, our analysis has excluded UK trade with two major markets, the US and the EU. In this subsection, we extend our econometric analysis to the entire extra-EU dataset, including UK exports to the US. In the next subsection, we adapt our model for an analysis of EU data and examine elasticities for sales to the EU and to the whole world. The EU and US represent large and important markets for British exporters, comprising about one-half and one-tenth of aggregate British exports,

[36]We report estimates for markup elasticities using alternative specifications that include firm-product-destination and firm-product-time fixed effects in Online Appendix OA6.3. The results are qualitatively similar to those from the TPSFE estimator, but the quantitative magnitudes differ. Notably, the estimate for the degree of pricing-to-market for LCI transactions is smaller in magnitude when we exclude trade pattern fixed effects. An analysis of model simulated data in Corsetti, Crowley, Han and Song (2018) suggests that failing to control for a firm's product-level trade pattern introduces a downward bias into markup elasticity estimates when a firm's marginal cost includes destination-specific components. See the discussion in Online Appendix OA6.3.

respectively. Thus, if pricing-to-market are important phenomena in UK trade, we would expect to find evidence of this in a lower average ERPT and larger markup elasticity when data from the US and EU are included in the analysis. We would also expect to find a larger markup elasticity when dollar-invoiced sales to the US are added to the sample of other LCI transactions.

5.3.1 Trade with the US

Estimates for the larger dataset of UK trade to all extra-EU destinations including the US are shown in table 6. Relative to our main findings in table 5, the price and markup elasticities in table 6 are higher across all invoicing schemes, consistent with our hypothesis that inclusion of the large, important US market would lower the average ERPT and raise the extent of pricing-to-market. For LCI transactions in particular, including US data raises the estimates of the markup elasticity substantially, and makes them statistically significant at all frequencies (see column (3) in the table). The contribution of adjustments to the destination-specific component of markups to incomplete pass-through now ranges from 68% in the monthly frequency sample, to 88% in the annual frequency sample.

These findings suggest that the lower exchange rate pass through into import prices (the higher export price elasticity estimates) in the enlarged sample (compare column (1) in table 6 with column (1) in table 5), reflects stronger adjustment of US-specific markups to dollar-sterling bilateral exchange rate movements. We should stress that our evidence logically complements the results of studies documenting a high degree of stickiness of US import prices in dollars (Gopinath, Itskhoki and Rigobon (2010)); UK exporters to the US that invoice in US dollars adjust markups (i.e., keep prices stable) in response to the economic conditions in this important market.

5.3.2 Trade with the EU

For EU destinations, the currency of invoicing is not reported—hence we cannot replicate our analysis by currency scheme. Moreover, the bilateral exchange rates

Table 6: Price and markup elasticities conditional on invoicing currency
– extra-EU destinations including the US
– monthly, quarterly, and annual frequencies over 2010-2017

Freq.	Exports	Price		Markup		n. of obs
		NEX (1)	CPI (2)	NEX (3)	CPI (4)	
Annual	All	0.32***	0.55***	0.10*	0.15	2,936,692
	PCI	0.23***	0.46***	0.04	0.06	2,016,191
	VCI	0.30***	0.48***	0.04	0.19	638,894
	LCI	0.51***	1.04***	0.45***	0.17	281,607
Quarterly	All	0.34***	0.56***	0.09***	0.00	5,635,328
	PCI	0.23***	0.43***	0.03	-0.11	3,804,695
	VCI	0.35***	0.54***	-0.03	0.00	1,243,333
	LCI	0.60***	0.99***	0.50***	0.30	587,300
Monthly	All	0.35***	0.54***	0.09***	-0.02	7,808,005
	PCI	0.24***	0.43***	0.03	-0.06	5,132,214
	VCI	0.35***	0.52***	0.06	-0.05	1,759,815
	LCI	0.63***	0.99***	0.43***	-0.20	915,976

Note: This table presents price and markup elasticities based on UK exports to *extra-EU destinations including the US* during 2010-2017. Transactions are aggregated at the monthly/quarterly/annual frequency and the trade pattern is calculated at the frequency of aggregation. The dependent variable is the unit value denominated in pounds sterling. The bilateral exchange rate is defined as units of sterling per foreign currency. Statistical significance, based on robust standard errors, is reported at the 1, 5 or 10 percent level which is indicated by ***, **, or * respectively. Data source: HMRC administrative datasets, UK's exports to extra-EU destinations, 2010-2017.

between the sterling and the currencies of the EU countries that do not use the euro are highly correlated with the euro-sterling exchange rate.[37] Hence the use of these European currencies together with the euro could possibly induce spurious estimates. For this reason, we choose to apply the same euro-sterling exchange rate to trade with all EU countries, including those outside the eurozone—implying that, when we apply our TPSFE estimator, we can only estimate markup adjustment to local CPI, not to the bilateral exchange rate.[38]

Before discussing our results, we should also point out that for transactions with the EU, the HMRC dataset is built on somewhat different criteria. The EU dispatches data includes records of export value and quantity at the firm-product-destination-time level only at the *monthly* frequency, and only for UK firms whose exports to the EU exceed £250,000 in a given calendar year. While this creates a difference in the composition of our sample across areas, reassuringly, UK firms whose exports exceed this threshold account for 96-98% of the total value of UK exports to the EU.[39]

In table 7, using the same layout as in the previous two tables, we report estimates using the EU dataset, the extra-EU dataset, and the comprehensive dataset of UK exports to the world.[40] The first two columns of the table show that, in the EU data, the estimated price elasticities with respect to both the bilateral exchange rates and the destination market CPI are comparable or higher (for CPI) than in the extra-EU data, at all frequencies. Note that the point estimates of the price elasticities to CPI for EU transactions are similar in magnitude to those for extra-EU LCI transactions (see the bottom row in each panel of table 6). The next two columns of table 7 show that firms' markup adjustments in response to *market-specific CPI changes* are rather high (0.5 - 0.6) and remain stable at all frequencies. We take this as evidence that, when UK firms sell to countries within the EU, they respond to

[37]The variation in bilateral exchange rates for these countries is shown in figure OA6-1 in Online Appendix OA6.5.

[38]We obtain similar estimates of the price elasticity to bilateral exchange rates and to the CPI when we use bilateral exchange rates of non-eurozone countries in the EU in the EU estimation sample. However, there is not enough variation among European exchange rates relative to the euro to identify the markup elasticity to the exchange rate.

[39]Author's calculations based on HMRC administrative datasets.

[40]The same estimates for the extra-EU dataset are reported in the "All" rows of table 6.

relative CPI growth and price discriminate across destinations.[41]

Table 7: Price and markup elasticities – EU versus extra-EU exports – monthly, quarterly, and annual frequencies over 2010-2017

Freq.	Exports	Price		Markup		n. of obs
		NEX (1)	CPI (2)	NEX (3)	CPI (4)	
Annual	EU	0.37***	1.46***	-	0.51***	8,566,122
	Extra-EU	0.32***	0.55***	0.10*	0.15	2,936,692
	World	0.28***	0.65***	-0.02	-0.01	11,250,686
Quarterly	EU	0.34***	1.44***	-	0.60***	21,762,505
	Extra-EU	0.34***	0.56***	0.09***	0.00	5,635,328
	World	0.31***	0.72***	0.25***	0.29***	27,050,252
Monthly	EU	0.35***	1.42***	-	0.56***	42,321,912
	Extra-EU	0.35***	0.54***	0.09***	-0.02	7,808,005
	World	0.33***	0.79***	0.22***	0.22***	49,770,612

Note: This table presents estimates of price and markup elasticities based on UK export transactions to EU destinations, extra-EU destinations including the US, and all export destinations, respectively. Transactions are aggregated at the monthly/quarterly/annual frequency and the trade pattern is calculated at the frequency of aggregation. The dependent variable is the unit value measured in pound sterling. The bilateral exchange rate is defined as units of sterling per foreign currency. Statistical significance, based on robust standard errors, is reported at the 1, 5 or 10 percent level which is indicated by ***, **, or * respectively. Data source: HMRC administrative datasets, UK's exports to EU and extra-EU destinations, 2010-2017.

A final piece of evidence suggesting price discrimination by UK firms comes from the variation in the markup estimates between the datasets for trade to extra-EU destinations versus world trade (including the EU). At each frequency, the second row of table 7 presents the markup elasticity for all extra-EU destinations—the point estimate is around 0.10 and does not vary across panels. Approximately one-third of incomplete exchange rate pass through [0.10/0.32 (annual); 0.09/0.34 (quarterly);

[41]We obtain similar findings by repeating the event study approach of Section 4 with British exports to the EU. See Online Appendix figure OA5-6. The sterling prices of EU transactions quickly caught up with the large depreciation after the Brexit referendum, suggesting that firms actively adjusted their sterling markups to maintain a stable destination price in euros.

and 0.09/0.35 (monthly)] is due to differential markup adjustments across foreign destinations by UK exporters. Relative to this benchmark, the magnitude of the markup elasticity more than doubles (monthly and quarterly frequencies) when the estimation dataset is expanded to include trade with the EU countries—as shown in the row labelled "World" in each panel of table 7. Although we cannot observe the invoicing currency for UK exports to the EU, our evidence of substantial pricing-to-market by UK exporters suggests that most British exports to the EU are likely to be invoiced in euros.

6 Conclusion

In this paper, we use transactions data to carry out an investigation into the invoicing currency patterns of UK exporters, and a comparative analysis of the dynamics of ERPT and pricing-to-market when sales are invoiced in different currencies.

Focusing on the export price response to the sterling depreciation after the Brexit referendum, we have shown that the dynamics of ERPT after the large unilateral depreciation differ by currency of invoicing. Our case study documents that over a period of six quarters following the Brexit referendum, export price adjustment *in sterling* was strikingly slower for transactions *invoiced in sterling* than for transactions *invoiced in local (destination market) and vehicle currencies*. In the very short run, when invoicing in sterling, firms allowed the sterling depreciation to pass through to lower prices in *the currency of the destination market*; when invoicing in local or vehicle currencies, firms kept prices relatively stable in destination and vehicle currencies. Most remarkably, however, these price differences across invoicing currencies significantly narrowed over time as sterling prices of exports rose to broadly align with the weaker pound.

For the longer sample 2010-2017, we have offered econometric evidence that the currency of invoicing predicts the extent to which exporters adjust their product prices and markups to changes in bilateral exchange rates and local conditions across markets. We show that the markups of exports invoiced in sterling or in a vehicle currency do not react differently. In striking contrast, markups on exports invoiced

in local currencies move with bilateral exchange rates and local market conditions —in particular, this applies to exports to the US invoiced in dollars and exports to the EU. For the latter, we produce evidence of substantial adjustment of markups to local CPI.

Our finding that the prices of UK exports invoiced in dollars to non-US destinations do not respond to bilateral exchange rate movements contributes novel and important evidence to the recent debate on the role of vehicle currencies in the international transmission mechanism (see, e.g., Gopinath (2015) and Gopinath et al. (2020)). At the heart of this discussion is the idea that firms invoicing in a vehicle currency, especially in dollars, also price their goods in the vehicle currency, keeping the international (dollar) prices for their products stable vis-à-vis bilateral exchange rate fluctuations. This implies that firms would not adjust prices and markups to market-specific shocks — as they price in relation to global demand for their product, and thus respond only to global disturbances. Our estimates suggest that, irrespective of nominal rigidities, UK firms invoicing in vehicle currencies do not make differential markup adjustments to destination-specific movements in exchange rates, and thus, provide micro-level empirical support for Gopinath's "international price system" hypothesis. At the same time, we provide nuanced evidence that firms accounting for about 60% of total UK export value (including trade with the US and the EU) seem to follow a different strategy of invoicing in local currency and adjusting markups to local market conditions.

UK data are a source of theoretically-relevant stylized facts on invoicing. UK exports are more diversified across different currencies of invoicing than exports of other countries for which there is comparable firm-level data. For instance, recent studies document that most Canadian imports and exports are invoiced in US dollars (Goldberg and Tille (2016) and Devereux, Dong and Tomlin (2017)). This difference can be rationalized by observing that the US is Canada's largest and closest market. Given that the UK's trade with the US is much smaller, it should not come as a surprise that the role of dollar invoicing in UK exports is not as large, and that UK exporters invoice in other currencies. Indeed, with the EU being the UK's closest major partner, one might expect that a significant share of UK trade would be

invoiced in euros. Although invoicing data for trade with the EU are not available, we have provided evidence of pricing-to-market by UK exporters associated with local CPI changes and consistent with possible local currency invoicing in euros.

Moreover, British firms invoice exports in multiple currencies – 99% of the UK's extra-EU export value originates from exporters invoicing in more than one currency. This invoicing diversity comes not just from sales in different countries; we find that many exporters invoice in multiple currencies even for the same product sold in the same destination during a single year. We also find a non-negligible degree of switching between invoicing currencies at a granular level. A pattern of multiple invoicing currencies suggests that firms may mix these currencies to manage idiosyncratic and global market risks. In this respect, our results lend empirical support to a small literature that early on emphasized multiple currency invoicing as optimal from the vantage point of value-maximizing firm managers (see Corsetti and Pesenti (2002) and Goldberg and Tille (2008)). Diversifying the portfolio of invoicing/pricing currencies allows exporters to pursue an optimal degree of exposure of their revenues and markups to exchange rate risk. Our empirical evidence clearly motivates more work, both empirical and theoretical, in these directions.

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Online Appendix for "Invoicing and the Dynamics of Pricing-to-market"*

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28 December 2021

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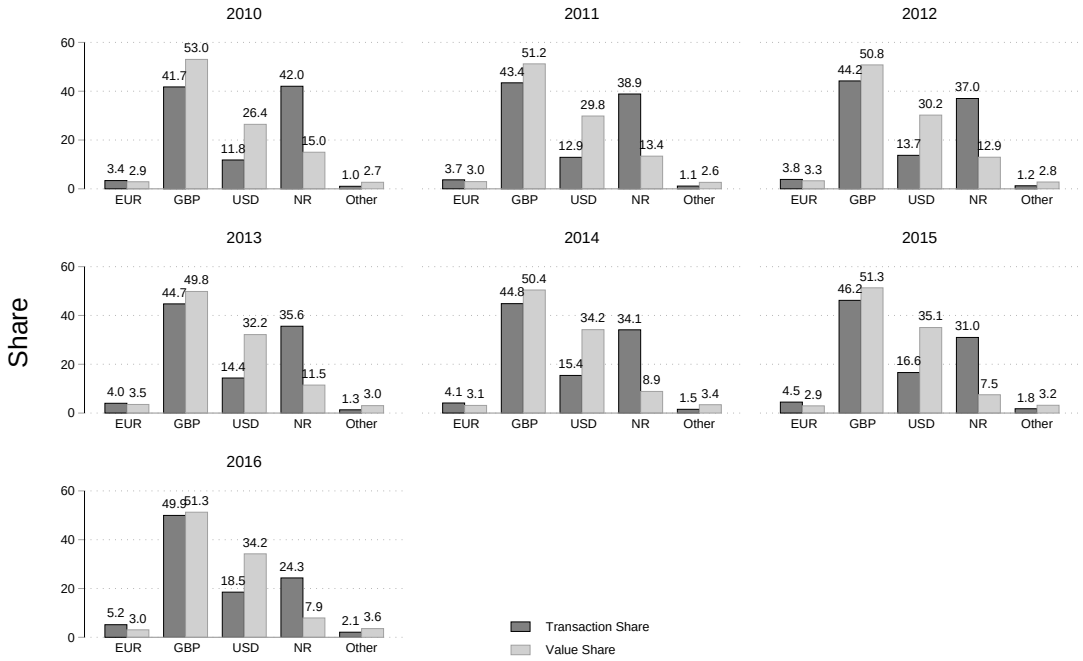
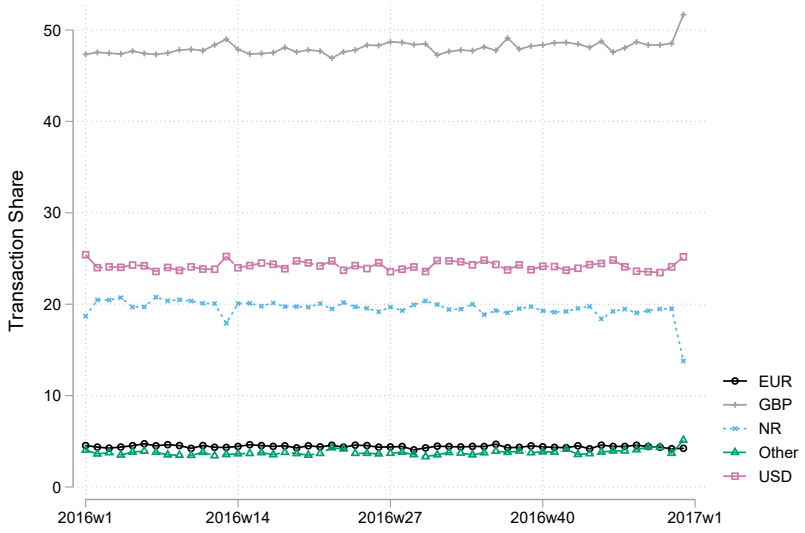
OA1 Statistics on the Granular Distribution of Invoicing Choices

Figure OA1-1: Top invoicing currencies for extra-EU exports



Note: Black bars indicate the invoicing share by the number of transactions. Grey bars indicate the share by total trade values.

Figure OA1-2: Transaction share by invoicing currencies for extra-EU exports in 2016



Note: "NR" standards for the transactions with no invoicing currency information available. Relative to the statistics reported for 2016 in Figure OA1-1, this figure drops 28,389 observations for which the exact date of the transaction was not reported.

Table OA1-1: Number of invoicing currencies for each firm-product-destination/origin-year quartet (extra-EU exports and imports, 2010-2017)

No. of Currencies	No. of Transactions	Share (Transaction %)	Share (Trade %)
1	11,938,314	86.1	59.0
2	1,665,754	12.0	30.6
3	215,577	1.6	6.8
4 plus	50,297	0.4	3.6
Total	13,869,942	100.0	100.0

Table OA1-2: Number of invoicing currencies for each firm-product-origin-year quartet (extra-EU imports, 2010-2017)

No. of Currencies	No. of Transactions	Share (Transaction %)	Share (Trade %)
1	6,804,261	87.7	66.1
2	793,630	10.2	22.8
3	122,946	1.6	6.0
4 plus	40,464	0.5	5.1
Total	7,761,301	100.0	100.0

Table OA1-3: Number of products vs. invoicing currencies (extra-EU exports, 2010-2017)

	No. of Invoicing Currencies				
No. of Products	1	2-5	6-10	10+	Total
(a) Share of Firms					
1	29.7	2.1	0.0	0.0	31.8
2-5	12.0	19.4	0.0	0.0	31.4
6-10	1.3	11.0	0.0	0.0	12.3
10+	0.5	22.4	1.5	0.2	24.5
Total	43.4	54.8	1.5	0.2	100.0
(b) Share of Trade Values					
1	0.4	0.7	0.0	0.0	1.0
2-5	0.2	1.7	0.0	0.0	1.9
6-10	0.0	2.3	0.8	0.1	3.3
10+	0.0	33.4	26.0	34.4	93.8
Total	0.7	38.0	26.9	34.5	100.0

Table OA1-3 shows the distribution of the number of products sold by firms by the number of invoicing currencies. The pattern is similar to the one found in table 1. Notably, most single-product firms invoice in a single currency—with only 6.6% (2.1/31.8) using multiple currencies.

Table OA1-4: Number of products vs. destinations (extra-EU exports, 2010-2017)

	No. of Destinations				
No. of Products	1	2-5	6-10	10+	Total
(a) Share of Firms					
1	29.7	2.0	0.1	0.0	31.8
2-5	9.9	19.9	1.3	0.3	31.4
6-10	1.2	6.9	3.2	0.9	12.3
10+	0.7	4.3	6.2	13.2	24.5
Total	41.6	33.1	10.9	14.4	100.0
(b) Share of Trade Values					
1	0.5	0.5	0.0	0.0	1.0
2-5	0.3	1.0	0.4	0.3	1.9
6-10	0.1	0.6	1.0	1.6	3.3
10+	0.1	1.2	2.7	89.8	93.8
Total	1.0	3.2	4.1	91.7	100.0

Table OA1-4 shows the product-destination distributions of firms, in the same vein as Mayer, Melitz and Ottaviano (2014). The lion's share of exports is by multi-destination and multi-product firms. Interestingly, we find a higher share of multi-product firms in the UK, relative to France (see Mayer, Melitz and Ottaviano (2014)) and China (see Corsetti, Crowley, Han and Song (2018)).

Table OA1-5: Number of destinations/products and invoicing schemes (extra-EU exports, 2010-2017)

	Invoicing Scheme			
No. of Destinations	LCI	PCI	VCI	Total
(a) Share of Firms				
1	0.8	26.2	6.9	33.8
2-5	1.5	22.0	10.4	33.9
6-10	1.2	7.0	5.3	13.5
10+	3.3	8.0	7.5	18.8
Total	6.8	63.2	30.0	100.0
(b) Share of Trade Values				
1	0.0	1.9	0.5	2.4
2-5	0.1	3.5	1.0	4.6
6-10	0.2	4.9	2.6	7.6
10+	4.5	48.8	32.1	85.4
Total	4.8	59.1	36.2	100.0
No. of Products	LCI	PCI	VCI	Total
(a) Share of Firms				
1	0.7	22.1	6.3	29.1
2-5	2.0	25.1	11.3	38.4
6-10	1.4	8.1	5.6	15.0
10+	2.8	7.9	6.8	17.4
Total	6.8	63.2	30.0	100.0
(b) Share of Trade Values				
1	0.1	1.2	0.5	1.7
2-5	0.3	4.1	1.9	6.3
6-10	0.4	7.0	3.2	10.6
10+	4.0	46.8	30.6	81.4
Total	4.8	59.1	36.2	100.0

Table OA1-5 provides a further breakdown by invoicing schemes. In this table, we focus on transactions for which we can detect a price change. Hence we drop all firm-product-destination triplets that appear only once in our sampling period. As can be seen from table OA1-5, small (single-product, single-destination) exporters

are more likely to invoice in their own producer currency. This is true both in terms of transactions and trade values. Large (multi-product, multi-destination) exporters invoice significantly more in local and vehicle currencies. However, note that sterling is still the dominant currency in terms of trade values.

Table OA1-6: Transition matrix of invoicing schemes (extra-EU imports, 2010-2017)

		To		
		LCI	PCI	VCI
From	LCI	90.05	1.29	8.66
	PCI	4.66	87.52	7.81
	VCI	2.34	0.66	97.00

Conditional on large transactions (top quarter by trade value)

		To		
		LCI	PCI	VCI
From	LCI	94.60	0.64	4.75
	PCI	3.45	92.06	4.49
	VCI	1.56	0.33	98.11

Note: This transition matrix is generated conditional on single invoicing currency transactions at the exporter-product-destination level.

Table OA1-6 presents the transition matrix of invoicing choices for UK imports. Overall, the probability of switching is much lower for importers compared to exporters.

OA1.1 Number of Invoicing Currencies in a Particular Year

The following tables break down the firms according to their number of exporting destinations/importing origins and the number of invoicing currencies used by a firm in a particular year (i.e., 2015, 2016, 2017). In each table, panel (a) shows the unweighed share of firms and panel (b) shows the trade weighted statistics.

OA1.1.1 Extra-EU Exports

Table OA1-7: Distribution of the number of exporting destinations and invoicing currencies used at the firm-year level (extra-EU exports, year 2015)

	No. of Invoicing Currencies				
No. of Destinations	1	2-5	6-10	10+	Total
(a) by Share of Firms					
1	35.2	2.2	0.0	0.0	37.4
2-5	26.3	11.9	0.0	0.0	38.2
6-10	4.7	7.2	0.0	0.0	11.9
10+	1.9	10.1	0.4	0.1	12.5
Total	68.0	31.5	0.5	0.1	100.0
(b) by Share of Trade Values					
1	1.5	0.4	0.0	0.0	2.0
2-5	2.3	4.4	0.0	0.0	6.8
6-10	1.1	7.4	0.2	0.0	8.7
10+	1.1	46.8	15.6	19.1	82.6
Total	6.0	59.1	15.8	19.1	100.0

Table OA1-8: Distribution of the number of exporting destinations and invoicing currencies used at the firm-year level (extra-EU exports, year 2016)

	No. of Invoicing Currencies				
No. of Destinations	1	2-5	6-10	10+	Total
(a) by Share of Firms					
1	36.3	2.4	0.0	0.0	38.7
2-5	24.9	12.4	0.0	0.0	37.3
6-10	4.5	7.4	0.0	0.0	12.0
10+	1.7	9.8	0.5	0.1	12.0
Total	67.4	32.0	0.5	0.1	100.0
(b) by Share of Trade Values					
1	1.8	0.9	0.0	0.0	2.7
2-5	2.2	4.1	0.0	0.0	6.2
6-10	1.3	5.5	0.8	0.0	7.6
10+	1.1	45.7	17.2	19.5	83.4
Total	6.4	56.2	17.9	19.5	100.0

Table OA1-9: Distribution of the number of exporting destinations and invoicing currencies used at the firm-year level (extra-EU exports, year 2017)

	No. of Invoicing Currencies				
No. of Destinations	1	2-5	6-10	10+	Total
(a) by Share of Firms					
1	37.3	2.5	0.0	0.0	39.8
2-5	24.3	12.7	0.0	0.0	36.9
6-10	4.2	7.3	0.0	0.0	11.5
10+	1.6	9.5	0.5	0.1	11.7
Total	67.4	32.0	0.5	0.1	100.0
(b) by Share of Trade Values					
1	1.5	0.9	0.0	0.0	2.3
2-5	2.1	4.8	0.0	0.0	6.9
6-10	0.9	6.1	0.6	0.0	7.5
10+	1.9	44.5	18.9	17.9	83.2
Total	6.4	56.3	19.4	17.9	100.0

OA1.1.2 Extra-EU Imports

Table OA1-10: Distribution of the number of exporting destinations and invoicing currencies used at the firm-year level (extra-EU imports, year 2015)

	No. of Invoicing Currencies				
No. of Destinations	1	2-5	6-10	10+	Total
(a) by Share of Firms					
1	53.1	4.3	0.0	0.0	57.4
2-5	14.8	21.0	0.0	0.0	35.8
6-10	0.4	4.4	0.2	0.0	5.1
10+	0.0	1.1	0.5	0.1	1.7
Total	68.3	30.8	0.8	0.1	100.0
(b) by Share of Trade Values					
1	4.4	1.7	0.0	0.0	6.0
2-5	5.3	16.3	0.0	0.0	21.6
6-10	1.3	12.9	0.7	0.0	14.9
10+	0.8	28.6	18.8	9.2	57.4
Total	11.8	59.4	19.5	9.2	100.0

Table OA1-11: Distribution of the number of exporting destinations and invoicing currencies used at the firm-year level (extra-EU imports, year 2016)

	No. of Invoicing Currencies				
No. of Destinations	1	2-5	6-10	10+	Total
(a) by Share of Firms					
1	54.0	4.4	0.0	0.0	58.5
2-5	14.8	20.0	0.0	0.0	34.8
6-10	0.4	4.3	0.2	0.0	5.0
10+	0.1	1.1	0.5	0.1	1.7
Total	69.3	29.9	0.8	0.1	100.0
(b) by Share of Trade Values					
1	4.5	1.4	0.0	0.0	5.9
2-5	4.3	12.7	0.0	0.0	17.1
6-10	1.7	13.6	0.9	0.0	16.2
10+	0.9	28.9	21.5	9.6	60.9
Total	11.4	56.6	22.4	9.6	100.0

Table OA1-12: Distribution of the number of exporting destinations and invoicing currencies used at the firm-year level (extra-EU imports, year 2017)

	No. of Invoicing Currencies				
No. of Destinations	1	2-5	6-10	10+	Total
(a) by Share of Firms					
1	54.6	4.5	0.0	0.0	59.0
2-5	14.5	19.9	0.0	0.0	34.5
6-10	0.4	4.2	0.2	0.0	4.8
10+	0.0	1.1	0.5	0.0	1.7
Total	69.6	29.7	0.7	0.0	100.0
(b) by Share of Trade Values					
1	4.1	2.8	0.0	0.0	6.9
2-5	4.5	13.1	0.0	0.0	17.6
6-10	2.2	16.1	0.6	0.0	18.9
10+	0.6	23.4	22.0	10.5	56.5
Total	11.4	55.4	22.6	10.5	100.0

OA1.2 Distribution of Price Changes for Extra-EU Exports and Imports

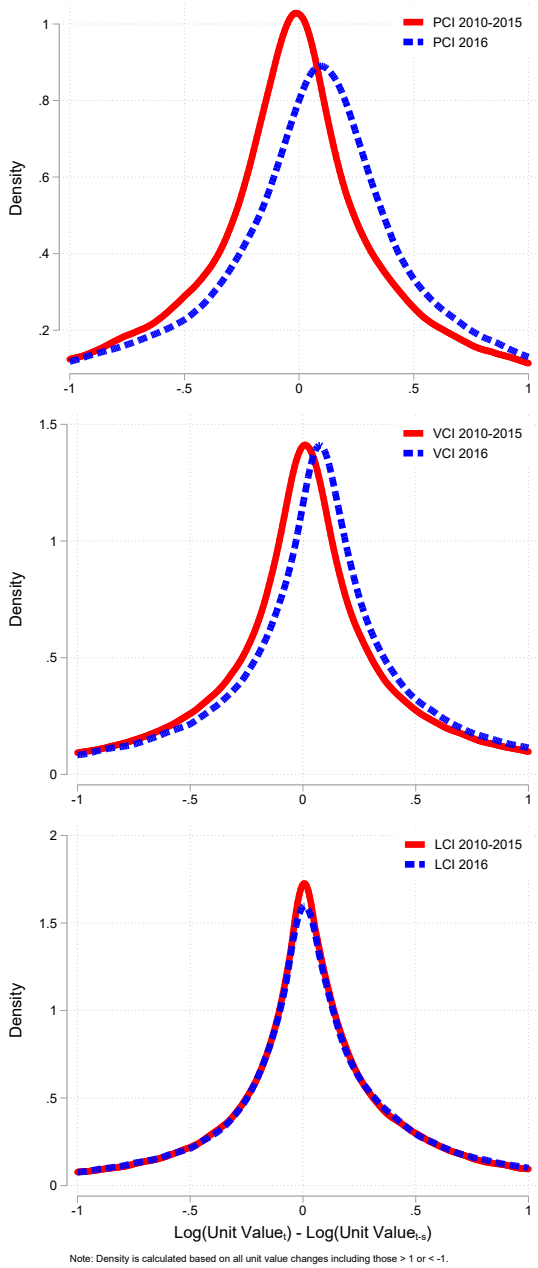
Table OA1-13: Magnitude of price changes by invoicing schemes (extra-EU exports, 2010-2017)

	Invoicing Scheme			
Magnitude of price changes	LCI	PCI	VCI	Total
Non-weighted				
No Change	0.1	1.8	0.4	1.3
Less than 1%	3.4	6.1	5.4	5.8
1% to 5%	8.6	11.7	11.1	11.4
5% to 10%	9.6	12.4	11.7	12.0
10% to 30%	18.1	18.6	18.7	18.6
30% to 50%	15.1	15.5	16.0	15.6
50% to 100%	20.0	17.1	18.0	17.5
Larger than 100%	25.0	16.7	18.7	17.7
Total	100.0	100.0	100.0	100.0
Trade-weighted				
No Change	0.0	0.1	0.0	0.1
Less than 1%	4.5	8.7	4.0	6.8
1% to 5%	9.2	14.0	15.4	14.3
5% to 10%	15.9	11.1	12.8	12.0
10% to 30%	22.7	32.0	28.9	30.4
30% to 50%	11.9	11.0	11.5	11.2
50% to 100%	13.9	10.7	12.3	11.4
Larger than 100%	22.0	12.3	15.1	13.8
Total	100.0	100.0	100.0	100.0

Table OA1-13 shows the magnitude of price changes (measured by sterling) by invoicing currency schemes. All transactions in HMRC Overseas Trade in Goods Statistics are recorded in sterling. In all our calculations, the unit value is calculated using trade value divided by quantity.[1]

[1]Supplementary units are used as the measure of quantity, i.e., units, pairs, cubic meters, etc., for products that report both supplementary units and netmass. Netmass is used as the quantity measure if not supplementary units are reported.

Figure OA1-3: Distribution of annual price changes for extra-EU **imports** in 2010-2015 versus 2016



Note: This graph shows the distribution of annual price changes of the UK's extra-EU imports over 2010-2015 versus 2016 by invoicing currency schemes: producer currency invoicing (PCI), vehicle currency invoicing (VCI), and local currency invoicing (LCI). Data source: HMRC administrative datasets, UK's extra-EU imports excluding the US, 2010-2016.

OA2 The Value Share Distributions of Multi-currency Uses

In this section, we report additional statistics on the distributions of trade shares of multi-currency invoicing users. Complementing to figure 1 in our draft, figure OA2-3 plots the value distributions of different invoicing currencies for extra-EU imports. Figures OA2-1 and OA2-2 present the value share distributions of firms in terms of a particular currency (GBP, USD, Other) for extra-EU imports and exports respectively. Figures OA2-4 and OA2-5 repeat the calculation of figure 1a of our draft at the monthly interval. The value share distributions are very similar.

OA2.1 Annual Estimates

Figure OA2-1: Invoicing Currency Value Share Distribution by Currency and the Firm's Number of Exporting Destinations **- Extra-EU Exports - Annual - 2010-2017**

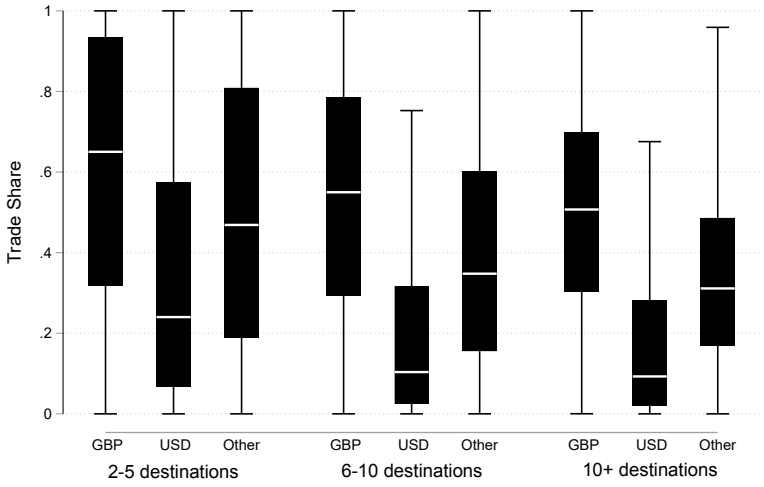


Figure OA2-2: Invoicing Currency Value Share Distribution by Currency and Firms' Number of Importing Origins **- Extra-EU Imports - Annual - 2010-2017**

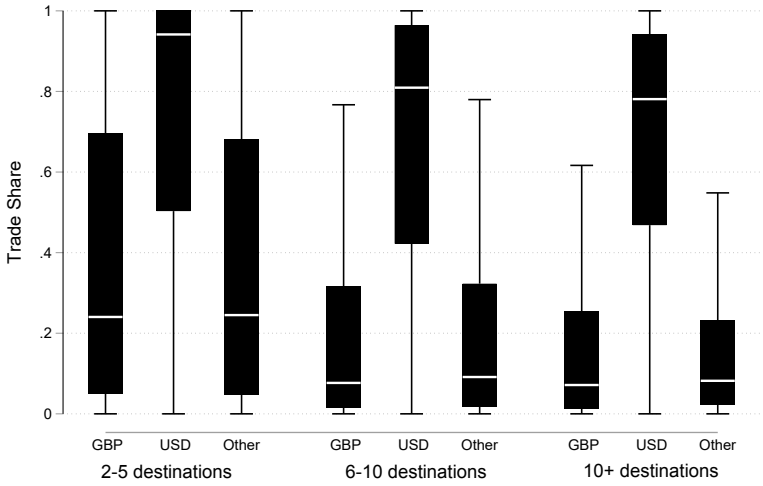
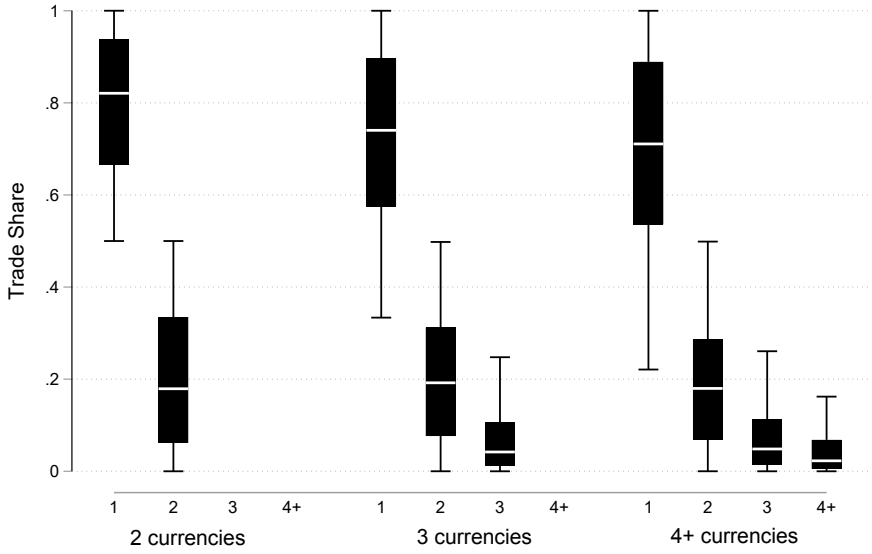
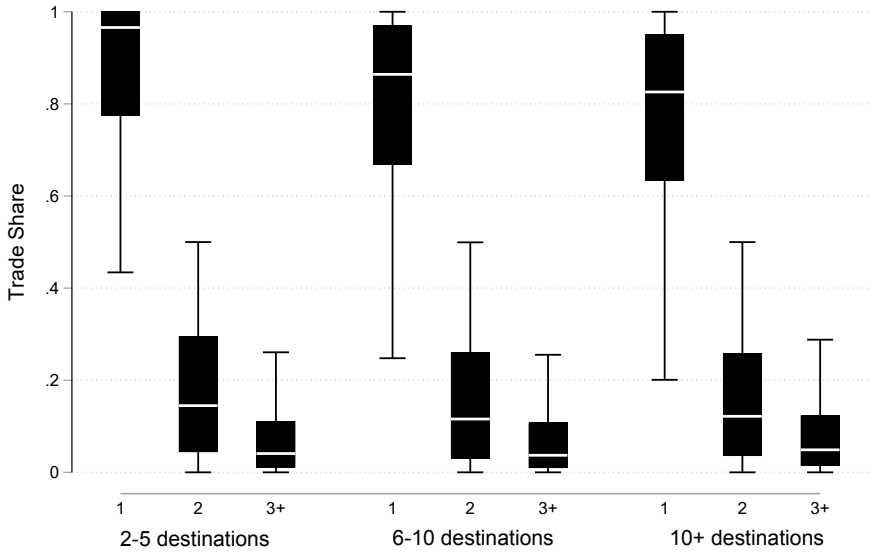


Figure OA2-3: The Value Share Distribution of Invoicing Currency Uses
(Extra-EU Imports, Annual, 2010-2017)

(a) Grouped by the number of currencies used at the FPDT level



(b) Grouped by the firm's number of sourcing origins



OA2.2 Monthly Estimates

Figure OA2-4: Invoicing Currency Value Share Distribution by Its FPDT Importance and Number of Currencies Used at the FPDT Level **- Extra-EU Exports - Monthly - 2010-2017**

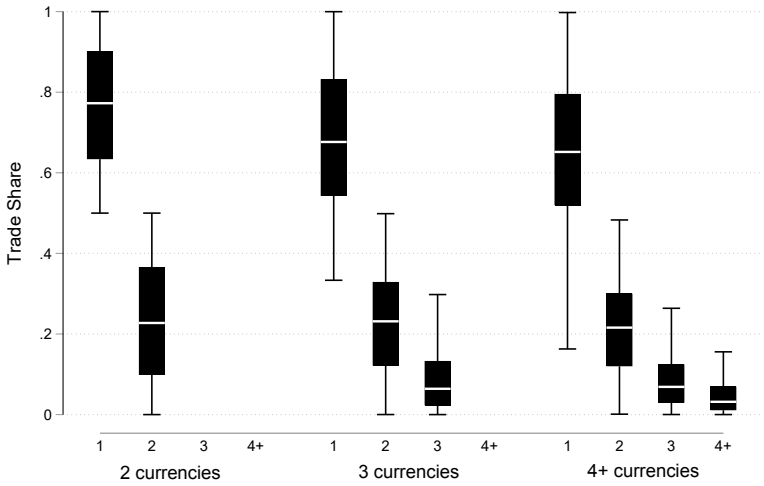
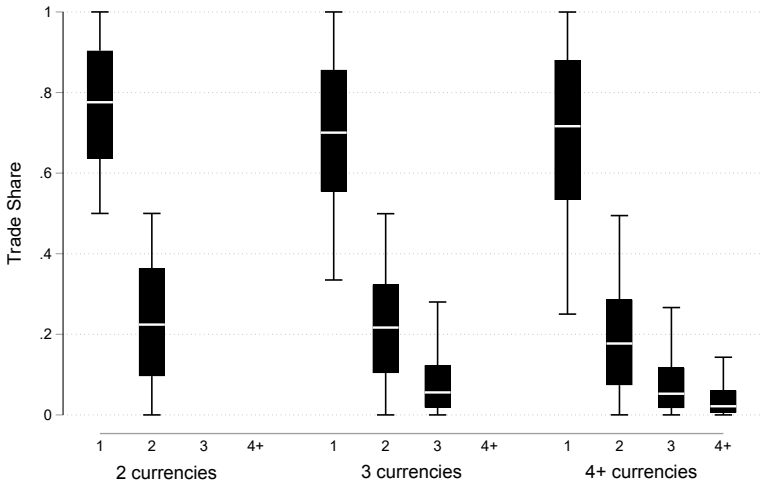


Figure OA2-5: Invoicing Currency Value Share Distribution by Its FPDT Importance and Number of Currencies Used at the FPDT Level **- Extra-EU Imports - Monthly - 2010-2017**



OA3 Invoicing Decomposition by Destination (Source) Markets

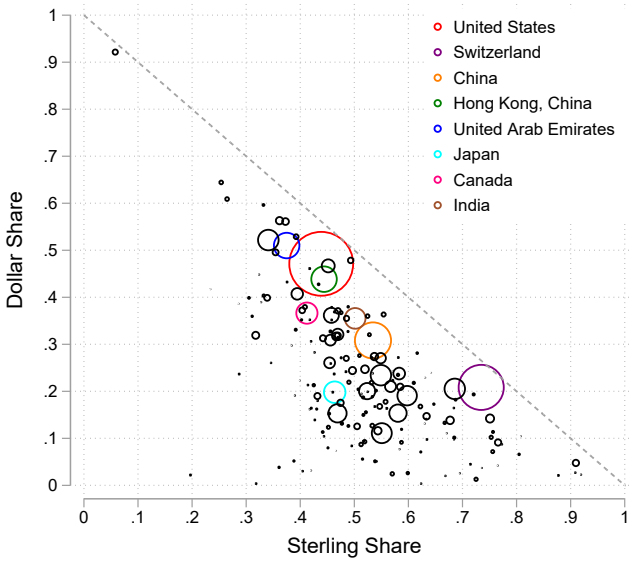
Figures OA3-1 and OA3-2 present the Amiti, Itskhoki and Konings (2018) style decomposition of currency uses for trade with extra-EU destinations/origins of UK firms. Each bubble represents a destination/origin market. The size of the bubble indicates the relative importance of the market, ranked by the total trade value of all firms within the grouping selling to the market (i.e., with firms grouped as having more than ten vs. ten or fewer destinations). The top eight markets by value, for the relevant group of firms, are color coded. The x and y axes represent the share of sterling and US dollars invoiced transactions respectively. The deviation from the 45 degree line indicates the share of other currencies (i.e., any invoicing currency other than sterling and the US dollar). The upper panel of each figure shows the decomposition for firms which trade with more than ten destinations/origins (corresponding to the fourth row of the panels in table 1). The bottom panel of each figure shows the decomposition for firms which trade with ten or fewer destinations/origins (corresponding to the first three rows of the panels in table 1).

To interpret the data in these figures, consider data on invoicing shares for exports to Japan by UK firms that sell to more than 10 extra-EU foreign markets. In figure OA3-1, panel (a), exports to Japan by UK firms reaching more than 10 destinations are represented by a light blue circle. When these firm-level exports are weighted by trade value, about 20% are invoiced in US dollars, 45% are invoiced in pound sterling, and the remaining 35% are invoiced in other currencies. Panel (b) reports the corresponding transaction shares, where only about 10% of export transactions are invoiced in US dollars, about 45% are invoiced in sterling, and the remaining 45% of transactions are invoiced in some other currency.

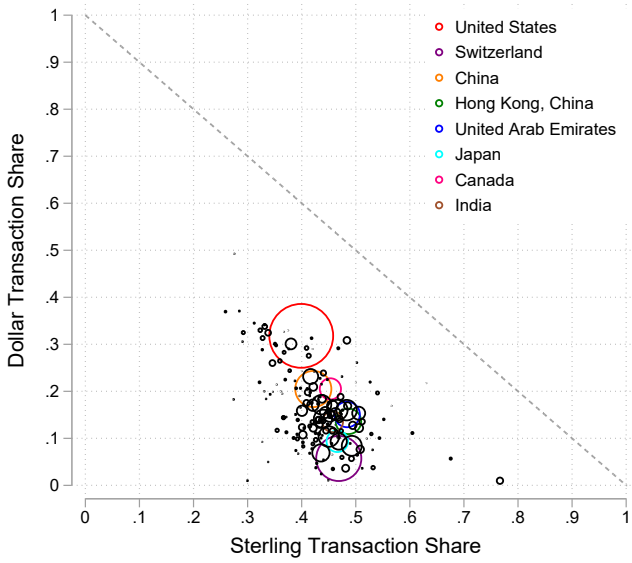
These figures demonstrate that firms exporting to a very large number of destinations use a variety of different currencies. The US dollar share in exports to most destinations (by trade value) for firms exporting to more than 10 destinations tends to be higher than the dollar share among firms that reach 10 or fewer destinations.

Figure OA3-1: Invoicing Decomposition of UK Extra-EU Exports (2010-2017)

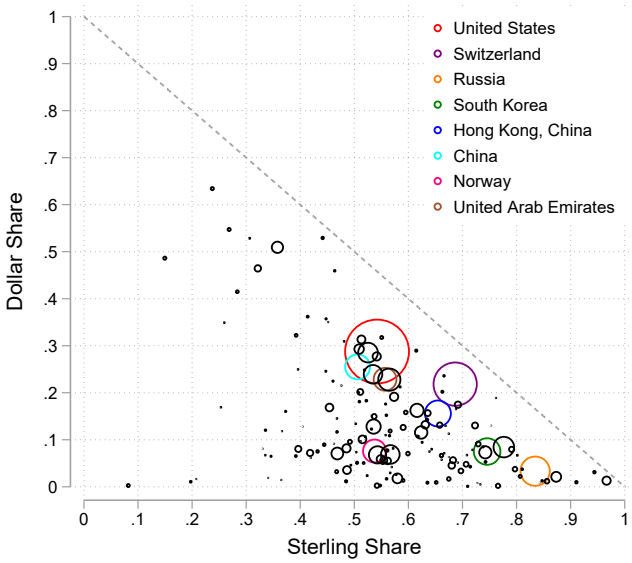
(a) Firms selling to > 10 destinations, value share



(b) Firms selling to > 10 destinations, transaction share



(c) Firms selling to ≤ 10 destinations, value share



(d) Firms selling to ≤ 10 destinations, transaction share

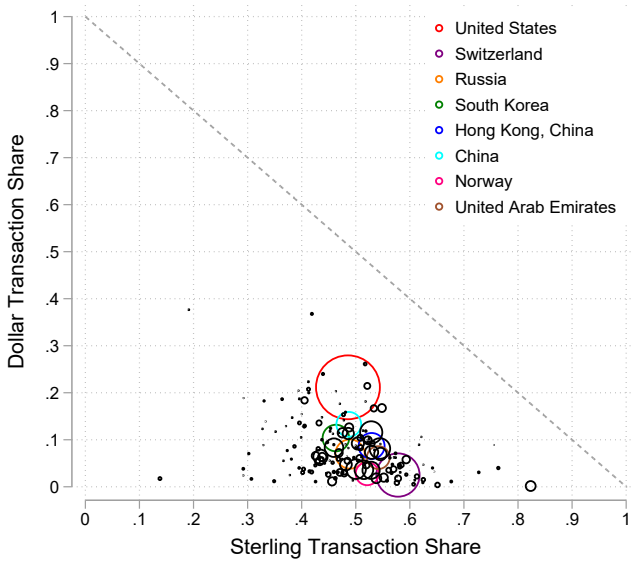
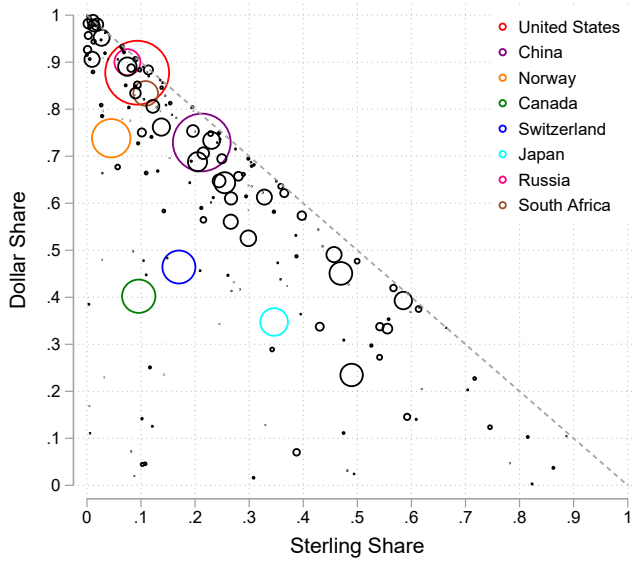
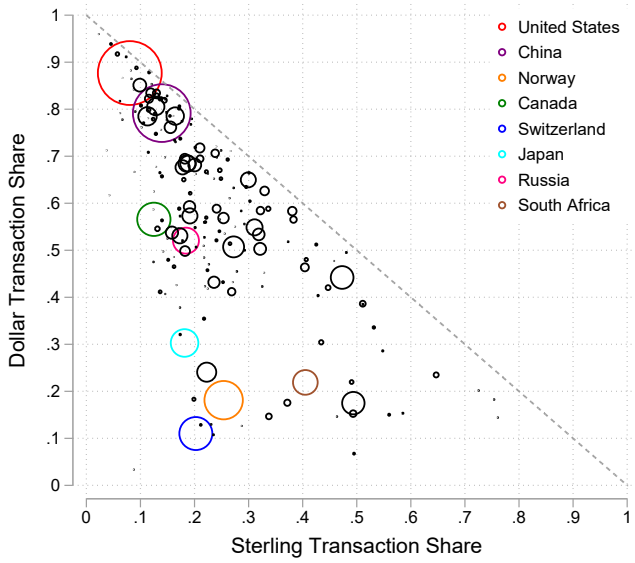


Figure OA3-2: Invoicing Decomposition of UK Extra-EU Imports (2010-2017)

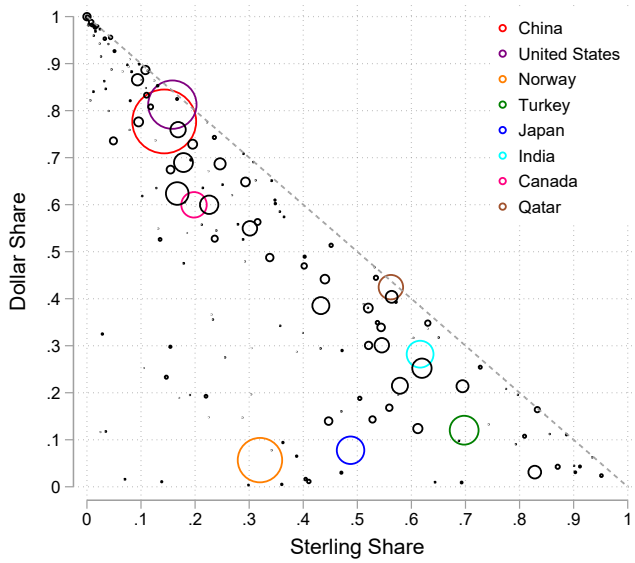
(a) Firms sourcing form > 10 origins, value share



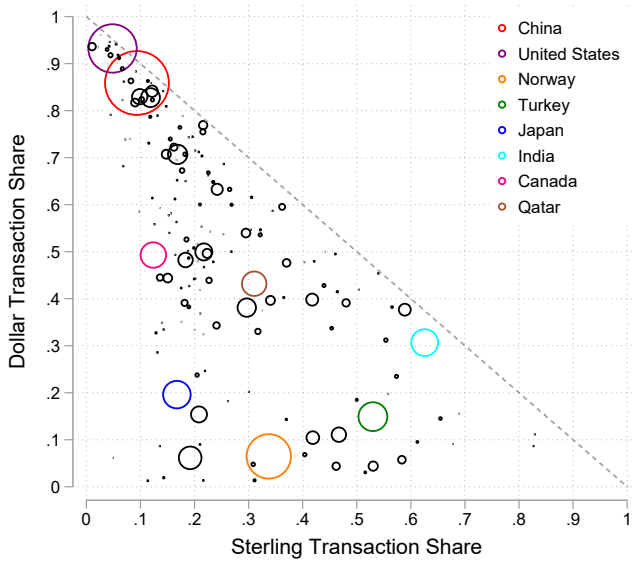
(b) Firms sourcing form > 10 origins, transaction share



(c) Firms sourcing form ≤ 10 origins, value share



(d) Firms sourcing form ≤ 10 origins, transaction share



OA4 Monthly Invoicing Currency Transition Matrices

Tables OA4-1–OA4-5 report the transition probabilities of different invoicing currency schemes (LCI, PCI and VCI) calculated at the monthly frequency for the UK's extra-EU exports and imports. Each table reports the monthly transition probabilities calculated in three subsamples, i.e., 18 Months from the Start of the Sample (Jan2010-Jun2011), 18 Months before the Brexit Referendum (Jan2015-Jun2016) and 18 Months after the Brexit Referendum (Jul2016-Dec2017).

Tables OA4-1 and OA4-2 reproduce the analysis of table 4 for large firms/transactions. Specifically, we rank the firms according to their trade value at the product-destination-month level and redo the calculation of table 4 restricting our sample to those firms ranked above the 50th (table OA4-1) and 75th (table OA4-2) percentiles. Tables OA4-3, OA4-4 and OA4-4 report the corresponding statistics for the UK's extra-EU imports.

Table OA4-1: Transition Matrix of Invoicing Schemes
Extra-EU Exports Excluding the US, Monthly Estimates on Large Transactions
(top 50% by trade value at the product-destination-month level)

			To		
18 Months from the Start of the Sample (Jan2010-Jun2011)	From		LCI	PCI	VCI
		LCI	82.92	12.68	4.40
		PCI	0.45	94.33	5.21
		VCI	0.46	14.00	85.54
			To		
18 Months before the Brexit Referendum (Jan2015-Jun2016)	From		LCI	PCI	VCI
		LCI	87.04	9.56	3.40
		PCI	0.61	94.00	5.38
		VCI	0.44	11.86	87.70
			To		
18 Months after the Brexit Referendum (Jul2016-Dec2017)	From		LCI	PCI	VCI
		LCI	88.50	8.28	3.22
		PCI	0.58	94.26	5.15
		VCI	0.51	10.89	88.59

Note: This transition matrix is generated conditional on single invoicing currency transactions at the exporter-product-destination-month level.

Table OA4-2: Transition Matrix of Invoicing Schemes
Extra-EU Exports Excluding the US, Monthly Estimates on Very Large Transactions (top 25% by trade value at the product-destination-month level)

			To		
18 Months from the Start of the Sample (Jan2010-Jun2011)	From		LCI	PCI	VCI
		LCI	85.30	10.98	3.72
		PCI	0.92	93.35	5.73
		VCI	0.73	13.02	86.25
			To		
18 Months before the Brexit Referendum (Jan2015-Jun2016)	From		LCI	PCI	VCI
		LCI	87.71	9.29	3.00
		PCI	1.04	93.38	5.58
		VCI	0.67	10.84	88.49
			To		
18 Months after the Brexit Referendum (Jul2016-Dec2017)	From		LCI	PCI	VCI
		LCI	89.13	7.54	3.33
		PCI	0.98	93.76	5.26
		VCI	0.83	9.93	89.24

Note: This transition matrix is generated conditional on single invoicing currency transactions at the exporter-product-destination-month level.

Table OA4-3: Transition Matrix of Invoicing Schemes
Extra-EU Imports Excluding the US, Monthly Estimates on All Transactions

			To		
18 Months from the Start of the Sample (Jan2010-Jun2011)	From		LCI	PCI	VCI
		LCI	94.20	0.76	5.04
		PCI	2.98	92.10	4.92
		VCI	1.89	0.47	97.64
			To		
18 Months before the Brexit Referendum (Jan2015-Jun2016)	From		LCI	PCI	VCI
		LCI	93.60	0.71	5.69
		PCI	3.13	91.53	5.34
		VCI	1.96	0.42	97.62
			To		
18 Months after the Brexit Referendum (Jul2016-Dec2017)	From		LCI	PCI	VCI
		LCI	92.64	0.84	6.52
		PCI	3.16	91.54	5.30
		VCI	1.91	0.42	97.68

Note: This transition matrix is generated conditional on single invoicing currency transactions at the importer-product-origin-month level.

Table OA4-4: Transition Matrix of Invoicing Schemes
Extra-EU Imports Excluding the US, Monthly Estimates on Large Transactions
(top 50% by trade value at the product-origin-month level)

			To		
18 Months from the Start of the Sample (Jan2010-Jun2011)	From		LCI	PCI	VCI
		LCI	94.51	0.77	4.72
		PCI	3.21	92.33	4.46
		VCI	1.95	0.47	97.58
			To		
18 Months before the Brexit Referendum (Jan2015-Jun2016)	From		LCI	PCI	VCI
		LCI	93.95	0.68	5.36
		PCI	3.20	91.86	4.93
		VCI	2.01	0.41	97.57
			To		
18 Months after the Brexit Referendum (Jul2016-Dec2017)	From		LCI	PCI	VCI
		LCI	92.92	0.86	6.22
		PCI	3.34	91.88	4.78
		VCI	1.96	0.41	97.63

Note: This transition matrix is generated conditional on single invoicing currency transactions at the importer-product-origin-month level.

Table OA4-5: Transition Matrix of Invoicing Schemes
Extra-EU Imports Excluding the US, Monthly Estimates on Very Large Transactions (top 25% by trade value at the product-origin-month level)

			To		
18 Months from the Start of the Sample (Jan2010-Jun2011)	From		LCI	PCI	VCI
		LCI	95.63	0.58	3.80
		PCI	3.51	92.51	3.98
		VCI	1.51	0.24	98.25
			To		
18 Months before the Brexit Referendum (Jan2015-Jun2016)	From		LCI	PCI	VCI
		LCI	94.99	0.45	4.56
		PCI	3.31	92.14	4.55
		VCI	1.63	0.24	98.13
			To		
18 Months after the Brexit Referendum (Jul2016-Dec2017)	From		LCI	PCI	VCI
		LCI	94.34	0.57	5.10
		PCI	3.11	93.14	3.75
		VCI	1.49	0.23	98.27

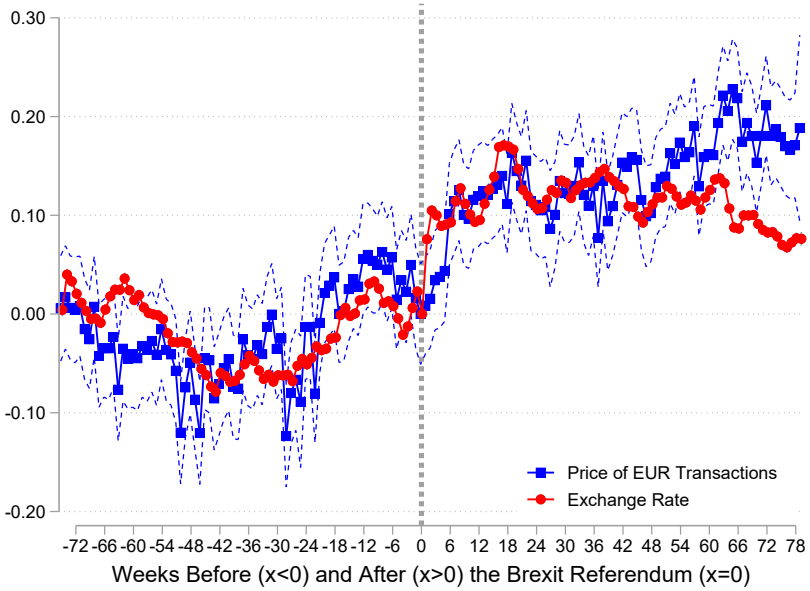
Note: This transition matrix is generated conditional on single invoicing currency transactions at the importer-product-origin-month level.

OA5 Results of Brexit Event Studies

OA5.1 Export Price Responses of Euro-Invoiced Transactions

The prices of exports invoiced in euros (appendix figure OA5-1) evolve similarly to those invoiced in US dollars (figure 7).

Figure OA5-1: Price responses of **euro** invoiced transactions (**extra-EU exports**, 2015-2017)



OA5.2 UK Import Price Responses to the Brexit Depreciation

Figures OA5-2–OA5-5 document that the sterling price of UK imports invoiced in sterling, producer's currency, US dollars, and euros, respectively, increased substantially in the year and a half after the Brexit depreciation. After 78 weeks, the sterling price increase for imports exceeded the decline in the value of the pound more than one-for-one, i.e., pass through appears to have exceeded 100%.

Figure OA5-2: Price responses of **sterling** invoiced transactions (**extra-EU imports**, 2015-2017)

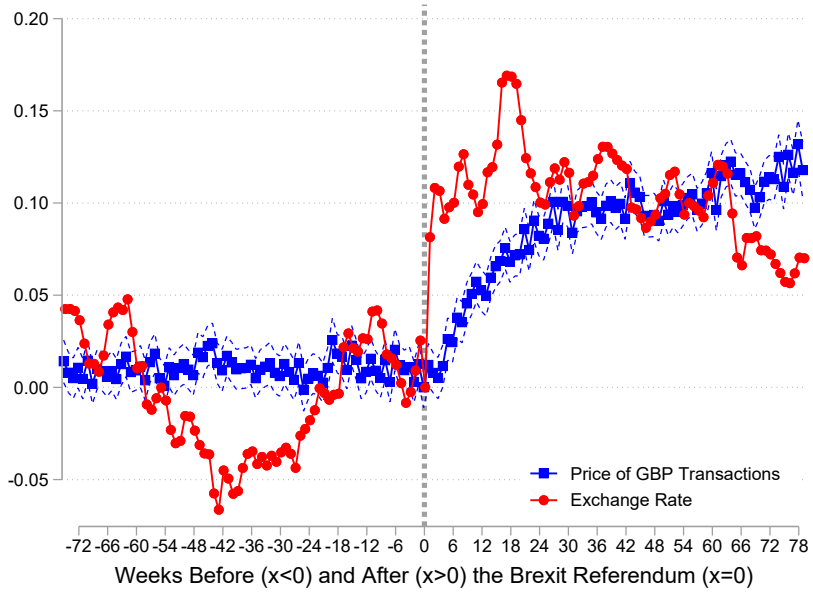


Figure OA5-3: Price responses of **producer currency** invoiced transactions (**extra-EU imports**, 2015-2017)

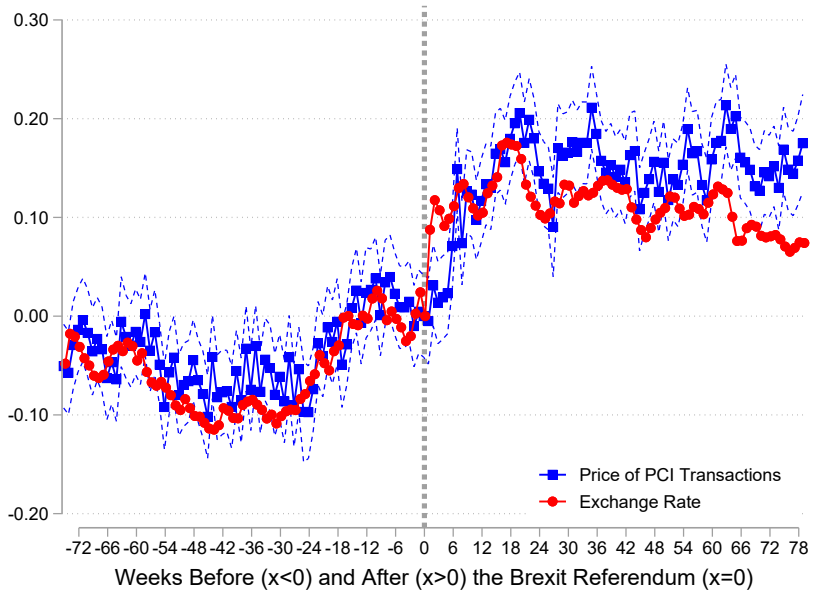


Figure OA5-4: Price responses of **dollar** invoiced transactions (**extra-EU imports**, 2015-2017)

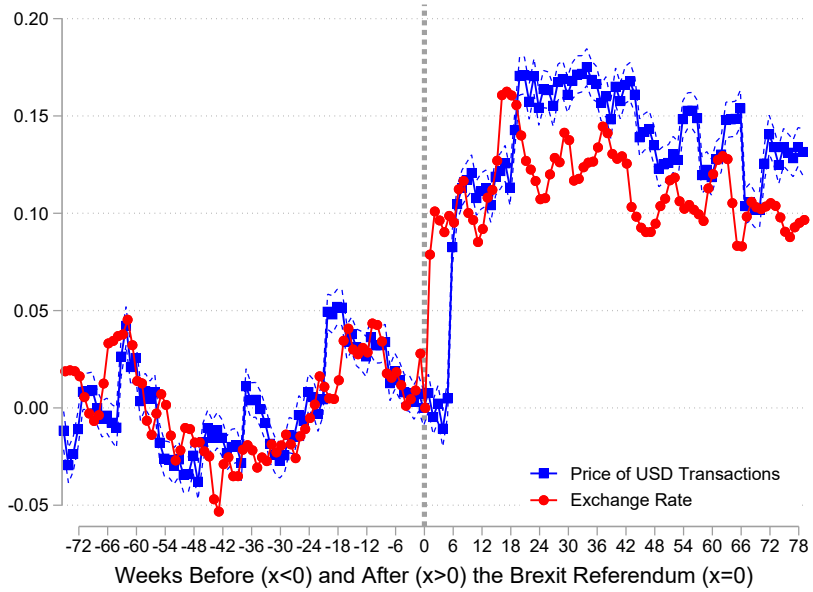
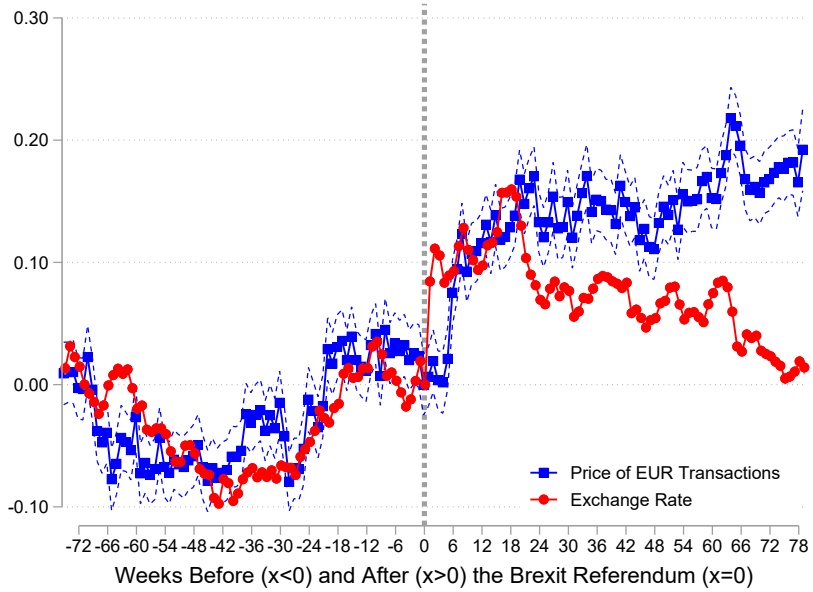


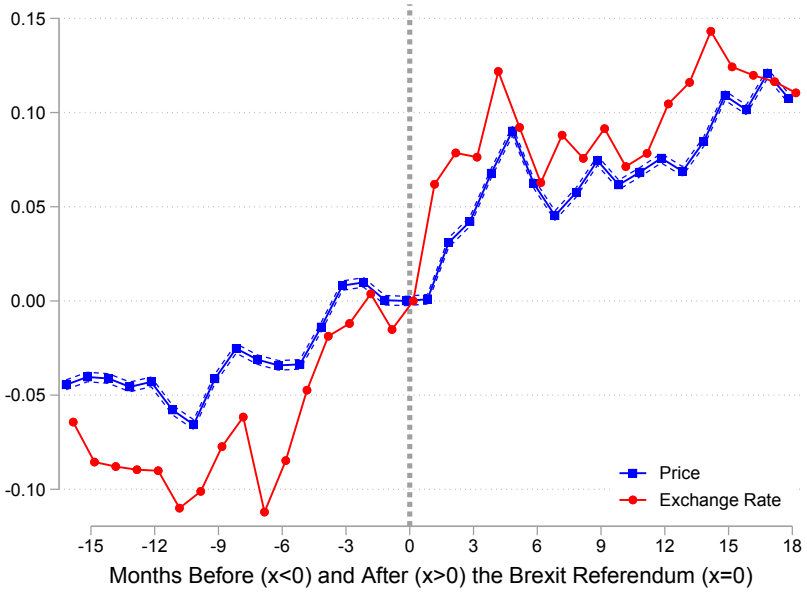
Figure OA5-5: Price responses of **euro** invoiced transactions (**extra-EU imports**, 2015-2017)



OA5.3 Price Responses of Exports to EU Countries

Figure OA5-6 documents that the price adjustments of UK exports to the EU after the Brexit referendum, *measured in sterling*, are fast and similar to those of local and vehicle currency invoiced extra-EU export transactions. The analysis is done at the monthly level, the highest frequency available in HMRC's EU Dispatches Dataset.

Figure OA5-6: Price responses of export transactions to **EU destinations**, 2015-2017



OA5.4 TPSFE Estimates

Table OA5-1: Price and markup elasticities by invoicing currency schemes – Weekly frequency, conditional on a price change

	(1) All	(2) PCI	(3) LCI	(4) VCI (Dollar)	(5) VCI (Euro)
Price	0.335***	0.244***	0.579***	0.411***	0.519***
	(0.0118)	(0.0177)	(0.0453)	(0.0364)	(0.0448)
Markup	0.0728***	0.0418	0.477***	0.0607	0.0507
	(0.0266)	(0.0384)	(0.0778)	(0.0778)	(0.106)
Observations	4,854,264	2,438,368	258,970	765,993	277,611

Note: This table presents price and markup elasticities based on HMRC administrative customs data of UK exports to non-EU destinations during 2015-2017. Transactions are aggregated at the *weekly* frequency and the trade pattern is calculated at the quarterly frequency. The dependent variable is the unit value denominated in pounds sterling. The bilateral exchange rate is defined as units of sterling per destination currency; an increase in the bilateral exchange rate is a depreciation of sterling. Robust standard errors are reported in parentheses. Statistical significance at the 1, 5 and 10 percent level is indicated by ***, **, and *.

OA6 Estimates of Pricing-to-Market

OA6.1 Note on Implementing Trade Pattern Sequential Fixed Effects (TPSFE)

We use the TPSFE estimator developed in Corsetti, Crowley, Han and Song (2018) as our main method for estimating markup adjustments to bilateral exchange rate movements. We group transactions into bins of different invoicing currency schemes (i.e., PCI, VCI and LCI) and implement the following three steps separately for each invoicing currency bin:[2]

1. For every product in every firm, we strip out the component of the price that is common across the collection of foreign destinations reached in period t. We calculate the destination residual of each dependent and independent variable by subtracting the mean value of each variable (across destinations) over all active destinations for a firm's product in a period:

$$\widetilde{x}_{fidt} \equiv x - \frac{1}{n^D_{fit}} \sum_{d \in D_{fit}} x \quad \forall x \in \{p_{fidt}, e_{dt}, cpi_{dt}\} \tag{OA6-1}$$

   where n^D_{fit} is the number of active foreign destinations of firm f selling product i in year t and D_{fit} denotes the set of destinations of this firm-product pair in year t; e_{dt} is the bilateral exchange rate defined as the units of sterling per unit of destination market currency and cpi_{dt} is the destination CPI. All variables are in logs.

2. Apply firm-product-destination-trade pattern ($fidD$) fixed effects to the residual prices, exchange rates, and other explanatory variables obtained in the first step. That is, we subtract the mean of the $\widetilde{x}_{fidt}$ variables for all time periods associated with the firm-product-destination-trade pattern $fidD$, i.e.,

[2] As detailed in the our data cleaning process OA7 (step 7), we drop the multi-currency invoicing transactions *within the same invoicing scheme*. Note that only firms using currencies other than sterling, dollar, euro or the local currency will be dropped under this criteria. For example, if a firm exported to the same destination using two currencies, say dollar and local currency, no observation will be dropped as these two observations will be allocated into VCI and LCI bins respectively.

$t \in T_{fidD}$:

$$\ddot{x}_{fidt} \equiv \widetilde{x}_{fidt} - \frac{1}{n^T_{fidD}} \sum_{t \in T_{fidD}} \widetilde{x}_{fidt} \quad \forall x \in \{p_{fidt}, e_{dt}, cpi_{dt}\} \tag{OA6-2}$$

where $\ddot{x}_{fidt}$ are the twice-differenced variables. Note that the aggregate variables which normally vary along only two dimensions d and t may "become" firm and product specific, i.e., $\ddot{e}_{fidt}$ and $\ddot{cpi}_{fidt}$ due to the unbalancedness of the panel.

3. Using these twice-differenced variables, we run an OLS regression that identifies how markups respond to the bilateral exchange rate; this approach exploits cross-destination variation in prices within a firm-product's trade pattern as well as intertemporal variation in prices within a *time pattern of export participation* at the destination and trade pattern level for a firm-product pair:[3]

$$\ddot{p}_{fidt} = \kappa_1 \ddot{e}_{fidt} + \kappa_2 \ddot{cpi}_{fidt} + \ddot{v}_{fidt}. \tag{OA6-3}$$

We refer to the above procedure as the *trade pattern sequential fixed effects* (TPSFE) estimator. κ_1 is the markup elasticity to bilateral exchange rates. We prove in Appendix C of Corsetti, Crowley, Han and Song (2018) that the above procedure is equivalent to directly estimating equation (2) in section 5, which requires the estimation of a large set of high dimensional fixed effects.

OA6.1.1 Creating trade pattern dummies while conditioning on price changes *and* invoicing scheme

In section 5.1 of the paper, we describe how trade pattern fixed effects work to refine the identification of markup elasticities to use price variation *within a trade pattern.* In this section, we provide a concrete example of how we construct trade pattern fixed effects when we introduce two complications into the basic problem. First, we want to construct trade pattern fixed effects that *condition on price changes of* $\pm 5\%$ so that our findings can be compared to previous papers such as Gopinath, Itskhoki and Rigobon (2010). Second, we want to construct fixed effects that condition on

[3]We account for the lost of degree of freedoms in the twice-demeaning steps and adjust the standard errors using standard panel data techniques as in Abowd, Creecy and Kramarz (2002).

a fifth factor - invoicing currency - so that the fixed effect is specified at the firm, product, destination, trade pattern, *and* invoicing scheme level.

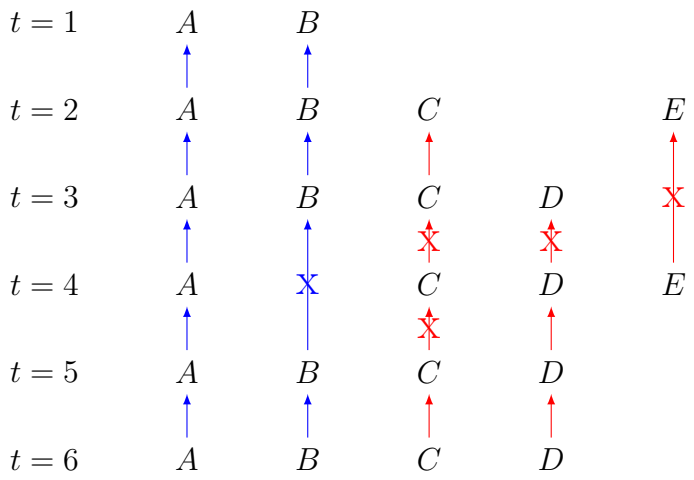
Consider a firm exporting a product to five countries, A through E, over 6 time periods. In the following matrix, $t = 1, 2, 3, ...$ indicates the time period and A, B, C, D, E indicates the country. Empty elements in the matrix indicate that there was no trade.

$t = 1$	A	B			
$t = 2$	A	B	C		E
$t = 3$	A	B	C	D	
$t = 4$	A		C	D	E
$t = 5$	A	B	C	D	
$t = 6$	A	B	C	D	

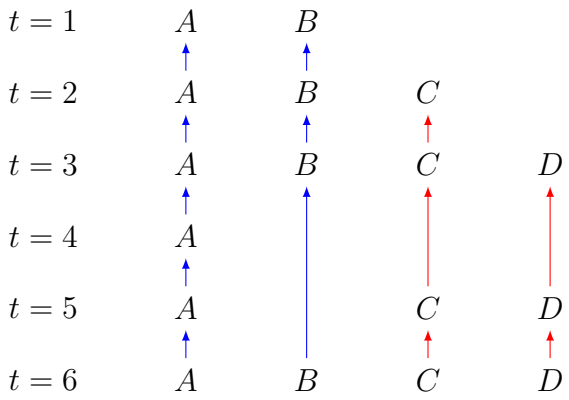
The following matrix records export prices by destination country and time:

$$\begin{bmatrix} p_{A,1} & p_{B,1} & \cdot & \cdot & \cdot \\ p_{A,2} & p_{B,2} & p_{C,2} & \cdot & p_{E,2} \\ p_{A,3} & p_{B,3} & p_{C,3} & p_{D,3} & \cdot \\ p_{A,4} & \cdot & p_{C,4} & p_{D,4} & p_{E,4} \\ p_{A,5} & p_{B,5} & p_{C,5} & p_{D,5} & \cdot \\ p_{A,6} & p_{B,6} & p_{C,6} & p_{D,6} & \cdot \end{bmatrix}$$

Now suppose the firm invoicing in local currencies in destinations A and B and sterling in destinations C, D and E. We compare export prices denominated in the currency of invoicing over time and at the firm-product-destination-invoicing scheme level as illustrated in the following figure and filer out observations with price changes less than 5% (marked with "x"). Transactions invoicing in local currencies are indicated in blue arrows and transactions invoicing in sterling are indicated in red arrows.



In doing so, our algorithm checks cumulative price changes recursively, dropping one observation (with in a firm-product-destination-invoicing currency quartet) at a time. For example, if $|p_{C,4} - p_{C,3}| < 5\%$ and $|p_{C,5} - p_{C,4}| < 5\%$ but $|p_{C,5} - p_{C,3}| > 5\%$, we drop observation $p_{C,4}$.[4] The resulting data are shown below:

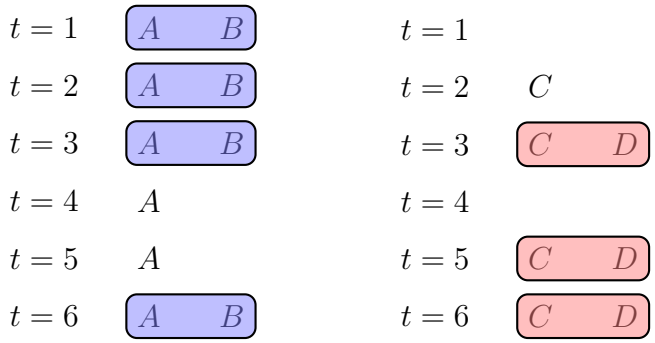


or in matrix form:

$$\begin{bmatrix} p_{A,1} & p_{B,1} \\ p_{A,2} & p_{B,2} \\ p_{A,3} & p_{B,3} \\ p_{A,4} & . \\ p_{A,5} & . \\ p_{A,6} & p_{B,6} \end{bmatrix} \qquad \begin{bmatrix} . & . \\ p_{C,2} & . \\ p_{C,3} & p_{D,3} \\ . & . \\ p_{C,5} & p_{D,6} \\ p_{C,6} & p_{D,6} \end{bmatrix}$$

[4] Variables are in logs.

Using the universe of observations with price changes, we formulate the trade pattern dummies as illustrated below:



In this example, we find two unique trade patterns in each invoicing scheme: A and A-B for local currency invoiced transactions and C and C-D for sterling invoiced transactions. We factor these trade patterns into dummy variables with each dummy representing a unique trade pattern. By formulating trade patterns as fixed effects, our estimator essentially restricts the comparison of prices and exchanges within each trade pattern. For a valid comparison to be made, we require the same trade pattern be observed at least two times in the price-change-filtered dataset.[5]

[5]The fact that our estimator restricts the identification to be within the same trade pattern does not necessarily reduce the total variation used for identification. For example, if a firm-product-invoicing scheme triplet alternates its set of destinations over time (e.g., A-B for periods 1, 3, 5 and A-B-C for periods 2, 4, 6), our estimator will still be able to use all of the observations to identify the markup elasticity (as in this case the trade pattern fixed effect just divides the sample into two groups, i.e., periods 1-3-5 and 2-4-6). The total variation for identification is reduced if a trade pattern is only observed once in the lifetime of a firm-product-invoicing scheme triplet. We show in Corsetti, Crowley, Han and Song (2018) that avoiding the use of variation from singleton trade pattern observations is the key to reducing omitted variable and selection biases in the markup elasticity when the underlying shocks are complex (e.g., changes driven by unobserved firm-product-destination-time specific marginal cost shocks). In an extreme case, if a firm-product-invoicing scheme triplet sells to a unique set of destinations in each time period (e.g., A-B in period 1, A-C in period 2, B-C in period 3, A-B-C in period 4), we will not be able to use any of its variation to identify the markup elasticity. Empirically, the set of destination markets a firm exports is not completely random and we observe many firm-product-invoicing scheme triplets with repeated trade patterns in our dataset.

OA6.2 TPSFE Estimates Not Conditioning on a Price Change

Table OA6-1: **TPSFE estimator, NOT conditioning on a price change**
Price and markup elasticities conditional on invoicing currency
– extra-EU destinations excluding the US
– monthly, quarterly, and annual frequencies over 2010-2017

Freq.	Invoicing	Price		Markup		n. of obs
		NEX (1)	CPI (2)	NEX (3)	CPI (4)	
Annual	All	0.22***	0.41***	-0.01	0.03	2,603,787
	PCI	0.17***	0.36***	-0.03	0.01	1,866,506
	VCI	0.30***	0.48***	0.02	0.06	674,093
	LCI	0.58***	1.14***	0.03	0.44	63,188
Quarterly	All	0.23***	0.40***	0.03	-0.05	5,150,064
	PCI	0.17***	0.33***	-0.00	-0.10	3,640,597
	VCI	0.33***	0.53***	0.01	-0.06	1,367,090
	LCI	0.62***	0.90***	0.51***	0.46	142,377
Monthly	All	0.23***	0.38***	0.04**	-0.03	7,087,461
	PCI	0.17***	0.32***	0.01	-0.04	4,919,170
	VCI	0.34***	0.50***	0.06	-0.05	1,975,747
	LCI	0.51***	0.68***	0.29***	0.23	192,544

Note: This table presents price and markup elasticities by invoicing currency schemes at different time frequencies. Transactions are aggregated at the monthly/quarterly/annual frequency and the trade pattern is calculated at the frequency of aggregation. The dependent variable is the unit value denominated in pounds sterling. The bilateral exchange rate is defined as units of sterling per destination currency; an increase in the bilateral exchange rate is a depreciation of sterling. Statistical significance, based on robust standard errors, is reported at the 1, 5 or 10 percent level which is indicated by ***, **, or * respectively. Data source: HMRC administrative datasets, UK's extra-EU exports, 2010-2017.

Table OA6-2: **TPSFE estimator, NOT conditioning on a price change**
Price and markup elasticities conditional on invoicing currency
– extra-EU destinations including the US
– monthly, quarterly, and annual frequencies over 2010-2017

Freq.	Exports	Price		Markup		n. of obs
		NEX (1)	CPI (2)	NEX (3)	CPI (4)	
Annual	All	0.31***	0.53***	0.07*	0.07	3,167,301
	PCI	0.21***	0.42***	0.00	-0.02	2,182,793
	VCI	0.31***	0.48***	0.01	0.07	684,337
	LCI	0.53***	0.99***	0.51***	0.45	300,171
Quarterly	All	0.33***	0.53***	0.10***	-0.02	6,314,657
	PCI	0.21***	0.39***	0.03	-0.12*	4,277,563
	VCI	0.33***	0.53***	0.00	-0.05	1,387,941
	LCI	0.62***	0.93***	0.55***	0.29	649,153
Monthly	All	0.34***	0.51***	0.08***	-0.04	8,943,396
	PCI	0.23***	0.39***	0.03	-0.07	5,905,499
	VCI	0.34***	0.50***	0.06	-0.07	2,008,259
	LCI	0.63***	0.98***	0.39***	-0.02	1,029,638

Note: This table presents price and markup elasticities based on UK exports to *extra-EU destinations including the US* during 2010-2017. Transactions are aggregated at the monthly/quarterly/annual frequency and the trade pattern is calculated at the frequency of aggregation. The dependent variable is the unit value denominated in pounds sterling. The bilateral exchange rate is defined as units of sterling per foreign currency. Statistical significance, based on robust standard errors, is reported at the 1, 5 or 10 percent level which is indicated by ***, **, or * respectively. Data source: HMRC administrative datasets, UK's exports to extra-EU destinations, 2010-2017.

Table OA6-3: **TPSFE estimator, NOT conditioning on a price change**
Price and markup elasticities – EU versus extra-EU exports
– monthly, quarterly, and annual frequencies over 2010-2017

Freq.	Exports	Price		Markup		n. of obs
		NEX (1)	CPI (2)	NEX (3)	CPI (4)	
Annual	EU	0.38***	1.33***	-	0.29***	9,502,464
	Extra-EU	0.31***	0.53***	0.07*	0.07	3,167,301
	World	0.29***	0.66***	-0.01	0.03	12,379,964
Quarterly	EU	0.39***	1.42***	-	0.39***	25,442,775
	Extra-EU	0.33***	0.53***	0.10***	-0.02	6,314,657
	World	0.32***	0.74***	0.15***	0.16***	31,334,099
Monthly	EU	0.39***	1.39***	-	0.39***	50,451,648
	Extra-EU	0.34***	0.51***	0.08***	-0.04	8,943,396
	World	0.34***	0.81***	0.18***	0.18***	58,946,919

Note: This table presents estimates of price and markup elasticities based on UK export transactions to EU destinations, extra-EU destinations including the US, and all export destinations, respectively. Transactions are aggregated at the monthly/quarterly/annual frequency and the trade pattern is calculated at the frequency of aggregation. The dependent variable is the unit value measured in pound sterling. The bilateral exchange rate is defined as units of sterling per foreign currency. Statistical significance, based on robust standard errors, is reported at the 1, 5 or 10 percent level which is indicated by ***, **, or * respectively. Data source: HMRC administrative datasets, UK's exports to EU and extra-EU destinations, 2010-2017.

OA6.3 Estimates from Alternative Estimation Specifications

In what follows, we present results from alternative fixed effect specifications. We estimate the price elasticity to exchange rates by regressing the price, p_{fidt}, on the bilateral exchange rate, e_{dt}, and the destination CPI, cpi_{dt}, with firm-product-destination fixed effects, δ_{fid}:

$$p_{fidt} = \gamma_0 + \gamma_1 e_{dt} + \gamma_2 cpi_{dt} + \delta_{fid} + u_{fidt} \tag{OA6-4}$$

All variables enter the estimation equation in logs. The firm-product-destination fixed effects absorb the time-invariant price component at the firm product level and force identification of price elasticities to exchange rates to use the time variation within a firm-product-destination triplet.

We then estimate the markup elasticity to exchange rates by adding the firm-product-time fixed effects, η_{fit}, to equation (OA6-4):

$$p_{fidt} = \kappa_0 + \kappa_1 e_{dt} + \kappa_2 cpi_{dt} + \delta_{fid} + \eta_{fit} + u_{fidt} \tag{OA6-5}$$

Since the firm-product-time fixed effects control for the non-destination-specific marginal cost of the firm, the κ_1 coefficient reflects the markup adjustments to exchange rates. Note that the firm-product-destination and firm-product-time fixed effects reflect the most stringent controls that have been applied in the existing literature. Adding firm-product-destination-time fixed effects is not feasible as it will absorb all the variation of the prices.

As shown in the following tables, most of the results from specifications (OA6-4) and (OA6-5) are qualitatively consistent with our benchmark estimates using the TPSFE estimator. For example, the markup elasticity to bilateral exchange rates is significant and large for LCI transactions and small for PCI and VCI transactions.

However, comparing tables 5, 6 and 7 in our paper with tables OA6-4, OA6-5 and OA6-6 reveals that the quantitative magnitudes differ. Notably, the estimate for the degree of pricing-to-market for LCI transactions is smaller in magnitude in the specifications which use firm-product-destination fixed effects rather than trade pattern fixed effects. An analysis of model simulated data in Corsetti, Crowley, Han and Song (2018) suggests that failing to control for a firm's product-level trade pattern introduces a downward bias into markup elasticity estimates when a firm's marginal cost includes destination-specific components.

Table OA6-4: **HDFE estimator, conditioning on a price change**
Price and markup elasticities conditional on invoicing currency
– extra-EU destinations excluding the US
– monthly, quarterly, and annual frequencies over 2010-2017

Freq.	Invoicing	Price		Markup		n. of obs
		NEX (1)	CPI (2)	NEX (3)	CPI (4)	
Annual	All	0.21***	0.43***	0.02	0.04**	2,407,326
	PCI	0.18***	0.39***	0.01	0.01	1,719,388
	VCI	0.26***	0.49***	0.03	0.09***	629,323
	LCI	0.59***	0.96***	-0.02	-0.17	58,615
Quarterly	All	0.23***	0.43***	0.03***	0.03**	4,577,505
	PCI	0.18***	0.37***	0.02**	0.02	3,226,606
	VCI	0.30***	0.53***	0.03	0.06**	1,224,890
	LCI	0.70***	0.82***	0.22**	0.10	126,009
Monthly	All	0.23***	0.42***	0.04***	0.05***	6,154,892
	PCI	0.18***	0.35***	0.04***	0.03*	4,255,848
	VCI	0.31***	0.54***	0.03**	0.07***	1,732,086
	LCI	0.62***	0.41***	0.18**	-0.48***	166,958

Note: This table presents price and markup elasticities by invoicing currency schemes at different time frequencies, estimated according to specifications (OA6-4) and (OA6-5). Transactions are aggregated at the monthly/quarterly/annual frequency. The dependent variable is the unit value denominated in pounds sterling. The bilateral exchange rate is defined as units of sterling per destination currency; an increase in the bilateral exchange rate is a depreciation of sterling. Statistical significance, based on robust standard errors, is reported at the 1, 5 or 10 percent level which is indicated by ***, **, or * respectively. Data source: HMRC administrative datasets, UK's extra-EU exports, 2010-2017.

Table OA6-5: **HDFE estimator, conditioning on a price change**
Price and markup elasticities conditional on invoicing currency
– extra-EU destinations including the US
– monthly, quarterly, and annual frequencies over 2010-2017

Freq.	Exports	Price		Markup		n. of obs
		NEX (1)	CPI (2)	NEX (3)	CPI (4)	
Annual	All	0.26***	0.48***	0.03***	0.04**	2,936,692
	PCI	0.21***	0.42***	0.02	0.01	2,016,191
	VCI	0.26***	0.49***	0.03	0.09***	638,894
	LCI	0.55***	0.96***	0.40***	0.18	281,607
Quarterly	All	0.28***	0.49***	0.04***	0.04***	5,635,328
	PCI	0.21***	0.41***	0.03***	0.02	3,804,695
	VCI	0.30***	0.53***	0.03	0.06**	1,243,333
	LCI	0.66***	0.88***	0.48***	0.15	587,300
Monthly	All	0.29***	0.49***	0.05***	0.05***	7,808,005
	PCI	0.22***	0.40***	0.04***	0.03*	5,132,214
	VCI	0.31***	0.54***	0.04**	0.07***	1,759,815
	LCI	0.68***	0.83***	0.33***	-0.46***	915,976

Note: This table presents price and markup elasticities based on UK exports to *extra-EU destinations including the US* during 2010-2017. The elasticities are estimated according to specifications (OA6-4) and (OA6-5). Transactions are aggregated at the monthly/quarterly/annual frequency and the trade pattern is calculated at the frequency of aggregation. The dependent variable is the unit value denominated in pounds sterling. The bilateral exchange rate is defined as units of sterling per foreign currency. Statistical significance, based on robust standard errors, is reported at the 1, 5 or 10 percent level which is indicated by ***, **, or * respectively. Data source: HMRC administrative datasets, UK's exports to extra-EU destinations, 2010-2017.

Table OA6-6: **HDFE estimator, conditioning on a price change**
Price and markup elasticities – EU versus extra-EU exports
– monthly, quarterly, and annual frequencies over 2010-2017

Freq.	Exports	Price		Markup		n. of obs
		NEX (1)	CPI (2)	NEX (3)	CPI (4)	
Annual	EU	0.47***	1.46***	-	0.70***	8,566,122
	Extra-EU	0.26***	0.48***	0.03***	0.04**	2,936,692
	World	0.35***	0.72***	0.06***	0.11***	11,250,686
Quarterly	EU	0.48***	1.42***	-	0.66***	21,762,505
	Extra-EU	0.28***	0.49***	0.04***	0.04***	5,635,328
	World	0.39***	0.78***	0.07***	0.14***	27,050,252
Monthly	EU	0.49***	1.41***	-	0.68***	42,321,912
	Extra-EU	0.29***	0.49***	0.05***	0.05***	7,808,005
	World	0.42***	0.84***	0.10***	0.18***	49,770,612

Note: This table presents estimates of price and markup elasticities based on UK export transactions to EU destinations, extra-EU destinations including the US, and all export destinations, respectively. The elasticities are estimated according to specifications (OA6-4) and (OA6-5). Transactions are aggregated at the monthly/quarterly/annual frequency. The dependent variable is the unit value measured in pound sterling. The bilateral exchange rate is defined as units of sterling per foreign currency. Statistical significance, based on robust standard errors, is reported at the 1, 5 or 10 percent level which is indicated by ***, **, or * respectively. Data source: HMRC administrative datasets, UK's exports to EU and extra-EU destinations, 2010-2017.

OA6.4 Estimates Conditioning on a Single VCI Currency (i.e., USD versus EUR)

Table OA6-7: Price and markup elasticities conditional on a single VCI currency
(extra-EU exports excluding the US, quarterly and annual frequencies over 2010-2017)

Freq.	Invoicing	Estimator	Conditional on a price change	Price		Markup		n. of obs
				NEX	CPI	NEX	CPI	
Annual	VCI (USD)	TPSFE	Yes	0.22***	0.46***	0.07	0.20	470,289
		TPSFE	No	0.23***	0.46***	0.05	0.08	501,475
		HDFE	Yes	0.21***	0.49***	-0.00	0.07*	470,289
		HDFE	No	0.22***	0.49***	0.01	0.07**	501,475
	VCI (EUR)	TPSFE	Yes	0.44***	0.51***	0.01	0.15	151,137
		TPSFE	No	0.44***	0.53***	-0.01	0.07	164,368
		HDFE	Yes	0.42***	0.59***	0.08	0.19*	151,137
		HDFE	No	0.41***	0.56***	0.07	0.16*	164,368
Quarterly	VCI (USD)	TPSFE	Yes	0.28***	0.52***	-0.06	-0.04	910,709
		TPSFE	No	0.27***	0.52***	-0.02	-0.15	1,008,947
		HDFE	Yes	0.26***	0.52***	0.02	0.05	910,709
		HDFE	No	0.26***	0.52***	0.02	0.05*	1,008,947
	VCI (EUR)	TPSFE	Yes	0.45***	0.55***	0.14	0.20	296,725
		TPSFE	No	0.42***	0.52***	0.13	0.22	339,391
		HDFE	Yes	0.44***	0.63***	-0.01	0.03	296,725
		HDFE	No	0.42***	0.59***	0.02	0.05	339,391

Note: This table presents estimates of price and markup elasticities based on UK export transactions to extra-EU destinations excluding the US. The dependent variable is the unit value measured in pound sterling. The bilateral exchange rate is defined as units of sterling per foreign currency. Results of HDFE are estimated according to specifications (OA6-4) and (OA6-5). Statistical significance, based on robust standard errors, is reported at the 1, 5 or 10 percent level which is indicated by ***, **, or * respectively. Data source: HMRC administrative datasets, UK's exports to extra-EU destinations, 2010-2017.

OA6.5 Bilateral Exchange Rate and CPI Variation of EU Destinations

Figure OA6-1: Bilateral exchange rates of EU countries that do not use the euro

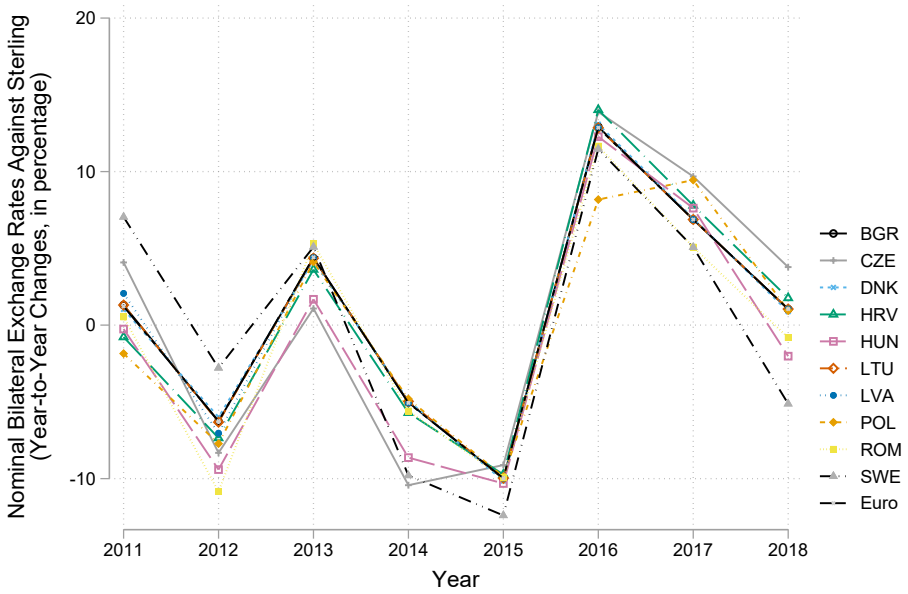
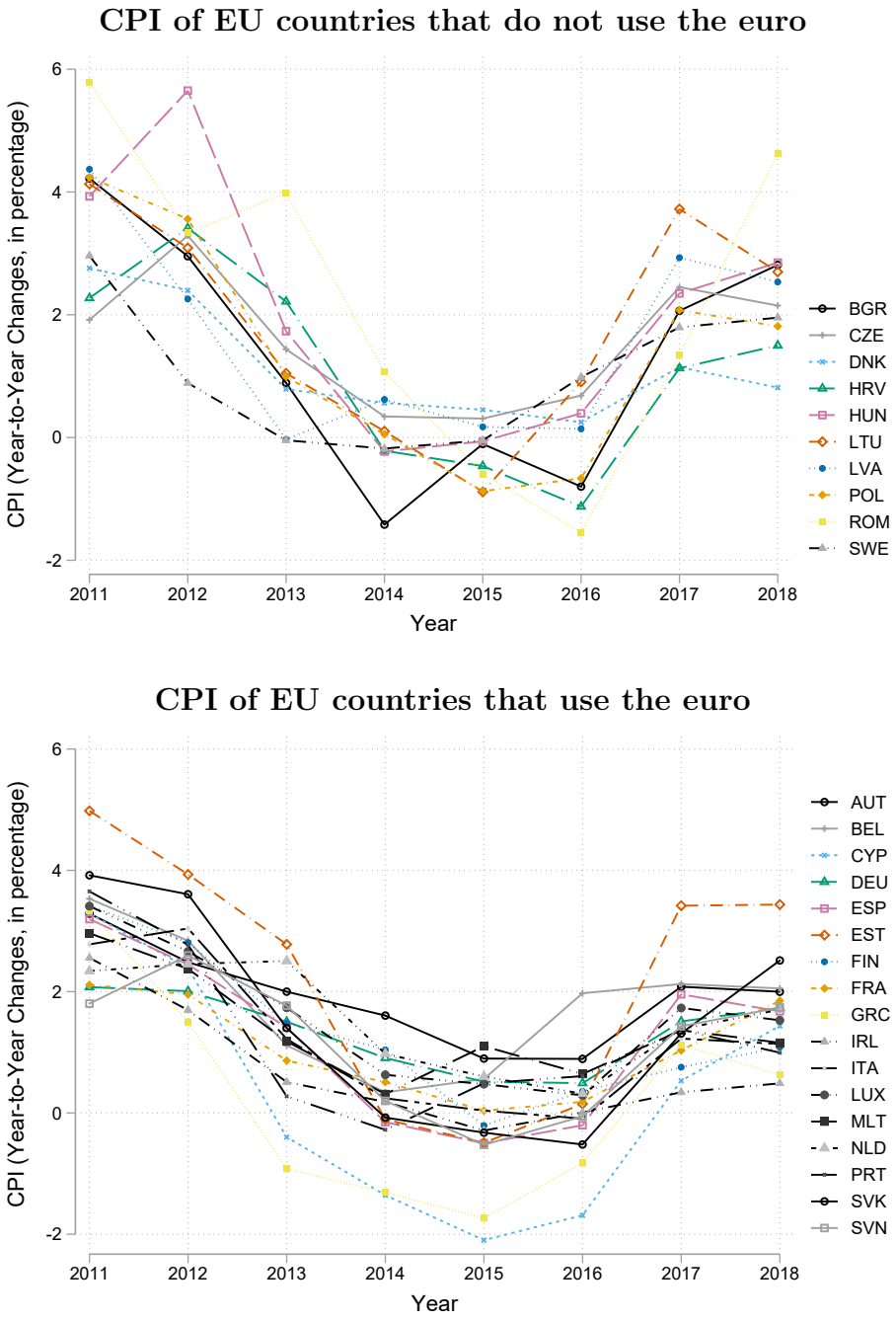


Figure OA6-2: CPI of EU countries are less synchronized compared to their exchange rates



OA7 Construction of Estimation Samples

We describe the construction of the estimation samples, "Extra-EU exports excluding the US," used in table 5 (conditional on a price change) of the paper and table OA6-1 (not conditioned on a price change) of this Online Appendix, in detail. Construction of other estimation samples follows a similar algorithm.

0. Starting from the universe of HMRC extra-EU trade transactions, 2010-2017:

    - Transactions are aggregated at the firm-product-destination-supplementary unit-invoicing currency-time level, where product is measured at the 8-digit CN code; destination refers to the final destination of the shipment; supplementary unit reports the measurement unit of quantity; invoicing currency refers to the reported currency for each transaction; and time refers to the period over which transactions are aggregated, i.e., annually/quarterly/monthly/weekly.

1. Drop US from the estimation sample (to avoid the ambiguity associated with classification of US export transactions invoiced in US dollars as vehicle currency pricing or local currency pricing).

2. Match with the country concordance tables.

    - HMRC uses the Geonomenclature country coding system. We import external macroeconomic series (such as exchange rates, CPI, etc.) and merge them with the administrative trade transactions at HMRC by matching country codes.

3. Merge with series of bilateral exchange rates (defined as LCU per sterling).

    - In the matching process, 29 destinations are not matched: Ceuta and Mellila[6], Vatican City (code 45), Western Sahara (code 206, affected years 2013-2017), South Sudan (code 225, affected years 2013-2017), Ivory Coast (code 272, affected years 1996-2017), St Helena (code 329, affected years 1996-2017), Mayotte (code 377, affected years 1996-2013), Bonaire (code

[6]No match is found from the ISO coding system. In addition, the internal code for these two destinations has changed in the year 1999. Ceuta and Mellila shared the same code (21) during the period 1996-1998. From 1999 onwards, the internal codes of Ceuta and Mellila are 22 and 23 respectively.

475, affected years 2013-2017), Curacao (code 476, affected years 2013-2017), Saint Maarten (477, affected years 2013-2017), Saint Bartholomew (478 and 479, affected years 1996-2017), Timur-Leste (code 699, affected years 2001-2017), Austral Oceania (code 802, affected years 1996-2000), US Oceania (code 810, affected years 1996-2000), French Polynesia (code 822, affected years 1996-2017), Guam (code 831, affected years 2001-2017), US Minor Islands (code 832, affected years 2001-2017), Heard & McDonald (code 835, affected years 2001-2017), Polar Regions (code 890, affected years 1997-2000), Antarctica (code 891, affected years 2001-2017), Bouvet Island (code 892, affected years 2001-2017), South Georgia Island (code 893, affected years 2001-2012), French Southern Territory (code 894, affected years 2001-2017), Abu Dhabi (code 914, affected years 1996-2017), Dubai (code 917, affected years 1996-2017), Sharjah Etc (code 920, affected years 1996-2017), Niue Island (code 923, affected years 2001-2017), Cook Islands (code 926), Stores & Provis. (code 951 and 952, affected years 2015-2017).

4. Merge with other macro variables, e.g., CPI, real GDP and import-to-GDP ratio; Correct formats of comcodes (i.e., product codes used in HMRC trade data).

    - The comcodes in earlier years are reported with 8-digits and those in later years are reported with 15-digits. The 15-digit codes do not contain more information on the substance of the product, but merely add details on the tax and tariff codes of the related product. We use 8-digit measures throughout our analysis.
    - Some datasets report comcodes as a numeric variable, while others report comcodes at a string variable. We use string formats and add a zero in front of the numeric variables if necessary.

5. Convert concordance tables

    - There were major changes in the product definitions of CN codes in the years 2012 and 2017, and some minor changes in other years during our sampling period. We wrote an algorithm to covert product classifications

according to the official concordance tables and keep the maximum number of intertemporally-consistent product definitions.

6. Check and drop observations with obvious entry errors; import and integrate exchange rates of the reported invoicing currency for each transaction; Allocate transactions into bins of invoicing currency schemes (discussed in the main text).

7. Drop duplicates at the firm-comcode-country-invoicing scheme-time level.

8. Drop the observation if its unit value, associated bilateral exchange rates, or CPI is missing.

9. Drop firm-comcode-destination-invoicing scheme quartets that do not survive for at least two time periods.

10. Drop extra-EU exports with no invoicing currency reported; Construct variables necessary for the TPSFE estimator. We refer this sample as the "full sample without conditioning on a price change."

11. Starting from stage 9, filter out absolute price changes that are less than 5% at the firm-comcode-destination-invoicing scheme level.

12. Drop extra-EU exports with no invoicing currency reported; construct variables necessary for the TPSFE estimator. We refer this sample as "the sample conditional on price changes."

OA7.1 Note on the Observations in Each Stage of the Data Cleaning Process

Table OA7-1: Extra-EU exports – annual sample

Stage	Observations	Trade Value (million £)	Firms	Products	Countries	Currencies	Years
0	9,144,028	1,297,646	172,194	10,699		137	8
1	7,777,932	964,740	155,060	10,621		133	8
2	7,745,492	963,056	154,832	10,611	189	133	8
3	7,726,667	962,225	154,628	10,608	172	131	8
4	7,726,667	962,225	154,628	10,527	172	131	8
5	7,607,344	940,492	153,952	9,025	172	129	8
6	7,607,344	940,492	153,952	9,025	172	128	8
7	7,518,511	900,512	153,919	9,025	172	122	8
8	7,121,270	881,556	150,307	9,007	151	121	8
9	3,953,627	785,444	63,251	8,178	151	86	8
10	2,603,787	706,879	52,946	7,918	151	86	8
11	3,757,166	674,232	63,251	8,178	151	86	8
12	2,407,326	595,667	52,946	7,918	151	86	8

Table OA7-2: Extra-EU exports – quarterly sample

Stage	Observations	Trade Value (million £)	Firms	Products	Countries	Currencies	Years
0	13,732,689	1,297,646	172,194	10,699		137	8
1	11,569,030	964,740	155,060	10,621		133	8
2	11,525,266	963,056	154,832	10,611	189	133	8
3	11,493,022	961,312	154,615	10,609	169	131	8
4	11,493,022	961,312	154,615	10,528	169	131	8
5	11,310,091	939,584	153,939	9,025	169	129	8
6	11,310,091	939,584	153,939	9,025	169	128	8
7	11,224,500	919,939	153,924	9,025	169	123	8
8	10,651,299	901,130	150,332	9,007	151	122	8
9	7,740,055	834,550	73,020	8,358	151	95	8
10	5,150,064	752,022	61,140	8,163	151	95	8
11	7,167,496	639,454	73,020	8,358	151	95	8
12	4,577,505	556,925	61,140	8,163	151	95	8

Table OA7-3: Extra-EU exports – monthly sample

Stage	Observations	Trade Value (million £)	Firms	Products	Countries	Currencies	Years
0	18,450,503	1,297,646	172,194	10,699		137	8
1	15,341,884	964,740	155,060	10,621		133	8
2	15,287,838	963,056	154,832	10,611	189	133	8
3	15,242,341	960,943	154,572	10,609	167	131	8
4	15,242,341	960,943	154,572	10,528	167	131	8
5	14,994,860	939,217	153,895	9,025	167	129	8
6	14,994,860	939,217	153,895	9,025	167	128	8
7	14,916,434	928,177	153,890	9,025	167	127	8
8	13,160,444	873,962	144,448	8,985	143	125	8
9	10,526,190	816,248	72,867	8,389	143	100	8
10	7,087,461	738,244	61,071	8,192	143	100	8
11	9,593,621	581,421	72,867	8,389	143	100	8
12	6,154,892	503,417	61,071	8,192	143	100	8

Table OA7-4: EU exports – annual sample

Stage	Observations	Trade Value (million £)	Firms	Products	Countries	Years
0	11,283,558	1,155,153	38,096	10,882		8
1	11,283,558	1,155,153	38,096	10,882		8
2	11,283,477	1,154,455	38,096	10,882	27	8
3	11,283,477	1,154,455	38,096	10,882	27	8
4	11,283,477	1,154,455	38,096	10,882	27	8
5	11,074,969	1,100,276	37,800	9,153	27	8
6	11,074,969	1,100,276	37,800	9,153	27	8
7	11,021,478	1,093,864	37,796	9,153	27	8
8	10,998,143	1,093,605	37,739	9,153	27	8
9	9,502,464	1,063,853	28,531	8,847	27	8
10	9,502,464	1,063,853	28,531	8,847	27	8
11	8,566,122	839,261	28,531	8,847	27	8
12	8,566,122	839,261	28,531	8,847	27	8

Table OA7-5: EU exports – quarterly sample

Stage	Observations	Trade Value (million £)	Firms	Products	Countries	Years
0	27,231,570	1,155,153	38,096	10,882		8
1	27,231,570	1,155,153	38,096	10,882		8
2	27,231,336	1,154,455	38,096	10,882	27	8
3	27,231,336	1,154,455	38,096	10,882	27	8
4	27,231,336	1,154,455	38,096	10,882	27	8
5	26,717,436	1,100,276	37,800	9,153	27	8
6	26,717,436	1,100,276	37,800	9,153	27	8
7	26,643,764	1,097,014	37,799	9,153	27	8
8	26,586,793	1,096,641	37,742	9,153	27	8
9	25,442,775	1,082,868	32,134	8,937	27	8
10	25,442,775	1,082,868	32,134	8,937	27	8
11	21,762,505	701,555	32,134	8,937	27	8
12	21,762,505	701,555	32,134	8,937	27	8

Table OA7-6: EU exports – monthly sample

Stage	Observations	Trade Value (million £)	Firms	Products	Countries	Years
0	52,728,128	1,155,153	38,096	10,882		8
1	52,728,128	1,155,153	38,096	10,882		8
2	52,727,521	1,154,455	38,096	10,882	27	8
3	52,727,521	1,154,455	38,096	10,882	27	8
4	52,727,521	1,154,455	38,096	10,882	27	8
5	51,698,042	1,100,276	37,800	9,153	27	8
6	51,698,042	1,100,276	37,800	9,153	27	8
7	51,605,130	1,098,403	37,799	9,153	27	8
8	51,495,998	1,097,972	37,742	9,153	27	8
9	50,451,648	1,086,644	32,799	8,967	27	8
10	50,451,648	1,086,644	32,799	8,967	27	8
11	42,321,912	649,964	32,799	8,967	27	8
12	42,321,912	649,964	32,799	8,967	27	8

OA7.2 Note on Constructing the Weekly Sample

The construction of the weekly estimation sample used in the Brexit event studies.

0. Starting from the universe of trade transactions.
1. Drop US from the estimation sample as we cannot distinguish whether an export transaction invoiced in dollar is vehicle currency pricing or local currency pricing.
2. Check and drop observations with obvious entry errors.
3. Aggregate data at the firm-product-destination-invoicing currency-week level.
4. Drop those destinations that use Dollar or Euro as their domestic currency.
5. Drop those transactions whose invoicing currency is neither sterling, nor dollar, nor euro, nor local currency.
6. Drop if the absolute price change is less than 5%.
7. Merge with series of weekly bilateral exchange rates (defined as units of local currency per sterling);[7] Drop if the weekly bilateral exchange rate of the destination is not available.

Table OA7-7: Extra-EU Exports 2015-2017 – Weekly Sample

Stage	Observations	Trade Value (million £)	Firms	Products	Countries	Currencies
0	11,984,123	475,888	111,502	9,419	210	114
1	9,268,745	348,153	98,964	9,343	209	111
2	9,268,397	348,079	98,961	9,298	209	111
3	8,266,168	348,079	98,961	9,298	209	111
4	8,263,692	348,049	98,947	9,298	202	111
5	8,221,721	346,032	98,834	9,296	202	23
6	7,328,066	251,819	98,834	9,296	202	23
7	4,854,264	181,252	80,000	8,971	27	23

[7] Weekly exchange rates are calculated as the average of daily rates published by the Bank of England.

Table OA7-8: Invoicing currencies
in the extra-EU exports
2015-2017 weekly sample -
Conditional on a Price Change

Currency	Transactions	Freq.
AUD	45,753	1.2
CAD	35,771	1.0
CHF	31,853	0.9
CNY	8,506	0.2
DKK	273	0.0
EUR	277,611	7.4
GBP	2,438,368	65.2
HKD	18,875	0.5
ILS	1,852	0.0
INR	1,373	0.0
JPY	34,088	0.9
KRW	14,440	0.4
MYR	1,426	0.0
NOK	23,569	0.6
NZD	4,912	0.1
RUB	8,497	0.2
SAR	711	0.0
SGD	6,512	0.2
THB	2,789	0.1
TRY	2,082	0.1
TWD	2,347	0.1
USD	765,993	20.5
ZAR	13,341	0.4
Total	3,740,942	100.0

Note: Statistics are calculated based on the Stage 6 sample described in Table OA7-7. The total number of observations in the Stage 6 sample is 4,854,264 , which includes 1,113,322 observations with no invoicing currency reported.

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