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Evidence on international pricing by UK exporters

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Abstract

Using administrative data on export transactions, we show that UK firms invoice in multiple currencies — even when shipping the same product to the same destination — and switch invoicing currencies over time. We then provide microeconometric evidence that the currency in which a cross-border sale is invoiced predicts systematic differences in exchange rate pass-through and destination-specific markup adjustment, at the granular level of firm-product-destination and time. Based on an event study around the 2016 Brexit depreciation and econometric analysis of a longer period (2010-2017), we examine the export price elasticity to the exchange rate *measured in sterling* to find that this is low for transactions invoiced in producer currency and comparably high for sales invoiced either in a vehicle or in the destination market currency. However, our analysis of markup elasticities reveals that firms price-to-market only when they invoice sales in the destination market currency. Altogether, our findings imply that currency movements may cause significant short-run deviations from the law of one price not only across but also within borders; these are systematically linked to the firm's choice of invoicing currencies. Dynamically, we find that the stark differences in price changes across invoicing currencies that emerged in the aftermath of the Brexit depreciation atrophied within six quarters, as all prices came to align broadly with the weaker pound. These findings enrich our understanding of the 'international price system' underpinning the international transmission of shocks (Gopinath (2015)), with crucial implications for open macro modelling and policy design.

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1 Introduction

Import prices at the border are remarkably insensitive to exchange rate movements. With the exception of commodities and a few homogeneous goods, the international prices of differentiated goods do not move with currencies as much as would be required to accommodate the effects of exchange rate movements on relative costs. The stability of import prices in local currency is highly consequential for open macro theory and policy design: a vast literature has delved into producing reliable evidence at both the aggregate and micro levels to provide guidance to modelling.[1]

While micro data on pricing at the border are in scarce supply, 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, suggesting that survey evidence on invoicing could provide valuable information on pricing. A recent instance of this approach is the influential work by Gopinath on the International Price System (Gopinath (2015)). She builds on the observation that asymmetries in the use of vehicle currencies, such as the US dollar, map into asymmetries in pass through in order to call attention to the dominant role of dollar pricing in goods trade (Amiti, Itskhoki and Konings (2018); Gopinath et al. (2019); Boz, Gopinath and Plagborg-Møller (2019); Maggiori, Neiman and Schreger (2019); Chen, Chung and Novy (2019)).

In this paper, we take the same approach, but go granular to ask: what can be learned about export pricing and the structure of the International Price System (IPS) from detailed micro econometric analyses of invoicing currencies? We articulate this question with three precise investigations. First, do firms invoice in one currency, or more than one currency—and do they switch currencies over time? Evidence could

[1] Open macro has traditionally taken low pass through as evidence of nominal price rigidities and then worked out how stabilization rules may differ according to the degree of exchange rate pass through into import prices (e.g., Obstfeld and Rogoff (1995), Chari, Kehoe and McGrattan (2002) and Devereux, Engel and Storgaard (2004*b*)). More recently, a new strand of the literature calls attention to the role of the structure of production costs (imported inputs in production) and/or market structure (e.g., Atkeson and Burstein (2008) and Corsetti and Dedola (2005)) in preventing profit maximizing firms from raising export prices one-to-one with a nominal depreciation, independent of nominal frictions. In both approaches, reliable empirical evidence on pricing in international trade is a key building block to modelling.

shed light on whether firms engage in active management of invoicing currencies, possibly implying the use of pricing strategies in which ERPT is endogenous and state contingent at the firm and product level. Second, are invoicing currencies correlated with the degree of exchange rate pass through in transaction-level trade data? In an analysis of the strategic choice of the invoicing currency in relation to pricing, it is important to examine whether exchange rate pass through into the export prices of individual products systematically differs (even when sold in the same destination) with the currency in which a trade transaction is invoiced. Finally, does pricing to market (PTM) vary systematically with the currency of invoicing? The fact that 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 charge different prices in response to asymmetric and local shocks. Exploring destination-specific markup adjustments *conditional on invoicing currency* can provide insight into the relationship between currency choice and pricing to market.

We address these questions by relying on a unique dataset covering the universe of the United Kingdom's trade transactions in goods, the Overseas Trade in Goods Statistics from Her Majesty's Revenue and Customs. Since 2010, this dataset includes records of the currency of invoicing at the transaction level for all importing firms and for all firms that export more than £100,000 in a year, with the notable exception of trade with EU countries (for which the currency of invoicing is not recorded). 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. 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 between VCI and LCI. For this reason, we focus part of our analysis on a sample excluding trade not only with the EU (for which we do not have information on invoicing) but also the US. Together, British exports to all countries in the world

except the EU and the US comprise roughly 40 percent of the UK's total export value. For this sample, about two-thirds of export transactions are invoiced in sterling, 30 percent are invoiced in a vehicle currency, and the remaining share is invoiced in the local currency of the foreign destination. The opposite is true for the UK's imports: the majority of transactions are invoiced in a vehicle currency, a smaller share are invoiced in pounds. Remarkably, these aggregate shares are relatively stable over 2010-2017.

Concerning our first question, we document that 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, we find that around 15% of export transactions originate from firms that use more than one currency to invoice sales of the same product sold in the same destination in a given year. These multi-currency exports at the firm, product and destination level account for nearly half of the UK's extra-EU export value. Finally, we document that a small proportion of British exporters switches the invoicing currency for sales of the same product in the same destination between one year and the next.

To address our second question, on invoicing and pass through, we take advantage of the the large sterling depreciation after the Brexit referendum. Focusing on a three year window around the referendum in mid 2016, we show that the short-run response of British export prices, excluding those to the US and EU, differs significantly according to the currency in which UK firms invoice their cross-border transactions. British export prices measured in foreign currency fall with the exchange rate rapidly and completely only for trade invoiced in pounds (PCI), 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, VCI) or destination currencies (LCI) keep their prices in the destination market stable over a short-run horizon of about six months, implying no gain in price competitiveness. This differential response attenuates in about six quarters; differences in the price responses *measured in sterling* significantly narrow across all invoicing schemes; export prices under all schemes become more closely aligned with the weaker pound. At no horizon do we detect any change in the relative shares of PCI, VCI, and LCI in the aftermath

of the referendum.

To assess pricing-to-market, our third question, we apply a novel econometric model to our longer horizon sample (2010-2017) which we extend, in steps, to include first the US and later the EU. While confirming the pattern of pass through found in Brexit event study,[2] our econometric model yields a key novel result: firms adjust destination-specific markups to bilateral exchange rates—hence they price to market—only when they invoice in local currency (LCI). For LCI transactions, about one half of a bilateral depreciation of the pound is absorbed by destination-specific markup adjustments; these account for, on average, two-thirds of incomplete exchange rate pass through. Under PCI and VCI, firms seem to price to the 'global' market, i.e., 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 US or the EU in the analysis, both large markets for UK exports. Expanding the dataset to include UK trade with the US invoiced in US dollars, we find that destination specific market adjustment in LCI transactions becomes more pronounced, accounting for up to 70 percent of the incomplete exchange rate pass through. For trade with EU countries, although we have no data on the invoicing currency, we infer the importance of pricing to market in two distinct 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 LCI transactions. Second, we show that when we add exports to the EU to the sample of exports to extra-EU destinations, the average share of incomplete ERPT accounted for by destination-specific markup adjustments to all foreign markets rises from 25 to 67 percent.

On methodological grounds, we carry out our econometric analysis by using both pass-through regressions and the pricing-to-market estimator built on *trade pattern sequential fixed effects* (TPSFE) developed in Corsetti, Crowley, Han and Song (2018). By using *trade pattern fixed effects* to control for variation in the set of

[2]In our extended sample, we find that exchange rate pass through is higher under PCI (around 80%) than under VCI and LCI (around 65% and 45%, respectively)

destination markets, our approach addresses selectivity issues raised by the possibility that the set of destinations served by a firm changes endogenously with exchange rate movements. In addition, by applying trade pattern fixed effects *sequentially*, our pricing-to-market estimator takes advantage of multi-destination exporters to differentiate out, for each product, the common marginal cost and markup charged in all markets in order to detect destination-specific market adjustments in reaction to exchange rate fluctuations. It thus allows us to correlate the use of a currency of invoicing directly with pricing-to-market behaviour. UK transaction-level data are particularly suitable in this respect—99% of UK exports to extra-EU countries originate from multi-destination exporters.[3] We refer to Corsetti, Crowley, Han and Song (2018) for a detailed discussion of the properties of the TPSFE estimator. For our econometric analysis, we apply the methodology proposed by Gopinath, Itskhoki and Rigobon (2010) and condition our analysis on a price change. The combination of this methodology with trade pattern fixed effects implies that we analyze cumulative changes in the price of a good over a variable but generally long time span, mitigating concerns about the effects of nominal rigidities on the short run dynamics of pass through (see Corsetti, Dedola and Leduc (2008) for a discussion).

Literature. Our results are closely related to two strands of the literature. The first consists of the contributions that have produced empirical evidence of "strategic complementarities" in relation to firms' invoicing decisions—a topic extensively discussed in theoretical models of endogenous currency choice (see, e.g., Devereux, Engel and Storgaard (2004*a*), Engel (2006), Gopinath, Itskhoki and Rigobon (2010), and Mukhin (2017)). Leading examples are provided by recent contributions that have linked the choice of the invoicing currency (impinging on exchange rate pass through) to the import intensity in production (see e.g., Goldberg and Tille (2008), Amiti, Itskhoki and Konings (2014), Chung (2016)). The main idea is that firms are likely to invoice and price in the currency in which their imported inputs are invoiced and priced in order to mitigate the impact of exchange rate fluctuations on marginal costs. The empirical implementation of this idea nonetheless faces a number of hurdles. First, it is often difficult to distinguish whether the imported good is

[3]Authors' calculations. See the first row of table 1b.

used as a production input or is sold to the firm's domestic customers. Second, for a multi-product firm, is difficult to tell which imported input is used to produce which product—or whether a particular product has any imported inputs at all. To the extent that our empirical method (the TPSFE estimator) is successful in differencing out marginal costs at the product level, our estimates overcome these empirical difficulties. Notably, after controlling for firm-product specific factors, we find no destination-specific markup adjustments for transactions invoiced in producer or vehicle currency, but an economically significant destination-specific markup elasticity for transactions invoiced in local currency.

Second, and most importantly, our results contribute to the recent debate on the role of vehicle currencies in the international transmission mechanism (see, e.g., Gopinath (2015) and Gopinath et al. (2019)). At the heart of this discussion is the idea that firms invoicing in a vehicle currency, say dollars, also price their goods in the vehicle currency. A further logical step is that these firms would set one global dollar price for their product—maximizing their profits relative to global demand taken as a whole. Indeed, one possible (extreme) implication of what Gopinath has dubbed the International Price System (IPS) is that pricing in dollars overcomes market segmentation and translates into a *Reference Price System*, by which firms do not exploit market-specific demand elasticities, but price in relation to global demand. Irrespective of nominal rigidities, our estimates suggest that, in their extra-EU and extra-US trade, UK firms invoicing in vehicle currencies do not make destination-specific markup adjustments, and thus, provides micro-level empirical support for Gopinath's IPS hypothesis. At the same time, we provide nuanced evidence that firms accounting for about 60% of UK export value seem to follow a different strategy of invoicing in local currency and adjusting markups to local market conditions.[4] Moreover, we show that firms sometimes switch across currencies. In this respect, our contribution is closely related to the open macro literature that specifies models featuring variable markups, as well as to empirical studies of firms' pricing strategies which exploit the increasing availability of high-dimensional administrative customs

[4]This 60% export value includes the trade flows to the EU and the US.

databases.[5] Beyond the many determinants of pricing-to-market revealed in existing research, we document a specific role of invoicing currencies in shaping market-specific adjustment.

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 the invoicing currency. Section 6 concludes.

2 Data

Our dataset includes the universe of UK export and import transactions over the period 2010-2017. 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 of our empirical analysis to include trade with the EU.[6] 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 day combi-

[5] Seminal contributions of theoretical open macro models include Krugman (1986), Dornbusch (1987), Corsetti and Dedola (2005), Atkeson and Burstein (2008), Corsetti, Dedola and Leduc (2008). Recent papers which study firms' pricing strategy using micro data include Berman, Martin and Mayer (2012), Chatterjee, Dix-Carneiro and Vichyanond (2013), Amiti, Itskhoki and Konings (2014), Fitzgerald and Haller (2014), De Loecker, Goldberg, Khandelwal and Pavcnik (2016), Auer and Schoenle (2016), Fitzgerald and Haller (2018), Corsetti, Crowley, Han and Song (2018), Amiti, Itskhoki and Konings (2019) and Bonadio, Fischer and Saure (2019).

[6] 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/Statistics/Pages/Annual-Tables.aspx`.

nation.[7] 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).

3 Four facts about invoicing currencies

In this section we document a set of novel stylized facts about invoicing based on the UK's international trade transactions. First, most exporters invoice in more than

[7]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.

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, firm switch currencies. Last but not least, we show the rich and complex patterns unveiled by our granular analysis are hidden beneath aggregate invoicing shares which remain remarkably 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-year level. Specifically, for each firm and each year of data, we calculate the total number of destinations reached and the total number of invoicing currencies used in all transactions within a calendar year, and then allocate each firm-year dyad 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 exporters sell their products using a single currency of invoicing. Among these, the overwhelming majority are single-destination firms—accounting for 35% of firm-year dyads. The bottom panel of the table shows that the economic importance of exporters invoicing in a single currency is actually very limited. When observations are trade-weighted, these exporters account for less than 1% of export value. Remarkably, even firms that export to only a single destination use more than one currency. Single-destination exporters that use multiple currencies are the source of 15% (6.4/41.6) of firm-year dyads and 60% (0.6/1.0) of export value among single-destination firms.

Turning to column 2 of table 1, we find that the use of more than one invoicing 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 only 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.

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 show the proportion of firm-year dyads, the bottom panel show 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.

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. Specif-

ically, 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 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. This is a key fact that, to our knowledge, has not been documented in the literature. Multi-currency invoicing at the firm, product, destination and time period level is a challenge to theoretical models which typically assume that a firm invoices in only a single currency to a given destination.

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

No. of Currencies	No. of FPDT quarters	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.

3.3 Firms switch the currency of invoicing from year to year

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 choice over time.

Table 3: Invoicing scheme transition matrix (extra-EU exports, 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 level. Data source: HMRC Overseas Trade in Goods Statistics, UK's extra-EU exports, 2010-2017.

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 use 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.

Two principal conclusions can be drawn from the table. 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. The percentages on the diagonal of the table are quite high. Yet, there is a fair amount of switching. As shown in the top panel of the table, 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 the table 3. The main finding is that, for these transactions, the probability of a switch in the currency of invoicing is slightly lower—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)).

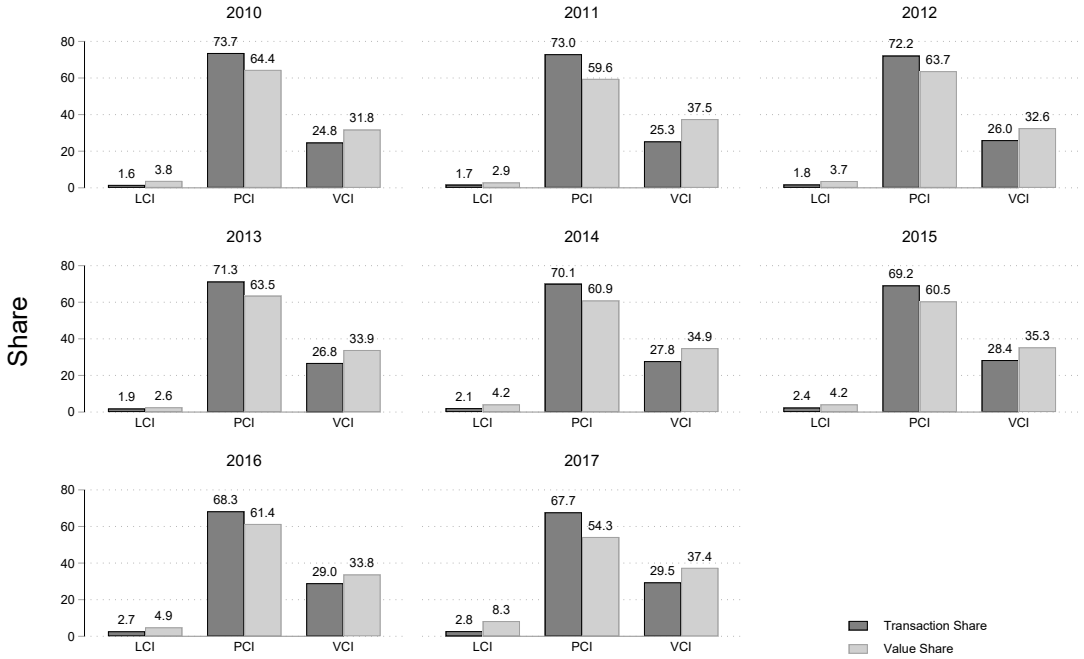
3.4 Aggregate shares of invoicing currencies are stable over time

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 currency, we omit all trade with the US from the analysis.[8] 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.

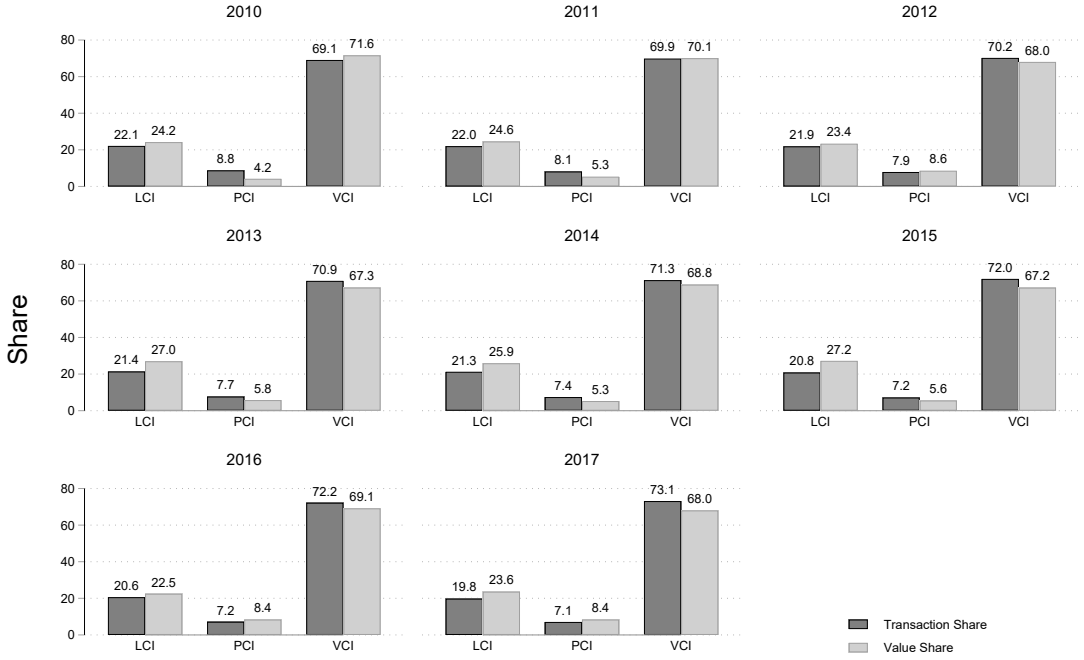
In each year, we define the unit of observation as the quintuplet comprised of a (1) firm, (2) product, (3) country of origin (imports) or destination (exports),

[8] In appendix A, figure A1 presents statistics on the top invoicing currencies for British exports, including exports to the US.

Figure 1: Aggregate composition of invoicing schemes



(a) UK exports to extra-EU destinations, excluding the US



(b) UK imports from extra-EU sources, excluding the US

(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 1 shows the aggregate share of the three invoicing schemes for each year in our sample, distinguishing exports (top panel) and imports (bottom panel). In the graphs, dark bars refer to shares of "transactions"; light grey bars refer to the shares of export value.

Two facts are notable. First, the invoicing patterns differ across exports and imports; exports are dominated by PCI, while imports are dominated by VCI. Second, while granular information suggests that firms use multiple currencies by product and destination and sometimes switch invoicing currencies, when we aggregate individual transactions, the share of each invoicing currency scheme is remarkably stable throughout all the years in the sample. Figure 1a shows that UK exports are primarily invoiced in producer currency, the pound sterling; PCI accounts for 68-74% of firm-product-destination-quantity measure-currency (FPDQC) transactions and 54-65% 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 (figure 1b). 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%).

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

In this and the next section, we address our core question of whether the currency of invoicing is informative about firms' pricing and markup adjustments. We begin with an event study; we exploit the large sterling depreciation after the Brexit referendum to analyze whether the dynamics and magnitudes of adjustment in export prices systematically vary across PCI, VCI, and LCI transactions. In section 5, we estimate destination-specific markup adjustments to exchange rate changes, apply-

Figure 2: Movements of sterling bilateral exchange rates

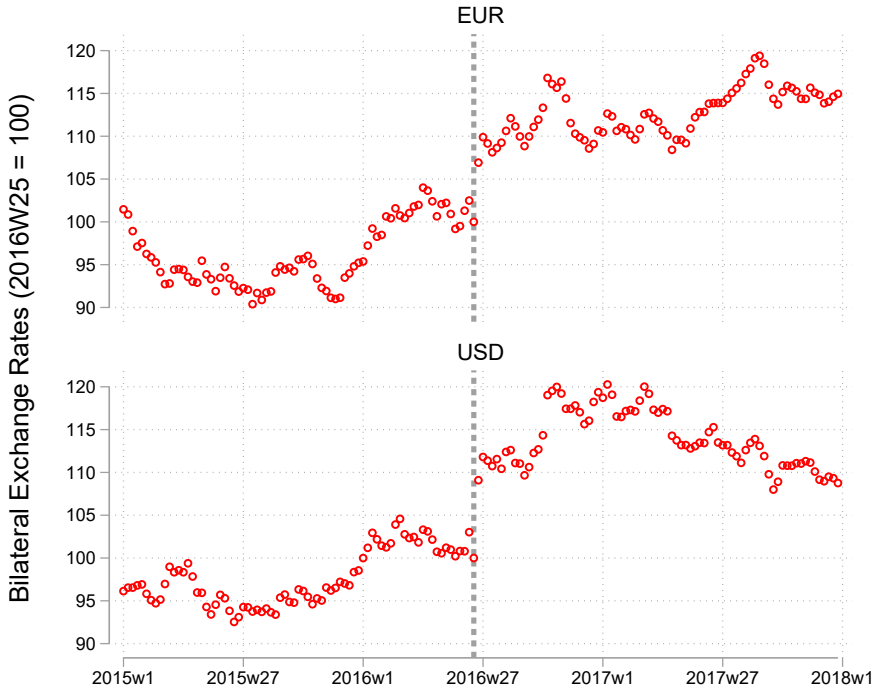
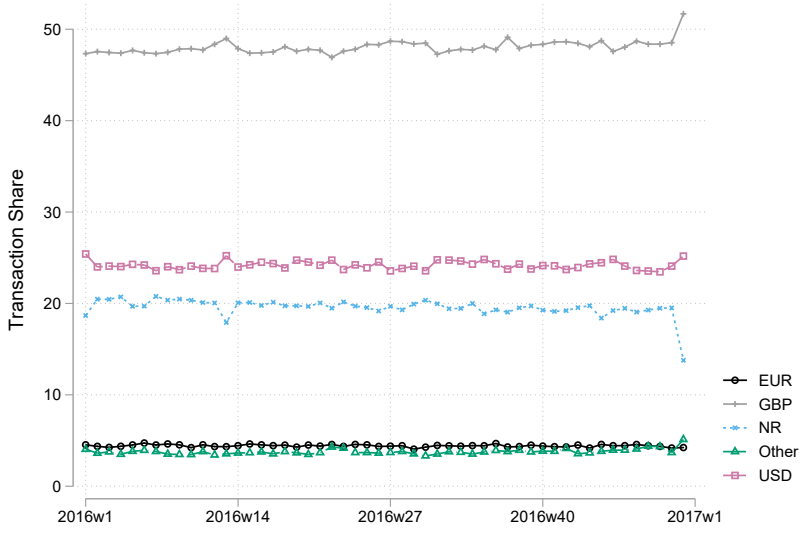


Figure 3: Transaction share by invoicing currencies for extra-EU exports in 2016



Note: "NR" standards for the transactions with no invoicing currency information available.

ing the method developed in our previous work (Corsetti, Crowley, Han and Song (2018)) and extending the sample — always distinguishing among different invoicing currency schemes.

The Brexit event study allows us to study pricing and invoicing conditional a specific, although quite complex, shock that resulted in an idiosyncratic, large and persistent nominal depreciation of the sterling. Figure 2 plots the nominal exchange rate of the sterling around the Brexit referendum.[9] In light of the size and persistence of the sterling depreciation, we find it remarkable that the large exchange rate adjustment following the 2016 referendum did not result in noticeable changes in the aggregate shares of PCI, LCI or VCI transactions. This is shown in figure 3. However, when we examine the distributions of price changes for each invoicing scheme, we observe distinct shifts to the right at the time of the depreciation for VCI and LCI transactions (see figure 4). This is evidence that, after the referendum, UK firms that were *not invoicing in sterling* maintained relatively stable prices in the foreign currencies in which they were invoicing — and thus let their prices *measured in sterling* rise with the fall in the currency.[10]

4.1 The empirical model for the event study

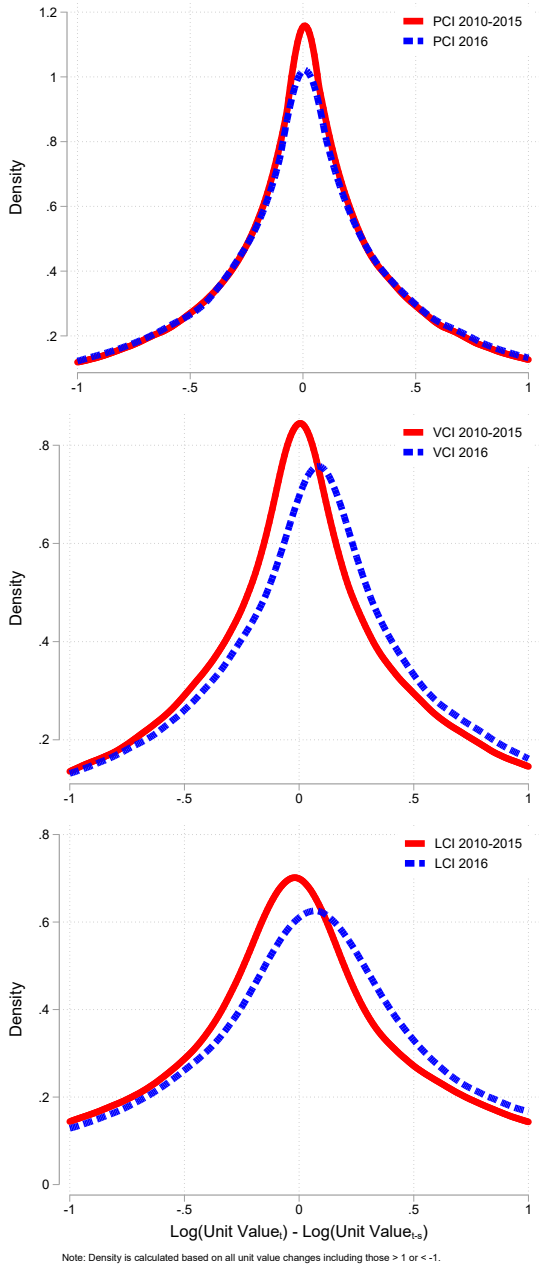
In our event study, we analyze how export prices changed over time following Bonadio, Fischer and Saure (2019). Specifically, we use data from the first week of 2015 through the last week of 2017 to estimate:

$$y_{ifdct} = \sum_{\tau=1}^{156} \lambda_\tau + \delta_{ifd} + v_{ifdct} \quad y \in \{p_{ifdct}, e_{dt}\} \tag{1}$$

[9]Of course, over our entire sample 2010-2017, the sterling recorded a number of large swings against some currencies, more modest ones against others, reflecting a variety of regional and global shocks. But given the specificities of the Brexit-related depreciation, the results of our event study are more likely to reflect possible non-linearities in the response of prices to exchange rate movements.

[10]In the top panel of figure 4, the distribution of price changes is unaffected by the large depreciation, suggesting that firms invoicing in sterling exploited the sterling's weakness to gain price competitiveness in foreign markets. Beginning with the middle and bottom panels, we see that the distributions of price changes for VCI transactions and LCI transactions over 2016-2017 are shifted to the right relative to the distributions for the six years prior to the Brexit referendum. The contrast with the result for transactions invoiced in sterling (top panel) is apparent.

Figure 4: Distribution of annual price changes for extra-EU exports over 2010-2015 versus 2016-2017 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 2016-2017 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, 2010-2017.

where the subscripts i, f, d, c, and t stand for product, firm, destination country, invoicing currency, and time (*in weeks*), respectively; p_{ifdct} 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 bilateral exchange rate, where an increase in e_{dt} means an appreciation of the destination country's currency.[11] All variables enter the estimating equation in logs.

Essentially, the empirical model (1) decomposes the variation of the dependent variable y_{ifdct} into three terms: (i) a time-invariant term (δ_{ifd}) capturing firm-product-destination specific features; (ii) a set of week dummies ($\sum_{\tau=1}^{156} \lambda_\tau$) capturing the average price changes over time; and (iii) a pure idiosyncratic term (v_{ifdct}). 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 short, medium and long time horizons.

4.2 Price responses to the Brexit depreciation

A summary of the evolution of UK export prices around the Brexit depreciation is shown in Figures 5-7. Our main conclusion from the event study is that export price evolution differs markedly across invoicing currency schemes with the most pronounced difference between PCI on the one hand and LCI and VCI on the other. Each figure plots our estimates of λ_τ from (1) based on transactions conducted over 156 weeks from the beginning of 2015 through the end of 2017.[12] In each graph, 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

[11] 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, CN08product, 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.

[12] 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_τs for each scheme.

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 changes in the foreign currency-sterling bilateral exchange rate (i.e., increases reflect a decline in the value of sterling). The solid blue line shows our estimates of 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.

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

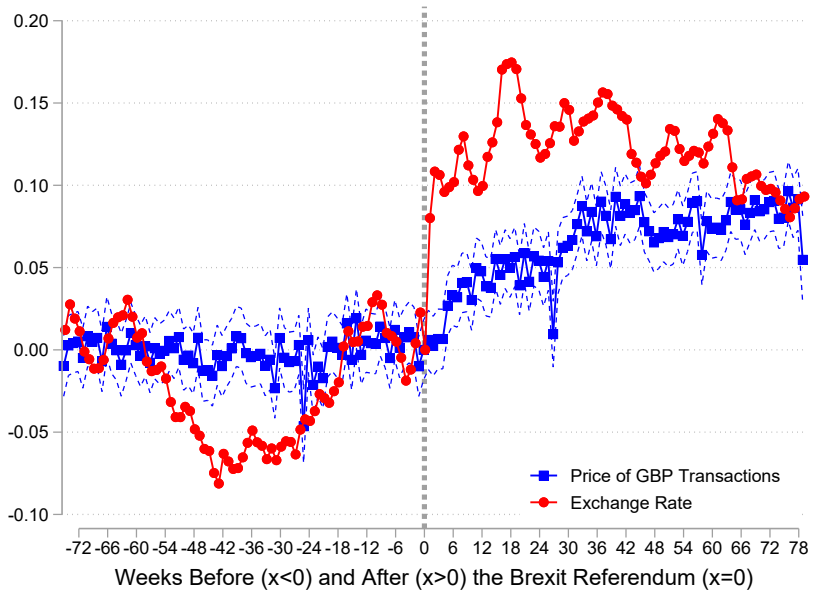


Figure 6: Price responses of local currency invoiced transactions (extra-EU exports, 2015-2017)

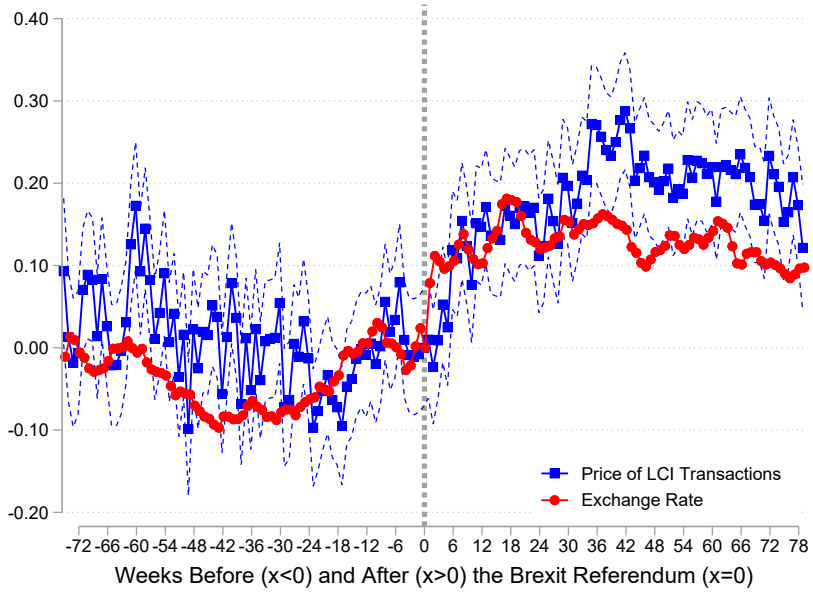
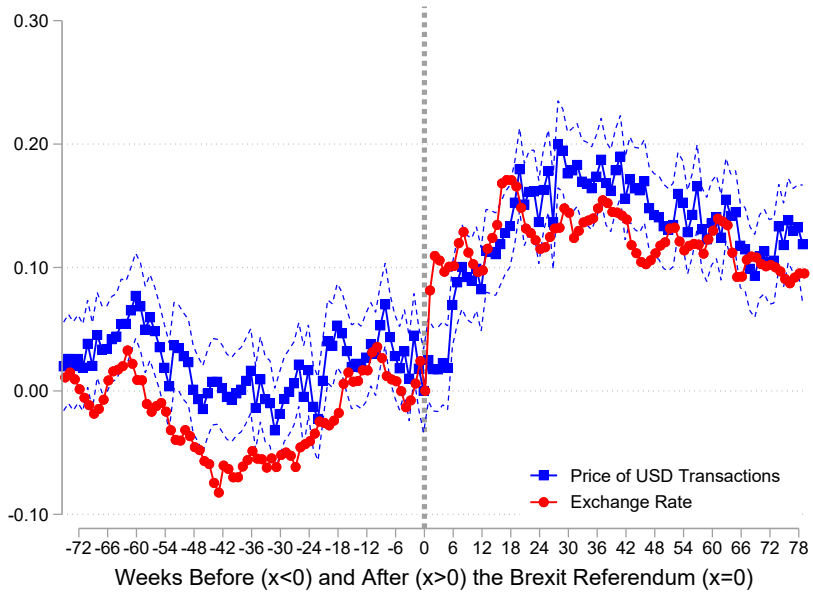


Figure 7: Price responses of dollar invoiced transactions (extra-EU exports, 2015-2017)



As can be seen in all three figures, the change in the export price measured in

sterling is close to zero in the four weeks following the referendum across PCI, VCI, and LCI transactions. Arguably, the lack of any price response in the four weeks after the depreciation may in part reflect administrative rules which require that custom forms be submitted prior to the arrival of the goods to the port.[13] Regardless, a stable export price for sterling invoiced transactions means that, from the perspective of an importer, the price measured in the local currency drops one-to-one with the the exchange rate—an "exchange rate pass through" of close to 100%. To the extent that a firm's marginal costs do not move in the very short run, this pricing evidence suggests that firms invoicing in sterling did not adjust their markups at all in response to currency movements in these first few weeks.

Differences across invoicing currencies start to become apparent in the fifth week. For the sterling-invoiced transactions in figure 5, export prices increase gradually over time and converge to the rate of the sterling depreciation at around 72 weeks, implying that exchange rate pass through into *import prices* fell steadily from almost 100% on impact to around 0% after a year and a half. Interestingly, the magnitude of the export price change remains much smaller than the change in the exchange rate for the first 66 weeks (15 months) after the depreciation. With UK *import prices* rising gradually with the weaker exchange rate, the evolution of sterling-invoiced export prices likely reflects some combination of higher marginal costs and increases in markups.[14]

In sharp contrast to the case of PCI transactions, the sterling price adjustment to exchange rate changes is much faster and larger when transactions are invoiced in the local currency of destination markets. As shown in figure 6, the movements in the sterling price of LCI transactions and the exchange rate largely aligned with each other in just six weeks' time, implying a relatively stable price in local currency and

[13] "For most goods you'll make a full declaration which must be made before the goods arrive at the port of export." (https://www.gov.uk/guidance/customs-declarations-for-goods-taken-out-of-the-eu). "Your courier or freight forwarder will use your commercial invoice to make an official customs declaration. Your goods can be held up in customs if the information you give is not accurate." (https://www.gov.uk/starting-to-export/outside-eu).

[14] See appendix figures B2-B5 documenting the rising cost of UK imports. 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.

suggesting a substantial increase in the exported product's markup when measured in sterling. After around 36 weeks, the increase in the sterling price began to exceed the change in the value of the pound; this means that the import price *in local currency* rose slightly after the depreciation, presumably reflecting increases in the cost of imported inputs to the British producer.

Most interestingly, the same pattern characterizes the responses of prices when firms invoice in a vehicle currency. See figure 7 for US dollar-invoiced transactions to non-US destinations. While dollar-invoiced prices (measured in sterling) hardly moved in the first 4 or 5 weeks after the Brexit vote, they adjusted quickly afterwards. In six weeks' time, dollar-invoiced export prices (measured in sterling) had risen with the exchange rate almost one to one. Sometime around 20 weeks' horizon, these dollar-invoiced export prices in sterling had adjusted to the extent that exchange rate pass through into import prices appeared to be close to zero.[15]

A final important observation is that although the price adjustment to the fall in the value of the pound in 2016 differed markedly across invoicing currency schemes in the aftermath the referendum, over about 70-78 weeks, sterling export prices came into alignment with the weaker currency under all invoicing schemes. The remarkable headline conclusion from our Brexit depreciation event study is the extent of export price adjustment in sterling. By the end of the 2017, UK export prices in sterling and the pound sterling exchange rate were basically aligned, i.e., on average, UK export prices in the currencies of the destination markets were essentially unaffected by the Brexit depreciation.

Because the sterling depreciation was large and common against all currencies, it had a significant impact on the cost of imported inputs across the board, a result that is borne out in the analysis of UK import prices in appendix figures B2-B5. Against increasing production costs from imported goods, it appears that British producers updated their export prices in a matter of months, possibly eroding cost competitiveness gains from the exchange rate.

[15] Appendix figure B1 documents that the evolution of the sterling price of euro-invoiced exports to extra-EU destinations is very similar to that of dollar-invoiced transactions to non-US destinations in figure 7.

5 Invoicing and markup adjustment

In this section, we turn to econometric methods to investigate whether price adjustment to exchange rate movements in UK export data can be attributed to markup adjustment or changes in marginal costs. We do so by first focusing on the same three year window around the Brexit referendum that we use in the event study. We then extend our sample to the period 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. In what follows we present and discuss estimates of both price and destination-specific markup elasticities with respect to the exchange rate, employing the methodology developed in our previous work (Corsetti, Crowley, Han and Song (2018)).

5.1 Econometric model

To study pass through and pricing to market, we rely on two regression models. First, we estimate the export price elasticity to the exchange rate (2) as follows:

$$p_{ifdt} = \gamma_0 + \gamma_1 e_{dt} + \gamma_2 cpi_{dt} + TP_{d,D_{ift}} + u_{ifdt} \tag{2}$$

where $TP_{d,D_{ift}}$ denotes the trade pattern fixed effect, defined on the set of markets served by a firm exporting a specific product within a period; p_{ifdt} 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; and all variables are entered in logs. The export price elasticity to the exchange rate, γ_1, is the complement to 1 of the degree of exchange rate pass through (a higher γ_1 indicates a lower ERPT).

Second, to study pricing-to-market, we estimate equation (3) using destination-demeaned variables together with trade pattern fixed effects:

$$\widetilde{p}_{ifdt,D_{ift}} = \kappa_0 + \kappa_1 \widetilde{e}_{dt,D_{ift}} + \kappa_2 \widetilde{cpi}_{dt,D_{ift}} + TP_{d,D_{ift}} + \widetilde{u}_{ifdt,D_{ift}} \tag{3}$$

The key difference between (2) and (3) is that in (3) prices, exchange rates, and CPI are all expressed as deviations from their means (in logs) calculated over a corresponding trade pattern D_{ift} that is firm, product and time specific. Here κ_1 measures the destination-specific markup elasticity to the bilateral exchange rate.

Two comments are in order to explain the properties of our estimators. The first concerns the differences between the elasticities identified by the two regression specifications above. 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 (2) estimates the combined response of these three unobserved terms (correcting for endogenous market participation). Our pricing-to-market specification (3) differences out (a) and (b), and thus captures (c).[16]

The second comment concerns the *trade-pattern fixed effects* that we include in our estimators to control for the possibility that the set of export destinations served by a firm varies endogenously in response to exchange rate movements. Specifically, because a firm's decision to enter or exit a specific market depends on its relative cost competitiveness as well as relative demand shifts associated with currency fluctuations, failure to control for endogenous market participation may result in a bias in ERPT estimates. In the regression model (2), by introducing a *trade pattern fixed effect* at the firm-product level into a standard ERPT model, we identify the export price elasticity using intertemporal price variation within the same set of destination markets over time; this restricts the variation of observed and unobserved factors

[16]The maintained hypothesis in our approach is that the changes in the composition of subgoods within an 8-digit product category sold by a single firm are orthogonal to changes in bilateral exchange rates. A key advantage of the TPSFE estimator is that it can be used in assessing the markup response to both exchange rate and tariff shocks. 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). It is worth stressing that our approach does not require detailed balance sheet data.

that lead firms to participate in different markets and, thus, reduces selection bias.[17] In the regression model (3), we go beyond standard ERPT analysis, by exploiting cross-sectional price variation *across destinations within a firm-product trade pattern* through the *sequential* application of trade pattern fixed effects. The *trade pattern sequential fixed effects* (TPSFE) estimator thus controls for the combined effect of unobserved changes in marginal costs and markups that are common in all destinations, as well as endogenous market participation. It thus isolates destination-specific markup adjustment (i.e. pricing to market) in response to exchange rate changes.[18]

An important difference between this paper and our previous work 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 conditional on the currency of invoicing. We proceed by first constructing each firm's product-level time-varying trade pattern across all extra-EU foreign sales, regardless of invoicing currency, in order to estimate price and destination-specific markup elasticities averaged over "All" destinations and invoicing currencies. We next construct firm-product trade patterns for PCI, VCI, and LCI separately. This enables us to investigate which invoicing scheme(s) is/are associated with destination-specific adjustment in markups, i.e., pricing-to-market. We carry out our analysis conditional on a price change, as in Gopinath, Itskhoki and Rigobon (2010), and at different time frequencies.[19]

The analysis begins in subsection 5.2 with a dataset of exports to all destinations except the EU and US. The analysis is then extended to the US in subsection 5.3

[17]Our approach can be considered as a variation of the fixed effects estimator by Kyriazidou (1997) and works in a similar way as the control function approach by Heckman (1979) when the variables causing the bias are observable. See Corsetti, Crowley, Han and Song (2018) for more details. Empirically, trade patterns vary considerably over time at the firm-product level, and are endogenous to the value of the exchange rate. See appendix B.2.2 for an example of a firm-product trade pattern over time and see Han (2018) for empirical evidence on the endogeneity of trade patterns to the exchange rate.

[18]See appendix B.2 for details.

[19]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 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.

and to the whole world in subsection 5.3.2.[20]

5.2 Results excluding UK trade with the US

In what follows, we present and discuss the two principal results from our econometric analysis. First, our estimates from the export price elasticity specification (2) confirm the main conclusion of section 4 — the overall price responses of PCI-exports are considerably different from those of LCI and VCI exports. Second, our estimates from the pricing-to-market specification (3) provide evidence that only LCI transactions have a significant destination-specific markup elasticity.

5.2.1 Results at the weekly frequency: 2015-2017

For comparison with our event study in section 4, we start our analysis by applying our regression models (2) and (3) to *weekly* price data over the 3-year period around the Brexit referendum, 2015-2017. Results are summarized in table 4.[21] The first column, under the headline "All," shows estimates for the full sample without conditioning on invoicing choices. In column (2), under the headline "PCI," the estimation sample is restricted to firm-product-destination transactions that are invoiced in British pounds. Similarly, in columns (3) through (5), the estimation samples are restricted to firm-product-destination transactions that are invoiced in local currency "LCI," US dollars "VCI (Dollar)," and euros "VCI (Euro)," respectively.

The first row of table 4 reports the sterling price elasticity with respect to the exchange rate, that is, one minus exchange rate pass through. In column (2), for instance, a price elasticity of 0.24 for sterling invoiced transactions means that, against a 1% bilateral depreciation of sterling, the sterling price of exports increases by 0.24%—corresponding to an exchange rate pass through into the foreign currency price of 76%. Note that the estimated price elasticities for dollar and local currency invoiced transactions are both significantly higher than those for sterling invoiced

[20]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.

[21]Weekly data on consumer price indices are not available and thus cpi_{dt} is not included as a control variable for estimates in table 4.

Table 4: Price and DSM elasticities conditional on currency – weekly frequency over 2015-2017 – extra-EU destinations excluding the US

	(1) All	(2) PCI	(3) LCI	(4) VCI (Dollar)	(5) VCI (Euro)
Price	0.333***	0.241***	0.577***	0.406***	0.520***
	(0.0118)	(0.0177)	(0.0453)	(0.0365)	(0.0448)
DSME	0.0733***	0.0435	0.482***	0.0591	0.0506
	(0.0267)	(0.0384)	(0.0778)	(0.0779)	(0.106)
Observations	4,854,264	2,438,368	258,970	765,993	277,611

Note: This table presents estimates of price and destination-specific markup elasticities (DSME) by invoicing currency schemes. 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 *. Data source: HMRC administrative datasets, UK's extra-EU exports, 2015-2017.

transactions. This means that our econometric results are consistent with the pattern unveiled by our Brexit event study – the pass through into *import prices* is higher for PCI relative to LCI and VCI transactions over most of the year and a half after the Brexit referendum.

But while the magnitudes of the price elasticities for the dollar and the local-currency invoiced transactions are close to each other, the relative markup adjustments are profoundly different. This is shown in the second row of table 4, reporting estimates from the TPSFE pricing-to-market model (3). Here, destination-specific markup adjustment is significant only for LCI transactions—not for transactions that are invoiced in producer or vehicle currency. It should be stressed that, in our estimates, the destination-specific markup adjustments in LCI transactions are not only significant, but also sizeable. They act as a serious brake to the transmission of currency movements across countries—accounting for over 80% of the incomplete pass through (0.482/0.577). In light of this evidence, price adjustments for sales invoiced in producer and vehicle currencies appear to be driven by either changes in marginal

costs or in the component of the markup that is common across destinations, or in both. 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).

5.2.2 Results at monthly, quarterly and annual frequencies: 2010 - 2017

In table 5, we present results from extending our analysis to a longer time window, 2010 - 2017, using data at annual, quarterly, and monthly frequencies.[22] At these frequencies, we additionally have information on CPIs. Hence, the table includes estimates of price and destination-specific 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 elasticity, the next two present the pricing-to-market results.

A first notable result highlighted by the table is that the price elasticities with respect to the exchange rate and the CPI (columns (1) and (2)) are significantly different from zero across all invoicing schemes, and roughly stable when estimated at different frequencies.[23] Conversely, the results on pricing-to-market in columns (3) and (4) are significant only for LCI transactions at monthly and quarterly frequencies with respect to the exchange rate. A second notable result is that the price elasticities with respect to both the exchange rate and the CPI in the first two columns are significantly higher for LCI transactions than for PCI and VCI transactions.[24]

[22] As before, results shown are conditional on a price change. See appendix table B1 for results that do not condition on a price change.

[23] 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.

[24] 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.

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

Freq.	Invoicing	Price		DSME		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 destination-specific markup elasticities (DSME) 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 at the 1, 5 and 10 percent level is indicated by ***, **, and *. Data source: HMRC administrative datasets, UK's extra-EU exports, 2010-2017.

These results are fully consistent with the picture from table 4, suggesting that the overall lesson emerging from our econometric analysis of the three year window around Brexit continues to hold over the longer horizon of 2010-2017. In particular, for LCI transactions, our estimates suggests that destination-specific markup adjustments are responsible for 55% to 65% of incomplete exchange rate pass through at the monthly and quarterly frequencies, respectively.

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. We prefer to exclude the first in view of a possible ambiguity in the classification of exports invoiced in the US dollars reaching the US; we excluded the EU because of the lack of data on invoicing currency. We now extend our econometric analysis in two directions. First, we run our models using the entire extra-EU dataset, including UK exports to the US. Second, we adapt our model for analysis of the EU data. Since both markets are large, and use currencies with international status, we expect our models to give more weight to LCI-type transactions—in terms of a lower average pass through and more pronounced pricing-to-market. We will show below that this conjecture is fully supported by the evidence.

5.3.1 Trade with the US

Estimates for the larger sample including UK trade with the US are shown in table 6. Comparing this with table 5, it is apparent our main conclusions are robust to extending the sample. However, in table 6 the price and markup elasticities are higher across all invoicing schemes. For LCI transactions in particular, including US data raises the estimates of the DSME substantially, and makes them statistically significant at all frequencies. The contribution of destination-specific markup adjustments to incomplete pass-through now ranges from 68% in the monthly frequency sample, to 88% in the annual frequency sample.

These findings suggest the lower exchange rate pass through into import prices,

observed in the higher export price elasticity estimates in column (1) of table 6 versus table 5, reflects the strong adjustment of US-specific markups to dollar-sterling bilateral exchange rate movements shown in column (3). This is evidence that the prices of UK exports to the US *invoiced in dollars* are quite sticky – consistent with Gopinath, Itskhoki and Rigobon (2010).

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

Freq.	Exports	Price		DSME		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 destination-specific markup elasticities (DSME) 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 at the 1, 5 and 10 percent level is indicated by ***, **, and *. Data source: HMRC administrative datasets, UK's exports to extra-EU destinations, 2010-2017.

5.3.2 Trade with the EU

The extension of our analysis to EU destinations faces at least three hurdles. Firstly, the currency of invoicing is not reported. We cannot replicate our analysis by currency scheme. Secondly, 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.[25] Finally, the bilateral exchange rates 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.[26] Because the use of these European currencies together with the euro could possibly induce spurious estimates, we choose to apply the same euro-sterling exchange rate to trade with all EU countries, including those outside the eurozone. This means that, when we apply our TPSFE estimator, we can only estimate destination-specific markup adjustment to local CPI, not to the bilateral exchange rate.[27]

In table 7, we report estimates using the EU dataset, the extra-EU dataset, and the comprehensive dataset of UK exports to the world.[28] Beginning with price elasticities in the first two columns of the table, a first key finding is that the estimates with respect to bilateral exchange rates in the EU data are higher than or equal to those in the extra-EU data at all frequencies. Furthermore, the price elasticities with respect to the destination market CPI are significantly higher for EU transactions than for extra-EU transactions. Interestingly, the estimated price elasticities to CPI for EU transactions are similar in magnitude to those for extra-EU LCI transactions

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

[26] The variation in bilateral exchange rates for these countries is shown in figure B9 in appendix B.2.4.

[27] Using bilateral exchange rates of non-eurozone countries in the EU gives very similar results on price elasticities to both bilateral exchange rate and CPI movements. However, there is not enough variation among European exchange rates in relation to the euro to identify the destination-specific markup elasticity to the exchange rate.

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

(see the bottom row in each panel of table 6).

Turning to markup elasticities, the TPSFE estimator cannot be applied to the EU dataset to estimate the DSME with respect to the bilateral exchange rate because of the lack of variation between the euro and the other European currencies. Yet, remarkably, the destination-specific markup adjustments to changes in *the local market CPI* 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 relative CPI growth and price discriminate across destinations.[29]

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

		Price		DSME		
Freq.	Exports	NEX (1)	CPI (2)	NEX (3)	CPI (4)	n. of obs
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	-0.04	11,502,814
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***	0.71***	0.24***	0.29***	27,397,833
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	0.34***	0.79***	0.23***	0.21***	50,129,917

Note: This table presents estimates of price and destination-specific markup elasticities (DSME) 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 at the 1, 5 and 10 percent level is indicated by ***, **, and *. Data source: HMRC administrative datasets, UK's exports to EU and extra-EU destinations, 2010-2017.

[29]We obtain similar findings by repeating the event study approach of Section 4 with British exports to the EU. See appendix figure B6. The sterling prices of EU transactions quickly catch up with the large depreciation after the Brexit referendum, suggesting firms are actively adjusting their sterling markups to maintain a stable destination (euro) price.

A final piece of evidence regarding price discrimination by UK firms comes from the change in the DSME across the extra-EU and world (including the EU) datasets. At each frequency, the second row of table 7 presents the DSME 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); and 0.09/0.35 (monthly)] is due to destination-specific adjustments in the markup charged by UK exporters. Relative to this benchmark, the magnitude of the DSME more than doubles (monthly and quarterly frequencies) when the estimation dataset is expanded to include trade with the EU countries. This is 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 British exports to the EU are likely to be primarily invoiced in euros.

6 Conclusion

In this paper, we use granular data to examine the extent to which a firm's choice of an invoicing currency for an export transaction provides information about its pricing and markup decisions. We document that, while the aggregate shares of different invoicing currencies in UK trade are stable over time, a lot is going on behind the scene. British firms export 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.

We provide novel econometric evidence that a firm's choice of invoicing currencies matters for pricing at the finest product-transaction level. Using both an event study and econometric analysis, we show that the currency in which a sale is invoiced is closely related not only to the dynamics of ERPT, but also to whether a firm adjusts its product price to local market conditions. This implies that, in any given period,

the prices of the same product sold in the same destination can differ when different sales were invoiced in different currencies. Exchange rate fluctuations may therefore induce deviations from the law of one price not only across, but also within borders.

We show these results, first, by taking advantage of the large sterling depreciation after the Brexit referendum. We show that export price adjustment in sterling is strikingly slower for transactions invoiced in sterling than in transactions invoiced in local (destination market) and vehicle currencies. In the very short run, when invoicing in sterling, firms let the sterling depreciation pass through to lower their prices in *the currency of the destination market*; when invoicing in local or vehicle currencies, firms keep prices stable in destination and vehicle currencies. Yet, these price differences across invoicing currencies significantly narrow over a time span of six quarters.

Second, we document novel findings that the markups of exports invoiced in sterling or in a vehicle currency do not react differentially to local market conditions. In contrast, the markups of exports invoiced in local currencies do—in particular, this applies to UK exports to the US invoiced in US dollars and UK exports to the EU. For the latter, we produce evidence of substantial adjustment of destination-specific markups to local CPI. One important conclusion from our study is that the option of invoicing in local currency and adjusting markups to local market conditions is pursued by a significant proportion of firms, accounting for nearly 60% of UK export values.

These results have significant implications for open macro modelling, as they impinge on the mechanisms that regulate the transmission of fundamental shocks across countries. First, evidence that the prices of UK exports invoiced in dollars to non-US destinations do not respond to bilateral exchange rate movements suggests that firms may set one global dollar price for their products. If pricing in dollars overcomes market segmentation, we could think of vehicle currencies as creating a 'Reference Price System,' by which firms do not exploit market-specific demand elasticities, but price in relation to global demand. In contrast, pricing-to-market (i.e., destination-specific markup adjustment) is systematically associated only with transactions invoiced in local currency. This conjecture of a 'Reference Price System'

around vehicle currencies would further specify the properties of what Gopinath has dubbed the 'International Price System'.

Second, our results offer a valuable set of stylized facts to guide theoretical analysis of the determinants of export pricing. One may note that 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)). But 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.

Finally, the facts about multiple invoicing currencies raise questions about how firms manage idiosyncratic and global market risks and exploit market power to extract rents from specific markets, given that their ability to do so may change as currencies move. 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 (2015) 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 the needs for more work, both empirical and theoretical, in these directions.

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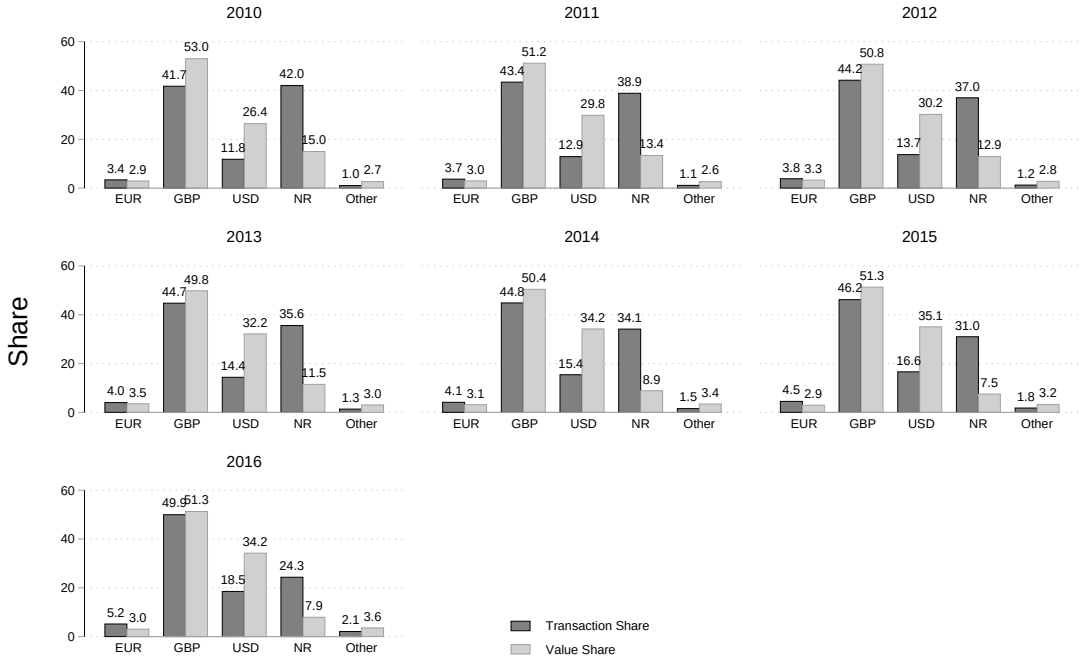
A Statistics on the Granular Distribution of Invoicing Choices

Figure A1: 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.

Table A1: 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 A2: 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 A3: Number of products v.s. 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 A3 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 A4: Number of products v.s. 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 A4 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 A5: 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 A5 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 A5, 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 A6: 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 A6 presents the transition matrix of invoicing choices for UK imports. Overall, the probability of switching is much lower for importers compared to exporters.

A.1 Distribution of price changes for extra-EU imports and exports (based on raw data)

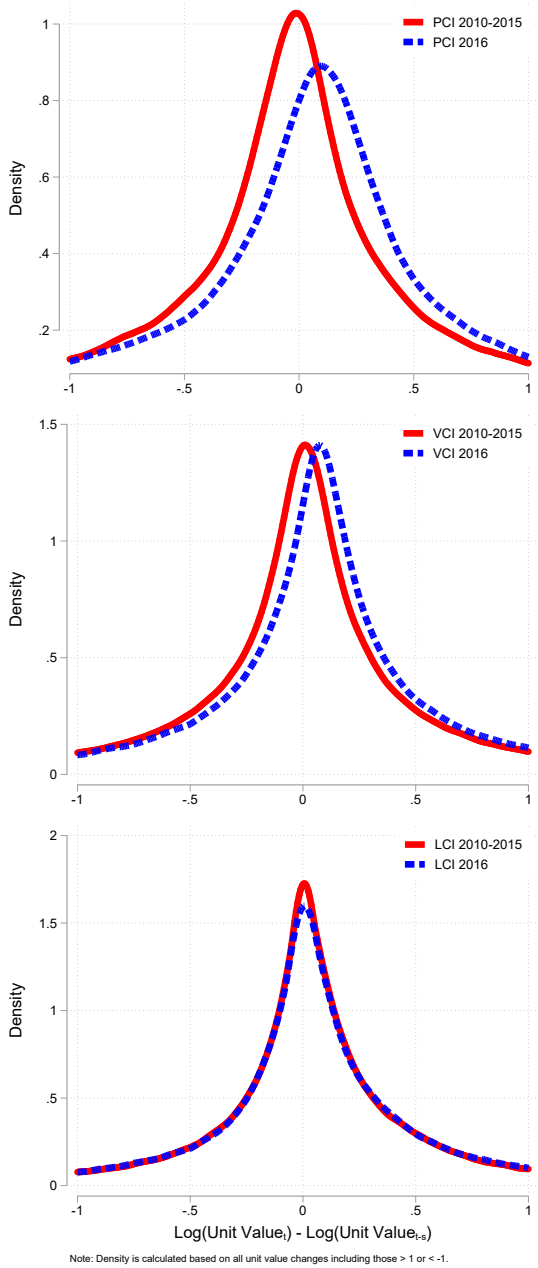
Table A7: Magnitude of price changes by invoicing schemes (extra-EU exports, 2010-2017)

	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 A7 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.[30]

[30]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 A2: Distribution of annual price changes for extra-EU **imports** in 2010-2015 versus 2016



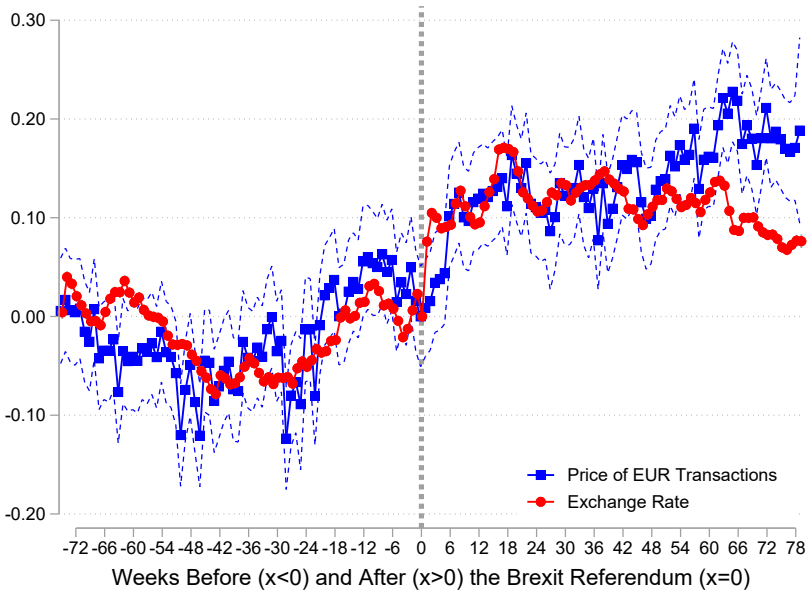
B Further Estimation Results

B.1 The Event Study Approach

(a) Export Price Responses of Euro-Invoiced Transactions

The prices of exports invoiced in euros (appendix figure B1) evolve similarly to those invoiced in US dollars (figure 7).

Figure B1: Price responses of **euro** invoiced transactions (**extra-EU exports**, 2015-2017)



(b) UK Import Price Responses to the Brexit Depreciation

Figures B2–B5 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 B2: Price responses of **sterling** invoiced transactions (**extra-EU imports**, 2015-2017)

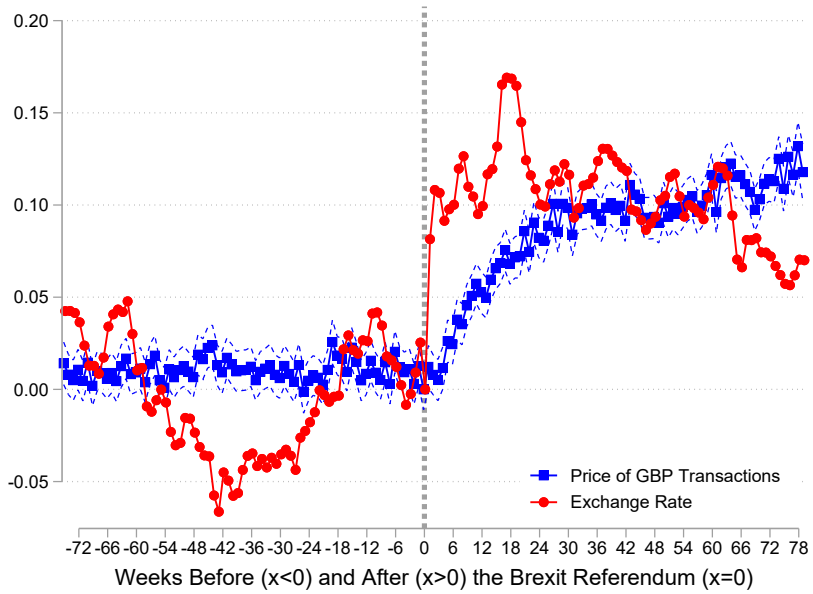


Figure B3: Price responses of **producer currency** invoiced transactions (**extra-EU imports**, 2015-2017)

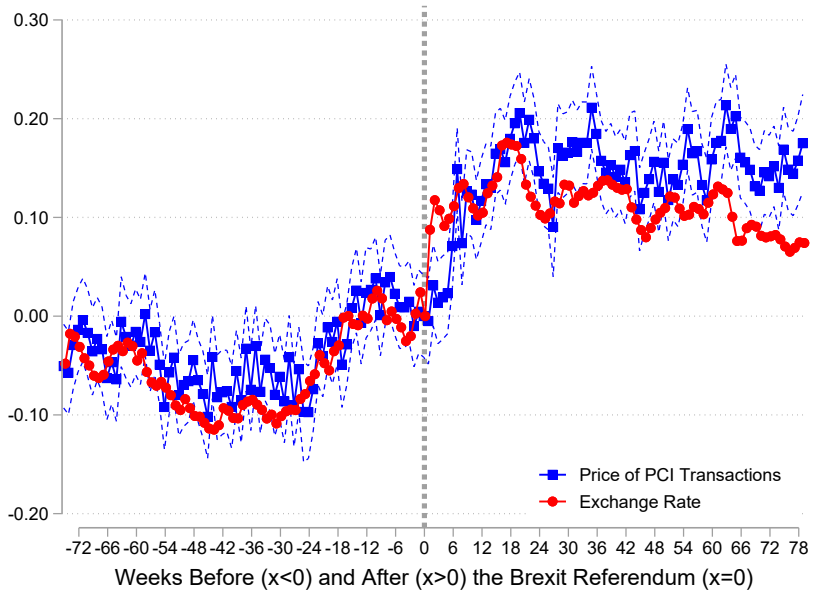


Figure B4: Price responses of **dollar** invoiced transactions (**extra-EU imports**, 2015-2017)

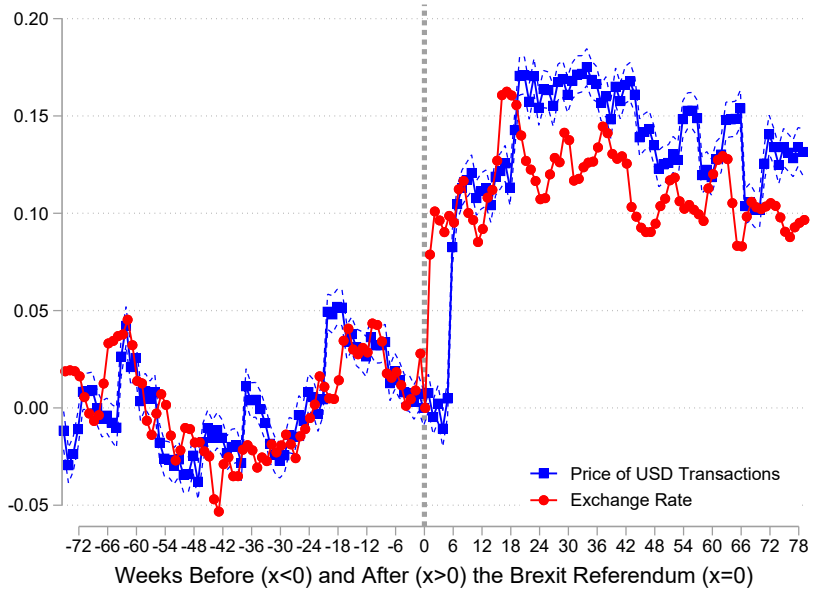
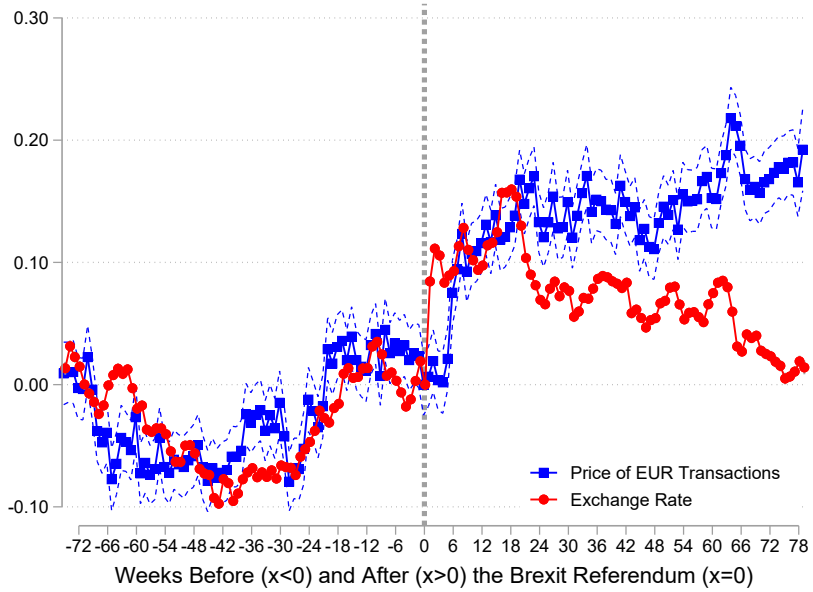


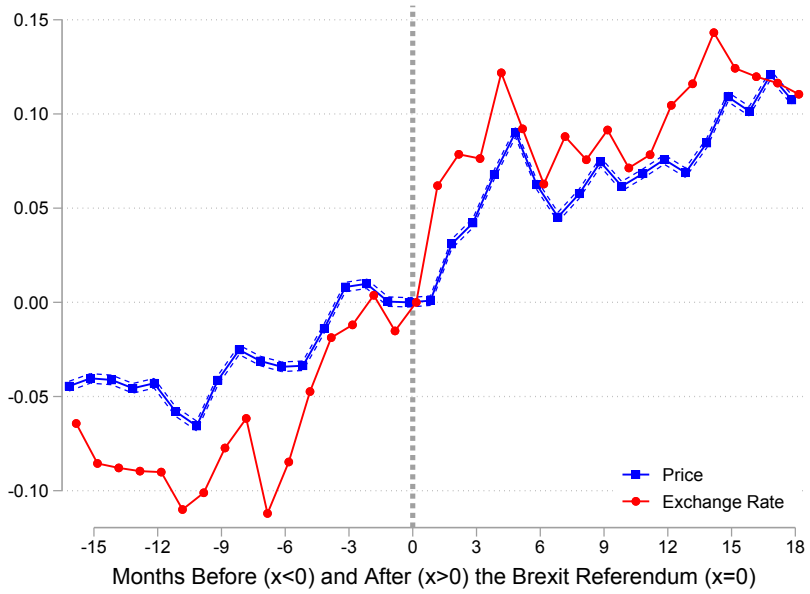
Figure B5: Price responses of **euro** invoiced transactions (**extra-EU imports**, 2015-2017)



(c) Export Price Responses of Exports to EU countries

Figure B6 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 B6: Price responses of export transactions to **EU destinations**, 2015-2017



B.2 The Fixed Effects Approach

B.2.1 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 destination-specific markup adjustments. 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:

1. Demean each variable in the dataset at the firm-product-time level, so to express each variable as a destination-specific deviation from the mean. This step strips out the firm's time-varying marginal production cost at the product level, as well as any global factor that is common across all the destinations a firm-product pair serves.[31]

   (a) For each firm-product-time triplet, calculate the mean of each dependent and independent variable over all destinations the firm serves, i.e., calculate:

   $$\frac{1}{n^D_{ift}} \sum_{d \in D_{ift}} x_{ifdt} \quad \forall x \in \{p_{ifdt}, e_{dt}, X_{dt}\} \tag{4}$$

   where n^D_{ift} is the number of foreign destinations for each firm-product-time triplet and X_{dt} represents a vector of control variables.

   (b) Remove the mean over all destinations in order to obtain the residual variation in the variable by destination:

   $$\widetilde{x}_{ifdt,D_{ift}} = x_{ifdt} - \frac{1}{n^D_{ift}} \sum_{d \in D_{ift}} x_{ifdt} \quad \forall x \in \{p_{ifdt}, e_{dt}, X_{dt}\} \tag{5}$$

[31] As detailed in the complimentary Online Appendix (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.

2. Identify the trade pattern for each product sold by a firm in each time period conditional on the invoicing currency; turn this information into a "trade pattern fixed effect" that incorporates information about the destination associated with each observation as well as the set of all destinations reached by the firm-product pair in that period.

   For each firm-product-time (f, i, t) triplet:

   (a) Collect the set of destinations served:

$$\{d : p_{i'f'dt'} \text{ is observed} : i' = i, f' = f, t' = t\}. \tag{6}$$

   (b) Generate a string variable that identifies this set of destinations. For example, VN-KR-JP is attached to a firm f which exports product i to Vietnam, Korea, and Japan invoiced in sterling in a year t. Notationally, denote this string as D_{ift}.

   (c) Create a trade pattern fixed for each $ifdt$ observation by appending the destination country for that observation to the front of its trade pattern string. For example, for the trade pattern fixed effects VN-VN-KR-JP, KR-VN-KR-JP and JP-VN-KR-JP, the first string is associated with a firm's shipment to Vietnam in a year in which the firm sells to Vietnam, Korea and Japan. The second string is associated with that firm's shipment to Korea in the same year, etc. Notationally, denote this trade pattern fixed effect as $TP_{d,D_{ift}}$.

3. Run a regression using destination-demeaned variables and the trade pattern fixed effects.

$$\widetilde{p}_{ifdt,D_{ift}} = \kappa_0 + \kappa_1 \widetilde{e}_{dt,D_{ift}} + \widetilde{X}'_{dt,D_{ift}} \kappa_2 + TP_{d,D_{ift}} + \widetilde{u}_{ifdt,D_{ift}} \tag{7}$$

We regress prices in deviations from means on exchange rates and destination CPI with the trade-pattern fixed-effect. The destination-specific markup elasticity to exchange rates is captured by κ_1.

B.2.2 An example on identifying price changes and creating trade pattern dummies

In this subsection we use the following example to illustrate how we identify price changes at the firm-product-destination-invoicing scheme level and trade patterns across destinations at the firm-product-invoicing scheme level in the data.

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.

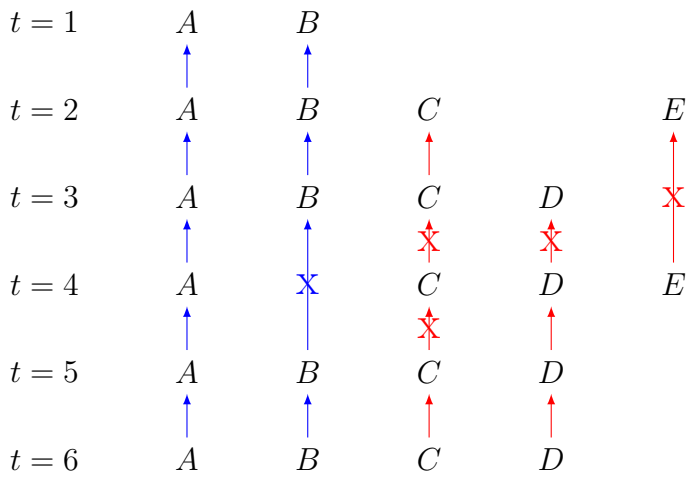
$$\begin{array}{lccccc} t=1 & A & B & & & \\ t=2 & A & B & C & & E \\ t=3 & A & B & C & D & \\ t=4 & A & & C & D & E \\ t=5 & A & B & C & D & \\ t=6 & A & B & C & D & \end{array}$$

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. Price changes less than 5% are marked with "x". Transactions invoicing in local currencies are indicated in blue arrows and

transactions invoicing in sterling are indicated in red arrows.

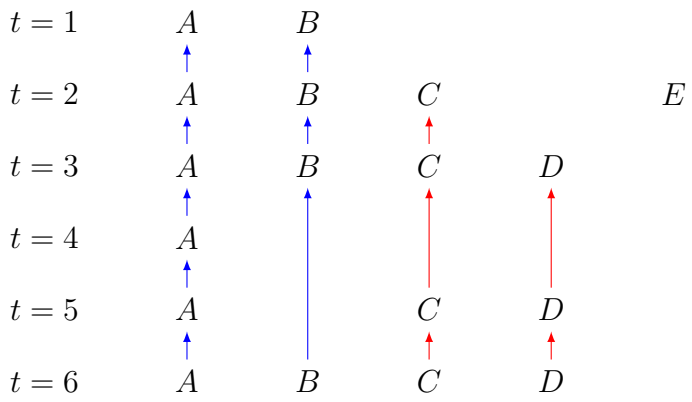


We then set the batch of individual prices associated with a price changes below $\pm 5\%$ $(p_{B,5}, p_{C,4}, p_{D,4}, p_{E,4})$ to missing. This gives

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

Note that we did not treat $p_{C,5}$ as missing at this stage. This is because $|p_{C,5} - p_{C,3}|$ could be $> 5\%$ even if both $|p_{C,4} - p_{C,3}| < 5\%$ and $|p_{C,5} - p_{C,4}| < 5\%$.[32] Rather, we repeat the above step using the remaining observations as illustrated below.

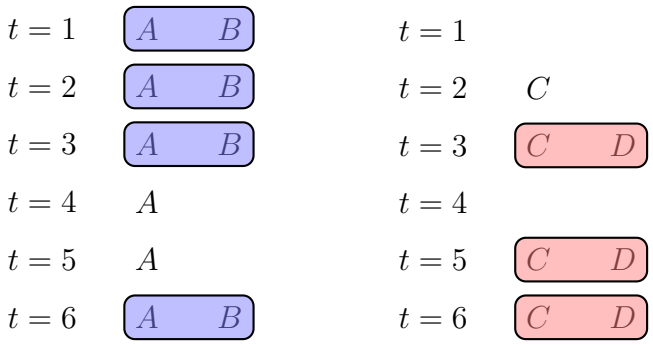
[32] Variables are in logs.



In this example, we indeed find $|p_{C,5} - p_{C,3}| > 5\%$ and the remaining pattern is given as follows. As no prices are sticky, we can stop the iteration.[33] Note that as no price changes can be formulated for the single trade record $p_{E,2}$, this observation is dropped from our sample.

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

Now we have identified the universe observations with price changes. The next step is to formulate the trade pattern dummy.



[33] In the real dataset, the algorithm often needs to iterate several times before reaching this stage.

In this example, we find 2 trade patterns in each invoicing scheme: A and $A - B$ for local currency invoiced transactions and C and $C - D$ for sterling invoiced transactions. To compare the change in relative prices across destinations, we require the same trade pattern be observed at least two times in the price-change-filtered dataset. Essentially, by formulating trade pattern fixed effects, we are restricting the comparison within a comparable environment.

B.2.3 Robustness checks

For the sake of clarity and conciseness, we summarize our results graphically. In each figure, the first three estimates refer to the entire sample (All), showing result for the annual (AllA), quarterly (AllQ) and monthly frequency (AllM). The following sets of three estimates refer to LCI, PCI and VCI, respectively, again at the three (A,Q,M) relevant frequencies.

Figure B7 presents estimates conditional on a price change in the invoicing currency. Figure B8 provides unconditional estimates for the whole sample. The graphs show that, unequivocally, elasticities within each currency-invoicing bin are not statistically different across time frequencies. The only substantial deviations from zero concern, as expected, trade invoiced in local currency. Note that in this case averages are slightly higher in the sample of transactions conditional on a price change.

Figure B7: Price and markup elasticities at different time frequencies (conditional on a price change)

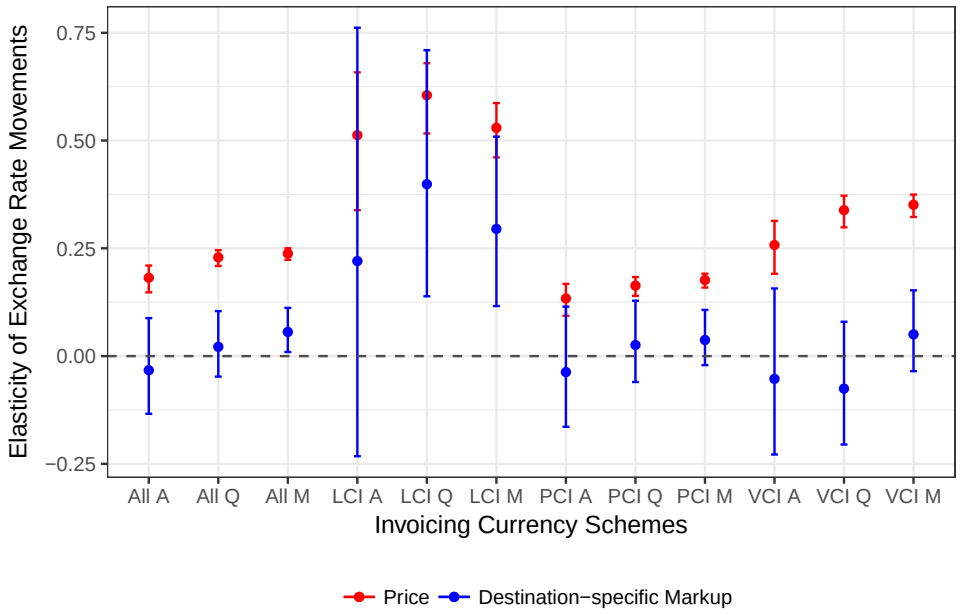


Figure B8: Price and markup elasticities at different time frequencies (not conditional on a price change)

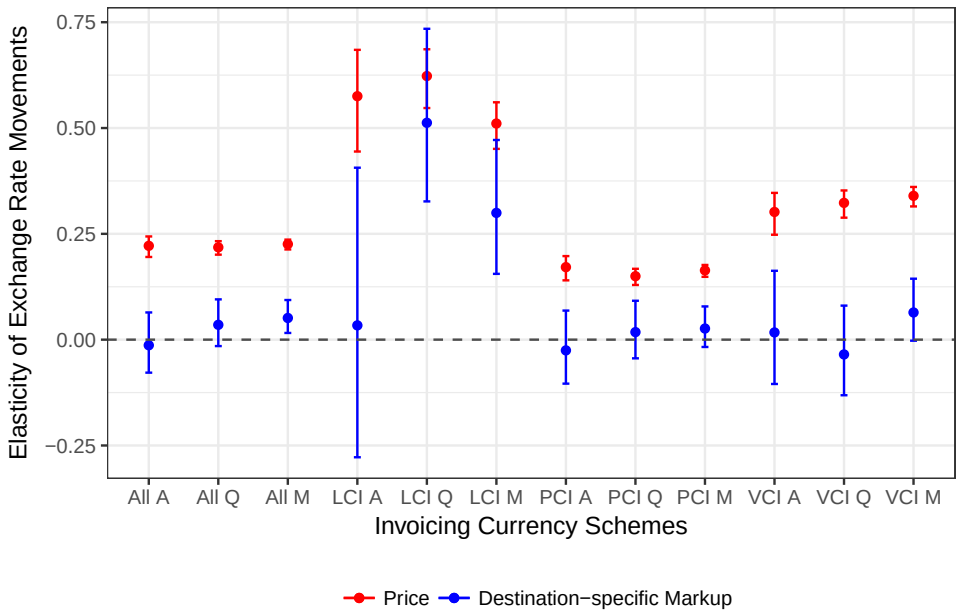


Table B1: Extra-EU exports, 2010-2017
Estimation sample: Not conditional on a price change,
all destinations (excluding the US)

		Price		DSME		
Freq.	Invoicing	NEX	CPI	NEX	CPI	n. of obs
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	0.22***	0.40***	0.04	-0.03	4,956,864
	PCI	0.15***	0.32***	0.02	-0.05	3,505,945
	VCI	0.32***	0.54***	-0.03	-0.12	1,314,181
	LCI	0.62***	0.98***	0.51***	0.59*	136,738
Monthly	All	0.23***	0.38***	0.05***	-0.01	6,940,902
	PCI	0.16***	0.32***	0.03	-0.02	4,819,032
	VCI	0.34***	0.51***	0.06	-0.04	1,932,037
	LCI	0.51***	0.71***	0.30***	0.21	189,833

Data source: HMRC administrative datasets, UK exports to extra-EU destinations, 2010-2017.

B.2.4 Bilateral exchange rates and CPI variation in the estimation sample of EU destinations

Figure B9: Bilateral exchange rates of EU countries that do not use Euro

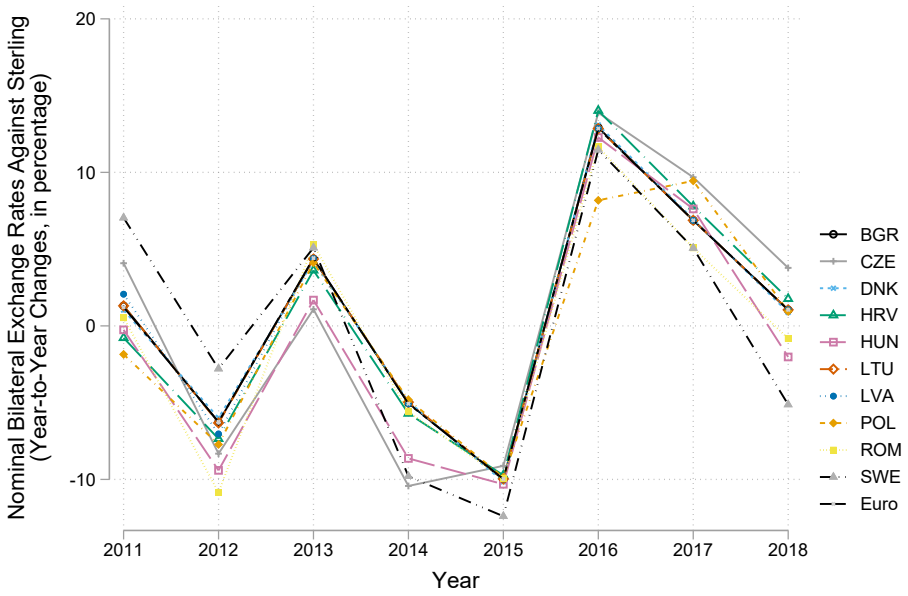
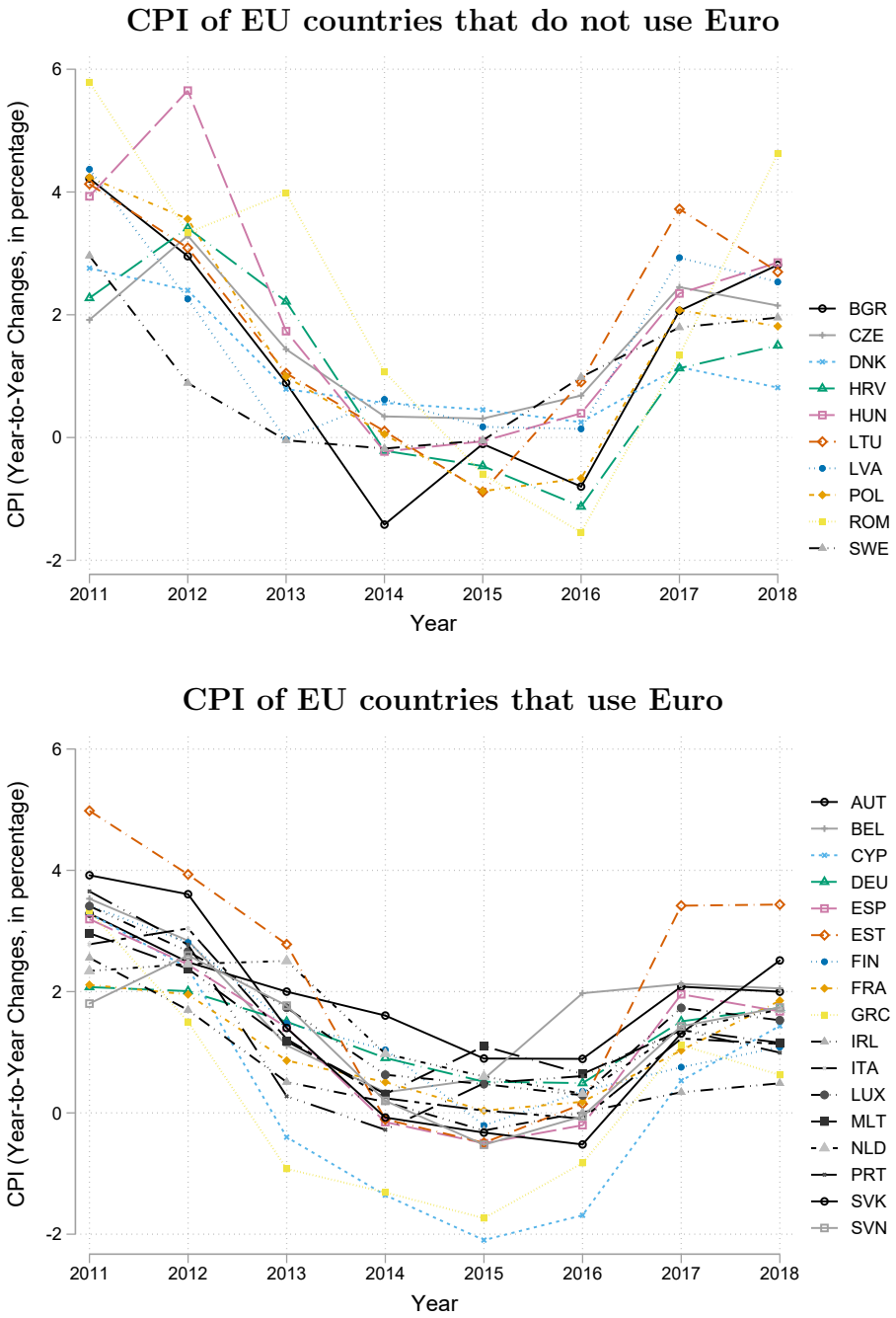


Figure B10: CPI of EU countries are less synchronized compared to their exchange rates



Online Appendix for "Invoicing and Pricing-to-market: Evidence on international pricing by UK exporters"*

Giancarlo Corsetti[†] Meredith Crowley[‡] Lu Han[§]

February 2020

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1 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) and appendix table B1 (not conditioned on a price change), 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 transaction invoiced in US dollar as vehicle currency pricing or local currency pricing).

2. Match with the country concordance tables

    - HMRC uses its internal country coding system which is different from the ISO standard adopted by most international organizations. To import external macroeconomic series (such as exchange rates, CPI, etc.), we match the internal coding system of HMRC with international standard country codes by creating a concordance table matching strings of country names between these two coding systems.

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[1], Vatican City (code 45), Western Sahara (code 206, affected years 2013-2017), South Sudan (code 225, affected years 2013-2017), Ivory Coast

[1]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 code of Ceuta and Mellila is 22 and 23 respectively.

(code 272, affected years 1996-2017), St Helena (code 329, affected years 1996-2017), Mayotte (code 377, affected years 1996-2013), Bonaire (code 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 or 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. Save as the "full sample." This is the sample used in table 5 of the paper.

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. Save as "the sample conditional on price changes." This is the sample used in appendix table B1.

1.1 Note on the observations in each stage of the data cleaning process

Table 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 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 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 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 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 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

1.2 Note on constructing the weekly sample

The construction of the weekly sample used in table 4.

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);[2] Drop if the weekly bilateral exchange rate of the destination is not available.

Table 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

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

Table 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 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.