INVOICING AND THE DYNAMICS OF PRICING-TO-MARKET
EVIDENCE FROM UK EXPORT PRICES AROUND THE BREXIT REFERENDUM

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Invoicing and the Dynamics of Pricing-to-market
Evidence from UK Export Prices around the Brexit Referendum

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Abstract

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1 Introduction

International economists have long noted that aggregate exchange rate pass through (ERPT) is significantly correlated with the currency in which most international trade transactions are invoiced. In recent years, the availability of large datasets has boosted this line of research; leading papers have identified empirical regularities that have propelled the frontier of open macro and trade theory forward (see, e.g., Amiti, Itskhoki and Konings (2018); Gopinath et al. (2020); Boz, Gopinath and Plagborg-Møller (2017); Boz, Gopinath and Plagborg-Møller (2019)). Most notably, in light of the widespread use of the US dollar in invoicing, Gopinath (2015) put forward the view that the bulk of global trade operates under a dollar-dominated “international price system”—implying significant asymmetries in the international transmission of monetary and real shocks at odds with the received wisdom on the role of exchange rate as shock absorber.

In this paper we provide novel evidence on how invoicing currencies influence the pricing of traded goods with two investigations into the dynamics of ERPT and pricing-to-market using granular administrative data—the universe of UK foreign trade transactions—between 2010 and 2017. This period allows us to begin our analysis with a study of the sharp fall in the sterling after the 2016 Brexit referendum using the approach pioneered by Bonadio, Fischer and Saure (2019). We then proceed to an application of the new panel data method of Corsetti, Crowley, Han and Song (2018) which exploits variation in local destination markets to examine pricing-to-market. UK data are particularly suitable for the purpose of our comparative study of pricing by invoicing currency because significant shares of foreign sales are invoiced in pounds sterling, dollars, and euros as well as in the currency of destination markets (see also Chen, Chung and Novy (2019))—and the dataset records the destination market for exports and the origin country for imports.

We articulate our analysis with three distinct but complementary questions.

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1 See the discussion in Burstein and Gopinath (2014).
3 Cravino (2017) and Auer, Burstein, Erhardt and Lein (2018) examine pricing and invoicing currency focusing on episodes of large unilateral currency movements.
First, are the shares of invoicing currencies stable over time and circumstances, e.g., in response to shocks causing large exchange rate adjustment, such as the Brexit Referendum? Second, are invoicing currencies correlated with the degree of exchange rate pass through in transaction-level export data? If yes, over which time frame? The answer to these questions at the most granular level could shed light on the extent to which the prevailing pattern of invoicing currencies in a country impinges on the adjustment of export prices to exchange rate changes. The use of the Brexit referendum as a case study enables us to better identify systematic differences in the dynamics of ERPT due to invoicing, as we study them against a large domestic disturbance which caused the sterling to depreciate unilaterally against all currencies.

Our final and core question is: is there evidence that pricing to market (PTM) varies systematically with the currency of invoicing? Evidence 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 adjust its prices differently across markets in response to asymmetric local shocks. Establishing whether firms do or do not practice destination-specific markup adjustments in response to exchange rate movements conditional on invoicing in dollars would provide insight into the extent to which Gopinath’s “international price system” specifically impinges on markup adjustment.

Our analysis of the stability of invoicing currency shares over time begins with an examination of the use of different invoicing currencies by firms. 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. Although an aggregation of firm-level data to the country-level reveals that the shares of different currencies are remarkably stable over time, we find that a proportion of British exporters switch the invoicing currency for sales of the same product in the same destination between
one year and the next. Nonetheless, in the aggregate, at no horizon do we detect significant changes in the relative shares of invoicing currencies in the aftermath of the referendum.

Next, we document that, in the wake of the Brexit depreciation, the dynamic responses of British export prices differed significantly according to the currency in which UK firms invoiced their cross-border transactions. 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. In the short run, British export prices measured in foreign currency fall with the exchange rate rapidly and completely only for trade invoiced in pounds, implying close to 100% exchange rate pass through in the very short run for the majority of export transactions. In contrast, firms invoicing in vehicle (e.g., dollars) or destination currencies kept their prices in the destination market stable over a short-run horizon of about six months, implying no gain in price competitiveness. This differential response remains significant but attenuates relatively quickly. In about six quarters, differences in the price responses measured in sterling significantly narrow across all invoicing schemes.

Finally, to investigate pricing-to-market, we apply the econometric model developed in Corsetti, Crowley, Han and Song (2018) to a longer panel, over 2010-2017. While confirming the pattern of pass through found in the Brexit event study, 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. For transactions invoiced in local currency, about one-half

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4Since the United States and the European Union are the homes of the two most important vehicle currencies used in the UK’s trade, there is a possible ambiguity in the classification of sales as invoiced in vehicle or local currency. For this reason, we begin our analysis on a subsample that excludes the US and EU, comprising 40% of the UK’s total export value. We then extend our sample to include first the US and then the EU. Because the UK government does not record the invoicing currency on transactions with the EU, the last extension requires some modifications to our methodology.

5In our extended sample, which initially omits US and EU exports, we find that exchange rate pass through is higher when trade is invoiced in sterling (around 80%) relative to when it is invoiced in a vehicle or in local currency (around 65% and 45%, respectively).
of a bilateral depreciation of the pound is absorbed by destination-specific markup adjustments; these account for about one half of incomplete exchange rate pass through. When invoicing in pounds or a vehicle currency, 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 exports with the US invoiced in US dollars, we find that destination-specific market adjustment becomes more pronounced, accounting for up to 70% of incomplete exchange rate pass through—in line with the evidence of the dollar price stability of US imports (Gopinath, Itskhioki and Rigobon (2010)). 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 transactions invoiced in local currency. Second, we show that when we add exports to the EU to the sample of exports to extra-EU destinations, the average share of incomplete ERPT accounted for by destination-specific markup adjustments to all foreign markets, regardless of invoicing currency, rises from 25 to 67 percent.

In our analysis, we rely on the Overseas Trade in Goods Statistics from Her Majesty’s Revenue and Customs—a unique dataset covering the universe of the United Kingdom’s trade transactions in goods. 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). As already mentioned, what makes this dataset fit for our purposes is that UK exports and imports are invoiced in a variety of currencies and exchanged with a wide array of foreign markets, facilitating a comparative empirical analysis.

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 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 difference out, for each product, the common marginal cost and markup charged in all markets in order to detect destination-specific markup 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. In additional to applying trade pattern sequential fixed effects, we follow Gopinath, Itskhoki and Rigobon (2010) and condition our analysis on a change in an export price in the currency of invoicing above a given threshold. This approach 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).

Our econometric results contribute novel evidence to the recent literature exploring how invoicing currencies map into markup decisions by firms. Most notably, Fitzgerald and Haller (2014) find that Irish firms invoicing in sterling practice a specific form of pricing-to-market, such that, the markups for sterling-invoiced exports, in ratio to the markups charged on domestic sales, rise one-to-one with home currency depreciations. Since the Irish dataset does not systematically report the foreign destinations of firm-level exports, this result is not comparable to our estimates, which quantify differences in the elasticity of markups charged by UK exporters across invoicing currencies and destinations at a global level. In his study focused on productivity and quantity elasticities, Cravino (2017) provides evidence that Chilean export prices are rigid in the currency in which they are invoiced, so that, in a given destination, the relative price of products invoiced in different currencies fluctuates

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6 Authors’ calculations. See the first row of table 1b.
with the nominal exchange rate. UK data differ from Chilean data in the length of the panel and the diversity of currencies observed in aggregate trade shares and in firm-level transactions.

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. 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 combination. 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 ac-

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7 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.

8 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.
cording 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 Facts about invoicing currencies and their trade shares

In this section, we use firm-level transactions data from the UK to document a set of stylized facts about invoicing and the dynamics of invoicing shares. First, most exporters invoice in more than one currency. Second, a large share of exporters use multiple currencies for invoicing their transactions to the same destination and involving the same product within a calendar year. Third, a non-negligible share of firms switch the currency of invoicing from one year to the next. Together, these
three facts suggest that exporters do not invoice in a single currency—neither by product, nor by destination market, nor both; and that, at the margin, firms switch currencies. 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 invoic-
Table 1: Distribution of the number of exporting destinations and invoicing currencies used at the firm level (extra-EU exports, 2010-2017)

<table>
<thead>
<tr>
<th>No. of Destinations</th>
<th>1</th>
<th>2-5</th>
<th>6-10</th>
<th>10+</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) by Share of Firms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>35.2</td>
<td>6.4</td>
<td>0.0</td>
<td>0.0</td>
<td>41.6</td>
</tr>
<tr>
<td>2-5</td>
<td>7.8</td>
<td>25.3</td>
<td>0.0</td>
<td>0.0</td>
<td>33.1</td>
</tr>
<tr>
<td>6-10</td>
<td>0.4</td>
<td>10.4</td>
<td>0.1</td>
<td>0.0</td>
<td>10.9</td>
</tr>
<tr>
<td>10+</td>
<td>0.1</td>
<td>12.7</td>
<td>1.5</td>
<td>0.2</td>
<td>14.4</td>
</tr>
<tr>
<td>Total</td>
<td>43.4</td>
<td>54.8</td>
<td>1.5</td>
<td>0.2</td>
<td>100.0</td>
</tr>
</tbody>
</table>

(b) by Share of Trade Values

<table>
<thead>
<tr>
<th>No. of Destinations</th>
<th>1</th>
<th>2-5</th>
<th>6-10</th>
<th>10+</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.4</td>
<td>0.6</td>
<td>0.0</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>2-5</td>
<td>0.2</td>
<td>3.0</td>
<td>0.0</td>
<td>0.0</td>
<td>3.2</td>
</tr>
<tr>
<td>6-10</td>
<td>0.0</td>
<td>3.9</td>
<td>0.1</td>
<td>0.0</td>
<td>4.1</td>
</tr>
<tr>
<td>10+</td>
<td>0.0</td>
<td>30.4</td>
<td>26.7</td>
<td>34.5</td>
<td>91.7</td>
</tr>
<tr>
<td>Total</td>
<td>0.7</td>
<td>38.0</td>
<td>26.9</td>
<td>34.5</td>
<td>100.0</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>No. of Currencies</th>
<th>No. of FPDT quarters</th>
<th>Share (FPDT quartets %)</th>
<th>Share (Trade %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5,134,053</td>
<td>84.0</td>
<td>49.4</td>
</tr>
<tr>
<td>2</td>
<td>872,124</td>
<td>14.3</td>
<td>41.1</td>
</tr>
<tr>
<td>3</td>
<td>92,631</td>
<td>1.5</td>
<td>8.0</td>
</tr>
<tr>
<td>4 plus</td>
<td>9,833</td>
<td>0.2</td>
<td>1.5</td>
</tr>
<tr>
<td>Total</td>
<td>6,108,641</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

ing currency is the norm among multi-destination exporters (see rows indicating
2-5, 6-10 and 10+ destinations in the top panel). Only 14% of firm-year dyads
\([7.8+0.4+0.1]/[33.1+10.9+14.4]\) and 0.2% of export value \((0.2/[3.2+4.1+91.7])\) originate from multi-destination exporters that invoice in 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.

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

We next exploit the highly disaggregated information in our dataset to explore the
structure of invoicing patterns within a firm, product, destination, and year. Specifically, we calculate the total number of currencies used by the same firm selling the
same CN08 product in the same destination in a calendar year; we refer to 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.

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 choices over time.

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

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.\(^{10}\) 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

\(^{10}\)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
In each year, we define the unit of observation as the quintuplet comprised of a (1) firm, (2) product, (3) country of origin (imports) or destination (exports), (4) quantity measure, and (5) invoicing currency. We refer to these quintuplets as “transactions” and categorize them into the three currency schemes: PCI, VCI, and LCI. Figure 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 (i.e., by trade invoiced in dollars). Second, while granular information suggests that firms use multiple currencies by product and destination and sometimes switch invoicing currencies, when we aggregate individual transactions, 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

The Brexit event study in this section allows us to study pricing and invoicing conditional a specific, although complex, shock that resulted in an idiosyncratic, large and
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.
persistent nominal depreciation of the sterling. Figure 2 plots the nominal exchange rate of the sterling over a three year window centered around the Brexit referendum.

The large exchange rate adjustment following the 2016 referendum did not bring about any noticeable changes in the shares of PCI, LCI or VCI transactions. Figure 3 shows that, in the aggregate, there is no significant switch across currencies following the large depreciation of the pound. The effect of the depreciation on export pricing, however, differed markedly across invoicing schemes. To set the stage for our econometric analysis below, in the three panels of figure 4 we plot the empirical distribution of changes in export prices (in sterling), contrasting the 2016-17 period (dashed blue line), with the average of the previous 6 years (solid red line). In the second and third panels of this figure, for the VCI and LCI transactions, respectively, there is a distinct shift to the right of the distribution of price changes in the 2016-17 period, relative to the 2010-2015 period. This shift to the right suggests that UK export prices rose in sterling (and remained relatively stable in foreign currency) with the depreciation of the pound. In contrast, for UK trade invoiced in sterling, shown in the top panel, the two distributions of price changes overlap almost perfectly: there is no difference across the two subperiods. This suggests that UK exporters who were invoicing in sterling exploited the sterling’s weakness to gain price competitiveness in foreign markets.

4.1 The empirical model for the event study

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

$$y_{itfcdt} = \lambda_t + \delta_{ifd} + v_{itfcdt} \quad y \in \{p_{itfcdt}, e_{itdt}\}$$

(1)

where the subscripts $i, f, d, c,$ and $t$ stand for product, firm, destination country, invoicing currency, and time (in weeks), respectively; $p_{itfcdt}$ represents the unit value
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.
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 fixed effect (\( \delta_{ifd} \)) capturing firm-product-destination specific features; (ii) a set of week dummies (\( \lambda_t \) for \( t = 1, ..., 156 \)) 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 different time horizons.

### 4.2 Price responses to the Brexit depreciation

Our results are synthesized in figures 5 through 7, one for each invoicing currency scheme (PCI, LCI and VCI). Each figure plots our estimates of \( \lambda_t \) from (1) from the beginning of 2015 through the end of 2017. The x-axis indicates the number of weeks before and after the Brexit referendum, while the y-axis presents the percentage change in the pound sterling (red) or the UK export price measured in sterling (blue). For clarity, we normalize the bilateral exchange rates and the UK average export price in the week of the Brexit referendum to zero. The solid red line depicts changes in the foreign currency-sterling bilateral exchange rate (i.e., increases reflect a decline in the value of sterling).\(^{12}\) The solid blue line shows our estimates of the export price level (in logs) after absorbing factors specific to the firm, product, and

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\(^{11}\)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, CN08-product, currency, and destination at the weekly level. We then calculate the unit value as the total sterling value divided by the total reported quantity (i.e., units, pairs, etc. where reported and net mass in kilos when a unit-type measure is not available). We construct weekly average exchange rates from the official daily exchange rates reported by the Bank of England.

\(^{12}\)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 \( \lambda_t \)s for each scheme.
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)
These figures highlight striking differences in the export price response to the Brexit depreciation by currency of invoicing. Export prices measured in sterling for LCI and VCI transactions, shown in Figures 6 and 7, respectively, rose quickly and almost completely with the fall in the pound. Export prices measured in sterling for PCI transactions, shown in Figure 5, hardly moved on impact, and only rose quite slowly thereafter. The relatively stable export prices for sterling-invoiced transactions in the early months after the depreciation mean that, from the perspective of an importer, the prices measured in the local currency of the destination dropped almost one-to-one with the exchange rate—an “exchange rate pass through” of close to 100%.

Over time, figure 5 shows that export prices for sterling-invoiced transactions increased gradually and converged to the rate of the sterling depreciation after about 72 weeks. This pattern implies that the exchange rate pass through into import prices fell steadily from almost 100% on impact, to around 0% after a year and a half. In the interim period, for the first 66 weeks (15 months) after the depreciation, the magnitude of the export price change remained significantly smaller than the change
in the exchange rate. Increasing imported input costs likely played a non-negligible role in this evolution of sterling-invoiced export prices, as UK import prices also rose steadily with the weaker exchange rate. In the appendix, we document that, by week 36, UK import prices (invoiced in all currencies) had fully adjusted to the weaker pound (see the figures B2-B5).\textsuperscript{13}

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

Sterling prices also rose quickly for trade invoiced in a vehicle currency. Figure 7 depicts results for US dollar-invoiced transactions to non-US destinations.\textsuperscript{14} By week 6 after the referendum, dollar-invoiced export prices (measured in sterling) had risen with the exchange rate almost one to one. Sometime around week 20, the exchange rate pass through into foreign import prices became close to zero.

\textsuperscript{13}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.

\textsuperscript{14}Appendix figure B1 documents that the evolution of the sterling price of euro-invoiced exports to extra-EU destinations is similar to that of dollar-invoiced transactions to non-US destinations in figure 7.
By the end of the 2017, on average, UK export prices in the currencies of the destination markets had apparently lost the memory of the Brexit depreciation—the weaker currency did not translate into any persistent gain in price-competitiveness for UK exports. This is a remarkable headline conclusion. With UK import prices rising steadily over the post-referendum period, the evidence in this section raises questions about the extent to which adjustment in pricing was driven by costs reflecting rising imported input prices, as opposed to relative markup stabilization (see the discussion in Fitzgerald and Haller (2014). In the interim period, between the referendum and the end of 2017, the time pattern of price adjustment shown in our figures suggests that by invoicing in local and vehicle currency, UK exporters captured temporary but possibly large markup increases (in sterling), which were not observed for trade invoiced in sterling.

5 Invoicing and markup adjustment

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

Our approach is to employ the methodology developed in Corsetti, Crowley, Han and Song (2018) to estimate price and destination-specific markup elasticities for the entire timespan for which we have data on invoicing, 2010-2017. The longer sample includes movements in the sterling exchange rate that were less dramatic and more varied across countries than those in the aftermath of the Brexit referendum.
5.1 Econometric 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) augmenting a standard pass through regression with trade-pattern fixed effects (to be discussed below):

\[ p_{ifdt} = \gamma_0 + \gamma_1 e_{dt} + \gamma_2 cpi_{dt} + TP_{d,D_{if}} + u_{ifdt} \]  

where \( TP_{d,D_{if}} \) denotes the trade pattern fixed effect, defined on the destination, \( d \), and the set of markets, \( D_{if} \), 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, \( \gamma_1 \), is the complement to 1 of the degree of exchange rate pass through (a higher \( \gamma_1 \) indicates a lower ERPT).

Second, we study pricing-to-market, by re-estimating the above equation using destination-demeaned variables:

\[ \tilde{p}_{ifdt,D_{if}} = \kappa_0 + \kappa_1 \tilde{e}_{dt,D_{if}} + \kappa_2 \tilde{cpi}_{dt,D_{if}} + TP_{d,D_{if}} + \tilde{u}_{ifdt,D_{if}} \]  

Here \( \kappa_1 \) measures the destination-specific markup elasticity to the bilateral exchange rate. In the rest of the paper, we will refer to \( \gamma_1 \) and \( \kappa_1 \) as, respectively, the price elasticity (one minus the ERPT) and the destination specific markup elasticity (DSME) with respect to the exchange rate. 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 trade pattern \( D_{if} \) that is firm, product and time specific. To appreciate what this means, 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).\footref{foot:subgoods}

As discussed in our previous work (Corsetti, Crowley, Han and Song (2018)), the reason for including the trade pattern fixed effects in our estimating equations is that the set of export destinations served by a firm might vary endogenously with exchange rate movements. Specifically, because a firm’s decision to enter or exit an individual 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. To the extent that a trade pattern fixed effect at the firm-product level restricts the variation of observed and unobserved factors that lead firms to participate in different markets, its introduction in a standard ERPT model (2) reduces this selection bias.\footref{foot:tradepattern}

Further, the sequential application of trade pattern fixed effects means that identification of the markup elasticity (3) comes from the residual intertemporal price variation within the same set of destination markets over time; in other words, this approach controls for the combined effects of unobserved changes in marginal costs and markups that are common in all destinations.\footref{foot:sequential}

\footnotetext[15]{The maintained hypothesis in our approach is that the changes in the composition of sub-goods 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.}

\footnotetext[16]{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.}

\footnotetext[17]{In Corsetti, Crowley, Han and Song (2018), we show that the trade pattern sequential fixed effects (TPSFE) estimator is equivalent to applying high order fixed effects using standard statistical packages employed in the ERPT literature (e.g., Guimaraes and Portugal (2011), and Correia (2017)) if the correct, economically-relevant set of fixed effects are chosen. An advantage of the TPSFE is that it allows us to define explicitly the economic assumptions and mechanism underlying the econometric methodology. See appendix B.2 for details.}
We proceed by constructing each firm’s product-level time-varying trade pattern, at first across all extra-EU foreign sales (regardless of invoicing currency), then for PCI, VCI, and LCI separately. By doing so we can contrast our estimates of price and destination-specific markup elasticities averaged over “All” invoicing currencies, with the elasticities for each invoicing scheme—and investigate which invoicing scheme (if any) is associated with pricing-to-market. We carry out our analysis at different time frequencies, and, following Gopinath, Itskhoki and Rigobon (2010), conditional on a change in price. We start by focusing our analysis on the dataset of exports to all destinations except the EU and US in subsection 5.2; we extend the sample to include the US in subsection 5.3; and, finally, extend to the whole world in subsection 5.3.2.

5.2 Results excluding UK trade with the US

We begin by confirming the main results from the Brexit event study; using the export price elasticity specification (2) and a longer panel of data over 2010–2017, we find the overall price responses of PCI-exports are considerably different from those of LCI and VCI exports. We then present our key novel result; using the pricing-to-market specification (3), we find that only LCI transactions have a significant destination-specific markup elasticity (DSME). For the bulk of UK exports that are invoiced in sterling or a vehicle currency and sold outside the US or EU, UK firms do not respond to bilateral exchange rates or local inflation by adjusting their

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

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

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.
destination-specific markup.

Our econometric results are shown in table 4, at annual, quarterly, and monthly
frequencies.21 At these frequencies, we 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 elasticities from regression model (2), the next two
columns present the pricing-to-market elasticities from regression model (3). In each
of the three panels in the table (one for each data frequency), the row under the
headline “All” shows estimates for the full sample without conditioning on invoic-
ing choices. In the following rows, under the headlines “PCI”, “LCI”, and “VCI”,
the estimation sample is restricted to firm-product-destination transactions that are
invoiced in, respectively, British pounds, vehicle currencies and local currencies.

A first notable result 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.22 Conversely, the results on pricing-to-market (DSME) show
that the markup elasticity is only significant with respect to the exchange rate (col-
umn (3)) for LCI transactions and only at the monthly and quarterly frequencies.

A second notable result is that the price elasticities with respect to both the
exchange rate and the CPI in the first two columns differ by invoicing scheme.23 In
the first column of table 4, the estimated sterling price elasticity with respect to the

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21As in our Brexit event study, results shown are conditional on a price change. See appendix
table B1 for results that do not condition on a price change.

22Recall 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 4 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.

23Out of the firm-product-destination-year combinations in our regression sample that are clas-
sified 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 4: Price and Destination-Specific Markup Elasticities conditional on currency – extra-EU destinations excluding the US – monthly, quarterly, and annual frequencies over 2010-2017

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

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, based on robust standard errors, is reported at the 1, 5 or 10 percent level which is indicated by ***, **, or * respectively. Data source: HMRC administrative datasets, UK’s extra-EU exports, 2010-2017.
exchange rate for vehicle and local currency invoiced transactions are both significantly higher than those for sterling invoiced transactions. Recall that the sterling price elasticities shown in this column are equivalent to one minus the exchange rate pass through into import prices. For example, the price elasticity of 0.19 for sterling invoiced transactions means that, against a 1% bilateral depreciation of sterling, the sterling price of exports increases by 0.19% – this corresponds to an exchange rate pass through into foreign import prices of 81%. Altogether, the econometric results over the longer sample of 2010–2017 are broadly in line with the results of the Brexit event study where we found that the pass through into import prices was higher for PCI relative to LCI and VCI transactions. However, the estimates in table 4 also show that the degree of pass through is significantly lower for LCI than for VCI transactions.

But while exchange rate pass through is relatively low in both vehicle and local currency invoiced transactions, markup adjustment is profoundly different. Turn to the third column of table 4, which reports estimates from the TPSFE pricing-to-market model (3). Here, destination-specific markup adjustment is significantly different from zero only for LCI transactions. Furthermore, the magnitudes of the estimates are substantial; markup adjustments act as a serious brake to the transmission of currency movements across countries. Namely, they account for 56% and 65% of the incomplete pass through, at the quarterly and monthly frequencies (0.39/0.60 and 0.53/0.68), respectively.

In sum, our evidence suggests that 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).
5.3 Results extending the analysis to UK trade with the US and the EU

Thus far, our analysis has excluded UK trade with two major markets, the US and the EU. In this subsection, we extend our econometric analysis to the entire extra-EU dataset, including UK exports to the US. In the next subsection, we adapt our model for an analysis of EU data and examine elasticities for sales to the EU and to the whole world. The EU and US represent large and important markets for British exporters, comprising about one-half and one-tenth of aggregate British exports, respectively. Thus, if pricing-to-market and destination-specific markup adjustment are important phenomena in UK trade, we would expect to find evidence of this in a lower average ERPT and larger destination-specific markup elasticity when data from the US and EU are included in the analysis. We would also expect to find a larger destination-specific markup elasticity when dollar-invoiced sales to the US are added to the sample of other LCI transactions.

5.3.1 Trade with the US

Estimates for the larger dataset of UK trade to all extra-EU destinations including the US are shown in table 5. Relative to our main findings in table 4, the price and markup elasticities in table 5 are higher across all invoicing schemes, consistent with our hypothesis that inclusion of the large, important US market would lower the average ERPT and raise the extent of pricing-to-market. For LCI transactions in particular, including US data raises the estimates of the DSME substantially, and makes them statistically significant at all frequencies (see column (3) in the table). 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 that the lower exchange rate pass through into import prices (the higher export price elasticity estimates) in the enlarged sample (compare column (1) in table 5 with column (1) in table 4), reflects stronger adjustment of US-specific markups to dollar-sterling bilateral exchange rate movements. This evidence
suggests a possible mechanism for why US import prices are quite sticky in dollars (Gopinath, Itskhoki and Rigobon (2010)) – exporters to the US invoice and set prices in US dollars in response to local economic conditions in this important market.

Table 5: Price and Destination-Specific Markup Elasticities conditional on currency - extra-EU destinations including the US - monthly, quarterly, and annual frequencies over 2010-2017

<table>
<thead>
<tr>
<th>Freq.</th>
<th>Exports</th>
<th>Price</th>
<th>DSME</th>
<th>n. of obs</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>0.32***</td>
<td>0.55***</td>
<td>0.10*</td>
</tr>
<tr>
<td></td>
<td>PCI</td>
<td>0.23***</td>
<td>0.46***</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>VCI</td>
<td>0.30***</td>
<td>0.48***</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>LCI</td>
<td>0.51***</td>
<td>1.04***</td>
<td>0.45***</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>0.34***</td>
<td>0.56***</td>
<td>0.09***</td>
</tr>
<tr>
<td></td>
<td>PCI</td>
<td>0.23***</td>
<td>0.43***</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>VCI</td>
<td>0.35***</td>
<td>0.54***</td>
<td>-0.03</td>
</tr>
<tr>
<td></td>
<td>LCI</td>
<td>0.60***</td>
<td>0.99***</td>
<td>0.50***</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>0.35***</td>
<td>0.54***</td>
<td>0.09***</td>
</tr>
<tr>
<td></td>
<td>PCI</td>
<td>0.24***</td>
<td>0.43***</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>VCI</td>
<td>0.35***</td>
<td>0.52***</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>LCI</td>
<td>0.63***</td>
<td>0.99***</td>
<td>0.43***</td>
</tr>
</tbody>
</table>

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, based on robust standard errors, is reported at the 1, 5 or 10 percent level which is indicated by ***, **, or * respectively. Data source: HMRC administrative datasets, UK’s exports to extra-EU destinations, 2010-2017.

5.3.2 Trade with the EU

The extension of our analysis to EU destinations faces the hurdle that the currency of invoicing is not reported—hence we cannot replicate our analysis by currency scheme.
Moreover, 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.\textsuperscript{24} Hence the use of these European currencies together with
the euro could possibly induce spurious estimates. For this reason, we choose to
apply the same euro-sterling exchange rate to trade with all EU countries, including
those outside the eurozone—implying that, when we apply our TPSFE estimator,
we can only estimate destination-specific markup adjustment to local CPI, not to
the bilateral exchange rate.\textsuperscript{25}

Before discussing our results, we should also point out that 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.\textsuperscript{26}

In table 6, using the same layout as in the previous two tables, we report estimates
using the EU dataset, the extra-EU dataset, and the comprehensive dataset of UK
exports to the world.\textsuperscript{27} Looking at the first two columns of the table, our key result
is that, in the EU data, the estimated price elasticities with respect to both the
bilateral exchange rates and the destination market CPI are comparable or higher
(for CPI) than in the extra-EU data, at all frequencies. It is worth pointing out that
the point estimates of the price elasticities to CPI for EU transactions are similar in
magnitude to those for extra-EU LCI transactions (see the bottom row in each panel
of table 5).

Turning to markup elasticities, while we cannot apply the TPSFE estimator with

\textsuperscript{24}The variation in bilateral exchange rates for these countries is shown in figure B9 in appendix
B.2.4.

\textsuperscript{25}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.

\textsuperscript{26}Author’s calculations based on HMRC administrative datasets.

\textsuperscript{27}The same estimates for the extra-EU dataset are reported in the “All” rows of table 5.
respect to the bilateral exchange rate to the EU data because of the lack of variation between the euro and the other European currencies, we find that, for this dataset, 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.\textsuperscript{28}

Table 6: Price and Destination-Specific Markup Elasticities - EU versus extra-EU exports - monthly, quarterly, and annual frequencies over 2010-2017

<table>
<thead>
<tr>
<th>Freq.</th>
<th>Exports</th>
<th>Price</th>
<th>DSME</th>
<th>n. of obs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>NEX(1)</td>
<td>CPI(2)</td>
<td>NEX(3)</td>
</tr>
<tr>
<td>Annual</td>
<td>EU</td>
<td>0.37***</td>
<td>1.46***</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Extra-EU</td>
<td>0.32***</td>
<td>0.55***</td>
<td>0.10*</td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>0.28***</td>
<td>0.65***</td>
<td>-0.02</td>
</tr>
<tr>
<td>Quarterly</td>
<td>EU</td>
<td>0.34***</td>
<td>1.44***</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Extra-EU</td>
<td>0.34***</td>
<td>0.56***</td>
<td>0.09***</td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>0.31***</td>
<td>0.71***</td>
<td>0.24***</td>
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<tr>
<td>Monthly</td>
<td>EU</td>
<td>0.35***</td>
<td>1.42***</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Extra-EU</td>
<td>0.35***</td>
<td>0.54***</td>
<td>0.09***</td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>0.34***</td>
<td>0.79***</td>
<td>0.23***</td>
</tr>
</tbody>
</table>

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, based on robust standard errors, is reported at the 1, 5 or 10 percent level which is indicated by ***, **, or * respectively. Data source: HMRC administrative datasets, UK’s exports to EU and extra-EU destinations, 2010-2017.

A final piece of evidence suggesting price discrimination by UK firms comes from

\textsuperscript{28}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.
the variation in the DSME estimates between the datasets for trade to extra-EU destinations versus world trade (including the EU). At each frequency, the second row of table 6 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 \([0.10/0.32 \text{ (annual)}; 0.09/0.34 \text{ (quarterly)}; \text{ and } 0.09/0.35 \text{ (monthly)}]\) 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—as shown in the row labelled “World” in each panel of table 6. Although we cannot observe the invoicing currency for UK exports to the EU, our evidence of substantial pricing-to-market by UK exporters suggests that most British exports to the EU are likely to be invoiced in euros.

6 Conclusion

In this paper, we use transactions data to carry out a comparative analysis of the dynamics of ERPT and pricing-to-market when sales are invoiced in different currencies. Focusing on the export price response to the sterling depreciation after the Brexit referendum, we have shown that the dynamics of ERPT after a large unilateral depreciation differ by currency of invoicing. Based on econometric evidence, we have also shown that the currency of invoicing predicts the extent to which exporters adjust their product prices and markups to changes in bilateral exchange rates and local market conditions.

Our case study documents that over a period of six quarters following the Brexit referendum, export price adjustment in sterling was strikingly slower for transactions invoiced in sterling than for transactions invoiced in local (destination market) and vehicle currencies. In the very short run, when invoicing in sterling, firms allowed the sterling depreciation to pass through to lower prices in the currency of the destination market; when invoicing in local or vehicle currencies, firms kept prices relatively stable in destination and vehicle currencies. However, these price differences across invoicing currencies significantly narrowed over time as sterling prices of exports rose
to broadly align with the weaker pound.

Regarding pricing-to-market, we find that the markups of exports invoiced in sterling or in a vehicle currency do not react differentially to movements in bilateral exchange rates and local market conditions. In striking contrast, markups on exports invoiced in local currencies move with bilateral exchange rates and local market conditions—in particular, this applies to exports to the US invoiced in dollars and exports to the EU. For the latter, we produce evidence of substantial adjustment of destination-specific markups to local CPI.

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

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

Moreover, while we find that the aggregate shares of different invoicing currencies in UK trade are stable over time, we also document that 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. A pattern of multiple invoicing currencies suggests that firms may mix these currencies to 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 more work, both empirical and theoretical, in these directions.
References


A Statistics on the Granular Distribution of Invoicing Choices

Figure A1: Top invoicing currencies for extra-EU exports

Table A1: Number of invoicing currencies for each firm-product-destination/origin-year quartet (extra-EU exports and imports, 2010-2017)

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

Note: Black bars indicate the invoicing share by the number of transactions. Grey bars indicate the share by total trade values.
Table A2: Number of invoicing currencies for each firm-product-origin-year quartet (extra-EU imports, 2010-2017)

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

Table A3: Number of products v.s. invoicing currencies (extra-EU exports, 2010-2017)

<table>
<thead>
<tr>
<th>No. of Products</th>
<th>1</th>
<th>2-5</th>
<th>6-10</th>
<th>10+</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Share of Firms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>29.7</td>
<td>2.1</td>
<td>0.0</td>
<td>0.0</td>
<td>31.8</td>
</tr>
<tr>
<td>2-5</td>
<td>12.0</td>
<td>19.4</td>
<td>0.0</td>
<td>0.0</td>
<td>31.4</td>
</tr>
<tr>
<td>6-10</td>
<td>1.3</td>
<td>11.0</td>
<td>0.0</td>
<td>0.0</td>
<td>12.3</td>
</tr>
<tr>
<td>10+</td>
<td>0.5</td>
<td>22.4</td>
<td>1.5</td>
<td>0.2</td>
<td>24.5</td>
</tr>
<tr>
<td>Total</td>
<td>43.4</td>
<td>54.8</td>
<td>1.5</td>
<td>0.2</td>
<td>100.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(b) Share of Trade Values</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.4</td>
<td>0.7</td>
<td>0.0</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>2-5</td>
<td>0.2</td>
<td>1.7</td>
<td>0.0</td>
<td>0.0</td>
<td>1.9</td>
</tr>
<tr>
<td>6-10</td>
<td>0.0</td>
<td>2.3</td>
<td>0.8</td>
<td>0.1</td>
<td>3.3</td>
</tr>
<tr>
<td>10+</td>
<td>0.0</td>
<td>33.4</td>
<td>26.0</td>
<td>34.4</td>
<td>93.8</td>
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<td>Total</td>
<td>0.7</td>
<td>38.0</td>
<td>26.9</td>
<td>34.5</td>
<td>100.0</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>No. of Destinations</th>
<th>No. of Products</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>(a) Share of Firms</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>29.7</td>
</tr>
<tr>
<td>2-5</td>
<td>9.9</td>
</tr>
<tr>
<td>6-10</td>
<td>1.2</td>
</tr>
<tr>
<td>10+</td>
<td>0.7</td>
</tr>
<tr>
<td>Total</td>
<td>41.6</td>
</tr>
<tr>
<td>(b) Share of Trade Values</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>2-5</td>
<td>0.3</td>
</tr>
<tr>
<td>6-10</td>
<td>0.1</td>
</tr>
<tr>
<td>10+</td>
<td>0.1</td>
</tr>
<tr>
<td>Total</td>
<td>1.0</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Invoicing Scheme</th>
<th>No. of Destinations</th>
<th>LCI</th>
<th>PCI</th>
<th>VCI</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
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<td>26.2</td>
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<td>33.8</td>
</tr>
<tr>
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<td>2-5</td>
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<tr>
<td></td>
<td>6-10</td>
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<td>7.0</td>
<td>5.3</td>
<td>13.5</td>
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<tr>
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<td>Total</td>
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<td>63.2</td>
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<td>100.0</td>
</tr>
<tr>
<td>(b) Share of Trade Values</td>
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<td>1.9</td>
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</tr>
<tr>
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<td>3.5</td>
<td>1.0</td>
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</tr>
<tr>
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<td>4.9</td>
<td>2.6</td>
<td>7.6</td>
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<tr>
<td></td>
<td>10+</td>
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<td>48.8</td>
<td>32.1</td>
<td>85.4</td>
</tr>
<tr>
<td></td>
<td>Total</td>
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<td>59.1</td>
<td>36.2</td>
<td>100.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No. of Products</th>
<th>LCI</th>
<th>PCI</th>
<th>VCI</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Share of Firms</td>
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<td>11.3</td>
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<td>1.4</td>
<td>8.1</td>
<td>5.6</td>
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<td></td>
<td>10+</td>
<td>2.8</td>
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</tr>
<tr>
<td></td>
<td>Total</td>
<td>6.8</td>
<td>63.2</td>
<td>30.0</td>
</tr>
<tr>
<td>(b) Share of Trade Values</td>
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<td>1.2</td>
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<tr>
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<td>2-5</td>
<td>0.3</td>
<td>4.1</td>
<td>1.9</td>
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<td>59.1</td>
<td>36.2</td>
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</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>From</th>
<th>LCI</th>
<th>PCI</th>
<th>VCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCI</td>
<td>90.05</td>
<td>1.29</td>
<td>8.66</td>
</tr>
<tr>
<td>PCI</td>
<td>4.66</td>
<td>87.52</td>
<td>7.81</td>
</tr>
<tr>
<td>VCI</td>
<td>2.34</td>
<td>0.66</td>
<td>97.00</td>
</tr>
</tbody>
</table>

Conditional on large transactions (top quarter by trade value)

<table>
<thead>
<tr>
<th>From</th>
<th>LCI</th>
<th>PCI</th>
<th>VCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCI</td>
<td>94.60</td>
<td>0.64</td>
<td>4.75</td>
</tr>
<tr>
<td>PCI</td>
<td>3.45</td>
<td>92.06</td>
<td>4.49</td>
</tr>
<tr>
<td>VCI</td>
<td>1.56</td>
<td>0.33</td>
<td>98.11</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Magnitude of price changes</th>
<th>Invoicing Scheme</th>
<th>LCI</th>
<th>PCI</th>
<th>VCI</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Non-weighted</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Change</td>
<td></td>
<td>0.1</td>
<td>1.8</td>
<td>0.4</td>
<td>1.3</td>
</tr>
<tr>
<td>Less than 1%</td>
<td></td>
<td>3.4</td>
<td>6.1</td>
<td>5.4</td>
<td>5.8</td>
</tr>
<tr>
<td>1% to 5%</td>
<td></td>
<td>8.6</td>
<td>11.7</td>
<td>11.1</td>
<td>11.4</td>
</tr>
<tr>
<td>5% to 10%</td>
<td></td>
<td>9.6</td>
<td>12.4</td>
<td>11.7</td>
<td>12.0</td>
</tr>
<tr>
<td>10% to 30%</td>
<td></td>
<td>18.1</td>
<td>18.6</td>
<td>18.7</td>
<td>18.6</td>
</tr>
<tr>
<td>30% to 50%</td>
<td></td>
<td>15.1</td>
<td>15.5</td>
<td>16.0</td>
<td>15.6</td>
</tr>
<tr>
<td>50% to 100%</td>
<td></td>
<td>20.0</td>
<td>17.1</td>
<td>18.0</td>
<td>17.5</td>
</tr>
<tr>
<td>Larger than 100%</td>
<td></td>
<td>25.0</td>
<td>16.7</td>
<td>18.7</td>
<td>17.7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

| **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.\(^{29}\)

\(^{29}\)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

**Notes:**
- Density is calculated based on all unit value changes including those > 1 or < -1.

---

Log(Unit Value) - Log(Unit Value)

PCI 2010-2015
PCI 2016

VCI 2010-2015
VCI 2016

LCI 2010-2015
LCI 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.\(^{30}\)

   (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:
   \[
   \frac{1}{n_{D_{ift}}} \sum_{d \in D_{ift}} x_{iftd} \quad \forall x \in \{p_{iftd}, e_{dt}, X_{dt}\}
   \]  
   \(4\)

   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:
   \[
   \tilde{x}_{ift,d_{ift}} = x_{iftd} - \frac{1}{n_{D_{ift}}} \sum_{d \in D_{ift}} x_{iftd} \quad \forall x \in \{p_{iftd}, e_{dt}, X_{dt}\}
   \]  
   \(5\)

\(^{30}\)As detailed in the complimentary Online Appendix (step 7), we drop the multi-currency invoicing transactions \textit{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:

\[ \{d : p_{i't'd'} \text{ is observed : } i' = i, f' = f, t' = t\}. \] (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 \(ift\) 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.

\[ \tilde{p}_{ift,D_{ift}} = \kappa_0 + \kappa_1 \tilde{e}_{dt,D_{ift}} + \tilde{X}_{dt,D_{ift}}' \kappa_2 + TP_{d,D_{ift}} + \tilde{u}_{ift,D_{ift}} \] (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 \(\kappa_1\).
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.

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

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.

\[
t = 1 \quad A \quad B \\
t = 2 \quad A \quad B \quad C \quad E \\
t = 3 \quad A \quad B \quad C \quad D \quad X \\
t = 4 \quad A \quad \times \quad C \quad D \quad E \\
t = 5 \quad A \quad B \quad C \quad D \\
t = 6 \quad A \quad B \quad C \quad D
\]

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

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

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 \(|p_{C,5} - p_{C,4}| < 5\%\).\(^{31}\) Rather, we repeat the above step using the remaining observations as illustrated below.

\(^{31}\)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.\footnote{In the real dataset, the algorithm often needs to iterate several times before reaching this stage.} Note that as no price changes can be formulated for the single trade record $p_{E,2}$, this observation is dropped from our sample.

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

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

\begin{align*}
t = 1 & \quad \begin{bmatrix} A \end{bmatrix} & \quad t = 1 \\
t = 2 & \quad \begin{bmatrix} A \end{bmatrix} & \quad t = 2 \quad \begin{bmatrix} C \end{bmatrix} \\
t = 3 & \quad \begin{bmatrix} A \end{bmatrix} & \quad t = 3 \quad \begin{bmatrix} C & D \end{bmatrix} \\
t = 4 & \quad A & \quad t = 4 \\
t = 5 & \quad A & \quad t = 5 \quad \begin{bmatrix} C & D \end{bmatrix} \\
t = 6 & \quad \begin{bmatrix} A \end{bmatrix} & \quad t = 6 \quad \begin{bmatrix} C & D \end{bmatrix}
\end{align*}
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)

<table>
<thead>
<tr>
<th>Freq.</th>
<th>Invoicing</th>
<th>Price</th>
<th>DSME</th>
<th>n. of obs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>NEX</td>
<td>CPI</td>
<td>NEX</td>
</tr>
<tr>
<td>Annual</td>
<td>All</td>
<td>0.22***</td>
<td>0.41***</td>
<td>-0.01</td>
</tr>
<tr>
<td></td>
<td>PCI</td>
<td>0.17***</td>
<td>0.36***</td>
<td>-0.03</td>
</tr>
<tr>
<td></td>
<td>VCI</td>
<td>0.30***</td>
<td>0.48***</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>LCI</td>
<td>0.58***</td>
<td>1.14***</td>
<td>0.03</td>
</tr>
<tr>
<td>Quarterly</td>
<td>All</td>
<td>0.22***</td>
<td>0.40***</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>PCI</td>
<td>0.15***</td>
<td>0.32***</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>VCI</td>
<td>0.32***</td>
<td>0.54***</td>
<td>-0.03</td>
</tr>
<tr>
<td></td>
<td>LCI</td>
<td>0.62***</td>
<td>0.98***</td>
<td>0.51***</td>
</tr>
<tr>
<td>Monthly</td>
<td>All</td>
<td>0.23***</td>
<td>0.38***</td>
<td>0.05***</td>
</tr>
<tr>
<td></td>
<td>PCI</td>
<td>0.16***</td>
<td>0.32***</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>VCI</td>
<td>0.34***</td>
<td>0.51***</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>LCI</td>
<td>0.51***</td>
<td>0.71***</td>
<td>0.30***</td>
</tr>
</tbody>
</table>

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

CPI of EU countries that do not use Euro

CPI of EU countries that use Euro