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Vehicle Currency Pricing and Exchange Rate Pass-Through

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Abstract
Using detailed firm-level transactions data for UK imports, we find that invoicing in a vehicle currency is pervasive, with more than half of transactions in our sample invoiced in neither sterling nor the exporter's currency. We then study the relationship between invoicing currency choices and the response of import prices to exchange rate changes. We find that for transactions invoiced in a vehicle currency, import prices are much more sensitive to changes in the vehicle currency than in the bilateral exchange rate. Pass-through therefore substantially increases once we account for vehicle currencies. Our results help to explain the higher-than-expected pass-through into import prices during the Great Recession and after the EU referendum. Finally, within a theoretical framework we conceptualize an omitted variable bias arising in estimating pass-through with only bilateral exchange rates under vehicle currency pricing. Overall, our results contribute to understanding the disconnect between exchange rates and prices.

Key words: CPI, Dollar, Euro, Exchange Rate Pass-Through, inflation, invoicing, Sterling, UK, vehicle currency pricing
JEL Codes:F14; F31; F41

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1 Introduction

It is a well-established fact in the open economy macroeconomics literature that the prices of internationally traded goods only react modestly to changes in exchange rates. In other words, the pass-through of exchange rate changes into import and domestic prices is incomplete.[1] In a large class of models with nominal rigidities, the currency in which traded goods are priced has implications for the degree of exchange rate pass-through.[2] In the short run, pass-through is complete if prices are set in the exporter's currency ("Producer Currency Pricing," or PCP), while it is zero if prices are set in the importer's currency ("Local Currency Pricing," or LCP). In the long run, this difference in pass-through disappears if prices are set exogenously in either currency, while it persists if the currency choice is endogenous (Gopinath, Itskhoki, and Rigobon, 2010).

Using highly disaggregated firm-level data for UK imports from non-EU countries, this paper examines the relationship between the currency of invoicing and exchange rate pass-through. Our contribution is fourfold. First, we show that "Vehicle Currency Pricing" (or VCP) is pervasive for UK imports, with more than half of transactions in our sample invoiced in neither sterling nor the exporter's currency. Vehicle currency pricing has been rarely studied in the pass-through literature because the lack of bilateral invoicing currency data makes it difficult to distinguish between pricing in a vehicle currency and the partner's currency (Gopinath, 2016).[3] Moreover, the share of trade priced in a third currency is negligible for countries such as the US. Second, we estimate the sensitivity of import unit values to exchange rate fluctuations with a focus on vehicle currency pricing, in addition to pricing in producer or local currencies.[4] Third, we address the implications of our findings for inflation. We show that ignoring the currency of invoicing can lead researchers to mismeasure the effects of exchange rate changes on import price inflation. Fourth, we extend the theoretical framework of Engel (2006) to explain exchange rate pass-through in the presence of vehicle currency pricing.

To the best of our knowledge, our paper is the first to investigate the relationship between three different invoicing choices and the exchange rate response of firm-level import unit values. For this purpose, we focus our analysis on the UK economy. There are several reasons for this choice. First, the sterling nominal exchange rate is freely floating against other major currencies, and it has experienced significant fluctuations over time. Second, we were granted access to a highly disaggregated data set

[1] Exchange rate pass-through is defined as the percentage change in local currency import prices resulting from a one percent change in the exchange rate between the exporting and importing countries. For reviews of the literature, see Burstein and Gopinath (2014) and Goldberg and Knetter (1997).

[2] For instance, Obstfeld and Rogoff (1995) assume producer currency pricing, Betts and Devereux (2000) consider local currency pricing, while Devereux and Engel (2003) allow for both types of invoicing choices. Other factors that may lead to incomplete pass-through include the pricing-to-market behavior of exporters when they differentially adjust their markups across destinations in response to exchange rate changes (Knetter, 1989, 1993; Krugman, 1987), or the presence of local distribution costs in the destination market (Burstein, Neves, and Rebelo, 2003; Corsetti and Dedola, 2005).

[3] Exceptions are Corsetti, Crowley, and Han (2018) and Fabling and Sanderson (2015). Some papers (Goldberg and Tille, 2008, 2016) study vehicle currency pricing but not in relation to pass-through.

[4] As documented by Boz, Gopinath, and Plagborg-Møller (2017), and by Casas, Díez, Gopinath, and Gourinchas (2016), the vast majority of world trade is invoiced in a small number of currencies, rejecting the idea that prices in international markets are merely set in local or producer currencies.

from Her Majesty's Revenue and Customs (HMRC) which provides the universe of the Cost, Insurance, and Freight (CIF) import transactions of the UK economy. For each transaction we observe a unique trader identifier, the country of origin, the date of transaction, the 10-digit comcode product identifier, the value (in sterling), and the mass (in kilograms). Most importantly, we observe the currency of invoicing for each transaction from 2010 to 2017, but for non-EU transactions only. As we do not directly observe import prices, as a proxy we compute import unit values at the trader-product-currency-origin level. Crucially for our purposes, we observe large shares of import transactions invoiced in vehicle currencies. In fact, we have 91 different vehicle currencies in our sample, with the euro being the most widely used apart from the US dollar. Overall, vehicle currency pricing accounts for 55.0 percent of non-EU import transactions, whereas producer and local currency pricing represent 17.8 and 27.2 percent, respectively.[5]

Our main results can be summarized as follows. Across all transaction types, we find that short-run exchange rate pass-through is incomplete and low at 17.9 percent. We then demonstrate that pass-through varies substantially across invoicing choices. Pass-through is large at 62.0 percent for imports in producer currencies but insignificant for transactions in local currency (sterling). As to invoicing in vehicle currencies, pass-through is low at 24.2 percent when we estimate it based on the bilateral exchange rate between the exporting and importing countries. However, once we let vehicle transactions depend on the vehicle currency exchange rate, pass-through is much larger at 59.2 percent and thus in the same ballpark as for producer currency pricing. Using the bilateral rather than the vehicle currency exchange rate therefore substantially underestimates pass-through for goods priced in vehicle currencies (by 35.0 percentage points according to these estimates). Intuitively, the bilateral exchange rate is a noisy measure of the vehicle currency exchange rate and therefore leads to attenuated pass-through estimates.

Regarding long-run pass-through after two years, our results remain similar. Across all transaction types, pass-through is low at 41.3 percent. But by invoicing choice, it is large at 70.0 percent for the producer currency priced transactions, and zero for the local currency priced transactions. For the transactions in vehicle currencies, pass-through is low at 36.6 percent when we use bilateral exchange rates, but again much larger at 59.0 percent when we use vehicle currency exchange rates.

In our sample, although we observe 91 different vehicle currencies, vehicle import transactions are predominantly in US dollars (88.7 percent by value). According to the "Dominant Currency Paradigm" whereby firms choose to invoice in a dominant currency which is typically the US dollar, it is not the bilateral exchange rate but the dollar exchange rate that drives global trade prices (Boz, Gopinath, Plagborg-Møller, 2017; Casas, Díez, Gopinath, and Gourinchas, 2016; Gopinath, 2016). As we show, however, our results also hold for vehicle currencies other than the US dollar. This provides strong evidence that our findings are driven by the use of vehicle currencies in general and not just by the US dollar.

[5] The data set also provides the universe of the UK's Free on Board (FOB) export transactions for which the currency of invoicing is reported from 2011 to 2017. Appendix B shows that our results also hold for exports.

As a further illustration, we calculate a weighted pass-through elasticity across all invoicing choices in our sample. Once we let the transactions priced in vehicle currencies depend on vehicle currency exchange rates, we find that pass-through into import unit values is 43.6 percent on impact. This estimate is again substantially larger than the short-run pass-through rate of 17.9 percent that we obtain when we let import unit values depend on bilateral exchange rates only. Thus, by accounting for vehicle currency pricing in international trade, our results contribute to understanding the disconnect between exchange rates and world trade prices.

Our results are important because of their implications for import and consumer price inflation. To shed light on this issue, we focus on three quarterly episodes of large sterling fluctuations (during the Great Recession, the European Sovereign Debt Crisis, and after the EU referendum). We use our estimates to evaluate the dynamic response of import price inflation to these exchange rate shocks. Once we account for the currency of invoicing, we can explain the higher-than-expected pass-through into import prices during the Great Recession and after the EU referendum. The reason is that for the transactions priced in a vehicle currency, import unit values respond more to changes in the vehicle currency than to changes in the bilateral exchange rate. And since the US dollar is used extensively as a vehicle currency, the depreciation against the US dollar during the Great Recession and following the EU referendum is given a larger weight than the depreciation against the euro in affecting import unit values, resulting in higher import price inflation. By contrast, for the European Sovereign Debt Crisis, the average appreciation of sterling results in lower-than-expected pass-through because the fall in inflation induced by the appreciation against the euro is offset by the depreciation against the US dollar.

Interestingly, these patterns are consistent with the behavior of consumer and import price inflation observed after each of the exchange rate shocks. It is indeed well documented that the depreciation of sterling following the EU referendum and during the Great Recession increased domestic inflation by more than expected, while the appreciation of sterling against the euro during the European Sovereign Debt Crisis reduced it by less than anticipated. One year after the EU referendum, the Financial Times reported on June 13, 2017 that the recent jump in inflation was "above analysts' consensus forecasts." During the Great Recession, the Bank of England noted that the surprising strength in inflation was probably reflecting "stronger, or faster, exchange rate pass-through following the fall in sterling." In contrast, during the European Sovereign Debt Crisis, the Bank observed that "import prices have not fallen by as much as might have been expected [...]. The MPC judges that the earlier appreciation will be associated with somewhat less of a fall in import prices than previously assumed."[6]

For policy purposes, our results suggest that ignoring the currency of invoicing can produce misleading predictions regarding the effects of exchange rate changes on import prices and, as a result, on domestic prices. Our results have thus implications for the setting of monetary policy. We argue that policymakers should update their "rules of thumb" for predicting how currency fluctuations affect

[6] See the Bank of England's inflation reports of May 2009 and August 2015.

future prices (Forbes, Hjortsoe, and Nenova, 2018). In particular, they should take into account that when vehicle currency pricing is pervasive, bilateral exchange rates are inappropriate for determining the effects of exchange rate changes on prices for two reasons. First, the pass-through elasticity is larger for transactions priced in vehicle currencies. Second, the weight assigned to that elasticity and therefore the overall effect on inflation will be stronger for countries with larger shares of vehicle currency imports. Put simply, to predict how currency fluctuations affect prices, policymakers should construct an effective nominal exchange rate that is based on invoicing currency weights, not trade weights.

Lastly, we develop a theoretical framework based on Engel (2006) with flexible price setting to explain the effects of vehicle currency pricing on exchange rate pass-through. We delineate the omitted variable bias that arises if a researcher ignores the vehicle currency exchange rate and erroneously uses the bilateral exchange rate between the importing and exporting countries. We find strong empirical evidence that this bias is driven by the exchange rate correlation between the bilateral and the vehicle currency exchange rates. The stronger their correlation, the lower the bilateral pass-through elasticity, and accordingly the stronger the bias and potential disconnect between exchange rates and prices. Our conceptual framework thus challenges the conventional definition of exchange rate pass-through based on bilateral exchange rates. We argue that bilateral rates are typically inappropriate when vehicle currency pricing is an important feature of the data.

This paper builds on, and contributes to two strands of literature. The first one is the literature on exchange rate pass-through which usually finds a low degree of pass-through into import prices (Campa and Goldberg, 2005; Gopinath and Rigobon, 2008) or consumer prices (Campa and Goldberg, 2010).[7] Within this literature, papers most closely related to our work are those that investigate the relationship between the invoicing currency and pass-through.[8] Gopinath et al. (2010) provide evidence that pass-through is low for US imports priced in US dollars and large when priced in non-dollars. Gopinath (2016) shows that this pattern also holds in other countries as pass-through rises with the share of imports invoiced in a foreign currency. Cravino (2014) shows that exchange rate changes affect the prices of firm-level exports invoiced in the exporter's currency, but have no effect on export prices set in the destination's currency. Auer, Burstein, and Lein (2018) and Bonadio, Fischer, and Sauré (2019) study the large appreciation of the Swiss franc against the euro in 2015. Auer et al. (2018) find that the consumer prices of imported goods fell by more in product categories with larger reductions in import prices and a lower share of import prices invoiced in Swiss francs.[9] Bonadio et al.

[7] A number of recent papers estimate pass-through using firm- or product-level data. See Amiti, Itskhoki, and Konings (2014), Auer and Schoenle (2016), Berman, Martin, and Mayer (2012), Chen and Juvenal (2016), Fitzgerald and Haller (2014), Gopinath and Itskhoki (2010), Gopinath and Rigobon (2008), and Nakamura and Zerom (2010), among others. Mumtaz, Oomen, and Wang (2011) study pass-through into UK import prices using data at the industry level.

[8] A large body of the literature on currency of invoicing and pass-through is theoretical. Engel (2006) and Gopinath, Itskhoki, and Rigobon (2010) develop models where a firm's desired pass-through determines the currency of invoicing. In Bacchetta and van Wincoop (2003), currency choice explains why pass-through is lower into consumer than into import prices. Corsetti and Pesenti (2005) study optimal monetary policy in open economies and link the degree of pass-through to the invoicing currency. Also see Choudhri and Hakura (2012), and Devereux, Engel, and Storgaard (2004).

[9] Also see Devereux, Dong, and Tomlin (2017) who show that the market shares of both exporting and importing firms impact exchange rate pass-through and the currency of invoicing.

(2019) show that exchange rate pass-through into import unit values was complete for goods invoiced in euros, but incomplete for goods invoiced in Swiss francs. These studies, however, do not examine vehicle currencies.

Among the papers that emphasize the role of the US dollar as a dominant currency, Casas et al. (2016) show that controlling for the peso to US dollar exchange rate knocks down the effect of the bilateral exchange rate in explaining the prices of Colombian firm-level exports. Using bilateral industry-level trade data combined with country-level data on invoicing currency choices, Boz et al. (2017) show that it is not the bilateral exchange rate but the dollar exchange rate that drives trade prices. Consistent with these papers, we challenge the view that bilateral exchange rates are appropriate to evaluate pass-through. But we show that this view applies not just to the US dollar but to all vehicle currencies in our sample.

To the best of our knowledge, only two papers examine vehicle currency pricing empirically. For New Zealand, Fabling and Sanderson (2015) find that pass-through is high for firm-level exports invoiced in domestic currency and low when priced in local and vehicle currencies. Corsetti, Crowley, and Han (2018) show that destination-specific markup adjustment to changes in bilateral exchange rates is substantial for UK firm-level exports invoiced in the destination's currency, but is non-existent for the transactions priced in sterling or in a vehicle currency. We differ from these papers by studying import unit values as this allows us to assess the sensitivity of imported inflation to exchange rate shocks.

Second, our paper is related to studies investigating the factors that influence invoicing currency choices.[10] At the country level, Goldberg and Tille (2008) provide evidence that country size matters, whereas hedging considerations and transaction costs play a minor role. At a disaggregated level, Goldberg and Tille (2016) analyze import transactions by size and conclude that the invoicing choice results from a bargaining process between trading partners. Lyonnet, Martin, and Méjean (2016) document that exporters using financial instruments to hedge against exchange rate risk are more likely to price in a foreign currency. Chung (2016) shows that UK exporters relying on foreign currency-denominated imported inputs are less likely to invoice in their home currency.[11] By finding that the difference in pass-through into US import prices in dollars versus non-dollars is large even at a two-year horizon, Gopinath et al. (2010) conclude that invoicing choices are endogenous. In this paper, we do not explain invoicing choices. Instead, we investigate how invoicing choices and exchange rate pass-through interact with each other.

The paper is organized as follows. Section 2 describes our firm-level customs data and provides descriptive statistics. Section 3 presents our main empirical results. Section 4 derives the implications

[10] For models investigating the determinants of currency choice, see Bacchetta and van Wincoop (2005), Devereux et al. (2017), Engel (2006), Friberg (1998), Goldberg and Tille (2008), and Gopinath et al. (2010). Gopinath and Stein (2018) argue that the complementarity between a currency's role for invoicing and as a safe store of value can explain why a dominant currency such as the US dollar is heavily used for both trade invoicing and global finance.

[11] At a disaggregated level, see also Donnenfeld and Haug (2003), Friberg and Wilander (2008), or Ito, Koibuchi, Sato, and Shimizu (2010, 2013, 2016). On the euro as an invoicing currency, see Kamps (2006) and Ligthart and Werner (2012).

of our findings for import price inflation. Section 5 analyzes exchange rate pass-through under vehicle currency pricing from a conceptual point of view. It derives theoretically founded pass-through specifications and provides corresponding estimates. Section 6 concludes.

We also provide an appendix with additional results. Appendix A reports robustness checks. Appendix B presents results for export unit values, while Appendix C describes our findings for export and import quantities. Appendix D explains how we calculate our back-of-the-envelope estimates of how exchange rate changes affect import price inflation. Appendix E provides theoretical derivations and additional estimations.

2 Data and Descriptive Statistics

Our data set uses transaction-level customs data for the UK economy. Quarterly consumer price indices and nominal exchange rates are from the International Financial Statistics of the International Monetary Fund.

2.1 Customs Data

Transaction-level CIF imports for the UK are obtained from Her Majesty's Revenue and Customs (HMRC), a non-ministerial Department of the UK government responsible for the collection of taxes, the payment of state support, and the collection of trade in goods statistics. Data access is only granted to approved projects, and all empirical output is subject to HMRC's code of statistical disclosure.

For each import transaction the data set provides us with a unique trader identifier, the country of origin, the transaction date, the 5-digit SITC Revision 3 and the 4-digit HS Revision 2007 classifications, the 10-digit comcode product code (the first eight digits correspond to the Combined Nomenclature), the value (in sterling), the mass (in kilograms) and, most importantly, the currency of invoicing but for non-EU transactions only.[12] While the trade data are available since 1996, we concentrate our analysis on the 2010–2017 period because reporting the currency of invoicing has only become compulsory since 2010 for non-EU imports. Non-EU imports represent 50 percent of total UK imports between 2010 and 2017. Data on the currency of invoicing for trade with EU countries are not available. Given that import prices are not observed, we compute the unit values of imports as the ratio between the value of a transaction in sterling and the corresponding mass in kilograms.[13] As we rely on unit values, we are unable to observe when firms adjust their prices.[14]

We clean the data in several ways. First, we drop the few transactions for which the currency of invoicing is missing. Second, we exclude the "Not classified" industry (SITC 9). Third, we drop the

[12] In general, the currency of invoice and the currency of settlement are the same (Friberg and Wilander, 2008).

[13] Alternatively, unit values can be measured per unit rather than per kilogram. In results available upon request we show that our results remain very similar although the sample size is reduced.

[14] We are therefore unable to estimate pass-through conditional on an observed price change (Gopinath and Rigobon, 2008). Another issue is that unit values may conflate price changes with changes in the composition or quality of traded goods. This problem is, however, less severe the more disaggregated the data (in our case, at the 10-digit level).

observations for which the value of imports is indicated as positive but the corresponding quantity is zero. Fourth, we aggregate the data at quarterly frequency. Finally, to minimize the influence of potential outliers, we exclude the 0.5 percent of observations with the largest and smallest log changes in unit values (i.e., we drop one percent of the sample).[15]

2.2 Descriptive Statistics

As shown in Table 1, our sample between 2010 and 2017 includes 121,596 firms, 16,295 products (at the 10-digit comcode level), and 181 origin countries with a total of 5,792,400 observations. These firms import an average of 4.6 different products from 1.8 origin countries (at the 5^{th} and 95^{th} percentiles, the products per importer are 1 and 15, and the origin countries per importer are 1 and 5).[16] The mean import transaction is valued at 215,472 pound sterling in each quarter, or 748.3 pound sterling per kilogram. The mean change in import unit values is equal to 0.8 percent per quarter.

Table 1: Summary Statistics

	Mean	Median	Std. dev.	5^{th} percentile	95^{th} percentile
Importers	121,596	–	–	–	–
Products	16,295	–	–	–	–
Origin countries	181	–	–	–	–
Products per importer	4.6	2	15.1	1	15
Origins per importer	1.8	1	1.8	1	5
Unit values (sterling/kg)	748.3	13.5	59,302.3	1	1,114.6
Change in log unit values (~%)	0.8	0.5	0.7	-102.9	104.8
Transaction values (sterling)	215,472	17,928	4,295,486	1,248	504,656

Notes: For each variable, the table reports its mean, median, standard deviation, and values at the 5^{th} and 95^{th} percentiles. Changes in log unit values (in ~%) are calculated quarterly.

Our sample covers a large range of origin countries that differ in terms of economic development, including OECD countries such as Canada, Switzerland and the US but also emerging markets such as China, India, Nigeria and Vietnam as well as developed Asian countries such as Hong Kong and Japan. The largest market for non-EU imports is China (20.9 percent of total non-EU imports between 2010 and 2017), followed by the US (16.6 percent), Norway (6.2 percent), Japan (5.3 percent), Switzerland (4.6 percent), Hong Kong (3.9 percent), Turkey (3.6 percent), and India (3.4 percent).

Table 2 reports descriptive statistics by invoicing currency. Vehicle currency pricing represents the largest share of the sample (in terms of number of observations, importers, products, origin countries, and the value share of imports in the sample). In particular, the value share of imports invoiced in a vehicle currency amounts to 55.0 percent, whereas the shares in producer or local currencies are 17.8 and 27.2 percent.[17] In total, 91 different vehicle currencies are used, but 88.7 percent of the value of the

[15] Our results remain very similar if we instead winsorize the data.

[16] Due to confidentiality reasons we are unable to report the maximum and minimum values.

[17] In the full sample that includes the "Not classified" industry, the producer, local, and vehicle currency shares are equal to 20.0, 24.4, and 55.5 percent, respectively.

vehicle currency priced transactions is in US dollars and 10.8 percent in euros. In terms of transaction counts, these correspond to shares of 88.1 and 10.8 percent, respectively. Other main vehicle currencies include the Hong Kong dollar, the Japanese yen, the Emirati dirham, the Australian dollar, and the Swiss franc. On average, unit values are the highest for goods priced in producer currencies at a value of 1,017.4 pound sterling per kilogram.

Table 2: Descriptive Statistics by Invoicing Currency

	Obs.	Firms	Products	Origins	Products per firm	Origins per firm	Unit values	Import values	Import shares
LCP	1,270,283	39,319	10,936	156	3.51	1.46	508.26	268,986	27.25
PCP	1,559,920	55,082	12,217	96	3.58	1.18	1,017.42	146,022	17.76
VCP	2,962,197	78,909	13,643	170	4.13	1.74	718.78	231,651	55.00
VCP (USD)	2,611,303	70,481	12,865	161	4.20	1.68	776.47	232,949	88.68
VCP (Euro)	320,242	20,743	8,256	141	2.23	1.34	228.07	232,213	10.79
VCP (Other)	30,652	3,028	2,804	92	2.28	1.18	919.39	119,345	0.53

Notes: For each invoicing currency choice, the table reports the number of observations, importers, products, origin countries, products per firm, origin countries per firm, the mean unit value (in sterling per kilogram), the mean import value (in sterling), and imports as a share of total non-EU imports (in %).

The left panel of Table 3 reports import shares by invoicing currency and industry (at the 1-digit SITC level). Vehicle currency pricing is the dominant strategy for most sectors, and its share is the largest for "Animal and vegetable oils" (85.54 percent) which are homogeneous goods (Gopinath et al., 2010; Goldberg and Tille, 2008). The vehicle currency share is also large at 85.08 percent for "Mineral fuels." Instead, local currency pricing is the most widely adopted strategy for "Beverages and tobacco" at 68.97 percent, while producer currency pricing is the least used among most sectors (with the exception of "Beverages and tobacco" and "Animal and vegetable oils"). The right panel of the table splits the data by region of origin. With the exception of the US, vehicle currency pricing is the dominant strategy for all regions. Its share varies from 51.62 percent for Asia to 76.64 percent for China. Given that the US mostly exports in US dollars (Goldberg and Tille, 2008), UK imports from the US are mainly invoiced in the producer's currency (85.67 percent).[18]

Finally, Table 4 describes the extent of stickiness in unit values by reporting the share of unit value changes falling below a threshold value of one percent (Fabling and Sanderson, 2015).[19] This share is calculated for unit values converted into three different currencies (producer, local, and vehicle, if applicable), and is reported separately by currency of invoicing. The table shows that 6.02 percent of the unit values priced in the producer's currency are sticky when measured in the producer's currency, compared to 5.71 percent when converted to the local currency (sterling). Similarly, for the unit values priced in local currency (sterling), 9.97 percent are sticky when measured in sterling, versus 7.38 percent when converted to the producer's currency. Finally, for the goods priced in a vehicle currency,

[18] The patterns remain very similar if we calculate the invoicing shares for each industry by region of origin.

[19] As we use quarterly data, we define the threshold at one percent. Instead, Fabling and Sanderson (2015) use monthly data and consider a threshold of 0.1 percent.

Table 3: Invoicing Currency by Industry and Region

Industry (SITC)	PCP	LCP	VCP	Share	**Origin**	PCP	LCP	VCP	Share
Food, live animals	11.55	33.17	55.28	4.87	US	85.67	12.75	1.58	16.63
Beverages, tobacco	18.52	68.97	12.51	1.04	China	0.77	22.59	76.64	20.88
Crude materials	30.35	28.15	41.50	2.90	East/S. East Asia	5.47	42.91	51.62	26.55
Mineral fuels	4.68	10.23	85.08	14.02	Europe excl. EU	5.35	26.58	68.07	18.59
Animal, vegetable oils	10.88	3.58	85.54	0.20	Other Americas	8.81	23.77	67.42	6.11
Chemicals	28.62	29.59	41.79	8.05	All others	3.25	23.34	73.41	11.25
Manufactured goods	12.74	22.16	65.10	12.08					
Machinery	25.06	27.88	47.06	34.47					
Miscellaneous manuf.	13.25	35.70	51.06	22.39					

Notes: The table reports the import share in terms of value by industry at the SITC 1-digit level, by origin country group, and by currency of invoicing (in %).

7.97 percent of the unit values are sticky when measured in the vehicle currency, versus 7.04 and 6.77 percent when expressed in producer or local currencies, respectively. In other words, unit values tend to be stickier in their currency of invoicing (indicated in boldface).[20]

Table 4: Shares of Sticky Unit Values by Currency and Invoicing Currency

	Invoicing Currency		
Currency of Calculation	Producer	Local	Vehicle
Producer	**6.02**	7.38	7.04
Local (sterling)	5.71	**9.97**	6.77
Vehicle	–	–	**7.97**

Notes: The table reports the share (in %) of quarterly unit value changes falling below a threshold of one percent. The unit values are calculated in three different currencies (producer, local, and vehicle – if applicable), and the share of sticky unit values is reported separately by currency of invoicing choice. The numbers in boldface indicate the cells where the unit value changes are calculated in the same currency as the currency of invoicing.

3 Empirical Analysis

To compare exchange rate pass-through in our sample with the estimates reported in the literature, we first estimate a standard pass-through regression (Gopinath et al., 2010):

$$\Delta \ln UV_{ijk,t} = \sum_{n=0}^{N} \beta_n \Delta \ln e_{j,t-n} + \sum_{n=0}^{N} \alpha_n \pi^*_{j,t-n} + D_{i,t} + D_{jk} + \epsilon_{ijk,t}, \tag{1}$$

where $UV_{ijk,t}$ is the unit value of product k (defined at the comcode level) imported by firm i from country j in quarter t, expressed in sterling per kilogram. It is our proxy for import prices. The bilateral exchange rate between sterling and the currency of country j in quarter t is denoted by

[20] The values in Table 4 are very similar to those reported by Fabling and Sanderson (2015) for unit values of New Zealand exports. Gopinath and Itskhoki (2010) observe prices instead of unit values. They report that US import prices adjust every one to five quarters, implying a higher degree of stickiness on average. It is not surprising that our data display a lower degree of stickiness since we use import unit values rather than import prices.

$e_{j,t}$ (an increase in $e_{j,t}$ indicates a bilateral depreciation of sterling), and $\pi^*_{j,t}$ is the quarterly foreign inflation rate calculated using the consumer price index. We include up to eight lags for the nominal exchange rate and the foreign inflation rate, where N is the number of lags. Given our quarterly data this corresponds to lags of up to two years. Δ is the first difference operator and $\epsilon_{ijk,t}$ is an error term. We include firm-quarter $D_{i,t}$ as well as origin country-product fixed effects D_{jk}. Short-run pass-through is given by the coefficient β_0 on the contemporaneous change in the exchange rate, whereas the cumulative estimate $\beta(n) \equiv \sum_{n=0}^{N} \beta_n$ evaluates long-run pass-through. Given the level of disaggregation of the data, changes in exchange rates are assumed to be exogenous to the import unit values faced by firms. Robust standard errors are adjusted for clustering at the origin country-year level.

As a benchmark, we first estimate equation (1) on the full sample of imports. Next, to investigate whether invoicing choices are associated with different pass-through rates, we regress equation (1) separately on three subsamples of import transactions invoiced in producer, local, and vehicle currencies. Recall that our aim is not to explain invoicing choices. Instead, we investigate how different invoicing currencies and exchange rate pass-through interact with each other.

For the transactions invoiced in producer or local currencies, it is intuitive to regress the sterling import price on the bilateral exchange rate between sterling and the origin country's currency, as we do in equation (1). For the transactions priced in vehicle currencies, we would instead expect that it is the exchange rate with the vehicle currency that matters. To explore this possibility we decompose the bilateral exchange rate in equation (1) as follows (Fabling and Sanderson, 2015):

$$\Delta \ln e_{j,t} \equiv \Delta \ln e_{DEST/ORIG_t} = \Delta \ln e_{DEST/VCP_t} + \Delta \ln e_{VCP/ORIG_t}, \tag{2}$$

where $e_{j,t}$ is the bilateral exchange rate between sterling, or the destination country's currency ($DEST$) and the currency of the origin country ($ORIG$). Its change can be decomposed into the change in the sterling to vehicle currency exchange rate, and the change in the vehicle to origin country's currency exchange rate. For the transactions priced in vehicle currencies we then estimate:

$$\Delta \ln UV^{VCP}_{ijk,t} = \sum_{n=0}^{N} \theta_n \Delta \ln e_{DEST/VCP_{t-n}} + \sum_{n=0}^{N} \psi_n \Delta \ln e_{VCP/ORIG_{t-n}} + \sum_{n=0}^{N} \chi_n \pi^*_{j,t-n} + D_{i,t} + D_{jk} + \varepsilon_{ijk,t}, \tag{3}$$

where we allow for separate coefficients θ_n and ψ_n on the two exchange rates.[21] If unit values are sticky in their currency of invoicing (as suggested by Table 4), we would expect pass-through into import unit values to be larger when sterling fluctuates against the vehicle currency. We also estimate a simpler version of equation (3) where we omit the exchange rate between the vehicle and the origin country's currency, $\Delta \ln e_{VCP/ORIG_t}$. In Section 5 we explain in detail from a theoretical perspective how the two alternative specifications can be interpreted.

[21] We refer to Section 5 and equation (8) in particular where we theoretically motivate why the two coefficients may not be the same.

Finally, we also run the following specification on the full sample of import transactions:

$$\Delta \ln UV_{ijk,t} = \left[\sum_{n=0}^{N} \zeta_n \Delta \ln e_{j,t-n} \right] D_{IC} + \sum_{n=0}^{N} \lambda_n \pi^*_{j,t-n} + D_{i,t} + D_{jk} + D_{IC} + \nu_{ijk,t}, \tag{4}$$

where D_{IC} is a dummy variable for the three invoicing choices. When estimating equation (4), we first include the bilateral exchange rate $e_{j,t}$ for all transactions. Then, for the vehicle currency transactions, we decompose the bilateral exchange rate according to equation (2), or we only control for the sterling to vehicle currency exchange rate.

3.1 Short-Run Pass-Through

We start by analyzing short-run exchange rate pass-through into import unit values. We estimate equations (1), (3), and (4) but only report and discuss the contemporaneous exchange rate elasticities. The long-run elasticities are discussed in Section 3.2.

Column (1) of Table 5 reports the results of estimating equation (1) on the full sample of imports, as is typically done in the literature.[22] The coefficient on the contemporaneous change in the bilateral exchange rate is equal to 0.179 (significant at the one percent level). In response to a ten percent depreciation, import unit values (in sterling) rise by 1.79 percent. Pass-through is therefore low at 17.9 percent. This finding is consistent with other papers finding a low degree of exchange rate pass-through into import prices (Campa and Goldberg, 2005; Gopinath and Rigobon, 2008).

Table 5: Pass-Through into Import Unit Values: Subsamples

	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \ln e_{DEST/ORIG}$	0.179^a (0.028)	0.696^a (0.107)	0.059 (0.040)	0.123^a (0.033)	–	–
$\Delta \ln e_{DEST/VCP}$	–	–	–	–	0.612^a (0.149)	0.535^a (0.155)
$\Delta \ln e_{VCP/ORIG}$	–	–	–	–	0.094^a (0.035)	–
Invoicing currency	All	PCP	LCP	VCP	VCP	VCP
Observations	5,212,592	1,272,714	1,065,852	2,599,543	2,599,543	2,599,543
R-squared	0.146	0.186	0.206	0.176	0.176	0.176

Notes: Firm-quarter and origin country-product fixed effects are included. Contemporaneous and eight lags of the origin country's quarterly inflation rate, as well as eight lags of the log change in each exchange rate are also included (not reported). Robust standard errors adjusted for clustering at the country-year level are reported in parentheses. [a] indicates significance at the one percent level. The dependent variable is the quarterly log change import unit value (in sterling per kilogram).

To investigate whether invoicing choices are associated with different pass-through rates, we then regress equation (1) separately on three subsamples of import transactions invoiced in producer, local, and vehicle currencies.[23] The results are reported in columns (2) to (4), respectively. They show

[22] The regression in column (1) only uses 5,212,592 of the 5,792,400 observations available because the observations that are perfectly predicted by the firm-quarter and origin country-product fixed effects (i.e., singletons) are dropped.

[23] Forbes, Hjortsoe, and Nenova (2018) argue that pass-through varies substantially depending on the nature of the shocks that move the exchange rate in the first place. Allowing for endogenous exchange rate changes can therefore,

that exchange rate pass-through varies substantially across invoicing choices. Pass-through is large at 69.6 percent for producer pricing (column 2), low at 12.3 percent for vehicle pricing (column 4), and insignificantly different from zero for local pricing (column 3). These results highlight that estimating a single pass-through coefficient as in column (1) hides a significant amount of heterogeneity in the pass-through elasticities across invoicing choices.

Next, in column (5), for the subsample of vehicle currency priced transactions, we regress equation (3) and decompose the bilateral exchange rate according to equation (2). This exercise has a dramatic effect on pass-through. Pass-through is large at 61.2 percent for the sterling to vehicle currency exchange rate, which is similar in magnitude to the pass-through for producer priced transactions in column (2) at 69.6 percent. But it is low at 9.4 percent for the vehicle to origin country's currency exchange rate.[24] These findings are consistent with prices being sticky in the currency in which they are invoiced. Column (6) excludes the exchange rate between the vehicle and the origin country's currency, and pass-through remains large at 53.5 percent.

Table 6: Pass-Through into Import Unit Values: Full Sample

	(1)	(2)	(3)	(4)
$\Delta \ln e_{DEST/ORIG} \times D_{PCP}$	0.445^a (0.044)	0.649^a (0.049)	0.620^a (0.051)	0.631^a (0.050)
$\Delta \ln e_{DEST/ORIG} \times D_{LCP}$	−0.066 (0.040)	0.031 (0.035)	0.002 (0.036)	0.013 (0.036)
$\Delta \ln e_{DEST/ORIG} \times D_{VCP}$	0.242^a (0.031)	–	–	–
$\Delta \ln e_{DEST/VCP}$	–	0.649^a (0.056)	0.592^a (0.058)	–
$\Delta \ln e_{VCP/ORIG}$	–	0.108^a (0.036)	–	–
$\Delta \ln e_{DEST/VCP} \times D_{USD}$	–	–	–	0.483^a (0.105)
$\Delta \ln e_{DEST/VCP} \times D_{non-USD}$	–	–	–	0.591^a (0.059)
Observations	5,212,592	5,212,592	5,212,592	5,212,592
R-squared	0.146	0.146	0.146	0.146

Notes: Firm-quarter, origin country-product, and currency of invoicing fixed effects are included. Contemporaneous and eight lags of the origin country's quarterly inflation rate, as well as eight lags of the log change in each exchange rate are also included (not reported). Robust standard errors adjusted for clustering at the country-year level are reported in parentheses. ^{a} indicates significance at the one percent level. The dependent variable is the quarterly log change import unit value (in sterling per kilogram).

Table 6 reports the results of estimating equation (4). Consistent with Table 5, column (1) shows that when the bilateral exchange rate fluctuates, pass-through is relatively large (at 44.5 percent) for producer currency pricing, low (at 24.2 percent) for vehicle currency pricing (we can reject at the one percent level that the two elasticities are equal), and zero for local currency pricing. Once we decompose the bilateral exchange rate for vehicle currency priced goods, column (2) shows that pass-through is large, and of the same magnitude, for producer priced and vehicle currency priced transactions when

they claim, explain why pass-through rates change over time. In our paper, we focus on pass-through elasticities that are heterogeneous by invoicing currency. Table A2 in Appendix A shows that our results continue to hold in the period following the EU referendum of June 2016.

[24] We can reject at the one percent level that the two estimated coefficients are equal.

the sterling to vehicle currency exchange rate fluctuates (the estimated coefficients are both equal to 0.649). In contrast, the response of import unit values invoiced in vehicle currencies to changes in the vehicle to origin country's currency exchange rate is low at 10.8 percent, and zero for local currency priced goods when the bilateral exchange rate fluctuates. The results remain similar in column (3) once the exchange rate between the vehicle and origin country's currency is omitted from the regression.

Recall that in our sample we observe 91 different vehicle currencies, although the US dollar is used predominantly (followed by the euro). Boz et al. (2017), Casas et al. (2016), and Gopinath (2016) argue that if the US dollar is mainly used as an invoicing currency, then it is the dollar exchange rate and not the bilateral exchange rate that determines the prices of globally traded goods. To ensure that our results continue to hold for vehicle currencies other than the US dollar, we further interact the vehicle currency exchange rates with dummy variables for the US dollar and non-dollar currencies. The estimates reported in column (4) provide strong evidence that it is the use of vehicle currencies generally, and not just the US dollar specifically, that is driving our results (the coefficients on the two vehicle currency exchange rates are not significantly different from each other).

Table 7: Pass-Through into Import Unit Values: By Industry

Industry (SITC)	(1)	(2)	(3)	(4)	(5)		(6)
Exchange rate		$DEST/ORIG$			$DEST/VCP$	$VCP/ORIG$	$DEST/VCP$
Food, live animals	0.140^a	0.615^a	0.155^b	0.086	0.710^a	0.036	0.657^a
	(0.047)	(0.187)	(0.068)	(0.060)	(0.157)	(0.066)	(0.161)
Beverages, tobacco	0.124	0.879^a	-0.182^b	0.341	1.246^a	0.085	1.180^a
	(0.091)	(0.177)	(0.087)	(0.233)	(0.372)	(0.275)	(0.366)
Crude materials	0.161^a	0.740^a	0.172	0.052	0.426^b	0.110	0.346^c
	(0.061)	(0.257)	(0.122)	(0.100)	(0.215)	(0.101)	(0.210)
Mineral fuels	0.066	0.601	0.822	-0.041	0.675^c	-0.097	0.664^c
	(0.172)	(0.466)	(0.559)	(0.177)	(0.371)	(0.178)	(0.357)
Animal, vegetable oils	0.155	0.382	0.290	0.332	0.508^c	0.549^b	0.298
	(0.167)	(0.387)	(0.489)	(0.203)	(0.303)	(0.276)	(0.320)
Chemicals	0.188^a	0.762^a	0.051	0.122	0.650^a	0.062	0.582^a
	(0.061)	(0.135)	(0.137)	(0.074)	(0.154)	(0.092)	(0.157)
Manufactured goods	0.130^a	0.578^a	0.012	0.127^a	0.599^a	0.127^a	0.512^a
	(0.034)	(0.132)	(0.063)	(0.040)	(0.162)	(0.045)	(0.166)
Machinery	0.244^a	0.731^a	0.195^b	0.123^b	0.580^a	0.119^b	0.491^a
	(0.041)	(0.119)	(0.077)	(0.054)	(0.160)	(0.060)	(0.162)
Miscellaneous manuf.	0.169^a	0.649^a	0.032	0.134^a	0.638^a	0.073	0.566^a
	(0.034)	(0.121)	(0.051)	(0.051)	(0.164)	(0.066)	(0.172)
Invoicing currency	All	PCP	LCP	VCP	VCP		VCP
Observations	5,212,592	1,272,714	1,065,852	2,599,543	2,599,543		2,599,543
R-squared	0.146	0.186	0.206	0.176	0.176		0.176

Notes: Firm-quarter and origin country-product fixed effects are included. Contemporaneous and eight lags of the origin country's quarterly inflation rate, as well as eight lags of the log change in each exchange rate are also included (not reported). Robust standard errors adjusted for clustering at the country-year level are reported in parentheses. ^{a}, ^{b}, and ^{c} indicate significance at the one, five, and ten percent levels, respectively. The dependent variable is the quarterly log change import unit value (in sterling per kilogram).

As a further check, we demonstrate that our results are not driven by the industry composition of our sample but rather by heterogeneity across invoicing choices. In Table 7 we report the same specifications as in Table 5 but we interact the exchange rates with dummy variables for each industry.[25]

[25] The results are similar if we regress equation (4) with interactions between the exchange rates and industry dummies.

Overall, across industries, we observe a similar pattern as in Table 5. The exchange rate elasticities are on average large for producer currency priced transactions (column 2), and mostly insignificant for the local currency priced ones (column 3). For transactions in a vehicle currency, the sensitivity of unit values to changes in exchange rates is large when the sterling to vehicle currency exchange rate fluctuates, but low or often insignificant when the vehicle to origin country's currency exchange rate changes (columns 5 and 6). Our results are therefore not driven by any specific industry.

In summary, we obtain two main results. First, we show that exchange rate pass-through varies substantially across invoicing choices. This finding contrasts with the low degree of pass-through that is typically estimated in the literature. This means that for policy purposes, ignoring the currency of invoicing can lead to misguided predictions regarding the effects of exchange rate changes on import unit values (see Section 4). Second, by comparing columns (1) and (3) of Table 6, we show that using the bilateral rather than the sterling to vehicle currency exchange rate underestimates pass-through for the transactions priced in vehicle currencies by 35.0 percentage points ($59.2 - 24.2 = 35.0$).[26] In Section 5 we formally show why the bilateral exchange rate underestimates pass-through.

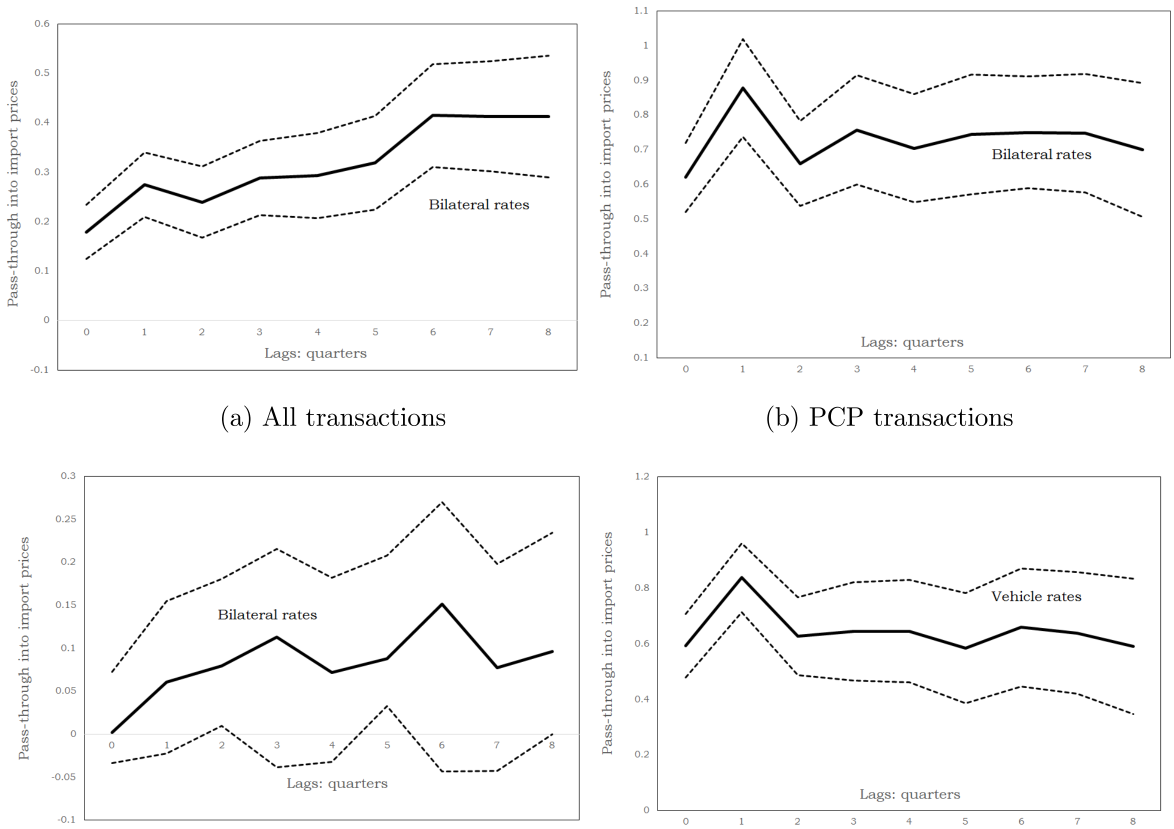
3.2 Long-Run Pass-Through

Due to the inclusion of eight lags on the exchange rates, we depict long-run pass-through graphically. Panel (a) of Figure 1 plots the cumulative exchange rate estimates obtained from the specification reported in column (1) of Table 5, where the unit values of all import transactions are regressed on bilateral exchange rates only. The contemporaneous pass-through rate is equal to 17.9 percent, and reaches 41.3 percent after eight quarters (significant at the one percent level).

Panels (b) to (d) show the dynamics of pass-through by currency of invoicing. They are based on the specification reported in column (3) of Table 6, which estimates exchange rate pass-through separately for producer, local, and vehicle currency priced transactions, and lets the transactions priced in a vehicle currency depend on the sterling to vehicle currency exchange rates. For the producer currency priced transactions in Panel (b), contemporaneous pass-through is equal to 62.0 percent and reaches 70.0 percent after eight quarters (significant at the one percent level). For the local currency priced transactions, Panel (c) shows that pass-through increases from zero percent on impact to 9.6 percent after two years (the estimate is, however, insignificant). Finally, Panel (d) focuses on the transactions priced in vehicle currencies. Pass-through is equal to 59.2 percent on impact. After eight quarters, the pass-through elasticity is significant at the one percent level at a value of 0.590, and therefore of the same magnitude as the contemporaneous elasticity.

According to Figure 1, the pass-through rates for producer and local currency priced transactions do not appear to converge even after two years. This finding is consistent with Gopinath et al. (2010) who find that the difference in pass-through into US import prices in dollars versus non-dollars is large

[26] In results available upon request, we show that our results remain similar if we weight observations by trade volumes.



(a) All transactions (b) PCP transactions

(c) LCP transactions (d) VCP transactions

Figure 1: Cumulative exchange rate pass-through into import unit values. (a) All transactions (based on the specification reported in column 1 of Table 5), (b) PCP transactions, (c) LCP transactions, and (d) VCP transactions (based on the specification reported in column 3 of Table 6). 95 percent confidence intervals reported as dashed lines.

even at a two-year horizon, suggesting that the invoicing choice is endogenous. They argue that when prices are sticky, firms choose their currency of invoicing based on their average desired pass-through. Intuitively, if a firm desires a low pass-through, it will choose local currency pricing. Conversely, if the desired pass-through is high, the firm will choose producer currency pricing which results in complete pass-through.[27]

3.3 Average Pass-Through

To evaluate the magnitude of exchange rate pass-through implied by our estimates, we calculate a weighted average of the pass-through elasticities estimated separately for each invoicing choice (reported in column 3 of Table 6 and shown in Panels b to d of Figure 1). As weights we use the currency of invoicing shares in our sample (listed in Table 2). Pass-through is equal to 43.6 percent on impact and

[27] Cao, Dong, and Tomlin (2015) instead observe convergence in pass-through into Canadian export prices invoiced in US dollars and Canadian dollars.

to 53.2 percent after two years (both significant at the one percent level). These estimates are larger than the short and long-run pass-through rates of 17.9 and 41.3 percent that we obtain when using bilateral exchange rates only to explain import unit values (column 1 of Table 5 and Panel a of Figure 1). In summary, allowing for invoicing currencies therefore helps us to understand the disconnect between exchange rates and world trade prices.[28]

3.4 Robustness and Extensions

Appendix A reports robustness checks. We provide evidence that our estimates remain robust to controlling for changes in the trade-weighted exchange rate, and therefore to accounting for strategic complementarities in price setting at the firm level (Gopinath and Itskhoki, 2011). We show that our pass-through elasticities remain similar in magnitude in the period after June 2016 when sterling depreciated following the EU referendum. We provide results when we aggregate our data at monthly or annual frequency. Interestingly, at monthly frequency we find that the effects of exchange rate changes kick in after one month. We run our regressions separately for manufacturing industries, for the goods produced in the exporting country, for intermediate, final, and capital goods, and excluding homogeneous commodities from the sample. We report regressions where we exclude the US, China, or the countries with fixed exchange rate regimes, crawling pegs, or with pegs to the US dollar or the euro. We distinguish between firms based on their average import shares. Finally, we demonstrate that our results remain robust to using alternative combinations of fixed effects.

Appendix B shows that our results also hold for export unit values. Again, we document that pass-through varies substantially across invoicing currencies. The coefficient on the contemporaneous bilateral exchange rate change is insignificant for the transactions priced in producer and vehicle currencies, and large for the ones in local currencies. For the subsample of vehicle currency priced transactions, export unit values react to changes in the sterling to vehicle currency exchange rate, but do not change when the vehicle to destination country's currency exchange rate fluctuates. Appendix C reports results for export and import quantities. We find that export and import quantities react modestly, if at all, to changes in exchange rates, regardless of the currency of invoicing.

4 Implications for Import Price Inflation

Our results demonstrate that the pass-through of exchange rate changes into import prices is significantly larger once we consider the currency of invoicing and let the import unit values priced in a vehicle currency depend on the sterling to vehicle currency exchange rate. As changes in import prices feed into consumer prices, our results imply that the pass-through into consumer prices should in turn be larger once we allow for invoicing choices. Pass-through into consumer prices is, however, typically lower than into import prices because consumer prices contain a higher non-traded component due

[28] Our estimates are similar if we use the invoicing shares we observe in the full sample of non-EU imports (i.e., including the "Not classified" industry), and if we use the shares we calculate for world imports (see Section 4 and Appendix D).

to local distribution costs, and they include the prices of non-traded and tradable goods only sold domestically.

To derive the implications of our results for consumer price inflation, we would need to match import unit values with the microdata underlying the construction of the UK consumer price index (Auer et al., 2018). These data, however, are not available by invoicing currency. We therefore focus our analysis on import price inflation instead, assuming that the patterns we find for import prices are then transmitted to consumer prices. As shown in Figure 2, the year-on-year monthly consumer and import price inflation rates since January 2007 are indeed highly correlated (the correlation is equal to 72 percent), although the import price index is more volatile than the consumer price index (the year-on-year monthly percentage change varies between -8 and 18 for import prices, and between 0.2 and 4.8 for consumer prices). Given that the import component of the UK consumer price index is around 30 percent (Forbes et al., 2018), the effects of exchange rate changes on consumer price inflation should amount to roughly a third of the magnitude of the effects that we report for import price inflation.

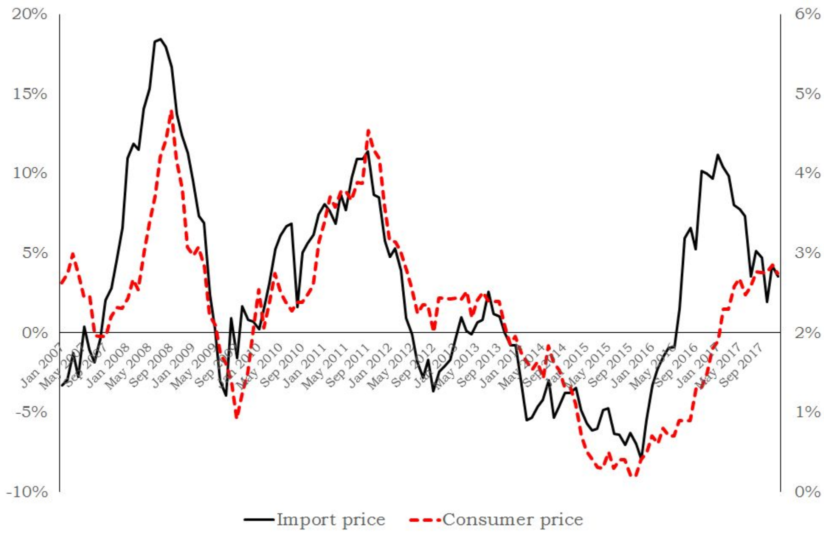


Figure 2: Consumer (right axis) and import (left axis) price inflation for the UK economy (% change over 12 months) from January 2007 to December 2017. Source: International Financial Statistics of the International Monetary Fund.

To illustrate how exchange rate movements affect UK import price inflation in the short run (i.e., one quarter) and in the long run (i.e., after eight quarters), we focus on three quarterly episodes of large sterling fluctuations. We use our estimates from Tables 5 and 6 to evaluate the dynamic response of import price inflation to these exchange rate shocks.[29] First, following the EU referendum, sterling

[29] The degree of pass-through could vary between the three episodes if the exchange rate changes in each period were driven by different types of shocks (Forbes et al., 2018). As our pass-through elasticities are estimated for the 2010–2017 period only, we view the exercise we carry out in this section as an illustration of how different exchange rate shocks affect the dynamics of import price inflation once we consider invoicing currencies. In Table D3 in Appendix D we recalculate

depreciated in June–August 2016 (relative to the previous quarter March–May 2016) by 7.09 percent on average (on a trade-weighted basis), and by 6.34 and 7.66 percent against the US dollar and the euro. Second, during the Great Recession sterling depreciated in November 2008–January 2009 by 12.94 percent on average, and by 19.43 and 12.34 percent against the US dollar and the euro. Finally, during the European Sovereign Debt Crisis, sterling *appreciated* in January–March 2015 by 2.66 and 6.24 percent on average and against the euro, but *depreciated* by 4.76 percent against the US dollar.[30] Figure 3 plots the monthly nominal exchange rates of sterling against the euro and the US dollar from January 2007 to December 2017, as well as the nominal effective exchange rate. The vertical shaded areas indicate the three quarterly episodes of sterling fluctuations that we focus on.

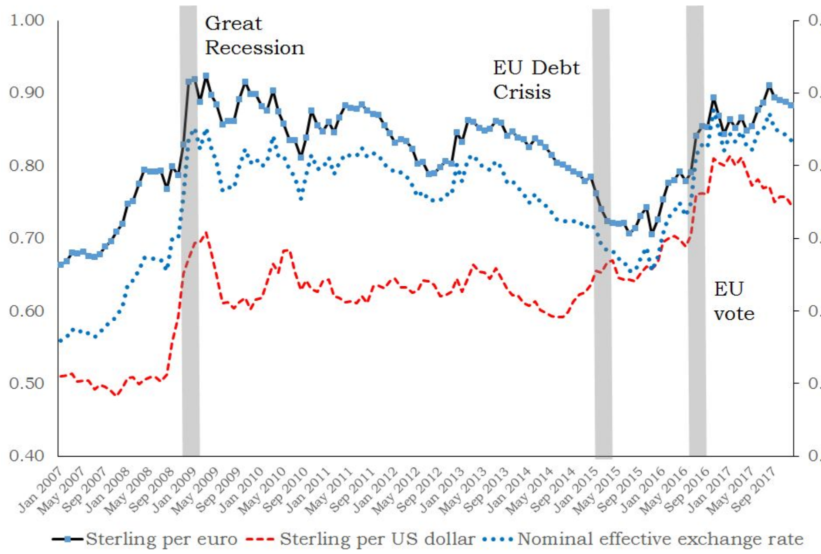


Figure 3: Sterling per euro and sterling per US dollar nominal exchange rates (left axis), and nominal effective sterling exchange rate (right axis) from January 2007 to December 2017. Source: International Financial Statistics of the International Monetary Fund.

We start with the depreciation of sterling following the EU referendum of June 2016. Our estimates are presented in columns (1) and (2) of Table 8. For details on how we calculate our back-of-the-envelope estimates we refer the reader to Appendix D.[31] When we consider the effects of bilateral exchange rates

our back-of-the-envelope estimates for the depreciation of sterling following the EU referendum of June 2016 using the pass-through elasticities we estimate for the post-referendum period only (see Table A2 in Appendix A). Reassuringly, our results remain similar.

[30] In January 2009, sterling depreciated strongly amid fears that the UK government would have to nationalize high-street banks. In March 2015, the European Central Bank began its government bond buying programme, resulting in an appreciation of sterling against the euro.

[31] Using data from Gopinath (2016), we explain how we derive the currency of invoicing shares for UK world imports. Due to data limitations, we consider two alternative scenarios for the magnitude of these shares. For each of the three episodes of large sterling fluctuations, we then describe how we measure the average appreciation or depreciation of the sterling bilateral and sterling to vehicle currency exchange rates. We also explain how we use our regression estimates from Tables 5 and 6 to evaluate the response of import price inflation to the three exchange rate shocks. In this section we only describe our results for the effects of world imports based on scenario 1 for the invoicing shares (Table D1). The results for scenario 2, and for the effects of non-EU imports, are relegated to Table D2 in Appendix D.

only (using the estimates in column 1 of Table 5), column (1) shows that the average (trade-weighted) depreciation of sterling increases import price inflation by 1.271 percentage points on impact. After eight quarters, inflation rises by 2.927 percentage points (column 2). The next two rows report the individual contributions of the US dollar and the euro. The depreciation against the euro increases import price inflation by more than the depreciation against the US dollar. The reason is that a large share (49.95 percent) of UK imports originates from the EU, therefore the depreciation against the euro is given a larger weight than the depreciation against the US dollar in driving import price inflation.[32]

Table 8: UK Import Price Inflation

		(1)	(2)	(3)	(4)	(5)	(6)
		EU Referendum		**Great Recession**		**EU Debt Crisis**	
		$t = 0$	$t = 8$	$t = 0$	$t = 8$	$t = 0$	$t = 8$
Bilateral rates	All currencies	1.271^a (0.199)	2.927^a (0.447)	2.320^a (0.363)	5.343^a (0.815)	-0.477^a (0.074)	-1.098^a (0.167)
	USD	0.105^a (0.016)	0.243^a (0.037)	0.323^a (0.050)	0.744^a (0.113)	0.079^a (0.012)	0.182^a (0.028)
	Euro	0.668^a (0.104)	1.537^a (0.234)	1.076^a (0.168)	2.477^a (0.378)	-0.544^a (0.085)	-1.252^a (0.191)
Bilateral/vehicle rates	All currencies	2.786^a (0.283)	3.154^a (0.609)	7.105^a (0.691)	7.774^a (1.492)	0.627^a (0.076)	0.474^a (0.147)
	USD	1.780^a (0.163)	1.817^a (0.349)	5.451^a (0.499)	5.564^a (1.069)	1.334^a (0.122)	1.362^a (0.262)
	Euro	0.870^a (0.104)	1.107^a (0.216)	1.402^a (0.168)	1.783^a (0.349)	-0.709^a (0.085)	-0.901^a (0.176)
Exchange rate shock		2016M6–2016M8		2008M11–2009M1		2015M1–2015M3	
All currencies against sterling (weighted)		+7.09%		+12.94%		-2.66%	
US dollar against sterling		+6.34%		+19.43%		+4.76%	
Euro against sterling		+7.66%		+12.34%		-6.24%	

Notes: Estimates reported in percentage points. The estimates reported in the rows "Bilateral rates" are obtained based on the regression in column (1) of Table 5. The estimates reported in the rows "Bilateral/vehicle rates" are obtained using the regression in column (3) of Table 6. [a] indicates significance at the one percent level.

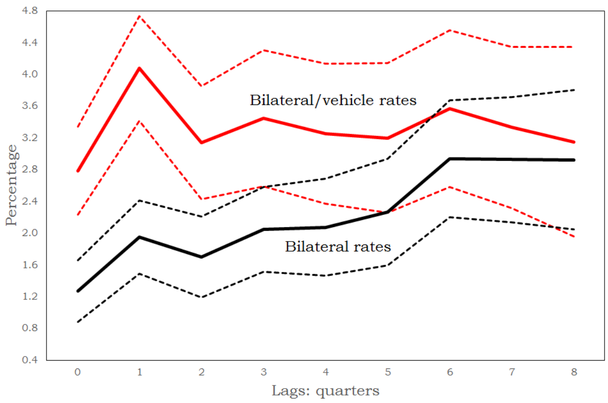
Once we account for the full breadth of invoicing currencies and relevant pass-through estimates (using column 3 of Table 6), our results yield much larger effects on import price inflation. Column (1) of Table 8 shows that the depreciation of sterling increases import price inflation by 2.786 percentage points on impact, and by 3.154 percentage points after eight quarters. The reason for such larger estimates is that the pass-through of vehicle currency exchange rate changes into import unit values priced in a vehicle currency is large. As the US dollar is used extensively as a vehicle currency, the depreciation against the US dollar is given a larger weight in affecting import prices (it increases import price inflation by 1.780 and 1.817 percentage points on impact and after two years). Overall, these estimates illustrate that ignoring vehicle currency exchange rates can lead to misleading predictions regarding the effects of exchange rate changes on import price inflation.

Columns (3) and (4) report our results for the Great Recession. Similarly to the EU referendum, we find that the depreciation of sterling has a larger inflationary impact once we let the transactions priced in a vehicle currency depend on the sterling to vehicle currency exchange rates. The higher

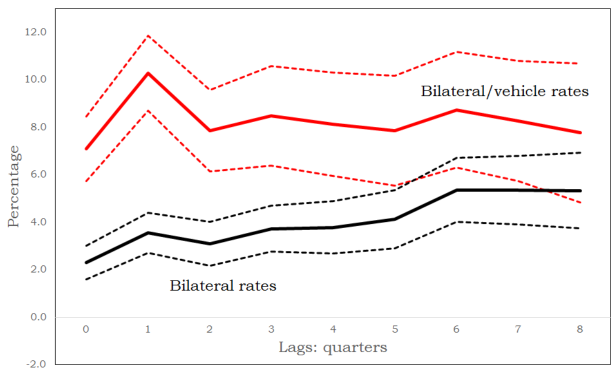
[32] Due to data restrictions we assume all EU origin countries use the euro. See Appendix D for details.

import price inflation is again driven by the US dollar as it is predominantly used as a vehicle currency.

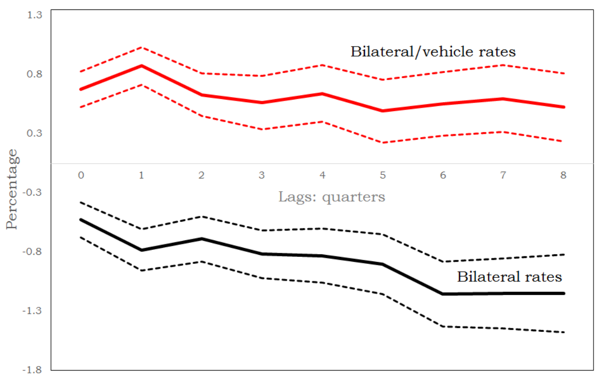
Finally, columns (5) and (6) focus on the European Sovereign Debt Crisis. When we only consider the effects of bilateral exchange rates, the average appreciation of sterling *reduces* import price inflation in the short and long run. Due to the intensity of trade between the UK and the EU, the fall in import price inflation is mainly driven by the appreciation against the euro, which outweighs the effect of the depreciation against the US dollar. But once we allow for the currency of invoicing, movements in sterling instead *increase* import price inflation in the short and long run. The reason is that the depreciation against the US dollar now outweighs the appreciation against the euro. The European Sovereign Debt Crisis is thus an example where accounting for the currency of invoicing does not only matter quantitatively but also qualitatively.



(a) EU Referendum



(b) Great Recession



(c) EU Sovereign Debt Crisis

Figure 4: Cumulative effects of the change in the value of sterling on import price inflation (a) after the EU referendum, (b) during the Great Recession, and (c) during the EU Sovereign Debt Crisis. The “Bilateral rates” estimates are obtained based on the regression in column (1) of Table 5, while the “Bilateral/vehicle rates” estimates are obtained using the regression in column (3) of Table 6. 95 percent confidence intervals reported as dashed lines.

Panels (a) to (c) of Figure 4 depict the dynamics of each exchange rate shock. Once we consider invoicing currencies, the depreciation of sterling increases inflation by more after the EU referendum and during the Great Recession (Panels a and b). For the European Sovereign Debt Crisis the fall in inflation induced by the appreciation against the euro is more than offset by the depreciation against the US dollar (Panel c).

5 A Conceptual Framework for Vehicle Currency Pass-Through

In this section, we examine from a conceptual viewpoint how vehicle currency prices may depend on exchange rate movements.[33] The aim is to understand how exchange rate pass-through should be estimated in the presence of vehicle currency pricing.

For this purpose, we model the perspective of a foreign firm exporting to the UK and invoicing in a vehicle currency. We build on the approach by Engel (2006) and extend it to vehicle currency pricing. In particular, we derive estimating equations that allow the firm's pricing behavior to be influenced by the three exchange rates depicted in Figure 5. That is, the firm's price can depend on either the *vehicle currency exchange rate* $e_{DEST/VCP}$ (sterling against the vehicle currency), the *bilateral exchange rate* $e_{DEST/ORIG}$ (between sterling and the exporter's currency), or the *vehicle-exporter exchange rate* $e_{VCP/ORIG}$ (between the vehicle currency and the exporter's currency).

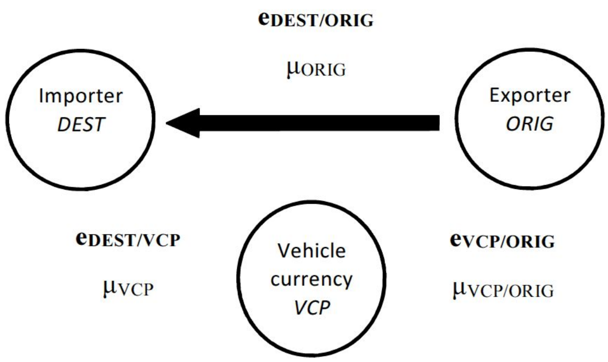


Figure 5: This figure denotes the exporter-importer relationship in the presence of a vehicle currency. Triangular arbitrage holds for exchange rates such that $\ln e_{DEST/ORIG} = \ln e_{DEST/VCP} + \ln e_{VCP/ORIG}$ as in equation (2). μ_{ORIG}, μ_{VCP}, and $\mu_{VCP/ORIG}$ refer to pass-through elasticities as in equations (6)–(8). See Section 5.1 for details.

We then take the estimating equations to the data to establish which exchange rates matter most in practice. In a final step, we delineate the bias in pass-through estimation if a researcher ignores the vehicle currency.

[33] We model prices in the theory, but as we explain in Section 2 we observe unit values in the data.

5.1 Three Pass-Through Elasticities

We consider a representative monopolistic foreign firm based in a foreign country that sells to the domestic country (the UK). There are three currencies in the world: the currency of the foreign country ($ORIG$), the domestic currency ($DEST$, which is sterling), and a third-country vehicle currency (VCP). We are interested in analyzing the pass-through behavior of firms who price in the vehicle currency. Thus, analogous to Engel (2006) we assume the representative firm can commit to setting its export price in the vehicle currency. It chooses the optimal price p^*_{VCP}, which is the price of its exports denominated in the vehicle currency. Prices are flexible (in the sense that the firm is allowed to choose its preferred pass-through level). Exchange rates are exogenous from the firm's point of view.

The foreign firm sells its goods to consumers in the domestic country. We assume the consumers face a price p_{DEST} in domestic currency. The relationship between the price faced by consumers and the price set by the foreign firm is therefore given by:

$$\ln p_{DEST} = \ln p^*_{VCP} + \ln e_{DEST/VCP}, \tag{5}$$

where $e_{DEST/VCP}$ is the exchange rate expressed as the price of the vehicle currency in units of the domestic currency (such that an increase in $e_{DEST/VCP}$ corresponds to a depreciation of sterling).

The firm can change its optimal price p^*_{VCP} in response to a movement in either of the three exchange rates in Figure 5. In Appendix E we go through each case in detail based on the approach by Engel (2006). There, we also derive the corresponding pass-through specifications that are crucial for our subsequent analysis. They are given as:

$$\Delta \ln p_{DEST} = \mu_{VCP} \Delta \ln e_{DEST/VCP} + \varepsilon_1, \tag{6}$$

$$\Delta \ln p_{DEST} = \mu_{ORIG} \Delta \ln e_{DEST/ORIG} - \Delta \ln e_{VCP/ORIG} + \varepsilon_2, \tag{7}$$

$$\Delta \ln p_{DEST} = \mu_{VCP/ORIG} \Delta \ln e_{VCP/ORIG} + \Delta \ln e_{DEST/VCP} + \varepsilon_3, \tag{8}$$

where ε_1, ε_2, and ε_3 are error terms. The coefficient μ_{VCP} in equation (6) is the pass-through elasticity of the vehicle currency into the domestic price. This is the elasticity we estimated in column (6) of Table 5 (where we also included lagged regressors). Equation (6) arises when the firm only considers the vehicle currency exchange rate $e_{DEST/VCP}$ when setting its price p^*_{VCP} (see Appendix E.1).

The coefficient μ_{ORIG} in equation (7) is the pass-through elasticity of the bilateral exchange rate $e_{DEST/ORIG}$ into the domestic price. We stress the additional exchange rate term on the right-hand side comprising the vehicle-exporter exchange rate $e_{VCP/ORIG}$. Intuitively, this additional term appears because linkages between all three currencies in Figure 5 are now involved. Consumers face the price in sterling. The firm sets it in the vehicle currency while considering the bilateral exchange rate $e_{DEST/ORIG}$ when making its optimal choice (see Appendix E.2). More specifically, the coefficient on $\Delta \ln e_{VCP/ORIG}$ is constrained to -1 because of triangular arbitrage between exchange rates.

Finally, $\mu_{VCP/ORIG}$ in equation (8) is the pass-through elasticity of the vehicle-exporter exchange rate into the domestic price. Again, an additional exchange rate term appears on the right-hand side because all three currencies are involved. The coefficient on $\Delta \ln e_{DEST/VCP}$ is constrained to $+1$ due to triangular arbitrage (see Appendix E.3). In Appendix E.5 we run regressions based on specifications (6)–(8). Apart from the constrained coefficients they are similar to those for the VCP sample in Table 5.

5.2 Pass-Through Bias with Bilateral Exchange Rates

In much of the literature it is commonplace to estimate exchange rate pass-through using the bilateral exchange rate between the importer and the exporter. This is adequate as long as the invoicing currency is either the importer's or the exporter's currency. However, if the currency of invoicing is in fact a vehicle currency, then using the bilateral exchange rate may be inappropriate. We now demonstrate the consequences of ignoring the vehicle currency.

Specifically, imagine a researcher is interested in estimating the pass-through elasticity of the bilateral exchange rate and uses a sample with transactions in a vehicle currency. Then according to our theoretical framework, we need to consider specification (7) where we estimate the pass-through elasticity μ_{ORIG} for the bilateral exchange rate $\Delta \ln e_{DEST/ORIG}$. This specification shows that the exchange rate between the vehicle currency and the exporter's currency, $\Delta \ln e_{VCP/ORIG}$, must be included as an additional regressor (with a constrained coefficient of -1). If this regressor is not included, this can lead to an omitted variable bias.

We estimate specification (7) with the vehicle exchange rate term included (see column 2 of Table E1 in Appendix E.5). Our coefficient for μ_{ORIG} is 1.069, which we refer to as the "true" bilateral pass-through elasticity. By contrast, in column (4) of Table 5 we estimated this coefficient *without* the vehicle exchange rate term included. We obtained a coefficient of 0.123. We refer to it as the "naive" bilateral pass-through elasticity as the underlying regression omits the vehicle exchange rate term. The difference between the two coefficients suggests that the naive specification suffers from downward bias (i.e., $0.123 < 1.069$). As the vehicle currency term in specification (7) has a negative sign, this finding is consistent with a positive correlation between the two exchange rate terms (i.e., $\text{corr}(\Delta \ln e_{DEST/ORIG}, \Delta \ln e_{VCP/ORIG}) > 0$).[34]

What is the economic interpretation of this result? A positive correlation between the exchange rate terms means that sterling moves against the exporter's currency in a similar way as the vehicle currency moves against the exporter's currency. Put differently, with respect to other currencies sterling tends to behave like the vehicle currency. As an example, consider a Japanese firm that uses the US dollar

[34] In the case of a zero correlation between the two exchange rates (i.e., $\text{corr}(\Delta \ln e_{DEST/ORIG}, \Delta \ln e_{VCP/ORIG}) = 0$), there would be no omitted variable bias. If the correlation was negative, we would obtain an upward bias. But this is not the coefficient pattern we observe in the data.

as its vehicle currency for exporting to the UK. A Japan-specific shock would make sterling and the US dollar move in lockstep against the yen.

We now test this argument about a downward bias in the bilateral pass-through elasticity more formally. In the above regressions we pooled all vehicle currencies and exporting countries together. But in practice, the correlation between the $e_{DEST/ORIG}$ and $e_{VCP/ORIG}$ exchange rates is specific to each $(VCP, ORIG)$ pair. We therefore have a testable prediction: the higher the exchange rate correlation, the lower the naive bilateral pass-through elasticity.

To evaluate this prediction we proceed in two steps. First, we estimate naive elasticities as in column (4) of Table 5 on a sample of vehicle currency priced transactions. But crucially, we allow these elasticities to vary by $(VCP, ORIG)$ pairs. This produces 154 distinct naive elasticities involving 16 vehicle currencies and 84 exporting countries (the importing country is always the UK).[35] Second, we regress these elasticities on their corresponding exchange rate correlations (constructed based on monthly exchange rate movements over the sample period from 2010 to 2017).

Table 9: Pass-Through Elasticities and Exchange Rate Correlations

	(1)	(2)	(3)	(4)	(5)
Dependent variable: "naive" bilateral pass-through elasticity					
$\text{corr}(\Delta \ln e_{DEST/ORIG}, \Delta \ln e_{VCP/ORIG})$	-0.210^c (0.109)	-0.221^a (0.072)	-0.292^a (0.052)	-0.268^a (0.005)	-0.227^a (0.039)
Vehicle currency fixed effects	No	Yes	Yes	Yes	Yes
Weighted	No	No	No	Yes	Yes
Observations	154	154	127	154	154
R-squared	0.010	0.168	0.017	0.020	0.103

Notes: All columns are based on the full sample except for column (3) where only the US dollar and the euro are included as vehicle currencies. In column (4) the weights are based on vehicle currency shares, and in column (5) the weights are based on the inverse of the standard errors of the pass-through elasticities. Robust standard errors adjusted for clustering at the vehicle currency level are reported in parentheses. ^{a} and ^{c} indicate significance at the one and ten percent levels, respectively. The dependent variable is the "naive" bilateral pass-through elasticity.

We report the regression results in Table 9. As suggested by our hypothesis, we find a negative relationship between the naive bilateral pass-through elasticities and the exchange rate correlations. In our preferred specification in column (2), we add vehicle currency fixed effects. In column (3) the sample size is slightly reduced because we only include elasticities for the US dollar and the euro as vehicle currencies. In column (4) we weight the observations by vehicle currency shares (the US dollar share in particular is close to 90 percent in terms of value). In column (5) we weight by the inverse of the standard errors of the pass-through elasticities estimated as in column (4) of Table 5. Overall, we strongly confirm our prediction of a negative relationship.[36]

[35] We build on our standard specification (1) by interacting the exchange rate with an extra dummy for each $(VCP, ORIG)$ pair. We only include contemporaneous exchange rate coefficients (results with lags are very similar). After obtaining these coefficients we trim the sample by excluding pairs with less than 30 observations. We therefore have a smaller number of vehicle currencies, but all major ones are included.

[36] In contrast to the signs of the coefficients, the magnitudes have no economically meaningful interpretation.

Overall, our results highlight the pitfalls of using bilateral exchange rates for estimating pass-through when prices are set in vehicle currencies. Table 9 shows that pass-through coefficients based on bilateral rates depend in a systematic way on triangular exchange rate correlations with vehicle currencies. Accounting for vehicle exchange rates is therefore important to avoid an omitted variable bias.

The difficulty researchers often face in practice is that they do not observe the vehicle currencies used in transactions. This is not a major concern if vehicle currency pricing is negligible for a particular importing country. In our UK data set, however, vehicle currency pricing applies to the majority of non-EU import transactions (55 percent, see Table 2). Ignoring vehicle currencies therefore poses a problem and leads to substantially weaker pass-through estimates, as we demonstrate throughout the paper.

6 Concluding Remarks

Using detailed firm-level transactions data for UK imports from non-EU countries, we establish that invoicing in a vehicle currency is pervasive. We then examine the relationship between the currency of invoicing and exchange rate pass-through for traded goods prices. Pass-through varies substantially across invoicing choices. It is large for imports invoiced in producer currencies but insignificant for local currency (sterling). Once we allow import unit values invoiced in vehicle currencies to depend on the vehicle currency exchange rate rather than the bilateral exchange rate, pass-through is large and in the same ballpark as for producer currency pricing. Overall, taking vehicle currencies into account raises exchange rate pass-through and contributes to understanding the disconnect between exchange rates and prices.

For policy purposes, our results imply that ignoring the currency of invoicing can produce misleading predictions regarding exchange rate pass-through into import prices and, therefore domestic prices. In particular, our findings can explain the higher-than-expected pass-through into UK inflation during the Great Recession and after the EU referendum relative to the European Sovereign Debt Crisis.

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A Robustness

To ensure the robustness of our findings, this appendix provides a number of sensitivity checks. For simplicity, we only report contemporaneous pass-through estimates.[37] Overall, the broad similarity of the results supports the paper's main conclusions.

Third-Country Exchange Rates As pointed out by Gopinath and Itskhoki (2011), strategic complementarities in price setting at the firm level can matter for exchange rate pass-through. To account for strategic complementarities, we further control for the quarterly trade-weighted nominal exchange rate of the UK economy in our regressions.[38] Movements in the trade-weighted exchange rate may to some extent capture the competition that a firm faces against the exporters of other countries. They may also impact the prices of a firm if it imports intermediate inputs from the rest of the world.

Table A1: Third-Country Exchange Rates

	(1)	(2)	(3)
$\Delta \ln e_{DEST/ORIG} \times D_{PCP}$	0.603^a (0.042)	0.710^a (0.040)	0.683^a (0.042)
$\Delta \ln e_{DEST/ORIG} \times D_{LCP}$	0.054^c (0.030)	0.103^a (0.027)	0.076^a (0.028)
$\Delta \ln e_{DEST/ORIG} \times D_{VCP}$	0.408^a (0.044)	–	–
$\Delta \ln e_{DEST/VCP}$	–	0.727^a (0.032)	0.664^a (0.038)
$\Delta \ln e_{VCP/ORIG}$	–	0.177^a (0.027)	–
residuals	0.120^b (0.050)	0.057 (0.045)	0.076^c (0.045)
Observations	5,674,778	5,674,778	5,674,778
R-squared	0.051	0.051	0.051

Notes: Firm-year, origin country-product, and currency of invoicing fixed effects are included. Contemporaneous and eight lags of the origin country's quarterly inflation rate, as well as eight lags of the log change in each exchange rate and of the residuals are also included (not reported). Robust standard errors adjusted for clustering at the country-year level are reported in parentheses. ^{a}, ^{b}, and ^{c} indicate significance at the one, five, and ten percent levels, respectively. The dependent variable is the quarterly log change import unit value (in sterling per kilogram). The term *residuals* refers to the residuals obtained from purging the change in the trade-weighted exchange rate from changes in the exchange rates included in each column (see footnote 42).

In Table A1 we re-estimate the specifications reported in columns (1) to (3) of Table 6, but we further control for the change in the trade-weighted exchange rate that we purge from movements in the bilateral or vehicle currency exchange rates (Gopinath and Itskhoki, 2011). To do so, in a first step we regress the (log) change in the trade-weighted exchange rate on the (log) change in the bilateral or vehicle currency exchange rates, and calculate the residuals.[39] The residuals capture movements in the trade-weighted exchange rate which are orthogonal to changes in the bilateral or vehicle exchange rates.

[37] The results for long-run pass-through are available upon request.

[38] The effective exchange rates are from the International Financial Statistics of the International Monetary Fund.

[39] In other words, in Table A1 the residuals are obtained from regressing the change in the trade-weighted exchange rate on the change in the bilateral exchange rate in column (1), on the change in the bilateral exchange rate for the PCP and LCP transactions and on the change in the sterling to vehicle and vehicle to origin country's currency exchange rates for the VCP transactions in column (2), and on the change in the bilateral exchange rate for the PCP and LCP transactions and on the change in the sterling to vehicle currency exchange rate for the VCP transactions in column (3).

In a second step we regress the change in import unit values on the change in the bilateral or vehicle exchange rates and the residuals. To avoid collinearity we now control for origin country-product and firm-year fixed effects.[40] We include eight lags on each exchange rate and on the residuals, but we only report the contemporaneous elasticities. Reassuringly, our results continue to hold (the pass-through elasticities for the local currency priced transactions become significant but they are small). We therefore conclude that our estimates remain robust to controlling for third-country exchange rates.

EU Referendum As the depreciation of sterling against all major currencies following the EU referendum of June 2016 can be considered as permanent/long lasting (at the time of writing in May 2019, the value of sterling has not returned to levels seen before the referendum), we investigate whether our results differ between the pre- and post-referendum periods.

Table A2: Robustness – EU Referendum

	(1)	(2)	(3)	(4)
$\Delta \ln e_{DEST/ORIG} \times pre$	0.191^a (0.035)	–	–	–
$\Delta \ln e_{DEST/ORIG} \times post$	0.132^a (0.034)	–	–	–
$\Delta \ln e_{DEST/ORIG} \times D_{PCP} \times pre$	–	0.496^a (0.055)	0.682^a (0.059)	0.659^a (0.060)
$\Delta \ln e_{DEST/ORIG} \times D_{PCP} \times post$	–	0.383^a (0.089)	0.590^a (0.118)	0.584^a (0.120)
$\Delta \ln e_{DEST/ORIG} \times D_{LCP} \times pre$	–	−0.069 (0.049)	0.031 (0.044)	0.004 (0.044)
$\Delta \ln e_{DEST/ORIG} \times D_{LCP} \times post$	–	0.010 (0.058)	0.120^c (0.063)	0.107^c (0.064)
$\Delta \ln e_{DEST/ORIG} \times D_{VCP} \times pre$	–	0.257^a (0.039)	–	–
$\Delta \ln e_{DEST/ORIG} \times D_{VCP} \times post$	–	0.159^a (0.043)	–	–
$\Delta \ln e_{DEST/VCP} \times pre$	–	–	0.691^a (0.079)	0.619^a (0.083)
$\Delta \ln e_{DEST/VCP} \times post$	–	–	0.513^a (0.098)	0.483^a (0.106)
$\Delta \ln e_{VCP/ORIG} \times pre$	–	–	0.112^b (0.046)	–
$\Delta \ln e_{VCP/ORIG} \times post$	–	–	0.033 (0.053)	–
Observations	5,212,592	5,212,592	5,212,592	5,212,592
R-squared	0.146	0.146	0.146	0.146

Notes: Firm-quarter and origin country-product fixed effects are included in (1). Firm-quarter, origin country-product, and currency of invoicing fixed effects are included in (2) to (4). Contemporaneous and eight lags of the origin country's quarterly inflation rate, as well as eight lags of the log change in each exchange rate are also included (not reported). Robust standard errors adjusted for clustering at the country-year level are reported in parentheses. ^{a}, ^{b}, and ^{c} indicate significance at the one, five, and ten percent levels, respectively. The dependent variable is the quarterly log change import unit value (in sterling per kilogram). The dummy variables *pre* and *post* are equal to one for the 2010Q1–2016Q2 and 2016Q3–2017Q4 periods, respectively.

In Table A2, we interact all exchange rates with a dummy for the pre- (2010Q1–2016Q2) and a dummy for the post-referendum (2016Q3–2017Q4) periods. The estimated coefficients for the post-

[40] We decompose changes in the quarterly trade-weighted exchange rate, which only varies over time, into changes in the quarterly bilateral exchange rate and the residuals. Changes in the bilateral exchange rate and the residuals are therefore perfectly collinear with the (firm)-quarter fixed effects. As a result we control for firm-year fixed effects instead.

referendum period tend to be slightly smaller in magnitude than for the earlier period (the sample is also shorter as it spans six quarters only). But in all columns we cannot reject that the coefficients are identical between the two periods. We therefore conclude that our results remain robust to the depreciation of sterling following the EU referendum.

Monthly Frequency Table A3 reports our results using monthly frequency data, and we include twelve lags on the exchange rates and foreign inflation rates. The table reports the coefficients on the contemporaneous and the first lag of each exchange rate change. All our results continue to hold, but interestingly the exchange rate effects kick in after a delay of one month.

Table A3: Robustness – Monthly Frequency

	(1)	(2)	(3)	(4)
$\Delta \ln e_{DEST/ORIG_t}$	0.068^b (0.028)	–	–	–
$\Delta \ln e_{DEST/ORIG_{t-1}}$	0.503^a (0.062)	–	–	–
$\Delta \ln e_{DEST/ORIG_t} \times D_{PCP}$	–	0.123 (0.083)	0.129 (0.082)	0.128 (0.082)
$\Delta \ln e_{DEST/ORIG_{t-1}} \times D_{PCP}$	–	0.787^a (0.099)	0.792^a (0.098)	0.791^a (0.099)
$\Delta \ln e_{DEST/ORIG_t} \times D_{LCP}$	–	0.043^c (0.024)	0.043^c (0.024)	0.042^c (0.024)
$\Delta \ln e_{DEST/ORIG_{t-1}} \times D_{LCP}$	–	0.162^a (0.036)	0.164^a (0.037)	0.162^a (0.037)
$\Delta \ln e_{DEST/ORIG_t} \times D_{VCP}$	–	0.067^c (0.038)	–	–
$\Delta \ln e_{DEST/ORIG_{t-1}} \times D_{VCP}$	–	0.574^a (0.086)	–	–
$\Delta \ln e_{DEST/VCP_t}$	–	–	0.085 (0.053)	0.084^c (0.046)
$\Delta \ln e_{DEST/VCP_{t-1}}$	–	–	0.916^a (0.089)	0.863^a (0.082)
$\Delta \ln e_{VCP/ORIG_t}$	–	–	0.004 (0.042)	–
$\Delta \ln e_{VCP/ORIG_{t-1}}$	–	–	0.155^a (0.052)	–
Observations	8,059,400	8,059,400	8,059,400	8,059,400
R-squared	0.030	0.030	0.030	0.030

Notes: Firm-month and origin country-product fixed effects are included in (1). Firm-month, origin country-product, and currency of invoicing fixed effects are included in (2) to (4). Contemporaneous and twelve lags of the origin country's monthly inflation rate, as well as twelve lags of the log change in each exchange rate are also included (not reported). Robust standard errors adjusted for clustering at the country-year level are reported in parentheses. ^{a}, ^{b}, and ^{c} indicate significance at the one, five, and ten percent levels, respectively. The dependent variable is the monthly log change import unit value (in sterling per kilogram).

Annual Frequency Table A4 shows that our results remain robust to aggregating the data at annual frequency. We include two lags on the exchange rates and foreign inflation rates.

Products In column (1) of Table A5 we only include manufacturing industries (SITC 6–8) in the sample. In column (2) we exclude homogeneous commodities such as "Crude materials" (SITC 2) and "Mineral fuels" (SITC 3) which prices are determined by world supply and demand (Gopinath, 2016). In column (3) we restrict the sample to the goods produced in the origin country (and exclude the

Table A4: Robustness – Annual Frequency

	(1)	(2)	(3)	(4)
$\Delta \ln e_{DEST/ORIG}$	0.188^{a} (0.039)	–	–	–
$\Delta \ln e_{DEST/ORIG} \times D_{PCP}$	–	0.489^{a} (0.058)	0.728^{a} (0.045)	0.708^{a} (0.046)
$\Delta \ln e_{DEST/ORIG} \times D_{LCP}$	–	-0.069 (0.045)	0.099^{b} (0.039)	0.072^{c} (0.039)
$\Delta \ln e_{DEST/ORIG} \times D_{VCP}$	–	0.201^{a} (0.034)	–	–
$\Delta \ln e_{DEST/VCP}$	–	–	0.738^{a} (0.052)	0.701^{a} (0.054)
$\Delta \ln e_{VCP/ORIG}$	–	–	0.056^{c} (0.030)	–
Observations	2,543,425	2,543,425	2,543,425	2,543,425
R-squared	0.133	0.133	0.133	0.133

Notes: Firm-year and origin country-product fixed effects are included in (1). Firm-year, origin country-product, and currency of invoicing fixed effects are included in (2) to (4). Contemporaneous and two lags of the origin country's annual inflation rate, as well as two lags of the log change in each exchange rate are also included (not reported). Robust standard errors adjusted for clustering at the country-year level are reported in parentheses. ^{a}, ^{b}, and ^{c} indicate significance at the one, five, and ten percent levels, respectively. The dependent variable is the annual log change import unit value (in sterling per kilogram).

goods produced in third countries).[41] Using information on the end use of goods as provided by the BEC classification, columns (4), (5), and (6) restrict the sample to intermediate, final, and capital goods, respectively.

Table A5: Robustness – Products

	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \ln e_{DEST/ORIG} \times D_{PCP}$	0.616^{a} (0.059)	0.619^{a} (0.052)	0.628^{a} (0.052)	0.638^{a} (0.074)	0.642^{a} (0.087)	0.578^{a} (0.152)
$\Delta \ln e_{DEST/ORIG} \times D_{LCP}$	0.019 (0.044)	0.001 (0.037)	0.012 (0.035)	0.001 (0.058)	-0.011 (0.045)	0.041 (0.121)
$\Delta \ln e_{DEST/VCP}$	0.586^{a} (0.066)	0.597^{a} (0.059)	0.601^{a} (0.050)	0.549^{a} (0.077)	0.665^{a} (0.083)	0.621^{a} (0.155)
Sample	Manuf.	Excl. raw	Origin	Interm.	Final	Capital
Observations	4,403,049	5,131,177	3,447,282	2,042,899	2,210,542	681,893
R-squared	0.147	0.146	0.189	0.169	0.176	0.195

Notes: Firm-quarter, origin country-product, and currency of invoicing fixed effects are included. Contemporaneous and eight lags of the origin country's quarterly inflation rate, as well as eight lags of the log change in each exchange rate are also included (not reported). Robust standard errors adjusted for clustering at the country-year level are reported in parentheses. ^{a} indicates significance at the one percent level. The dependent variable is the quarterly log change import unit value (in sterling per kilogram).

Countries In column (1) of Table A6 we exclude the US from the sample as their exports are mostly in US dollars. In column (2) we omit China due to its changing foreign exchange rate policy, while in columns (3), (4), (5), and (6) we exclude the countries with fixed exchange rate regimes, fixed exchange rates or crawling pegs, and the countries pegging their currency to the US dollar or the euro, respectively (the exchange rate regimes are identified using the International Monetary Fund's

[41] We use the variable "cooseq" which identifies the country where the goods are produced versus the country of dispatch.

De Facto classification).[42]

Table A6: Robustness – Countries

	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \ln e_{DEST/ORIG} \times D_{PCP}$	0.609^a (0.073)	0.616^a (0.055)	0.609^a (0.059)	0.610^a (0.059)	0.609^a (0.058)	0.622^a (0.051)
$\Delta \ln e_{DEST/ORIG} \times D_{LCP}$	0.004 (0.039)	0.001 (0.033)	−0.006 (0.034)	−0.005 (0.034)	−0.004 (0.034)	0.001 (0.036)
$\Delta \ln e_{DEST/VCP}$	0.610^a (0.067)	0.626^a (0.059)	0.556^a (0.055)	0.558^a (0.055)	0.563^a (0.054)	0.590^a (0.058)
Sample excluding	US	China	Fixed	Fixed/crawl	USD peg	Euro peg
Observations	3,966,909	3,536,819	3,034,515	3,031,115	3,051,771	5,196,440
R-squared	0.162	0.157	0.159	0.159	0.159	0.146

Notes: Firm-quarter, origin country-product, and currency of invoicing fixed effects are included. Contemporaneous and eight lags of the origin country's quarterly inflation rate, as well as eight lags of the log change in each exchange rate are also included (not reported). Robust standard errors adjusted for clustering at the country-year level are reported in parentheses. [a] indicates significance at the one percent level. The dependent variable is the quarterly log change import unit value (in sterling per kilogram).

Firm Size In Table A7 we distinguish between firms based on their average import shares in the sample. Column (1) reports our results excluding the one percent of firms with the largest import shares, while column (2) includes these firms only. Columns (3) and (4) repeat the same exercise but for the five percent of firms with the largest import shares.

Table A7: Robustness – Firm Size

	(1)	(2)	(3)	(4)
$\Delta \ln e_{DEST/ORIG} \times D_{PCP}$	0.635^a (0.059)	0.584^a (0.088)	0.563^a (0.075)	0.635^a (0.061)
$\Delta \ln e_{DEST/ORIG} \times D_{LCP}$	0.001 (0.046)	−0.009 (0.045)	0.048 (0.071)	−0.014 (0.037)
$\Delta \ln e_{DEST/VCP}$	0.643^a (0.067)	0.501^a (0.078)	0.579^a (0.078)	0.590^a (0.065)
Sample	Excl. top 1% firms	Top 1% firms only	Excl. top 5% firms	Top 5% firms only
Observations	3,514,253	1,688,155	2,033,827	3,166,163
R-squared	0.206	0.051	0.276	0.074

Notes: Firm-quarter, origin country-product, and currency of invoicing fixed effects are included. Contemporaneous and eight lags of the origin country's quarterly inflation rate, as well as eight lags of the log change in each exchange rate are also included (not reported). Robust standard errors adjusted for clustering at the country-year level are reported in parentheses. [a] indicates significance at the one percent level. The dependent variable is the quarterly log change import unit value (in sterling per kilogram).

Fixed Effects Finally, in Table A8 we check whether our results remain robust to using alternative combinations of fixed effects (recall that our estimations control for firm-quarter and origin country-product fixed effects). Due to space constraints, we now replicate the specifications of Table 5 but with alternative sets of fixed effects (the results remain similar if we instead estimate equation 4). We include no fixed effects in Panel A, origin country-product fixed effects in Panel B, and firm-quarter dummy variables in Panel C. Compared to Table 5, the contemporaneous pass-through elasticities are on average larger without any fixed effects (except for the producer currency priced transactions in

[42]In 2010, China changed its foreign exchange policy to a "crawl-like arrangement" relative to the US dollar. In 2016, the flexibility of the renminbi instead became limited relative to a basket of currencies.

column 2), and they increase in magnitude with origin country-product fixed effects. They are similar in magnitude, and even slightly smaller once we include firm-quarter fixed effects. But most importantly, the pattern of our results across invoicing choices remains very similar in the three panels.

Table A8: Robustness – Fixed Effects

	(1)	(2)	(3)	(4)	(5)	(6)
	All	PCP	LCP	VCP	VCP	VCP
Panel A – No fixed effects						
$\Delta \ln e_{DEST/ORIG}$	0.435[a] (0.033)	0.639[a] (0.040)	0.112[a] (0.023)	0.472[a] (0.050)	–	–
$\Delta \ln e_{DEST/VCP}$	–	–	–	–	0.661[a] (0.023)	0.606[a] (0.021)
$\Delta \ln e_{VCP/ORIG}$	–	–	–	–	0.169[a] (0.033)	–
Observations	5,792,400	1,559,920	1,270,283	2,962,197	2,962,197	2,962,197
Panel B – Origin country-product fixed effects						
$\Delta \ln e_{DEST/ORIG}$	0.455[a] (0.033)	0.650[a] (0.040)	0.129[a] (0.023)	0.502[a] (0.051)	–	–
$\Delta \ln e_{DEST/VCP}$	–	–	–	–	0.681[a] (0.023)	0.624[a] (0.021)
$\Delta \ln e_{VCP/ORIG}$	–	–	–	–	0.184[a] (0.035)	–
Observations	5,769,236	1,552,379	1,257,794	2,942,993	2,942,993	2,942,993
Panel C – Firm-quarter fixed effects						
$\Delta \ln e_{DEST/ORIG}$	0.172[a] (0.025)	0.705[a] (0.108)	0.058 (0.039)	0.117[a] (0.030)	–	–
$\Delta \ln e_{DEST/VCP}$	–	–	–	–	0.606[a] (0.142)	0.535[a] (0.147)
$\Delta \ln e_{VCP/ORIG}$	–	–	–	–	0.089[a] (0.033)	–
Observations	5,237,681	1,280,933	1,079,552	2,620,314	2,620,314	2,620,314
Panel D – Firm and origin country-product fixed effects						
$\Delta \ln e_{DEST/ORIG}$	0.460[a] (0.033)	0.660[a] (0.041)	0.132[a] (0.023)	0.510[a] (0.053)	–	–
$\Delta \ln e_{DEST/VCP}$	–	–	–	–	0.695[a] (0.024)	0.642[a] (0.022)
$\Delta \ln e_{VCP/ORIG}$	–	–	–	–	0.184[a] (0.036)	–
Observations	5,745,060	1,540,140	1,249,289	2,926,445	2,926,445	2,926,445
Panel E – Firm-year and origin country-product fixed effects						
$\Delta \ln e_{DEST/ORIG}$	0.447[a] (0.037)	0.680[a] (0.056)	0.133[a] (0.031)	0.496[a] (0.051)	–	–
$\Delta \ln e_{DEST/VCP}$	–	–	–	–	0.772[a] (0.029)	0.733[a] (0.031)
$\Delta \ln e_{VCP/ORIG}$	–	–	–	–	0.178[a] (0.043)	–
Observations	5,674,778	1,504,570	1,226,762	2,881,212	2,881,212	2,881,212

Notes: Contemporaneous and eight lags of the origin country's quarterly inflation rate, as well as eight lags of the log change in each exchange rate are also included (not reported). Robust standard errors adjusted for clustering at the country-year level are reported in parentheses. [a] indicates significance at the one percent level. The dependent variable is the quarterly log change import unit value (in sterling per kilogram). To save space, the R-squared are not reported but are available upon request.

Given that around 90 percent of the transactions priced in a vehicle currency are in US dollars (Table 2), it is likely that many firms use exclusively the US dollar as a vehicle currency in a given quarter. For these firms, the variation in the sterling to vehicle currency exchange rate is therefore fully absorbed by the firm-quarter fixed effects. To address this issue, in Panels D and E we control for origin country-product and for firm-, or firm-year fixed effects, respectively. Compared to Table 5, the pass-through elasticities are on average larger (except for the producer currency priced transactions), but across invoicing choices they remain low for the local currency priced transactions, and large for the producer currency priced and the vehicle currency priced transactions.

B Export Unit Values

In this appendix we show that our results hold for export unit values. We describe our sample and proceed with the estimation of exchange rate pass-through for export unit values by invoicing currency.

B.1 Descriptive Statistics

Transaction-level FOB exports are obtained from HMRC. We observe a unique trader identifier, the destination country, the transaction date, the 5-digit SITC Revision 3 and the 4-digit HS Revision 2007 classifications, the 10-digit comcode product code, the value (in sterling), the mass (in kilograms), and the currency of invoicing between 2011 and 2017 for non-EU transaction values exceeding £100,000 only. In our data set, non-EU exports represent 54 percent of total UK exports. Export unit values are obtained by dividing the quarterly transaction value in sterling by its mass in kilograms.

Compared to our sample for imports, Table B1 shows that for exports we observe fewer firms (53,338) and products (8,596) but more destination countries (190), with a total of 2,675,099 observations.[43] On average, these firms export 3.3 different products to 3.2 destination countries (at the 5^{th} and 95^{th} percentiles, the products per exporter are 1 and 10, while the destinations per exporter are 1 and 12). Exporters charge on average 230,459 pound sterling in each quarter, or 1,929.6 pound sterling per kilogram. The mean change in export unit values is equal to 0.6 percent per quarter.

Table B1: Summary Statistics

	Mean	Median	Std. dev.	5^{th} percentile	95^{th} percentile
Exporters	53,338	–	–	–	–
Products	8,596	–	–	–	–
Destination countries	190	–	–	–	–
Products per exporter	3.3	2	14.0	1	10
Destinations per exporter	3.2	1	4.9	1	12
Unit values (sterling/kg)	1,929.6	55.4	127,703.8	1.7	2,381.0
Change in log unit values (~%)	0.6	0.1	0.9	-145.3	147.2
Transaction values (sterling)	230,459	12,049	4,040,993	1,105	497,278

Notes: For each variable, the table reports its mean, median, standard deviation, and values at the 5^{th} and 95^{th} percentiles. Changes in log unit values (in ~%) are calculated quarterly.

The largest non-EU export markets of the UK are the US (34.4 percent of total non-EU exports between 2011 and 2017), China (9.7 percent), the United Arab Emirates (4.4 percent), Hong Kong (4.0 percent), Japan (3.5 percent), Canada (3.2 percent), and Singapore (3.2 percent).

Table B2 reports descriptive statistics for exports by invoicing currency. The largest share of exports is invoiced in producer currency (sterling) at 53.3 percent, followed by 25.1 percent in vehicle currency,

[43] In our sample, the UK exports to, but does not import from the Comoros, the Cook Islands, Eritrea, Guinea-Bissau, Kiribati, the Mariana Islands, Mayotte, Melilla, Montserrat, Pitcairn, Saint Pierre et Miquelon, and Timor-Leste. Instead, the UK imports from, but does not export to the Norfolk Islands, Tuvalu, and the US Minor Islands.

and 21.6 percent in local currency. A total of 65 different vehicle currencies are used, but 85.4 percent of the value of the transactions priced in a vehicle currency are in US dollars and 13.9 percent in euros. In terms of transaction counts, these correspond to shares of 73.7 and 24.5 percent. Unit values are the highest for vehicle currency priced goods at 2,887.7 pound sterling per kilogram.

Table B2: Descriptive Statistics by Invoicing Currency

	Obs.	Firms	Products	Dest.	Products per firm	Dest. per firm	Unit values	Export values	Export shares
LCP	345,354	14,110	5,570	75	2.93	1.23	1,836.60	451,502	21.60
PCP	1,701,237	47,803	8,318	189	2.92	2.84	1,631.11	242,714	53.33
VCP	628,508	16,761	6,251	171	2.85	3.06	2,887.70	285,232	25.07
VCP (USD)	463,399	12,451	5,559	164	2.90	3.02	3,533.74	285,152	85.42
VCP (Euro)	153,822	8,958	4,690	158	2.12	2.08	788.23	143,323	13.91
VCP (Other)	11,287	1,054	1,242	106	2.05	1.61	3,494.92	92,884	0.66

Notes: For each invoicing currency choice, the table reports the number of observations, exporters, products, destinations, products per firm, destinations per firm, the mean unit value (in sterling per kilogram), the mean export value (in sterling), and exports as a share of total non-EU exports (in %).

The left panel of Table B3 reports export shares by invoicing currency and industry (at the 1-digit SITC level). Producer currency pricing (sterling) is the dominant strategy for all industries, consistent with Table B2. Its share varies from 43.07 percent for "Chemicals" to 69.39 percent for "Mineral fuels." The right panel of the table splits the data by region of destination. Producer currency pricing is the most widely used strategy for all regions except for the US where local currency pricing dominates.

Table B3: Invoicing Currency by Industry and Region

Industry (SITC)	PCP	LCP	VCP	Share	**Destination**	PCP	LCP	VCP	Share
Food, live animals	63.28	14.38	22.34	1.87	US	47.02	50.83	2.15	34.41
Beverages, tobacco	48.98	33.55	17.47	3.51	China	65.60	5.45	28.95	9.72
Crude materials	64.87	4.98	30.14	2.87	East/S. East Asia	54.78	7.71	37.51	22.84
Mineral fuels	69.39	21.94	8.67	4.54	Europe excl. EU	60.08	5.89	34.03	11.13
Animal, vegetable oils	60.33	8.53	31.14	0.04	Other Americas	44.86	11.78	43.36	6.87
Chemicals	43.07	37.51	19.42	17.76	All others	56.52	2.34	41.13	15.02
Manufactured goods	50.86	11.41	37.74	9.69					
Machinery	53.30	18.44	28.27	47.03					
Miscellaneous manuf.	61.08	20.26	18.67	12.69					

Notes: The table reports the export share in terms of value by industry at the SITC 1-digit level, by destination country group, and by currency of invoicing (in %).

B.2 Exchange Rate Pass-Through

To evaluate exchange rate pass-through for export unit values, we estimate the following specification:

$$\Delta \ln UV_{ijk,t} = \sum_{n=0}^{N} \gamma_n \Delta \ln e_{j,t-n} + \sum_{n=0}^{N} \delta_n \pi^*_{j,t-n} + \sum_{n=0}^{1} \varrho_n Y^*_{j,t-n} + D_{i,t} + D_{jk} + \xi_{ijk,t}, \tag{B1}$$

where in contrast to equation (1), $UV_{ijk,t}$ is now the unit value of product k exported by firm i to country j in quarter t, expressed in sterling per kilogram, and j denotes the destination country for exports. In addition to controlling for the foreign inflation rate $\pi^*_{j,t}$, we also control for the growth of GDP in the destination country $Y^*_{j,t}$, included contemporaneously and with one lag (Gopinath et al., 2010).[44] Again, $e_{j,t}$ is the bilateral exchange rate between sterling and the currency of country j in quarter t (an increase in $e_{j,t}$ indicates a bilateral depreciation of sterling), and we include up to eight lags for the nominal exchange rate and the foreign inflation rate. We include firm-quarter $D_{i,t}$ and destination country-product fixed effects D_{jk}. Short-run pass-through into export unit values is captured by the coefficient γ_0 on the contemporaneous change in the exchange rate, whereas the cumulative estimate $\gamma(n) \equiv \sum_{n=0}^{N} \gamma_n$ evaluates long-run pass-through. Robust standard errors are adjusted for clustering at the destination country-year level.

We estimate equation (B1) using the full sample of exports, and separately for the three subsamples of export transactions invoiced in producer, local, and vehicle currencies. For the transactions in vehicle currencies we then decompose the bilateral exchange rate in equation (B1) as:

$$\Delta \ln e_{j,t} \equiv \Delta \ln e_{ORIG/DEST_t} = \Delta \ln e_{ORIG/VCP_t} + \Delta \ln e_{VCP/DEST_t}, \tag{B2}$$

where $ORIG$ denotes the origin country (now the UK) and $DEST$ the destination country for exports. We then estimate:

$$\begin{aligned} \Delta \ln UV^{VCP}_{ijk,t} &= \sum_{n=0}^{N} \vartheta_n \Delta \ln e_{ORIG/VCP_{t-n}} + \sum_{n=0}^{N} \zeta_n \Delta \ln e_{VCP/DEST_{t-n}} + \sum_{n=0}^{N} \varkappa_n \pi^*_{j,t-n} \\ &\quad + \sum_{n=0}^{1} \varpi_n Y^*_{j,t-n} + D_{i,t} + D_{jk} + \eta_{ijk,t}, \end{aligned} \tag{B3}$$

where we allow for separate coefficients ϑ_n and ζ_n on the two exchange rates with the vehicle currency. We estimate equations (B1) and (B3), but due to space constraints we only report and discuss the contemporaneous exchange rate elasticities. The long-run elasticities are available upon request.

Column (1) of Table B4 reports the results of estimating equation (B1) on the full sample of exports. The coefficient on the contemporaneous change in the bilateral exchange rate is equal to 0.036 but is not significant. Therefore, pass-through into import unit values is complete.

Columns (2) to (4) report the results of estimating equation (B1) separately for the transactions invoiced in producer, local, and vehicle currencies. The effect of exchange rate changes varies substantially across invoicing choices. The coefficient on the bilateral exchange rate is insignificant for the transactions priced in producer (column 2) and vehicle (column 4) currencies, and large at 0.589 for the ones in local currencies (column 3). As a result, pass-through into import unit values is complete for producer and vehicle currencies, and low for local currencies. These findings are consistent with Corsetti et al. (2018).

[44] The GDPs are from the International Financial Statistics of the International Monetary Fund.

Table B4: Pass-Through into Export Unit Values

	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \ln e_{ORIG/DEST}$	0.036 (0.030)	0.050 (0.040)	0.589^{a} (0.199)	-0.049 (0.047)	–	–
$\Delta \ln e_{ORIG/VCP}$	–	–	–	–	0.288^{b} (0.142)	0.343^{b} (0.137)
$\Delta \ln e_{VCP/DEST}$	–	–	–	–	-0.062 (0.047)	–
Invoicing currency	All	PCP	LCP	VCP	VCP	VCP
Observations	2,432,614	1,474,268	272,006	547,704	547,704	547,704
R-squared	0.136	0.178	0.224	0.167	0.167	0.167

Notes: Firm-quarter and destination country-product fixed effects are included. Contemporaneous and eight lags of the destination country's quarterly inflation rate, eight lags of the log change in each exchange rate, and the contemporaneous and one lag of the destination country's GDP growth rate are also included (not reported). Robust standard errors adjusted for clustering at the country-year level are reported in parentheses. ^{a} and ^{b} indicate significance at the one and five percent levels, respectively. The dependent variable is the quarterly log change export unit value (in sterling per kilogram).

For the subsample of vehicle currency priced transactions, we then regress equation (B3) and decompose the bilateral exchange rate according to equation (B2). Column (5) shows that export unit values react to changes in the sterling to vehicle currency exchange rate, but do not change when the vehicle to destination country's currency exchange rate fluctuates. These findings are again consistent with the premise that unit values are sticky in their currency of invoicing. Column (6) excludes the exchange rate between the vehicle and the destination country's currency, and the coefficient on the sterling to vehicle currency exchange rate is equal to 0.343.

In results available upon request, we show that our findings remain similar if we let the pass-through elasticities vary across industries. Our results also remain robust if we estimate a specification similar to equation (4) on the full sample of export unit values and include interactions between exchange rate changes and dummies for invoicing choices.

C Import and Export Quantities

The regressions for trade quantities take the same form as the pass-through regressions (1) and (3) for imports and (B1) and (B3) for exports, except that the dependent variable is the log change of import or export quantities (in kilograms), and the foreign inflation rates are omitted (the results remain similar if we control for the foreign inflation rates).

For both export and import quantities, the contemporaneous and lagged coefficients on the exchange rate changes are erratic and mostly insignificant. Table C1 only reports, for both exports and imports, the contemporaneous estimates on the exchange rate changes. For imports, all exchange rate elasticities are insignificant across all invoicing choices. For exports, the elasticities are either insignificant, positive (in column 4 for the transactions in a vehicle currency when the bilateral exchange rate fluctuates), or negative (in column 3 for the local currency priced transactions, and in columns 5 and 6 for the vehicle currency priced transactions when the sterling to vehicle currency exchange rate changes). The results remain similar if we express export and import quantities in units rather than in kilograms (although in that case, the sample sizes are smaller), and if we estimate specifications similar to equation (4) using the full samples of export and import quantities with interactions between changes in exchange rates and dummies for invoicing choices.

Table C1: Import and Export Quantities

	(1)	(2)	(3)	(4)	(5)	(6)
Imports						
$\Delta \ln e_{DEST/ORIG}$	0.039 (0.085)	0.076 (0.119)	0.103 (0.145)	−0.015 (0.098)	–	–
$\Delta \ln e_{DEST/VCP}$	–	–	–	–	−0.512 (0.383)	−0.505 (0.375)
$\Delta \ln e_{VCP/ORIG}$	–	–	–	–	−0.014 (0.091)	–
Observations	5,212,648	1,272,740	1,065,890	2,599,546	2,599,546	2,599,546
R-squared	0.156	0.208	0.202	0.183	0.184	0.184
Exports						
$\Delta \ln e_{ORIG/DEST}$	−0.004 (0.115)	−0.033 (0.153)	-0.558^{c} (0.291)	0.174^{c} (0.091)	–	–
$\Delta \ln e_{ORIG/VCP}$	–	–	–	–	-0.695^{b} (0.308)	-0.860^{a} (0.305)
$\Delta \ln e_{VCP/DEST}$	–	–	–	–	0.188^{b} (0.093)	–
Invoicing currency	All	PCP	LCP	VCP	VCP	VCP
Observations	2,432,696	1,474,309	272,001	547,746	547,746	547,746
R-squared	0.139	0.181	0.248	0.174	0.174	0.175

Notes: Firm-quarter and origin/destination country-product fixed effects are included. Eight lags of the log change in each exchange rate are also included (not reported). The contemporaneous and one lag of the destination country's GDP growth rate are included for exports (not reported). Robust standard errors adjusted for clustering at the country-year level are reported in parentheses. ^{a}, ^{b}, and ^{c} indicate significance at the one, five, and ten percent levels, respectively. The dependent variable is the quarterly log change of import or export quantities (in kilograms).

D Import Price Inflation

In this appendix we describe how we calculate our back-of-the-envelope estimates capturing how exchange rate movements affect UK import price inflation in the short and in the long run.

Currency of Invoicing Shares for World Imports In our data set, we only observe the currency of invoicing shares for non-EU imports. To obtain the shares for world imports, we rely on aggregate data from Gopinath (2016) showing that in 2015 total UK imports were priced in euros (14.78 percent), US dollars (47.16 percent), sterling (31.73 percent), and other currencies (6.33 percent). We assume that these shares do not change much over time, and therefore apply them to the 2010 to 2017 period we focus on in our analysis.[45] While the total LCP (sterling) share is 31.73 percent, the magnitude of the PCP and VCP shares is unknown as the data are unavailable by country of origin. As we explain below, we therefore calculate the PCP and VCP shares for world imports assuming that the US dollar and the euro are the main foreign currencies used to price UK imports.

To obtain the VCP share of UK world imports, we proceed as follows. First, to get the VCP share in US dollars, we subtract from the total import share in US dollars (47.16 percent) the import share from the US in US dollars.[46] In our full sample (i.e., including the "Not classified" industry that we exclude from our regressions), imports from the US in US dollars represent 14.51 percent of total non-EU imports.[47] As non-EU imports amount to 50.05 percent of total UK imports between 2010 and 2017 (Direction of Trade Statistics of the International Monetary Fund), the share of US imports in US dollars in total UK imports is 7.26 percent ($0.1451 \times 0.5005 = 0.0726$). The total VCP share in US dollars is therefore equal to 39.90 percent ($47.16 - 7.26 = 39.90$). Second, we observe that 5.32 percent of non-EU imports are in euros. It follows that the total VCP share in euros is equal to 2.66 percent ($0.0532 \times 0.5005 = 0.0266$).[48] The total VCP share is therefore equal to 42.56 percent ($39.90 + 2.66 = 42.56$).

Next, we define the total PCP share as the import share from the US in US dollars (7.26 percent), plus the import share from the EU in euros (i.e., 14.78 percent less 2.66 percent, or 12.12 percent), which amounts to 19.38 percent. We then allocate the 6.33 percent of UK world imports invoiced in other currencies to either the VCP or PCP shares, and we therefore consider two alternative scenarios for the magnitude of these shares, as reported in Table D1.

Exchange Rate Changes To measure the average appreciation or depreciation of sterling in each of the three quarterly episodes, we proceed in two steps. First, we calculate the log change of all

[45] Boz et al. (2017) observe that aggregate invoicing shares tend to remain fairly stable over time.

[46] We ignore here that some small countries use the US dollar as their main currency.

[47] Our results remain very similar if we exclude the "Not classified" industry.

[48] We assume that all EU countries use the euro because our data set does not allow us to identify the currency of invoicing for the EU countries which have not adopted the euro. In addition to the UK, eight EU member states do not use the euro (Bulgaria, Croatia, the Czech Republic, Denmark, Hungary, Poland, Romania, and Sweden, while Latvia and Lithuania adopted the euro in 2014). Between 2010 and 2017, the import shares of the UK from the EU and from the Eurozone are equal to 49.95 and 43.15 percent (Direction of Trade Statistics of the International Monetary Fund).

Table D1: Currency of Invoicing Shares for UK World Imports

Scenario 1		Scenario 2	
Currency choice	Share	Currency choice	Share
LCP	31.73%	LCP	31.73%
PCP	25.71%	PCP	19.38%
VCP	42.56%	VCP	48.89%

Source: Authors' calculations.

sterling bilateral exchange rates (with the UK's import partners), and of the sterling to vehicle currency exchange rates, between the quarter when the exchange rate shock took place and the previous quarter. Second, we calculate weighted averages of these exchange rate changes using weights computed for UK world imports: (1) the average of bilateral exchange rate changes weighted by bilateral import shares, (2) the average of bilateral exchange rate changes weighted by LCP or PCP bilateral imports as a share of total LCP or PCP imports, and (3) the average of the sterling to vehicle currency exchange rate changes weighted by imports in each vehicle currency as a share of total VCP imports. To assess the individual effects of the US dollar and the euro, we calculate weighted exchange rate changes for the two currencies only.

To calculate the import weights by invoicing currency for UK world imports, we multiply the non-EU invoicing shares of each country by 0.5005 (the UK's import share from non-EU countries between 2010 and 2017) to get the shares out of total UK imports, and we then divide by the invoicing shares (two different scenarios) reported in Table D1 to get the shares as a proportion of total LCP or PCP imports. For the EU as a whole, the LCP and PCP shares are obtained by subtracting from 100 percent the sum of the shares for the other countries. For the import shares in vehicle currencies, we follow the same procedure and further assume that all VCP imports from the EU are in US dollars. According to Gopinath (2016), apart from invoicing in euros EU countries mostly invoice in US dollars.

Pass-Through into Import Price Inflation For simplicity, we only explain here how we calculate the estimates reported in columns (1) and (2) of Table 8 for the depreciation of sterling following the EU referendum of 2016. Based on the standard pass-through regression (with bilateral exchange rates) reported in column (1) of Table 5, where the contemporaneous exchange rate elasticity is equal to 0.179, we calculate that the 7.09 percent average bilateral depreciation of sterling increases import price inflation by 1.271 percentage points on impact. The effect is calculated as $(0.0709 \times 0.179) = 1.271$ percentage points where 0.0709 is the average bilateral depreciation and 0.179 is the pass-through elasticity. After eight quarters, the pass-through elasticity increases to 0.413, implying that import price inflation rises by 2.927 percentage points.

Once we account for the currency of invoicing, our point estimates reported in column (3) of Table 6 imply that the depreciation of sterling increases import price inflation by 2.786 percentage points on impact, and by 3.154 percentage points after eight quarters. The contemporaneous effect is calculated as $(0.0752 \times 0.002 \times 0.3173) + (0.0727 \times 0.620 \times 0.2571) + (0.0643 \times 0.592 \times 0.4256) = 2.786$ percentage

Table D2: UK Import Price Inflation

		(1)	(2)	(3)	(4)
		World imports		**Non-EU imports**	
		$t=0$	$t=8$	$t=0$	$t=8$
EU Referendum (2016M6–2016M8)					
Bilateral rates	All currencies	1.271^a (0.199)	2.927^a (0.447)	0.588^a (0.092)	1.354^a (0.207)
	USD	0.105^a (0.016)	0.243^a (0.037)	0.103^a (0.016)	0.236^a (0.036)
	Euro	0.668^a (0.104)	1.537^a (0.234)	–	–
Bilateral/vehicle rates	All currencies	2.724^a (0.285)	3.052^a (0.617)	1.482^a (0.147)	1.615^a (0.318)
	USD	2.017^a (0.186)	2.054^a (0.398)	1.225^a (0.109)	1.264^a (0.233)
	Euro	0.570^a (0.084)	0.767^a (0.175)	0.121^a (0.012)	0.120^a (0.025)
All currencies against sterling (weighted)		+7.09%		+6.55%	
US dollar against sterling		+6.34%		+6.34%	
Euro against sterling		+7.66%		+7.66%	
Great Recession (2008M11–2009M1)					
Bilateral rates	All currencies	2.320^a (0.362)	5.343^a (0.815)	1.213^a (0.189)	2.792^a (0.426)
	USD	0.323^a (0.050)	0.744^a (0.113)	0.315^a (0.049)	0.724^a (0.110)
	Euro	1.075^a (0.168)	2.477^a (0.378)	–	–
Bilateral/vehicle rates	All currencies	7.349^a (0.730)	7.953^a (1.578)	4.198^a (0.400)	4.492^a (0.864)
	USD	6.179^a (0.570)	6.290^a (1.221)	3.752^a (0.334)	3.872^a (0.715)
	Euro	0.918^a (0.135)	1.236^a (0.282)	0.194^a (0.019)	0.194^a (0.041)
All currencies against sterling (weighted)		+12.94%		+13.52%	
US dollar against sterling		+19.43%		+19.43%	
Euro against sterling		+12.34%		+12.34%	
EU Debt Crisis (2015M1–2015M3)					
Bilateral rates	All currencies	−0.477^a (0.074)	−1.097^a (0.167)	0.065^a (0.010)	0.150^a (0.023)
	USD	0.079^a (0.012)	0.182^a (0.028)	0.077^a (0.012)	0.177^a (0.027)
	Euro	−0.544^a (0.085)	−1.252^a (0.191)	–	–
Bilateral/vehicle rates	All currencies	1.050^a (0.098)	0.928^a (0.198)	0.822^a (0.075)	0.863^a (0.161)
	USD	1.512^a (0.140)	1.540^a (0.299)	0.918^a (0.082)	0.948^a (0.175)
	Euro	−0.464^a (0.068)	−0.625^a (0.143)	−0.098^a (0.010)	−0.098^a (0.021)
All currencies against sterling (weighted)		-2.66%		+0.73%	
US dollar against sterling		+4.76%		+4.76%	
Euro against sterling		-6.24%		-6.24%	

Notes: Estimates reported in percentage points. The estimates in columns (1) and (2) for world imports are based on scenario 2 for the invoicing shares (Table D1). The estimates reported in the rows "Bilateral rates" are obtained based on the regression in column (1) of Table 5. The estimates reported in the rows "Bilateral/vehicle rates" are obtained using the regression in column (3) of Table 6. ^{a} indicates significance at the one percent level.

points. The values 0.0752 and 0.0727 are the average bilateral depreciations of sterling for the LCP and PCP transactions, while 0.0643 is the average depreciation of sterling against vehicle currencies for the VCP flows. The short-run pass-through elasticities for the LCP, PCP, and VCP transactions are equal to 0.002, 0.620, and 0.592. The values 0.3173, 0.2571, and 0.4256 are the LCP, PCP, and VCP invoicing shares for world imports (scenario 1). The individual effects of the US dollar and the euro are calculated in the same way as for the effects of all currencies, but we use the average exchange rate changes against these currencies only (weighted by their respective shares) to evaluate their pass-through into import prices.

Table 8 in the main text reports our estimates based on scenario 1 for the invoicing shares, while columns (1) and (2) of Table D2 rely on scenario 2. Overall, the two scenarios yield very similar results (notice that the estimates for bilateral exchange rates only are identical for both scenarios).

Columns (3) and (4) of Table D2 report our estimates for non-EU imports. These estimates are calculated in the same way as for world imports but with two differences. First, we use the currency of invoicing shares that we directly observe in our sample for non-EU imports, and we compute the corresponding weighted averages of exchange rate changes with non-EU trading partners only. Second, all estimates are further multiplied by 0.5005 which is the UK import share from non-EU countries between 2010 and 2017. As a result, the response of import price inflation to changes in exchange rates is smaller in magnitude for non-EU than for world imports.

Overall, the results for non-EU imports are qualitatively similar to the ones for world exports, with a few differences. First, for the specification with bilateral exchange rates only, the euro plays no role. Second, once we allow for the effects of vehicle currencies, the contribution of the euro is modest as it is only used as a vehicle currency in non-EU imports. Also, the contribution of the US dollar for non-EU imports (in columns 3 and 4 of Table D2) is smaller than for world imports (in columns 1 and 2) because EU countries widely use the US dollar as a vehicle currency. Finally, for the European Sovereign Debt Crisis, the specification with bilateral exchange rates only for non-EU imports shows that exchange rate movements increase import price inflation as the appreciation against the euro is not accounted for. Once we consider vehicle currencies, fluctuations in exchange rates also increase import price inflation as the fall in inflation induced by the appreciation against the euro (only used as a vehicle currency in non-EU imports) is offset by the depreciation against the US dollar.

EU Referendum Finally, in Table D3 we recalculate our back-of-the-envelope estimates for the depreciation of sterling following the EU referendum of June 2016 using the pass-through elasticities we estimate for the post-referendum period (reported in columns 1 and 4 of Table A2 in Appendix A). We also compute the different exchange rate series and the currency of invoicing shares for the 2016Q3–2017Q4 period only. As the pass-through elasticities are slightly smaller in the post-referendum period than in the full sample 2010–2017, the magnitude of our back-of-the-envelope estimates is now reduced (compared to the estimates reported in Tables 8 and D2). But overall, the patterns remain very similar.

When we consider bilateral exchange rates only, for world imports the depreciation against the euro increases import price inflation by more than the depreciation against the US dollar (columns 1–4). Once we account for invoicing currencies, the effects of exchange rate changes on import price inflation increase in magnitude because the depreciation against the US dollar is given a larger weight than the depreciation against the euro.

Table D3: UK Import Price Inflation after the EU Referendum

		(1)	(2)	(3)	(4)	(5)	(6)
Invoicing shares		**Scenario 1**		**Scenario 2**		**Non-EU imports**	
		$t = 0$	$t = 8$	$t = 0$	$t = 8$	$t = 0$	$t = 8$
Bilateral rates	All currencies	0.945^a (0.242)	2.333^a (0.699)	0.945^a (0.242)	2.333^a (0.699)	0.432^a (0.111)	1.066^a (0.319)
	USD	0.087^a (0.022)	0.214^a (0.064)	0.087^a (0.022)	0.214^a (0.064)	0.084^a (0.021)	0.206^a (0.062)
	Euro	0.496^a (0.127)	1.225^a (0.367)	0.496^a (0.127)	1.225^a (0.367)	–	–
Bilateral/vehicle rates	All currencies	2.674^a (0.532)	3.098^a (0.848)	2.583^a (0.523)	2.909^a (0.835)	1.371^a (0.269)	1.493^a (0.438)
	USD	1.497^a (0.298)	1.498^a (0.499)	1.701^a (0.341)	1.690^a (0.571)	1.060^a (0.204)	1.093^a (0.343)
	Euro	0.964^a (0.224)	1.291^a (0.337)	0.663^a (0.171)	0.903^a (0.254)	0.098^a (0.021)	0.090^b (0.036)
Exchange rate shock		2016M6–2016M8		2016M6–2016M8		2016M6–2016M8	
All currencies against sterling (weighted)		+7.14%		+7.14%		+6.64%	
US dollar against sterling		+6.34%		+6.34%		+6.34%	
Euro against sterling		+7.66%		+7.66%		+7.66%	

Notes: Estimates reported in percentage points. The estimates reported in the rows "Bilateral rates" are obtained based on the regression in column (1) of Table A2. The estimates reported in the rows "Bilateral/vehicle rates" are obtained using the regression in column (4) of Table A2. ^{a} and ^{b} indicate significance at the one and five percent levels, respectively.

E Theory

We extend the approach by Engel (2006) to vehicle currency pricing. Based on the framework outlined in Section 5.1, the firm can potentially change its optimal vehicle currency price p^*_{VCP} in equation (5) in response to a movement in either of the three exchange rates depicted in Figure 5. In the following we go through each case.

E.1 Reacting to the Vehicle Currency Exchange Rate

As the first case, we assume that when setting its price p^*_{VCP} in the vehicle currency, the firm only considers the *vehicle currency exchange rate* $e_{DEST/VCP}$, i.e., the exchange rate of the domestic country against the vehicle currency. Following Engel (2006) we assume that the firm can commit to flexibly setting p^*_{VCP} as an affine function of $e_{DEST/VCP}$ (in logarithms): $\ln p^*_{VCP} = \ln p_{0,VCP} - (1 - \mu_{VCP}) \ln e_{DEST/VCP}$, optimally choosing $p_{0,VCP}$ and μ_{VCP} where $p_{0,VCP}$ is denominated in the vehicle currency. Note that in Engel (2006) the price is set in "foreign currency," which refers to the destination country's currency. There is no vehicle currency in his paper. Based on the relationship in equation (5) it follows:

$$\ln p_{DEST} = \ln p_{0,VCP} + \mu_{VCP} \ln e_{DEST/VCP}, \tag{E1}$$

where μ_{VCP} is the pass-through elasticity of the vehicle currency exchange rate into the domestic price. Intuitively, suppose the firm chooses the particular parameter value $\mu_{VCP} = 1$. In that case, the price p^*_{VCP} set in vehicle currency does not depend on the exchange rate, and the firm prefers full pass-through. In contrast, when $\mu_{VCP} = 0$, the vehicle currency price responds to an exchange rate movement in a one-for-one manner such that the domestic price remains constant, which means the firm prefers zero pass-through (which is like local currency pricing). For intermediate values of μ_{VCP} with $0 < \mu_{VCP} < 1$, the firm prefers incomplete pass-through.

We now show how the firm's optimal choice of μ_{VCP} depends on expected profits, its cost structure, and the properties of the exchange rate (the solution to this optimization problem is, however, not crucial for our empirical analysis). Similar to Engel (2006), the firm maximizes the twice-differentiable concave profit function $\pi(\ln p^*_{VCP}, \ln \mathbf{x})$, where $\mathbf{x}$ is a cost vector of variables that affect the firm's profits but are exogenous to the firm. This cost vector $\mathbf{x}$ may include the exchange rate $e_{DEST/VCP}$. The firm has to choose the price for its products without knowledge about the cost vector $\mathbf{x}$.

The firm is assumed to maximize a second-order approximation of the profit function. We then solve for the optimal pass-through elasticity $\widehat{\mu}_{VCP}$, where $1 - \widehat{\mu}_{VCP}$ is the coefficient on the projection of $\ln \tilde{p}^*_{VCP}$ on the exchange rate $\ln e_{DEST/VCP}$. The result is given by:

$$1 - \widehat{\mu}_{VCP} = \frac{\pi_{px}\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right)'}{\pi_{pp}\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right)} \frac{cov\left(\ln e_{DEST/VCP}, \ln \mathbf{x}\right)}{var\left(\ln e_{DEST/VCP}\right)}, \tag{E2}$$

where $\ln \tilde{p}^*_{VCP}$ is the optimal price, $\ln \bar{\mathbf{x}}$ denotes the mean of $\ln \mathbf{x}$ around which we linearize the profit function, and $\widehat{\mu}_{VCP}$ is typically between 0 and 1.

The proof of the result in (E2) is as follows. We have the first-order condition $\pi_p\left(\ln p^*_{VCP}, \ln \bar{\mathbf{x}}\right) = 0$, and $\tilde{p}^*_{VCP}$ is the optimal price that satisfies it. Using this condition and following Engel (2006) we derive a second-order approximation of the firm's expected profits given the uncertainty of $\mathbf{x}$, defined as the firm's objective function Π:

$$
\begin{aligned}
\Pi \;\equiv\; & \mathrm{E}\, D\pi\left(\ln p^*_{VCP}, \ln \mathbf{x}\right) \approx \bar{D}\pi\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right) + \pi\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right) \mathrm{E}\left(D - \bar{D}\right) \\
& + \bar{D}\pi_p\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right) \mathrm{E}\left(\ln p^*_{VCP} - \ln \tilde{p}^*_{VCP}\right) + \bar{D}\pi_x\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right)' \mathrm{E}\left(\ln \mathbf{x} - \ln \bar{\mathbf{x}}\right) \\
& + 0.5 \left\{ \begin{array}{c} \bar{D}\pi_{pp}\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right) \mathrm{E}\left(\ln p^*_{VCP} - \ln \tilde{p}^*_{VCP}\right)^2 \\ + \bar{D}\, \mathrm{E}\left(\ln \mathbf{x} - \ln \bar{\mathbf{x}}\right)' \pi_{xx}\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right)\left(\ln \mathbf{x} - \ln \bar{\mathbf{x}}\right) \\ + 2\bar{D}\, \mathrm{E}\left(\ln p^*_{VCP} - \ln \tilde{p}^*_{VCP}\right) \pi_{px}\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right)' \left(\ln \mathbf{x} - \ln \bar{\mathbf{x}}\right) \end{array} \right\},
\end{aligned}
$$

where D is an exogenous discount factor. The expansion is around $\bar{D}$ (the mean of D) and $\ln \bar{\mathbf{x}}$ (the mean of $\ln \mathbf{x}$), and $\pi_{px}\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right)$ is a vector whose i^{th} element is $\partial^2 \pi\left(\ln p^*_{VCP}, \ln \mathbf{x}\right) / \partial \ln p^*_{VCP} \partial \ln x_i$.

Next, the objective function can be simplified using $\mathrm{E}\left(D - \bar{D}\right) = 0$, $\mathrm{E}\left(\ln \mathbf{x} - \ln \bar{\mathbf{x}}\right) = 0$, and $\pi_p\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right) = 0$ as:

$$
\Pi \propto \left\{ \begin{array}{c} \pi_{pp}\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right) \mathrm{E}\left(\ln p^*_{VCP} - \ln \tilde{p}^*_{VCP}\right)^2 \\ + \mathrm{E}\left(\ln \mathbf{x} - \ln \bar{\mathbf{x}}\right)' \pi_{xx}\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right)\left(\ln \mathbf{x} - \ln \bar{\mathbf{x}}\right) \\ + 2\, \mathrm{E}\left(\ln p^*_{VCP} - \ln \tilde{p}^*_{VCP}\right) \pi_{px}\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right)' \left(\ln \mathbf{x} - \ln \bar{\mathbf{x}}\right) \end{array} \right\}.
$$

Replacing $\ln p^*_{VCP}$ with $\ln p_{0,VCP} - (1 - \mu_{VCP}) \ln e$ (and dropping the subscript of e for simplicity), we find the first-order conditions for choosing $p_{0,VCP}$ and μ_{VCP}, respectively:

$$
\begin{gathered}
\pi_{pp}\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right) \mathrm{E}\left(\ln p_{0,VCP} - (1 - \widehat{\mu}_{VCP}) \ln e - \ln \tilde{p}^*_{VCP}\right) = 0, \\
\pi_{pp}\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right) \mathrm{E} \ln e \left(\ln p_{0,VCP} - (1 - \widehat{\mu}_{VCP}) \ln e - \ln \tilde{p}^*_{VCP}\right) \\
+ \pi_{px}\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right)' \mathrm{E} \ln e \left(\ln \mathbf{x} - \ln \bar{\mathbf{x}}\right) = 0,
\end{gathered}
$$

where $\widehat{\mu}_{VCP}$ is the value of μ_{VCP} that maximizes the objective function Π.

From the first condition above, we have $\ln p_{0,VCP} = (1 - \widehat{\mu}_{VCP}) \ln \bar{e} + \ln \tilde{p}^*_{VCP}$, where $\ln \bar{e}$ denotes the mean of $\ln e$. Substituting this into the second condition we obtain:

$$
-(1 - \widehat{\mu}_{VCP}) \pi_{pp}\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right) \mathrm{E} \ln e \left(\ln e - \ln \bar{e}\right) + \pi_{px}\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right)' \mathrm{E} \ln e \left(\ln \mathbf{x} - \ln \bar{\mathbf{x}}\right) = 0.
$$

Solving for $1-\widehat{\mu}_{VCP}$ we obtain equation (E2) as:

$$\begin{aligned} 1-\widehat{\mu}_{VCP} &= \frac{\pi_{px}\left(\ln\tilde{p}^*_{VCP},\ln\bar{\mathbf{x}}\right)'}{\pi_{pp}\left(\ln\tilde{p}^*_{VCP},\ln\bar{\mathbf{x}}\right)}\frac{\mathrm{E}\ln e\left(\ln\mathbf{x}-\ln\bar{\mathbf{x}}\right)}{\mathrm{E}\ln e\left(\ln e-\ln\bar{e}\right)} \\ &= \frac{\pi_{px}\left(\ln\tilde{p}^*_{VCP},\ln\bar{\mathbf{x}}\right)'}{\pi_{pp}\left(\ln\tilde{p}^*_{VCP},\ln\bar{\mathbf{x}}\right)}\frac{\mathrm{E}\ln e\left(\ln\mathbf{x}-\ln\bar{\mathbf{x}}\right)-\mathrm{E}\ln\bar{e}\left(\ln\mathbf{x}-\ln\bar{\mathbf{x}}\right)}{\mathrm{E}\ln e\left(\ln e-\ln\bar{e}\right)-\mathrm{E}\ln\bar{e}\left(\ln e-\ln\bar{e}\right)} \\ &= \frac{\pi_{px}\left(\ln\tilde{p}^*_{VCP},\ln\bar{\mathbf{x}}\right)'}{\pi_{pp}\left(\ln\tilde{p}^*_{VCP},\ln\bar{\mathbf{x}}\right)}\frac{\mathrm{E}\left(\ln e-\ln\bar{e}\right)\left(\ln\mathbf{x}-\ln\bar{\mathbf{x}}\right)}{\mathrm{E}\left(\ln e-\ln\bar{e}\right)^2} \\ &= \frac{\pi_{px}\left(\ln\tilde{p}^*_{VCP},\ln\bar{\mathbf{x}}\right)'}{\pi_{pp}\left(\ln\tilde{p}^*_{VCP},\ln\bar{\mathbf{x}}\right)}\frac{cov\left(\ln e,\ln\mathbf{x}\right)}{var\left(\ln e\right)}, \end{aligned}$$

where the second line is obtained by using $\mathrm{E}\left(\ln\mathbf{x}-\ln\bar{\mathbf{x}}\right)=0$ and $\mathrm{E}\left(\ln e-\ln\bar{e}\right)=0$.

E.2 Reacting to the Bilateral Exchange Rate

As the second case, we consider the scenario where the foreign firm sets its price in vehicle currency but this time it reacts to the *bilateral exchange rate* between the importer and the exporter. This exchange rate is denoted by $e_{DEST/ORIG}$ in Figure 5, defined as the price of the foreign currency in units of the domestic currency (such that an increase in $e_{DEST/ORIG}$ corresponds to a depreciation of sterling).

Analogous to the first case, we assume that the exporting firm chooses the price p^*_{VCP} in vehicle currency as a linear function of the bilateral exchange rate $e_{DEST/ORIG}$ (in logarithms): $\ln p^*_{VCP} = \ln p_{0,ORIG} - (1-\mu_{ORIG})\ln e_{DEST/ORIG}$, optimally choosing $p_{0,ORIG}$ and μ_{ORIG} where $p_{0,ORIG}$ is denominated in the vehicle currency. Substituting this function into equation (5), we obtain:

$$\ln p_{DEST} = \ln p_{0,ORIG} - (1-\mu_{ORIG})\ln e_{DEST/ORIG} + \ln e_{DEST/VCP}.$$

Using the triangular exchange rate relationship $\ln e_{DEST/VCP} = \ln e_{DEST/ORIG} - \ln e_{VCP/ORIG}$, we can rewrite this expression as:

$$\ln p_{DEST} = \ln p_{0,ORIG} + \mu_{ORIG}\ln e_{DEST/ORIG} - \ln e_{VCP/ORIG}. \tag{E3}$$

It follows that μ_{ORIG} is the pass-through elasticity of the bilateral exchange rate into the domestic price. But unlike in equation (E1), there is now a second exchange rate term on the right-hand side.

How does the firm choose μ_{ORIG}? Similar to expression (E2), the coefficient on the projection of $\ln\tilde{p}^*_{VCP}$ on the exchange rate $\ln e_{DEST/ORIG}$ follows as:

$$1-\widehat{\mu}_{ORIG} = \frac{\pi_{px}\left(\ln\tilde{p}^*_{VCP},\ln\bar{\mathbf{x}}\right)'}{\pi_{pp}\left(\ln\tilde{p}^*_{VCP},\ln\bar{\mathbf{x}}\right)}\frac{cov\left(\ln e_{DEST/ORIG},\ln\mathbf{x}\right)}{var\left(\ln e_{DEST/ORIG}\right)}. \tag{E4}$$

This gives rise to the bilateral pass-through elasticity $\widehat{\mu}_{ORIG}$.

E.3 Reacting to the Vehicle-Exporter Exchange Rate

As the third and final case, we consider the scenario where the foreign firm reacts to the exchange rate between the vehicle currency and the foreign currency, i.e., the *vehicle-exporter exchange rate*. It is denoted by $e_{VCP/ORIG}$ in Figure 5, defined as the price of foreign currency in units of the vehicle currency.

The linear pricing equation is in terms of $e_{VCP/ORIG}$ (in logarithms): $\ln p^*_{VCP} = \ln p_{0,VCP/ORIG} + \mu_{VCP/ORIG} \ln e_{VCP/ORIG}$, where the firm optimally chooses $p_{0,VCP/ORIG}$ and $\mu_{VCP/ORIG}$ and where $p_{0,VCP/ORIG}$ is denominated in the vehicle currency. Note the positive sign in front of $\mu_{VCP/ORIG}$. If the vehicle currency depreciates against the exporter's currency (i.e., if $e_{VCP/ORIG}$ increases), then the exporter should react by increasing the optimal vehicle currency price p^*_{VCP}. Substituting this function into equation (5), we obtain:

$$\ln p_{DEST} = \ln p_{0,VCP/ORIG} + \mu_{VCP/ORIG} \ln e_{VCP/ORIG} + \ln e_{DEST/VCP}. \tag{E5}$$

Thus, $\mu_{VCP/ORIG}$ is the pass-through elasticity of the vehicle-exporter exchange rate into the domestic price. Again, we have a second exchange rate term on the right-hand side.

As to the optimal choice of $\mu_{VCP/ORIG}$, the coefficient on the projection of $\ln \tilde{p}^*_{VCP}$ on the exchange rate $\ln e_{VCP/ORIG}$ follows as:

$$\widehat{\mu}_{VCP/ORIG} = \frac{-\pi_{px}\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right)'}{\pi_{pp}\left(\ln \tilde{p}^*_{VCP}, \ln \bar{\mathbf{x}}\right)} \frac{cov\left(\ln e_{VCP/ORIG}, \ln \mathbf{x}\right)}{var\left(\ln e_{VCP/ORIG}\right)}. \tag{E6}$$

E.4 Three Pass-Through Elasticities

We draw on the three pricing relationships (E1), (E3), and (E5) to arrive at estimating equations for the pass-through elasticities μ_{VCP}, μ_{ORIG}, and $\mu_{VCP/ORIG}$, respectively. In first differences we obtain:

$$\Delta \ln p_{DEST} = \mu_{VCP} \Delta \ln e_{DEST/VCP} + \varepsilon_1, \tag{E7}$$

$$\Delta \ln p_{DEST} = \mu_{ORIG} \Delta \ln e_{DEST/ORIG} - \Delta \ln e_{VCP/ORIG} + \varepsilon_2, \tag{E8}$$

$$\Delta \ln p_{DEST} = \mu_{VCP/ORIG} \Delta \ln e_{VCP/ORIG} + \Delta \ln e_{DEST/VCP} + \varepsilon_3, \tag{E9}$$

where we add the error terms ε_1, ε_2, and ε_3.

E.5 Estimation

We run these specifications in the subsample of import transactions priced in a vehicle currency. This is the same sample as in column (4) of Table 5 (the producer and local currency priced transactions are not included). We note that the coefficient on $\Delta \ln e_{VCP/ORIG}$ in equation (E8) is constrained to -1, and the coefficient on $\Delta \ln e_{DEST/VCP}$ in equation (E9) is constrained to $+1$. To be consistent with our main pass-through specifications in Section 3, we also control for firm-quarter and origin country-product fixed effects $D_{i,t}$ and D_{jk} and for the quarterly inflation rate of each country of origin. That is, we use the same specification as in equation (1) but without lagged regressors.[49]

Table E1: Three Pass-Through Elasticities: Full Sample and by Currency

	(1)	(2)	(3)
	μ_{VCP}	μ_{ORIG}	$\mu_{VCP/ORIG}$
Full sample	0.672^a (0.120)	1.069^a (0.033)	0.137^a (0.039)
R-squared	0.176	0.177	0.175
Invoicing currency			
USD	0.603^a (0.105)	1.054^a (0.038)	0.115^a (0.037)
Non-USD	0.616^a (0.120)	1.122^a (0.056)	0.247^a (0.072)
R-squared	0.176	0.177	0.175
Observations	2,599,543	2,599,543	2,599,543

Notes: Firm-quarter and origin country-product fixed effects are included. The origin country's quarterly inflation rate is also included (not reported). Robust standard errors adjusted for clustering at the country-year level are reported in parentheses. ^{a} indicates significance at the one percent level.

Column (1) of Table E1 reports the results of estimating equation (E7) with $\Delta \ln e_{DEST/VCP}$ as the key regressor. The specification thus captures how foreign exporters respond to changes in the vehicle exchange rate, with μ_{VCP} capturing the pass-through elasticity into domestic prices denominated in sterling. The top panel of Table E1 shows that in the full sample, the pass-through into import prices is 67.2 percent. Exporters thus respond to a change in the $e_{DEST/VCP}$ exchange rate by adjusting their prices set in vehicle currency by 32.8 percent of that change. We highlight that the 0.672 coefficient is remarkably similar to the 0.696 coefficient for producer currency pricing in column (2) of Table 5. Thus, we confirm our previous result from Table 5 that vehicle and producer pricing are similar in the sense that the respective pass-through elasticities are almost the same. In the bottom panel of column (1) where we estimate the pass-through elasticities by different vehicle currencies (US dollar versus non-dollar), we find no significant difference (we cannot reject the hypothesis of their being equal).

Column (2) runs specification (E8) with $\Delta \ln e_{DEST/ORIG}$ as the main regressor. We thus estimate the pass-through elasticity with respect to the bilateral exchange rate, μ_{ORIG}. The coefficient is close to unity (we cannot reject this hypothesis at the one percent level). Foreign exporters thus do not respond to bilateral exchange rates when they price in vehicle currencies (since $1 - \mu_{ORIG}$ is essentially zero; also see Appendix E.2). By different vehicle currencies (US dollar versus non-dollar) we again find no difference between the coefficients (we cannot reject the hypothesis of their being equal). We conclude that bilateral rates are not as important when exporters price transactions in a vehicle currency.[50]

[49] Results including lagged regressors are not qualitatively different. The results in column (6) of Table 5 correspond to specification (E7). The coefficients are not the same because lags are not included in Table E1. Equation (3) as estimated in column (5) of Table 5 is related to specification (E9) but differs because it does not have any constraint on the sterling to vehicle currency exchange rate.

[50] From the importer's perspective, the results suggest that after taking into account the $\Delta \ln e_{VCP/ORIG}$ rate as in

Column (3) runs specification (E9) with $\Delta \ln e_{VCP/ORIG}$ as the regressor of interest. We find a pass-through $\mu_{VCP/ORIG}$ of 13.7 percent. This means that in response to a depreciation of the vehicle currency against the exporter's currency (i.e., an increase in $e_{VCP/ORIG}$), exporters raise the vehicle currency price by 13.7 percent. Given a particular $e_{DEST/VCP}$ exchange rate level, through relationship (5) this translates into an increase of the sterling price by the same magnitude (see Appendix E.3 for details).[51] Again, we find no difference for US dollar versus non-dollar pricing (we cannot reject coefficient equality). This result is consistent with column (5) in Table 5 where the corresponding coefficient is 0.094. The vehicle-exporter exchange rate is therefore not irrelevant but quantitatively not very important for price adjustment.

Overall, as long as prices are set in a vehicle currency, our empirical evidence suggests that bilateral exchange rate movements are hardly important for exporters' price responses (see column 2 of Table E1). By contrast, exporters do respond to vehicle exchange rate movements but only to a modest extent (by 32.8 percent for $\Delta \ln e_{DEST/VCP}$ and by 13.7 percent for $\Delta \ln e_{VCP/ORIG}$ as implied by columns 1 and 3 of Table E1). Quantitatively, we find that the pass-through elasticity for vehicle currency pricing is similar to the one for producer currency pricing as long as the "relevant" exchange rate (between the importer's currency and the vehicle currency) is taken into account. This is consistent with our main findings in Section 3.[52]

specification (E8) we should observe close to full pass-through into import prices as exporters hardly respond to bilateral exchange rates. This finding is in contrast to the one in column (4) of Table 5 where $\Delta \ln e_{VCP/ORIG}$ is not taken into account. There, we find a low coefficient of 0.123, which implies that exporters respond strongly (87.7 percent) to bilateral rates. According to our analysis in Section 5.2, this contrast is due to the correlation between the two exchange rate movements, $\Delta \ln e_{DEST/ORIG}$ and $\Delta \ln e_{VCP/ORIG}$. Thus, the regression without $\Delta \ln e_{VCP/ORIG}$ is misspecified for the purpose of identifying exporters' responses to bilateral rates.

[51] If the exporter increases the vehicle currency price by 13.7 percent of the exchange rate shock, the price decreases by 86.3 percent of the shock when expressed in the exporter's currency.

[52] We run additional regressions where we allow the coefficients of Table E1 to vary across industries (available upon request). The coefficient patterns at the industry level are similar to those for the pooled sample.

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