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VEHICLE CURRENCY PRICING AND EXCHANGE RATE PASS-THROUGH

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JEL Classification: F14, F31, F41

Keywords: CPI; Dollar; Euro; Exchange Rate Pass-Through; Inflation; Invoicing; Sterling; UK; Vehicle Currency Pricing

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Vehicle Currency Pricing and Exchange Rate Pass-Through*†

Natalie Chen Wanyu Chung Dennis Novy‡

July 25, 2018

Abstract

Using detailed firm-level transactions data for UK imports, this paper studies 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. Aggregate pass-through therefore substantially increases once we account for vehicle currencies. We also show how this translates into higher pass-through for UK consumer prices, in particular during the Great Recession and in the period following the Brexit referendum. Finally, we develop a theoretical framework to conceptualize exchange rate pass-through in the context of vehicle currency pricing. Overall, our results contribute to understanding the exchange rate disconnect puzzle, and have implications for the setting of monetary policy.

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1 Introduction

One well-established fact in the open economy macroeconomics literature is 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. Common factors that lead to incomplete pass-through include the decision of exporters to price in a foreign currency in combination with price stickiness (Gopinath, Itskhoki, and Rigobon, 2010), the pricing-to-market behavior of exporters when they differentially adjust their markups across destinations in response to exchange rate movements (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).[1] One implication of partial pass-through is that the "expenditure switching" effect of exchange rate fluctuations is limited. That is, changes in exchange rates do not generate much substitution between domestic and foreign goods because their relative prices vary only little (Burstein and Gopinath, 2014; Engel, 2002).

In a large class of models with nominal rigidities, the currency in which traded goods are priced determines mechanically the degree of exchange rate pass-through and the extent of expenditure switching.[2] On the one hand, if prices are set in the exporter's currency ("Producer Currency Pricing," or PCP), the pass-through into import prices is complete. Exchange rate movements allow relative prices to adjust, inducing a substitution between domestic and foreign goods. On the other hand, if prices are set in the importer's currency ("Local Currency Pricing," or LCP), exporters price-to-market and pass-through is zero. As a result, there is no expenditure switching. Ultimately, when prices adjust in the long run, we would expect the currency of invoicing to no longer matter for the response of prices and quantities to exchange rate changes (Gopinath, 2016; Gopinath et al., 2010).

Using highly disaggregated firm-level transactions data for UK imports with non-EU countries, this paper examines the relationship between the currency of invoicing and the response of traded goods prices to changes in exchange rates. Our contribution is threefold. First, we estimate the sensitivity of import prices to exchange rate fluctuations by currency of invoicing. In contrast to papers that only consider pricing in producer or local currencies, we also allow for invoicing in a third, or vehicle, currency ("Vehicle Currency Pricing," or VCP).[3] The relation between vehicle currency pricing and pass-through has been rarely studied in the literature because the share of trade priced in a third currency is negligible for countries such as the US, and the unavailability of bilateral invoicing currency data precludes many papers from distinguishing between pricing in a vehicle or in the partner's currency (Gopinath, 2010, 2016).[4,5] Second, we investigate the implications of our findings for consumer price inflation in the UK. In particular, we show that ignoring the role of

[1] Exchange rate pass-through is traditionally 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.

[3] 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.

[4] Some papers (Goldberg and Tille, 2008, 2016) study vehicle currency pricing but not in relation to pass-through.

[5] Exceptions are Casas et al. (2016) and Fabling and Sanderson (2015).

the currency of invoicing can lead researchers to mismeasure the effect of exchange rate fluctuations on consumer price inflation. Finally, we extend the approach by Engel (2006) to allow for vehicle currency pricing. This forms our conceptual framework for explaining 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 prices. 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 with respect to other major currencies, and it has experienced significant fluctuations over time. Second, we were granted access to a highly disaggregated data set 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 2013, but for non-EU transactions only. As we do not directly observe import prices, as a proxy we compute import unit values at a quarterly frequency and at the trader-product-currency-origin levels. Finally, and crucially for our purposes, we observe large shares of import transactions invoiced in a vehicle currency. Vehicle currency pricing accounts for 55.3 percent of non-EU import transactions, whereas producer and local currency pricing represent 17.6 and 27.1 percent, respectively.[6]

Our main results can be summarized as follows. Across all transaction types, we find that on impact exchange rate pass-through is incomplete and low at 25.1 percent. We demonstrate, however, that pass-through varies substantially across invoicing choices. Pass-through is large at 61.8 percent for imports in producer currencies and not significantly different from zero for local currency (sterling). Pass-through is low at 30.6 percent for imports in vehicle currencies when we use the standard bilateral exchange rate between trading partners. However, once we allow import prices invoiced in vehicle currencies to depend on the vehicle currency exchange rate rather than the bilateral exchange rate, we find that pass-through is large at 68.9 percent and thus in the same ballpark as for producer currency pricing. This finding indicates that using the bilateral rather than the vehicle currency exchange rate substantially underestimates pass-through for goods priced in vehicle currencies (by 38.3 percentage points according to our estimates). After two years, our results remain similar. Across all transaction types, pass-through remains low at 42.2 percent. But by invoicing choice, it is large at 69.8 percent for the producer currency priced transactions, and zero for the local currency priced transactions. For the transactions in third currencies, pass-through is low at 37.1 percent when we use bilateral exchange rates, but complete when we instead consider vehicle currencies exchange rates.

In our sample, the import transactions invoiced in a vehicle currency are predominantly in US dollars (89.1 percent of the transactions in 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,

[6] 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 2013. Appendix A shows that our results also hold for exports.

however, our results continue to hold for vehicle currencies other than the US dollar. This provides strong evidence that our findings are driven by the use of vehicle currencies, and not exclusively by the US dollar as a dominant currency.

We then provide back-of-the-envelope estimates for how exchange rate movements affect UK consumer price inflation in the short run and the long run. Overall we show that, compared to predictions based on bilateral exchange rates only, the response of domestic inflation to changes in currency values can be quite different once we account for the currency of invoicing. The reason is that for the transactions priced in a third currency, import prices respond more to changes in the vehicle currency than to changes in the bilateral exchange rate. Since the US dollar is used extensively as a vehicle currency, movements in the sterling to US dollar exchange rate have a larger impact on domestic inflation.

We focus on three quarterly episodes of large sterling fluctuations and use our estimates to evaluate the dynamic response of consumer price inflation to these exchange rate shocks. Overall, our estimates can explain the higher pass-through to consumer prices that was observed during the Great Recession and following the Brexit referendum compared to the European Sovereign Debt Crisis. The reason is that the depreciation against the US dollar during the Great Recession and following the Brexit referendum is given a larger weight than the depreciation against the euro in affecting import prices, resulting in higher inflation. In contrast, during the European Sovereign Debt Crisis the fall in inflation induced by an appreciation against the euro is offset by a depreciation against the US dollar. Forbes, Hjortsoe, and Nenova (2015) argue that these differences in pass-through are driven by the nature of the shocks that move the exchange rate in the first place. We instead show that the variation in exchange rate pass-through can be explained by the currency of invoicing.

Given the strong presence of vehicle currency pricing in international trade, our results contribute to understanding the exchange rate disconnect puzzle whereby world trade prices do not seem to respond much to exchange rate movements. If we calculate a weighted average of the pass-through elasticities estimated separately for each invoicing choice (using as weights the currency of invoicing shares in our sample), allowing the transactions priced in third currencies to depend on vehicle currency exchange rates, we find that exchange rate pass-through into import prices is equal to 46.2 percent on impact, and 89.0 percent after two years. These estimates are nearly twice as large as the short and long-run pass-through rates of 25.1 and 42.2 percent that we obtain when we do not distinguish between currency of invoicing choices and use bilateral exchange rates only. For policy purposes, this suggests that not paying attention to the currency of invoicing can lead to misleading predictions regarding the effects of exchange rate changes on import prices and, in turn, on domestic inflation. 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 future inflation (Forbes et al., 2015). They should more accurately reflect the composition of invoicing currencies amongst import transactions, and in particular take into account that bilateral exchange rates are inappropriate to determine the effects of exchange rate changes on domestic inflation when a large share of imports is invoiced in third currencies.

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 may arise if a researcher ignores the vehicle currency exchange rate and erroneously focuses on the bilateral exchange rate between importer and exporter. 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 exchange rate disconnect. 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 incomplete pass-through and pricing-to-market. These papers usually find a low degree of pass-through into import prices (Campa and Goldberg, 2005; Gopinath and Rigobon, 2008) or consumer prices (Campa and Goldberg, 2010). A number of recent papers relate pass-through to firm- or product-level characteristics. Amiti, Itskhoki, and Konings (2014) document that Belgian exporters with high import shares and high export market shares have a lower pass-through to destination prices. Berman, Martin, and Mayer (2012) show that highly productive French exporters price-to-market more, leading to lower pass-through in the destination market.[7]

Within this literature, papers most closely related to our work are those that investigate the relationship between the invoicing currency and exchange rate pass-through. Due to the difficulty of obtaining invoicing currency data, especially at a disaggregated level, the available evidence is limited, however.[8] Gopinath et al. (2010) provide evidence that pass-through is low for disaggregated 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 a nominal appreciation increases the prices and reduces the quantities of firm-level exports invoiced in the exporter's currency, but has no effect when exports are priced in the destination's currency.[9] Casas et al. (2016) use firm-level price and quantity data for Colombian exports and imports but observe the currency of invoicing for exports only. Interestingly, more than 98 percent of exports are priced in US dollars. They show that for non-dollarized economies, controlling for the peso to US dollar exchange rate knocks down the effect of the bilateral exchange rate in explaining both the prices and the quantities of exports and imports. Using bilateral industry-level trade data across countries 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 and quantities. In contrast to these papers which focus mostly on the US dollar, our data set allows us to analyze 70 different vehicle currencies which are used to price UK imports.

To the best of our knowledge, Fabling and Sanderson (2015) are the only authors to allow for

[7] Other recent papers that study pass-through using disaggregated data include Auer and Schoenle (2016), Bernini and Tomasi (2015), Chatterjee, Dix-Carneiro, and Vichyanond (2013), 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 indeed theoretical. Engel (2006) and Gopinath et al. (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 the pass-through into consumer prices is lower than into import prices. Also see Choudhri and Hakura (2012), and Devereux, Engel, and Storgaard (2004).

[9] See, also, 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.

vehicle currency pricing (based on export data for New Zealand). They find that pass-through is high for firm-level exports invoiced in domestic currency, and low when priced in local and vehicle currencies. We differ from this paper in that we study the behavior of import prices which allows us to assess the sensitivity of domestic inflation to exchange rate shocks.

Second, our paper is related to studies that investigate the factors influencing 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. Using UK data, Chung (2016) shows that exporters relying more 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 currency of invoicing choices are endogenous. In this paper, we do not explain the currency of invoicing choice. Instead, we investigate how invoicing strategies and exchange rate pass-through interact with each other.

The paper is organized as follows. Section 2 describes our firm-level imports and macroeconomic data, and provides descriptive statistics. Section 3 presents our main empirical results. Section 4 derives the implications of our findings for consumer price inflation. Section 5 provides robustness checks while Section 6 theoretically analyzes exchange rate pass-through under vehicle currency pricing. Section 7 concludes.

We also provide an appendix with additional results. Appendix A reports results for export prices while Appendix B describes our findings for export and import quantities. Appendix C describes details on how we calculate the degree of exchange rate pass-through into UK consumer prices. Appendix D reports our robustness checks. Appendix E provides theoretical derivations.

2 Data and Descriptive Statistics

Our data set combines information from two different sources: transaction-level customs data and macroeconomic data.

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. Access to the data is

[10] For models that investigate 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 invoice currency, see Kamps (2006) and Ligthart and Werner (2012).

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 provided from 1996 to 2013, we concentrate our analysis on the 2010–2013 period because reporting the currency of invoicing has only become obligatory since 2010 for non-EU imports, and for transaction values exceeding £100,000 only.[13] In our data set, non-EU imports represent 52 percent of total UK imports. Data collection on the currency of invoicing for trade with EU countries is not available at the level of transactions. Given that import prices are not available, we compute the unit values of imports as the ratio between the value of a transaction in sterling and the corresponding mass in kilograms.[14] As we rely on unit values, we are unable to observe when firms adjust their prices.[15]

We clean up 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 observations where the value of imports is indicated as positive but the corresponding quantity is zero. Fourth, we aggregate the data at a quarterly frequency by computing the total quarterly transaction value for each unit of observation and then dividing by the corresponding mass in kilograms. 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).[16]

2.2 Macroeconomic Data

As shown in Figure 1, between January 2010 and December 2013 the UK experienced nominal and real exchange rate fluctuations against the US dollar exceeding a range of ten percent. The real exchange rate is defined as the ratio of consumer price indices times the monthly nominal exchange rate, where an increase indicates a real depreciation of sterling (the consumer price indices and nominal exchange rates are from the International Financial Statistics of the International Monetary Fund). On a monthly basis, sterling depreciated the most against the US dollar in February 2010 (by 6.0 and 5.6 percent in nominal and real terms), while the largest appreciation occurred in September 2013 (4.1 and 4.3 percent in nominal and real terms). For our empirical analysis in Section 3 we use the quarterly average exchange rates from the International Monetary Fund.

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

[13] However, our data set contains transactions below the £100,000 threshold because in practice, most firms report all transactions even if they fall below the threshold. The currency of invoicing is missing for around five percent of imports.

[14] Alternatively, unit values could 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 significantly reduced.

[15] 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 are (in our case, at the 10-digit level).

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

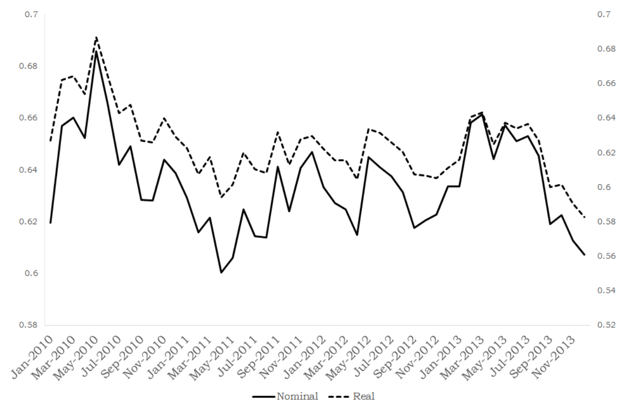


Figure 1: Sterling per US dollar, January 2010 to December 2013 (left scale for nominal, right scale for real exchange rate). Source: International Financial Statistics of the International Monetary Fund

2.3 Descriptive Statistics

As shown in Table 1, our sample between 2010 and 2013 includes 82,095 firms, 13,046 products (at the 10-digit comcode level), and 138 origin countries with a total of 2,641,208 observations. These firms import an average of 4.5 different products from 1.8 origin countries (at the 5^{th} and 95^{th} percentiles, the products per importer are 1 and 14, and the origin countries per importer are 1 and 5).[17] The mean import transaction is valued at 230,724 pound sterling in each quarter, or 827.85 pound sterling per kilogram. The mean change in import unit values is equal to 0.60 percent per quarter (at the 5^{th} and 95^{th} percentiles, the mean changes are -103.6 and 105.1 percent).

Table 1: Summary Statistics

	Mean	Median	Std. dev.	5^{th} percentile	95^{th} percentile
Importers	82,095	–	–	–	–
Products	13,046	–	–	–	–
Origin countries	138	–	–	–	–
Products per importer	4.5	2	14.25	1	14
Origins per importer	1.8	1	1.82	1	5
Unit values (sterling/kg)	827.85	13.30	67,914.40	1.05	1,108.62
Change in log unit values (%)	0.60	0.29	0.72	-103.59	105.09
Transaction values (sterling)	230,724	18,513	4,692,119	1,270	523,221

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 (19.5 percent of total non-EU imports between 2010 and 2013), followed by the US (16.1 percent), Norway (7.9 percent), Japan (5.7 percent), Hong Kong (4.3 percent), Switzerland (4.2 percent), Russia (3.9 percent), and India (3.4 percent).

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

Table 2: Descriptive Statistics by Invoicing Currency

	Obs.	Firms	Products	Origins	Products per firm	Origins per firm	Unit value	Import value	Import share
LCP	595,997	26,852	8,652	124	3.41	1.45	444.01	277,420	27.15
PCP	732,020	38,573	9,683	70	3.51	1.18	1,159.57	146,611	17.57
VCP	1,313,191	50,075	10,752	133	4.03	1.72	838.79	256,287	55.28
VCP (USD)	1,156,175	44,781	10,108	129	4.07	1.67	914.83	259,530	89.15
VCP (Euro)	141,995	12,595	6,260	112	2.21	1.34	249.50	241,992	10.23
VCP (Other)	15,021	1,918	1,873	68	2.20	1.17	499.11	137,990	0.62

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 %).

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 55.28 percent, whereas the shares in producer or local currencies are 17.57 and 27.15 percent. In total, 70 different vehicle currencies are used, but 89.15 percent of the value of these transactions is in US dollars and 10.23 percent in euros.[18] In terms of transaction counts, these correspond to shares of 88.04 and 10.81 percent, respectively. On average, unit values are the highest for goods priced in producer currency at a value of 1,159.57 pound sterling per kilogram.

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 "Mineral fuels" (90.68 percent) which are homogeneous goods (Gopinath et al., 2010; Goldberg and Tille, 2008). The vehicle currency share is also large at 85.06 percent for "Animal and vegetable oils." Instead, local currency pricing is the most widely adopted strategy for "Beverages and tobacco" at 70.91 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 49.50 percent for Asia to 76.92 percent for other regions. 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 (84.01 percent).

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 6.85 percent of the unit values priced in the producer's currency are sticky when measured in the producer's currency, compared to 5.79 percent when converted to the local currency (sterling). Similarly, for the unit values priced in local currency (sterling), 9.17 percent of them are sticky when measured in sterling, versus

[18] Other main vehicle currencies include the Hong Kong dollar, the Japanese yen, the Emirati dirham, the Australian dollar, and the Swiss franc.

[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	10.81	35.54	53.65	4.55	US	84.01	14.35	1.64	16.15
Beverages, tobacco	18.07	70.91	11.02	1.04	China	0.32	25.38	74.30	19.51
Crude materials	28.85	29.59	41.55	3.33	East/S. East Asia	6.15	44.34	49.50	26.28
Mineral fuels	3.80	5.52	90.68	15.59	Europe excl. EU	5.36	23.02	71.62	19.83
Animal, vegetable oils	10.91	4.03	85.06	0.20	Other Americas	9.91	23.56	66.52	6.90
Chemicals	29.22	34.33	36.45	8.34	All others	5.13	17.95	76.92	11.32
Manufactured goods	12.18	20.51	67.31	13.21					
Machinery	25.46	29.60	44.94	32.28					
Miscellaneous manuf.	14.24	36.38	49.38	21.46					

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 %).

6.90 percent when converted to the producer's currency. Finally, for the goods priced in a third currency, 8.30 percent of the unit values are sticky when measured in the vehicle currency, versus 7.77 and 6.73 percent when expressed in producer or local currencies, respectively. In other words, prices tend to be stickier in their currency of invoicing.

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

	Invoicing Currency		
Currency of Calculation	Producer	Local	Vehicle
Producer	**6.85**	6.90	7.77
Local (sterling)	5.79	**9.17**	6.73
Vehicle	–	–	**8.30**

Notes: The table reports the share (in %) of quarterly unit value changes that fall 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 $e_{j,t}$ (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 product-origin 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 bilateral exchange rates are assumed to be exogenous to the import prices faced by firms. Robust standard errors are adjusted for clustering at the origin country-quarter level.

As a benchmark, we first estimate equation (1) on the full sample of imports. Next, to investigate whether invoicing currency 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 currency of 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 of the sterling to vehicle currency exchange rate, and the change of the vehicle to origin country's currency exchange rate. For the transactions priced in vehicle currencies, we then estimate:

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

where we allow for separate coefficients θ_n and ψ_n on the two exchange rates. If prices are sticky in their currency of invoicing (as suggested by Table 4), we would expect pass-through into import prices 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, $\Delta \ln e_{VCP/ORIG_t}$.

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 currency 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 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 prices. We estimate equations (1), (3), and (4) but only report, and discuss, the contemporaneous exchange rate elasticities.

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. The coefficient on the contemporaneous change in the bilateral exchange rate is equal to 0.251, and is significant at the one percent level. In response to a ten percent sterling depreciation, import prices (in sterling) rise by 2.51 percent, therefore pass-through into import prices is low at 25.1 percent. This finding is consistent with other papers that find 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 Prices: Subsamples

	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \ln e_{DEST/ORIG}$	0.251^{a} (0.045)	0.714^{a} (0.150)	0.065 (0.066)	0.211^{a} (0.059)	–	–
$\Delta \ln e_{DEST/VCP}$	–	–	–	–	0.692^{a} (0.231)	0.526^{b} (0.222)
$\Delta \ln e_{VCP/ORIG}$	–	–	–	–	0.183^{a} (0.059)	–
Invoicing currency	All	PCP	LCP	VCP	VCP	VCP
Observations	2,641,208	732,020	595,997	1,313,191	1,313,191	1,313,191
R-squared	0.235	0.318	0.367	0.293	0.293	0.293

Notes: Firm-quarter and origin country-product fixed effects are included. Contemporaneous and eight lags of the origin country's quarterly inflation rates, 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-quarter 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 import unit value (in sterling per kilogram).

To investigate whether invoicing currency 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.[20] The results are reported in columns (2) to (4), respectively, and show that exchange rate pass-through varies substantially across invoicing choices. Pass-through is large at 71.4 percent for producer pricing (column 2), low at 21.1 percent for vehicle pricing (column 4), and is insignificantly different from zero for local pricing (column 3). These results highlight that estimating a single pass-through coefficient across all transaction types, 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 transactions, we regress equation (3) and decompose the bilateral exchange rate according to equation (2). This exercise has a dramatic effect on exchange rate pass-through. Pass-through is large at 69.2 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 71.4 percent. Instead, it is low at 18.3 percent for the vehicle to origin country's currency

[20] Focusing on the UK economy, Forbes, Hjortsoe, and Nenova (2015) show 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, they claim, explain why pass-through rates change over time. In our paper, we do not allow pass-through to be shock-dependent. We argue that this should not affect our analysis as the pass-through rates we estimate by currency of invoicing are all impacted by the same mix of exchange rate shocks over the period.

exchange rate.[21] These findings are consistent with prices being sticky in the currency in which they are invoiced (Fabling and Sanderson, 2015). Column (6) excludes the exchange rate between the vehicle and the origin country's currency, and pass-through remains large at 52.6 percent.

Table 6 reports the results of estimating equation (4). Consistent with Table 5, column (1) shows that, relative to the bilateral exchange rate, pass-through is relatively large (at 53.0 percent) for producer currency pricing, low (at 30.6 percent) for vehicle currency pricing (we can reject at the five 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 similar magnitude, for the producer priced and for the vehicle currency priced transactions relative to the sterling to vehicle currency exchange rate (the estimated coefficients are equal to 0.658 and 0.799, respectively, and are not significantly different from each other). In contrast, the response of import prices invoiced in third currencies to changes in the vehicle to origin country's currency exchange rate is low at 17.4 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, 70 different vehicle currencies are used, although the US dollar, followed by the euro, are predominantly chosen as third currencies. 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 should determine the prices of globally traded goods. We therefore check if our results continue to hold for the vehicle currencies other than the US dollar. We estimate equation (4) and for the vehicle currency priced transactions we interact the vehicle currency exchange rates with dummy variables for the US dollar versus non-dollar currencies. The estimates reported in column (4) provide strong evidence that it is the use of vehicle currencies, and not exclusively the US dollar, that is driving our results.

To illustrate that our results are driven by heterogeneity in currency of invoicing choices, and not by the industry composition of our sample, Table 7 reports the same specifications as in Table 5, but we interact the exchange rate elasticities with industry dummies.[22] Overall, across industries, we observe a similar pattern as in Table 5. The exchange rate elasticities are, on average, large for producer currency transactions (column 2), and insignificant for local currency priced goods (column 3). For the vehicle currency priced transactions, the sensitivity of import prices to changes in exchange rates is large when the sterling to vehicle currency exchange rate fluctuates, but low or often even insignificant when the vehicle to origin's currency exchange rate changes (columns 5 and 6).

In summary, we obtain two main results. First, we show that exchange rate pass-through varies substantially across invoicing currency 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 prices and, in turn, on domestic inflation (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

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

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

Table 6: Pass-Through into Import Prices: Full Sample

	(1)	(2)	(3)	(4)
$\Delta \ln e_{DEST/ORIG} \times D_{PCP}$	0.530^a (0.086)	0.658^a (0.084)	0.618^a (0.082)	0.643^a (0.082)
$\Delta \ln e_{DEST/ORIG} \times D_{LCP}$	−0.001 (0.061)	0.048 (0.055)	0.006 (0.054)	0.022 (0.052)
$\Delta \ln e_{DEST/ORIG} \times D_{VCP}$	0.306^a (0.050)	–	–	–
$\Delta \ln e_{DEST/VCP}$	–	0.799^a (0.105)	0.689^a (0.096)	–
$\Delta \ln e_{VCP/ORIG}$	–	0.174^a (0.049)	–	–
$\Delta \ln e_{DEST/VCP} \times D_{USD}$	–	–	–	0.684^a (0.125)
$\Delta \ln e_{DEST/VCP} \times D_{non-USD}$	–	–	–	0.618^a (0.131)
Observations	2,641,208	2,641,208	2,641,208	2,641,208
R-squared	0.235	0.235	0.235	0.235

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 rates, 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-quarter 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).

exchange rate underestimates pass-through for goods priced in third currencies by 38.3 percentage points ($68.9 - 30.6 = 38.3$).[23]

3.2 Long-Run Pass-Through

Due to the inclusion of eight lags on the exchange rate change, we depict long-run pass-through graphically. Figure 2a shows the cumulative exchange rate estimates obtained from the specification reported in column (1) of Table 5, which regresses the unit values of all import transactions on bilateral exchange rates. The contemporaneous pass-through rate is equal to 25.1 percent, and reaches 42.2 percent after eight quarters (significant at the one percent level).

Based on the specification reported in column (3) of Table 6, which estimates exchange rate pass-through separately for producer, local, and vehicle currency transactions, and allows the transactions priced in a third currency to depend on the sterling to vehicle currencies exchange rates, Figures 2b to 2d show the dynamics of pass-through by currency of invoicing. For the producer currency priced transactions in Figure 2b, contemporaneous pass-through is equal to 61.8 percent, and reaches 69.8 percent after eight quarters (significant at the one percent level). For the local currency priced transactions, Figure 2c shows that pass-through increases from zero percent on impact to 12.4 percent after two years (the estimate is, however, insignificant). Finally, Figure 2d focuses on the transactions priced in third currencies. Pass-through is equal to 68.9 percent on impact. After eight quarters, the elasticity of import unit values to changes in the sterling to vehicle currency exchange rate is significant at the one percent level and is equal to 1.322 (not significantly different from one), which means that pass-through is complete.

According to Figures 2b and 2c, the pass-through rates between producer and local currency pricing do not appear to be converging in the long run. This finding is consistent with Gopinath et

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

Table 7: Pass-Through into Import Prices: By Industry

Industry (SITC)	(1)	(2)	(3)	(4)	(5)		(6)
Exchange rate	*DEST/ORIG*				*DEST/VCP*	*VCP/ORIG*	*DEST/VCP*
Food, live animals	0.182[b] (0.074)	0.432 (0.314)	0.065 (0.122)	0.250[b] (0.103)	0.930[a] (0.296)	0.221[c] (0.120)	0.758[b] (0.297)
Beverages, tobacco	0.321[b] (0.140)	1.445[a] (0.395)	−0.075 (0.160)	0.230 (0.468)	1.909[b] (0.739)	−0.279 (0.400)	1.882[a] (0.691)
Crude materials	0.212[b] (0.105)	1.079[b] (0.441)	−0.033 (0.228)	0.161 (0.130)	0.863[a] (0.315)	0.076 (0.129)	0.735[b] (0.308)
Mineral fuels	−0.257 (0.398)	0.577 (1.118)	0.333 (0.905)	−0.118 (0.404)	1.321[b] (0.677)	−0.483 (0.429)	1.365[b] (0.669)
Animal, vegetable oils	0.266 (0.320)	1.032 (0.706)	0.039 (0.847)	0.534 (0.463)	1.313[b] (0.656)	0.456 (0.609)	1.062 (0.653)
Chemicals	0.235[b] (0.093)	0.518[b] (0.235)	0.020 (0.291)	0.331[b] (0.144)	0.917[a] (0.242)	0.246 (0.185)	0.731[a] (0.238)
Manufactured goods	0.195[a] (0.057)	0.764[a] (0.245)	0.002 (0.098)	0.168[b] (0.078)	0.665[b] (0.257)	0.151[c] (0.090)	0.507[b] (0.249)
Machinery	0.291[a] (0.090)	0.691[a] (0.163)	0.165 (0.136)	0.111 (0.123)	0.486[c] (0.250)	0.157 (0.127)	0.330 (0.239)
Miscellaneous manuf.	0.264[a] (0.051)	0.711[a] (0.186)	0.071 (0.083)	0.278[a] (0.073)	0.804[a] (0.245)	0.213[b] (0.086)	0.639[a] (0.234)
Invoicing currency	All	PCP	LCP	VCP	VCP		VCP
Observations	2,641,208	732,020	595,997	1,313,191	1,313,191		1,313,191
R-squared	0.235	0.318	0.367	0.293	0.293		0.293

Notes: Firm-quarter and origin country-product fixed effects are included. Contemporaneous and eight lags of the origin country's quarterly inflation rates, 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-quarter 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).

al. (2010) who find that the difference in pass-through into US import prices in dollars versus non-dollars is large even at a two-year horizon, suggesting that the choice of the currency of invoicing is endogenous.[24] 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 exchange rate pass-through in the short run, it will choose local currency pricing. This results in zero pass-through (in the short run). Conversely, if the short-run desired pass-through is high, the firm will choose producer currency pricing that results in complete pass-through.[25]

Appendix A 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 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 strongly to changes in the sterling to vehicle currency exchange rate, and do not change when the vehicle to destination country's currency exchange rate fluctuates. Appendix B reports results for export and import quantities. We find that both in the short and long run, export and import quantities react modestly, if at all, to changes in exchange rates, regardless of the currency of invoicing.

[24] Similarly to Gopinath et al. (2010), the selection of industries into different invoicing currencies that we document in Table 3 provides additional evidence against exogenous currency of invoicing choices.

[25] Cao, Dong, and Tomlin (2015) instead observe convergence in the degree of exchange rate pass-through into Canadian export prices invoiced in US dollars and in Canadian dollars.

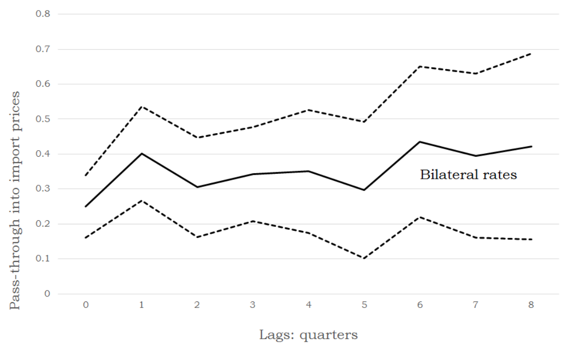


Figure 2a: All transactions

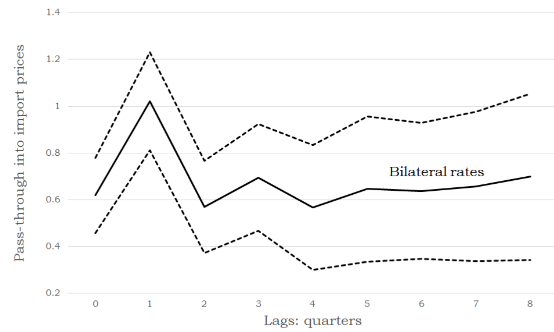


Figure 2b: PCP transactions

Figures 2a and 2b: Cumulative estimates of exchange rate pass-through into import prices, all transactions and PCP transactions (based on the specifications reported in column 1 of Table 5 and column 3 of Table 6, respectively). 95 percent confidence intervals reported as dashed lines

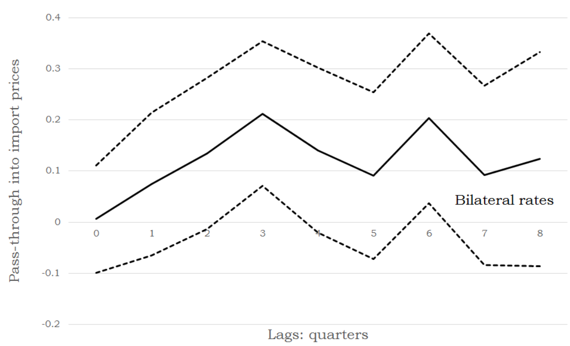


Figure 2c: LCP transactions

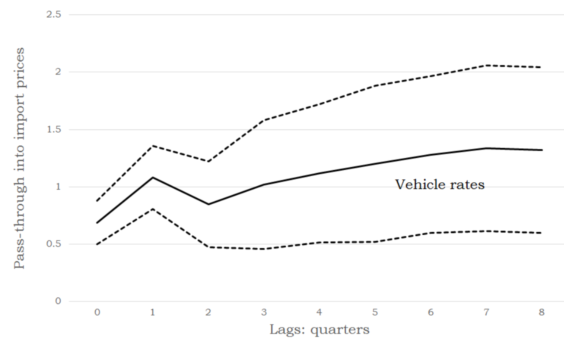


Figure 2d: VCP transactions

Figures 2c and 2d: Cumulative estimates of exchange rate pass-through into import prices, LCP and VCP transactions (based on the specification reported in column 3 of Table 6). 95 percent confidence intervals reported as dashed lines

3.3 Aggregate 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 in Figures 2b to 2d), using as weights the currency of invoicing shares in our sample (listed in Table 2). We find that exchange rate pass-through is equal to 46.2 percent on impact, and to 89.0 percent after two years (both significant at the one percent level). These estimates are nearly twice as large as the short and long-run pass-through rates of 25.1 and 42.2 percent that we obtain when using bilateral exchange rates only to explain import prices (column 1 of Table 5 and Figure 2a). Allowing for the effect of invoicing currencies therefore helps us to understand the exchange rate disconnect puzzle whereby world trade prices do not respond much to exchange rate movements.[26]

[26] Our estimates remain similar if we instead use the currency of 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, as explained in Section 4.

4 Pass-Through into Consumer Prices

We provide back-of-the-envelope estimates for how exchange rate movements affect UK consumer price inflation in the short run (i.e., one quarter) and in the long run (i.e., after eight quarters). To do so, we focus on three (quarterly) episodes of large sterling fluctuations, and use our estimates to evaluate the dynamic response of consumer price inflation to these exchange rate shocks. First, following the Brexit referendum, sterling depreciated in June–August 2016 (relative to the previous quarter March–May 2016) by 7.13 percent on average (against the currencies of the UK's trading partners weighted by bilateral import shares), 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 12.68 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 3.02 and 6.24 percent on average and against the euro, but depreciated by 4.76 percent against the US dollar.[27,28]

Figure 3 plots the year-on-year monthly CPI inflation rate for the UK economy since January 2007. Inflation rose in 2008 during the Great Recession, and again after the Brexit referendum of June 2016. Instead, inflation fell during the European Sovereign Debt Crisis of 2013–2015. The vertical shaded areas indicate the three quarterly episodes of large sterling fluctuations that we focus on in our analysis.

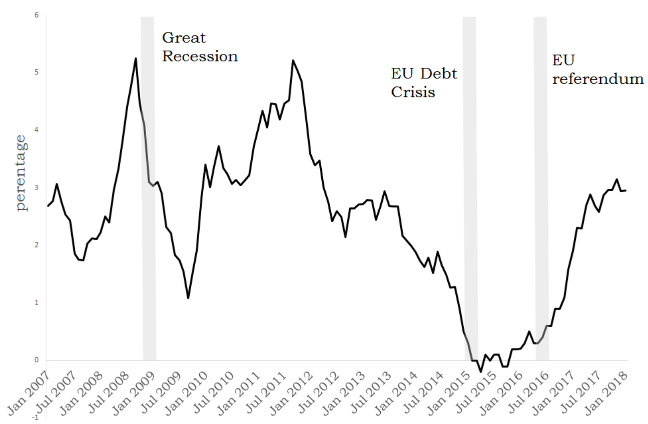


Figure 3: CPI inflation for the UK economy (% change over 12 months). Source: International Financial Statistics of the International Monetary Fund

To calculate our estimates, and as explained in more detail in Appendix C, we proceed as follows. In a first step, as we only observe the currency of invoicing shares for non-EU imports, we use aggregate data from Gopinath (2016) to derive the shares for world imports. Due to data limitations, we consider

[27] 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.

[28] The degree of pass-through could vary between the three episodes if the exchange rate movements in each period were driven by different types of shocks (Forbes et al., 2015). As our pass-through elasticities are estimated for the 2010–2013 period only, we view the exercise we carry out in this section as an illustration of how different types of exchange rate shocks affect the dynamics of consumer price inflation once we consider the role of invoicing currencies.

two alternative scenarios for the magnitude of these shares (see Table C1). In a second step, we measure the average appreciation or depreciation of sterling in each of the three quarters of exchange rate shocks (relative to the previous quarter) by computing weighted averages of the sterling bilateral and sterling to vehicle currencies exchange rate changes. Finally, using our regression estimates, we calculate how consumer inflation responds both in the short and the long run to the three exchange rate shocks, focusing on the average change in the value of sterling against all currencies, but also more specifically against the US dollar and the euro. In what follows, we describe our results for the effects of world imports based on scenario 1 for the invoicing shares (Table C1). The results for scenario 2 (which are very similar), and for the effects of non-EU imports, are relegated to Table C2 in Appendix C.

We start with the depreciation of sterling following the Brexit referendum of June 2016. The results are reported in columns (1) and (2) of Table 8. 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 0.251, column (1) shows that the average bilateral depreciation of sterling (of 7.13 percent) increases domestic inflation by 0.536 percentage point on impact. After eight quarters, the pass-through elasticity increases to 0.422, implying that inflation rises by 0.902 percentage point (column 2). The depreciation against the euro increases inflation by more (by 0.293 and 0.493 percentage points in the short and long run) than the depreciation against the US dollar (by 0.038 and 0.064 percentage points, respectively). The reason is that as a large share (48.08 percent) of UK imports originates from the EU, the depreciation against the euro is given a larger weight than the US dollar in affecting inflation.[29]

Once we account for the full set of invoicing currencies, our results yield much larger effects for UK inflation. Based on our point estimates reported in column (3) of Table 6, column (1) of Table 8 shows that the depreciation of sterling increases domestic inflation by 0.918 percentage point on impact, and by 1.566 percentage point after eight quarters. These effects are respectively 0.382 and 0.664 percentage points larger compared to the ones obtained using bilateral exchange rates only. The reason is that the pass-through elasticity for the vehicle currency priced transactions is larger than in the specification with bilateral exchange rates only (i.e., 0.689 versus 0.251), and as the US dollar is used extensively as a vehicle currency, the depreciation of sterling against the US dollar is given a larger weight in affecting inflation (it increases inflation by 0.606 and 1.096 percentage points on impact and after two years). Overall, these estimates illustrate that ignoring the currency of invoicing and accounting for fluctuations in bilateral exchange rates only can lead to misleading predictions regarding the effects of exchange rate changes on domestic inflation.

Columns (3) and (4) report our results for the Great Recession. Again, we find that the depreciation of sterling has a larger inflationary impact once we allow the transactions priced in a vehicle currency to depend on the sterling to vehicle currencies exchange rates. The depreciation of sterling increases inflation by 0.953 and 1.604 percentage points in the short and long run when we only consider bilateral exchange rates, and by 2.372 and 4.139 percentage points respectively when we allow for the effects of vehicle currencies exchange rates. The higher inflation is again driven by the US

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

Table 8: UK Consumer 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	0.536^{a} (0.097)	0.902^{a} (0.290)	0.953^{a} (0.172)	1.604^{a} (0.515)	-0.227^{a} (0.041)	-0.382^{a} (0.123)
	USD	0.038^{a} (0.007)	0.064^{a} (0.021)	0.117^{a} (0.021)	0.197^{a} (0.063)	0.029^{a} (0.005)	0.048^{a} (0.015)
	Euro	0.293^{a} (0.053)	0.493^{a} (0.158)	0.472^{a} (0.085)	0.795^{a} (0.255)	-0.239^{a} (0.043)	-0.402^{a} (0.129)
Bilateral/vehicle rates	All currencies	0.918^{a} (0.115)	1.566^{a} (0.382)	2.372^{a} (0.289)	4.139^{a} (1.022)	0.242^{a} (0.049)	0.518^{a} (0.180)
	USD	0.606^{a} (0.075)	1.096^{a} (0.285)	1.856^{a} (0.230)	3.358^{a} (0.872)	0.454^{a} (0.056)	0.822^{a} (0.213)
	Euro	0.266^{a} (0.042)	0.384^{a} (0.109)	0.428^{a} (0.068)	0.619^{a} (0.175)	-0.217^{a} (0.035)	-0.313^{a} (0.088)
Exchange rate shock		2016M6–2016M8		2008M11–2009M1		2015M1–2015M3	
All currencies against sterling (weighted)		+7.13%		+12.68%		-3.02%	
US dollar against sterling		+6.34%		+19.43%		+4.76%	
Euro against sterling		+7.66%		+12.34%		-6.24%	

Notes: All estimates are reported in percentage points. The estimates reported in the rows "Bilateral rates" are obtained based on the pass-through regression of column (1) in Table 5. The estimates reported in the rows "Bilateral/vehicle rates" are obtained using the pass-through regression of column (3) in Table 6. See Appendix C for details on the calculations of the PCP, LCP, and VCP shares, and of the corresponding changes in exchange rates. [a] indicates significance at the one percent level.

dollar (1.856 and 3.358 percentage points on impact and after two years) as it is predominantly used as a vehicle currency.

Finally, columns (5) and (6) focus on the European Sovereign Debt Crisis. In January–March 2015, sterling appreciated against all currencies on average, including the euro, but depreciated against the US dollar. The standard pass-through specification with bilateral exchange rates predicts that the average appreciation of sterling (of 3.02 percent) reduces inflation by 0.227 and 0.382 percentage points in the short and long run. Due to the intensity of trade between the UK and the EU, the fall in inflation is driven by the appreciation against the euro, which outweighs the effect of the depreciation against the US dollar. Once we allow for the currency of invoicing, movements in sterling now *increase* inflation by 0.242 and 0.518 percentage points in the short and the long run. The reason is that the depreciation against the US dollar, which is used extensively as a vehicle currency, increases inflation by 0.454 and 0.822 percentage points on impact and after two years, while the appreciation against the euro only reduces inflation by 0.217 and 0.313 percentage points, respectively.

Overall, we show that accounting for the currency of invoicing helps us to explain the reaction of domestic inflation to changes in currency values. For instance, it is well documented that the depreciation of sterling following the Brexit 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. One year after the Brexit referendum, the Financial Times reported on June 13, 2017 that "inflation jumped to 2.9 percent in May," which is "above analysts' consensus forecasts." During the Great Recession, the Bank of England noted in its May 2009 inflation report that the surprising recent strength in inflation "is likely to have reflected stronger, or faster, exchange rate pass-through following the fall in sterling." In contrast, during the

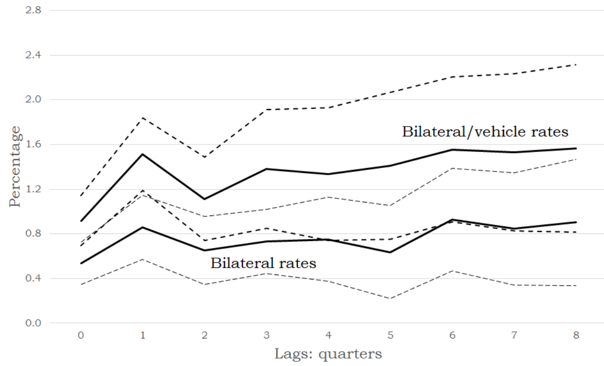


Figure 4a: EU Referendum

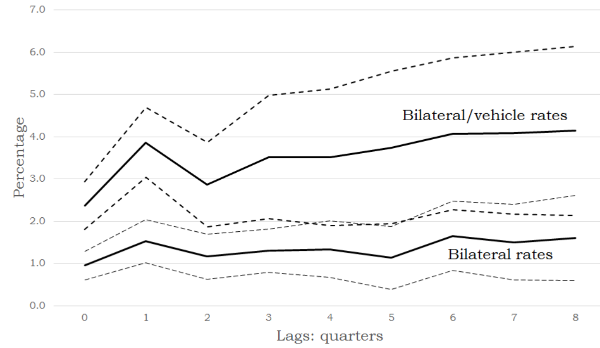


Figure 4b: Great Recession

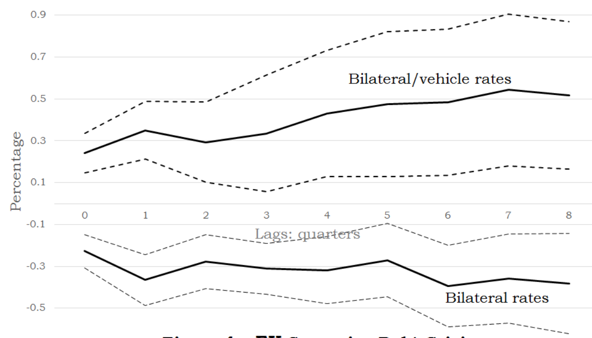


Figure 4c: EU Sovereign Debt Crisis

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

European Sovereign Debt Crisis the Bank noted in its August 2015 inflation report 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."

Forbes et al. (2015) argue that this difference in pass-through over time is driven by the nature of the shocks that move the exchange rate in the first place. We show instead that decomposing pass-through by currency of invoicing allows us to explain the higher pass-through to consumer prices during the Great Recession and following the Brexit referendum compared to the European Sovereign Debt Crisis. The reason is that the depreciation against the US dollar during the Great Recession and following the Brexit referendum is given a larger weight than the depreciation against the euro in affecting import prices, resulting in higher inflation. In contrast, during the European Sovereign Debt Crisis, the fall in inflation induced by the appreciation against the euro is offset by the depreciation against the US dollar.

Figures 4a to 4c depict the dynamics of each exchange rate shock on inflation. They show that once we allow for the currency of invoicing, the depreciation of sterling increases inflation by more for the period after the Brexit referendum and during the Great Recession (Figures 4a and 4b), while for the European Sovereign Debt Crisis the fall in inflation induced by the appreciation against the euro is offset by the depreciation against the US dollar (Figure 4c).[30]

5 Robustness

To ensure the robustness of our findings, this section discusses our results using alternative data samples. We estimate equation (4), and for simplicity only report short-run pass-through estimates.[31] We presents the results in Appendix D. Pass-through remains large for producer currency transactions, and zero for local currency priced goods. For vehicle currency transactions, the response of import prices is large when the sterling to vehicle currency exchange rate fluctuates. Overall, the broad similarity of the results supports the paper's main conclusions.

In column (1) of Table D1 in Appendix D, we focus on manufacturing industries only (SITC 6–8). In column (2), we exclude homogeneous commodities whose prices are determined by world supply and demand (Gopinath, 2016) such as "Crude materials" (SITC 2) and "Mineral fuels" (SITC 3). In column (3), we exclude the US from the sample as its exports are mostly in US dollars. In column (4), we restrict the sample to the goods produced in the origin country (and exclude the ones produced in third countries).[32] Using information on the end use of goods as provided by the BEC classification, columns (5), (6), and (7) restrict the sample to intermediate, final, and capital goods, respectively. The results remain qualitatively similar, with the exception of capital goods whose prices react to exchange rate movements only when invoiced in the producer's currency.

In Table D2 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) focuses on these firms only. Columns (3) and (4) repeat the same exercise but for the five percent of firms with the largest import shares. Overall, our results remain similar.

Finally, Table D3 shows that our results remain robust to aggregating the data at an annual frequency. We estimate equations (1) and (4), and include two lags on the exchange rates and foreign inflation rates. For the full sample of imports, column (1) shows that the pass-through of bilateral exchange rate changes into import prices is low at 37.6 percent. Column (2) shows that, relative to the bilateral exchange rate, pass-through is large (at 81.8 percent) for producer currency pricing, and low for both vehicle currency (at 20.8 percent) and local currency pricing (at 19.2 percent). Once we let the transactions priced in third currencies depend on the sterling to vehicle currency exchange rate, columns (3) and (4) show that pass-through is large, and of similar magnitude, for producer priced and vehicle currency priced transactions.

[30] The effects of bilateral and of bilateral/vehicle exchange rates are not significantly different from each other for the Brexit referendum and the Great Recession after four lags, while they are for the European Sovereign Debt Crisis.

[31] The corresponding robustness checks for long-run pass-through are available upon request. The exchange rate between the vehicle and the origin country's currency is omitted from the regressions, but we show that including this exchange rate does not qualitatively alter our conclusions.

[32] We use the variable "cooseq" which identifies the country where the goods were produced and the country of dispatch.

6 A Conceptual Framework for Vehicle Currency Pass-Through

In this section, we extend the approach by Engel (2006) to obtain a conceptual framework for thinking about the effects of vehicle currency pricing on exchange rate pass-through. Guided by this framework we then estimate the relevant pass-through elasticity on our sample of UK import transactions. We also delineate the estimation bias that may arise if a researcher ignores the vehicle currency exchange rate and erroneously focuses on the bilateral exchange rate between importer and exporter only.

6.1 General Setting: Pricing in a Vehicle Currency

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 j of the foreign country, the domestic currency m (sterling) and a third-country vehicle currency v.[33] 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. That is, it chooses the optimal price p_v^*, which is the log price of its exports denominated in the vehicle currency v. The choice of invoicing currency is exogenous to the firm.[34] Prices are flexible (in the sense that the firm is allowed to choose its preferred pass-through level). Exchange rates are also exogenous from the firm's point of view.

The foreign firm sells its good to consumers in the domestic country. We assume these consumers face a price p_m in domestic currency m when they go shopping. The relationship between the price faced by consumers and the price set by the foreign firm is therefore given by

$$p_m = p_v^* + e_{m/v}, \tag{5}$$

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

As Figure 5 illustrates, there are three bilateral exchange rates in this three-currency world. As we will show below, the firm can potentially change its optimal price p_v^* in response to a movement in either of the three exchange rates. In the following we will go through each case and highlight the implications for exchange rate pass-through into the price p_m faced by domestic consumers in the UK.

6.1.1 Reacting to the Vehicle Currency Exchange Rate

As the first case, we assume that when setting its price p_v^* in the vehicle currency, the firm only considers the *vehicle currency exchange rate* $e_{m/v}$, i.e., the exchange rate of the domestic country vis-à-vis the vehicle currency. Following Engel (2006) we assume that the firm can commit to flexibly

[33] The j, m, v notation corresponds to $ORIG$, $DEST$, VCP in Section 3. We choose it for brevity here.

[34] In Engel (2006), the currency of invoicing (PCP versus LCP) is assumed endogenous, determined by the firm's desired pass-through. Gopinath et al. (2010) provide evidence on endogenous currency choices by examining dollar versus non-dollar import prices for the US. Our empirical results are in line with those findings on PCP versus LCP. However, due to the lack of VCP observations in US data, little can be said about VCP strategies. Chung (2016) models endogenous VCP and provides evidence for the UK that VCP may be the result of industry-specific considerations such as a coalescing effect. The aim of our paper is not to explain the choice of invoicing currency, but rather to focus on its implications for pass-through.

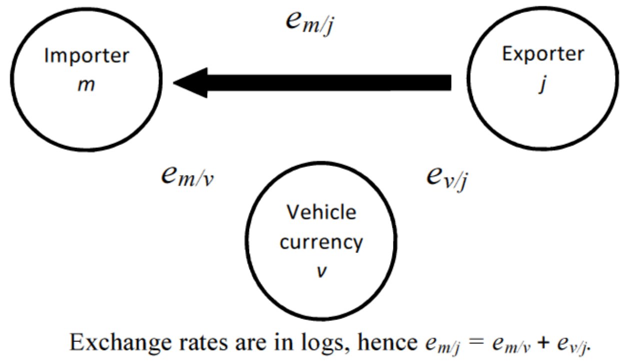


Figure 5: Exchange rates with a vehicle currency

setting p_v^* as an affine function of $e_{m/v} : p_v^* = p_0^v - \mu^v e_{m/v}$, optimally choosing p_0^v and μ^v where p_0^v is denominated in the vehicle currency.[35] Based on the relationship in equation (5) it follows

$$p_m = p_0^v + (1 - \mu^v)e_{m/v}, \tag{6}$$

where $1 - \mu^v$ is the pass-through elasticity of the vehicle currency exchange rate into the domestic price. Intuitively, suppose the firm chooses the particular parameter value $\mu^v = 0$. In that case, the price p_v^* set in vehicle currency does not depend on the exchange rate, and the firm prefers full pass-through. In contrast, when $\mu^v = 1$ 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 LCP). For intermediate values of μ^v with $0 < \mu^v < 1$ the firm prefers incomplete pass-through.

In Appendix E we show how the firm's optimal choice of μ^v depends on expected profits, its cost structure and the properties of the exchange rate. However, the solution to the optimization problem is not crucial for our empirical analysis.[36]

6.1.2 Reacting to the Bilateral Exchange Rate

As the second case, we consider the scenario where the foreign firm still 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 $e_{m/j}$ in Figure 5, defined as the log price of the foreign currency in units of the domestic currency (such that an increase in $e_{m/j}$ corresponds to a depreciation of sterling). In fact, exchange rate pass-through in the literature is conventionally measured based on the bilateral exchange rate.

Analogous to the setting in Section 6.1.1, we assume that the exporting firm chooses the price p_v^* in vehicle currency as a linear function of the bilateral exchange rate $e_{m/j} : p_v^* = p_0^{bil} - \mu^{bil} e_{m/j}$,

[35] 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.

[36] Although we theoretically derive the optimal degree of pass-through in Appendix E, we would require information on the exporter's cost structure to relate it to estimated pass-through coefficients. Such data on foreign exporters are not collected by HMRC.

optimally choosing p_0^{bil} and μ^{bil} where p_0^{bil} is denominated in the vehicle currency. Substituting this function into equation (5), we obtain

$$p_m = p_0^{bil} - \mu^{bil} e_{m/j} + e_{m/v}.$$

Using the triangular exchange rate relationship $e_{m/v} = e_{m/j} - e_{v/j}$, we can rewrite this expression as

$$p_m = p_0^{bil} + (1 - \mu^{bil}) e_{m/j} - e_{v/j}. \tag{7}$$

It follows that $1 - \mu^{bil}$ is the pass-through elasticity of the bilateral exchange rate into the domestic price. But unlike in equation (6), there is now a second exchange rate term on the right-hand side. In Appendix E we show how the firm optimally chooses μ^{bil}.

6.1.3 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 $e_{v/j}$ in Figure 5, defined as the log price of foreign currency in units of the vehicle currency.

The linear pricing equation is then in terms of $e_{v/j} : p_v^* = p_0^{exp} + \mu^{exp} e_{v/j}$, where the firm optimally chooses p_0^{exp} and μ^{exp} and where p_0^{exp} is denominated in the vehicle currency.[37] Substituting this function into equation (5), we obtain

$$p_m = p_0^{exp} + \mu^{exp} e_{v/j} + e_{m/v}. \tag{8}$$

Thus, μ^{exp} 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. Appendix E reports the optimal choice of μ^{exp}.

6.2 Empirical Evidence

We first estimate the three pass-through elasticities described above. We then characterize the estimation bias that occurs when the bilateral exchange rate is used to estimate the pass-through elasticity but the vehicle exchange rate is ignored.

6.2.1 Three Pass-Through Elasticities

We build on the three pricing equations (6)-(8) to estimate the pass-through elasticities $1-\mu^v$, $1-\mu^{bil}$, and μ^{exp}, respectively. We use the following empirical specifications in first differences:

$$\Delta p_m = (1 - \mu^v) \Delta e_{m/v} + \varepsilon_1, \tag{9}$$

$$\Delta p_m = (1 - \mu^{bil}) \Delta e_{m/j} - \Delta e_{v/j} + \varepsilon_2, \tag{10}$$

$$\Delta p_m = \mu^{exp} \Delta e_{v/j} + \Delta e_{m/v} + \varepsilon_3, \tag{11}$$

[37] Note the positive sign in front of μ^{exp}. If the vehicle currency depreciates against the exporter's currency (i.e., if $e_{v/j}$ increases), then the exporter should react by increasing the optimal vehicle currency price p_v^*.

where we add the error terms ε_1, ε_2, and ε_3. We test these specifications in the VCP subsample of import transactions, which is the same sample as in column (4) of Table 5 (PCP and LCP transactions are not included). We note that the coefficient on $\Delta e_{v/j}$ in equation (10) is constrained to -1, and the coefficient on $\Delta e_{m/v}$ in equation (11) 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} as well as the origin countries' quarterly inflation rates. That is, we use the same specification as in (1) but without lagged regressors.[38]

Table 9: Three Pass-Through Elasticities: By Industry and Currency

	(1) $1-\mu^v$	(2) $1-\mu^{bil}$	(3) μ^{exp}
Full sample	0.705^a (0.120)	1.147^a (0.058)	0.196^a (0.054)
Industry (SITC)			
Food, live animals	0.930^a (0.235)	1.186^a (0.102)	0.176 (0.126)
Beverages, tobacco	2.081^a (0.663)	1.171^b (0.461)	−0.484 (0.361)
Crude materials	0.909^a (0.233)	1.090^a (0.129)	0.046 (0.123)
Mineral fuels	1.548^b (0.641)	0.847^b (0.402)	−0.566 (0.409)
Animal, vegetable oils	1.250^b (0.644)	1.481^a (0.464)	0.352 (0.626)
Chemicals	0.904^a (0.169)	1.258^a (0.140)	0.211 (0.179)
Manufactured goods	0.685^a (0.162)	1.101^a (0.078)	0.167^c (0.090)
Machinery	0.508^a (0.156)	1.052^a (0.125)	0.248^b (0.118)
Miscellaneous manuf.	0.818^a (0.138)	1.214^a (0.071)	0.197^b (0.079)
Currency			
USD	0.612^a (0.201)	1.080^a (0.058)	0.120^b (0.054)
Non-USD	0.766^a (0.145)	1.376^a (0.121)	0.388^a (0.102)
Observations	1,313,191	1,313,191	1,313,191

Notes: Firm-quarter and origin country-product fixed effects are included. We control for the origin countries' quarterly inflation rates (not reported). Robust standard errors adjusted for clustering at the country-quarter level are reported in parentheses. ^{a}, ^{b}, and ^{c} indicate significance at the one, five, and ten percent levels, respectively.

Column (1) of Table 9 reports the results of estimating equation (9) with $\Delta e_{m/v}$ as the key regressor. The specification thus captures how foreign exporters respond to changes in the vehicle exchange rate, with $1-\mu^v$ capturing the pass-through elasticity into domestic prices denominated in sterling. The top panel of Table 9 shows that in the full sample which includes all industries, the pass-through elasticity to import prices is 70.5 percent. Exporters thus respond to a change in the $e_{m/v}$ rate by adjusting their prices set in vehicle currency by 29.5 percent of that change. We highlight that the 0.705 coefficient is remarkably similar to the 0.714 coefficient for PCP in column (2) of Table 5. Thus, we confirm our previous result from Table 5 that VCP is similar to PCP in the sense that

[38] Results including lagged regressors are not qualitatively different. Equation (11) corresponds to equation (3) without the constraint on the sterling to vehicle currency exchange rate, as estimated in column (5) of Table 5 and column (2) of Table 6. Equation (9) corresponds to the results in column (6) of Table 5 and column (3) of Table 6 with the vehicle to origin country exchange rate omitted.

the respective pass-through elasticities are almost the same.

In the second panel of column (1) of Table 9 we can see some variation across industries. This variation is consistent with our findings in column (5) of Table 7 when we use two decomposed rates in the same specification. In the third panel when we estimate the pass-through elasticities by different vehicle currencies (US dollar versus non-dollar), we find no significant difference (we reject the hypothesis of their being different at the one percent level).

Column (2) runs specification (10) with $\Delta e_{m/j}$ as the main regressor. We thus estimate the pass-through elasticity with respect to the bilateral exchange rate. The coefficients we obtain for the full sample as well as for all industries are not significantly different from unity (with the exception of "Miscellaneous manufacturing"). This implies that foreign exporters do not respond to bilateral exchange rates when they price in vehicle currencies (since μ^{bil} is not significantly different from zero). By different vehicle currencies (US dollar versus non-dollar) we again find no difference between the coefficients (we can reject the hypothesis of their being different at the one percent level). We conclude that bilateral rates are not as important for exporters when they price VCP transactions. From the importer's perspective, the results suggest that after taking into account the $\Delta e_{v/j}$ rate as in specification (10), they should observe close to full pass-through to 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 $\Delta e_{v/j}$ is not taken into account. There, we find a low coefficient of 0.211, which implies that exporters have a high response (79 percent) to bilateral rates.[39]

Column (3) runs regression (11) which examines to what extent foreign exporters respond to changes in the vehicle-exporter exchange rate, $\Delta e_{v/j}$. For the full sample the response is about 20 percent. But across industries only "Manufactured goods," "Machinery," and "Miscellaneous industries" mildly respond to this exchange rate. For other industries the response is not significantly different from zero. Again, we find no difference for US dollar versus non-dollar pricing (rejected at the one percent level), although the point estimate for non-dollar pricing is higher than for US dollar pricing. This result is consistent with column (5) in Table 5 where the corresponding coefficient is 0.183. The vehicle-exporter exchange rate is therefore relatively unimportant for price adjustment.

Overall, our empirical evidence suggests that as far as VCP transactions are concerned, bilateral exchange rate movements are hardly important for exporters' price responses. Exporters instead respond to $\Delta e_{m/v}$ and $\Delta e_{v/j}$ exchange rate movements to some extent (i.e., μ^{v} at 29.5 percent and μ^{exp} at 19.6 percent in columns 1 and 3 of Table 9). For import prices, we find that the pass-through elasticity for VCP is similar to the one for PCP, 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.

6.2.2 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 fine as long as the invoicing currency

[39] According to our analysis in Section 6.2.2 below, this contrast would be due to the correlation between the two exchange rate movements, $\Delta e_{m/j}$ and $\Delta e_{v/j}$. In that case, the specification without $\Delta e_{v/j}$ is misspecified for the purpose of identifying exporters' responses to bilateral rates.

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. Conceptually, we formalize this setting in Section 6.1.2 above. We now demonstrate the consequences of ignoring the vehicle currency.

More specifically, consider specification (10). Imagine a researcher is interested in estimating the pass-through elasticity $1-\mu^{bil}$ of the bilateral exchange rate, $\Delta e_{m/j}$, using a vehicle currency sample. Then the exchange rate between the vehicle currency and the exporter's currency, $\Delta e_{v/j}$, must be included as an additional regressor (with a constrained coefficient of -1). If this regressor is not included, this may lead to an omitted variable bias. We can distinguish three cases.

As the first case, suppose the correlation between the two exchange rate terms is zero (i.e., $\mathrm{Corr}(\Delta e_{m/j}, \Delta e_{v/j}) = 0$). Then there is no omitted variable bias. Leaving out the vehicle exchange rate term does not matter in this special case, and the estimated coefficient $1-\mu^{bil}$ is unbiased. In column (4) of Table 5 we estimate this coefficient as 0.211. We refer to it as the "naive" bilateral pass-through elasticity as the underlying regression omits the vehicle exchange rate term.

However, recall that in column (2) of Table 9 we estimate specification (10) with the vehicle exchange rate term included. Our coefficient for $1-\mu^{bil}$ in the full sample is 1.147, which we refer to as the "true" bilateral pass-through elasticity. It is very different from the naive elasticity. This finding suggests that the assumption of a zero exchange rate correlation is likely misguided (we shall explore this below).

As the second case, suppose the correlation is positive (i.e., $\mathrm{Corr}(\Delta e_{m/j}, \Delta e_{v/j}) > 0$). In that case the naive pass-through elasticity is biased downward. The reason for the downward bias is the negative sign of the vehicle currency term in specification (10). This fits the coefficient patterns just described (i.e., $0.211 < 1.147$). What is the economic interpretation of this case? 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. In other words, 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 as its vehicle currency for exporting to the UK. A Japan-specific shock would arguably mean that sterling and the US dollar move in lockstep against the yen.

As the third case, suppose the correlation is negative (i.e., $\mathrm{Corr}(\Delta e_{m/j}, \Delta e_{v/j}) < 0$). Then we should observe an upward bias. This is not consistent with the observed coefficient patterns.

We now test this argument more formally. The regressions in column (4) of Table 5 and column (2) of Table 9 are estimated with all vehicle currencies v and all exporting countries j pooled together. But in practice, the exchange rate correlation $\mathrm{Corr}(\Delta e_{m/j}, \Delta e_{v/j})$ is specific to each (v, j) pair. Based on the second case above, we therefore have a testable prediction: the higher the exchange rate correlation, the lower the naive bilateral pass-through elasticity.

We estimate naive elasticities as in column (4) of Table 5 on a sample of VCP transactions. But crucially, we allow these elasticities to vary by (v, j) pairs.[40] This produces 115 distinct naive

[40] We build on our standard specification (1) with an extra dummy for each (v, j) pair. Exchange rate lags are included but we only consider the contemporaneous coefficients. After obtaining these coefficients we trim the sample by excluding pairs with less than 30 observations.

elasticities involving eight vehicle currencies and 69 exporting countries (the importing country is always the UK). We then regress these elasticities on their corresponding exchange rate correlations (constructed based on monthly exchange rate movements over the sample period from 2010 to 2013).

Table 10: Regressing Pass-Through Elasticities on Exchange Rate Correlations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent variable: "Naive" bilateral pass-through elasticity							
$\text{Corr}(\Delta e_{m/j}, \Delta e_{v/j})$	-0.849^{a} (0.106)	-0.705^{a} (0.065)	-1.045^{a} (0.213)	-0.738^{a} (0.015)	-0.688^{c} (0.361)	-0.988^{a} (0.014)	-1.010^{a} (0.299)
Vehicle currency fixed effects	No	Yes	Yes	Yes	Yes	Yes	Yes
Exporter country fixed effects	No	No	No	No	Yes	Yes	Yes
Weighted	No	No	No	No	No	Yes	Yes
Observations	115	115	110	102	115	115	115
R-squared	0.117	0.188	0.189	0.109	0.742	0.916	0.691

Notes: All columns are based on the full sample except for column (3) where only positive values of the correlation regressor are included, and column (4) where all vehicle currencies apart from the US dollar and the euro are dropped. In column (6) the weights are based on vehicle currency shares, and in column (7) based on the inverse of the standard error of the pass-through elasticity. OLS regressions. 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. See the text for details.

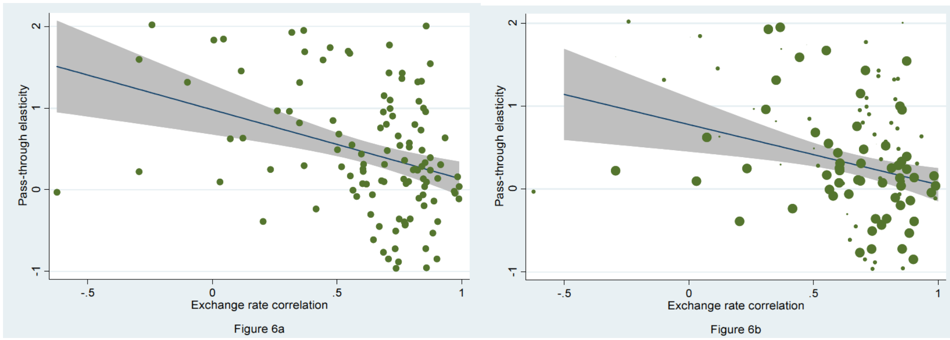
We report the regression results in Table 10. As suggested by our hypothesis, we find a negative relationship between the naive bilateral pass-through elasticities and the exchange rate correlations. This relationship is generally highly significant.[41] The individual regressions include various combinations of vehicle currency and exporter country fixed effects. In column (3) the sample size is slightly reduced because we only include observations for which the exchange rate correlation is positive (as stipulated by the second case above). In column (4) we only include elasticities for the US dollar and the euro as vehicle currencies. In column (6) we weight the observations by vehicle currency shares (the US dollar share in particular is about 90 percent in terms of value). In column (7) we weight by the inverse of the standard error of the pass-through elasticity estimated as in column (4) of Table 5. Overall, we strongly confirm our hypothesis of a negative relationship. We conclude that including the vehicle exchange rate term is indeed important to avoid an omitted variable bias in measuring bilateral pass-through.

We illustrate the negative relationship in Figures 6a and 6b. Figure 6a provides a scatter plot of naive bilateral pass-through elasticities against exchange rate correlations, with a fitted line drawn based on the regression in column (2) of Table 10 (the shaded area represents 95 percent confidence intervals). Figure 6b provides a weighted scatter plot based on column (6) of Table 10.

6.3 Summary

Overall, our results highlight the pitfalls of using bilateral exchange rates for estimating pass-through when in fact prices are set in vehicle currencies. Table 10 shows that pass-through coefficients based on bilateral rates depend in a systematic way on triangular exchange rate correlations with vehicle currencies.

[41] In contrast to the signs of the coefficients, the specific magnitudes have no direct interpretation that is economically meaningful.



Figures 6a and 6b: Naive bilateral pass-through elasticities plotted against exchange rate correlations by vehicle currency-exporter pair. Figure 6a plots unweighted observations. Figure 6b weights observations based on vehicle currency shares in terms of value. See the text for details

The difficulty researchers often face in practice is that they do not observe the vehicle currencies used in transactions. To the extent that vehicle currency pricing is negligible for a particular importing country, this may not be a major concern. In our UK data set, however, vehicle currency pricing applies to the majority of import transactions (around 55 percent, see Table 2). Ignoring vehicle currencies would therefore be a problem and lead to substantially weaker pass-through estimates, as we demonstrate throughout the paper. We conclude that for estimating exchange rate pass-through, researchers should heed the importance of vehicle currencies.

7 Concluding Remarks

Using detailed firm-level transactions data for UK imports from non-EU countries, this paper examines the relationship between the currency of invoicing and exchange rate pass-through for traded goods prices. Pass-through varies substantially across invoicing choices. Pass-through is large for imports invoiced in producer currencies but not significantly different from zero for local currency (sterling). Once we allow import prices 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 aggregate exchange rate pass-through.

For policy purposes, our results imply that ignoring the currency of invoicing can also produce misleading predictions regarding exchange rate pass-through into domestic consumer prices. In particular, our findings can explain the higher pass-through to UK consumer prices observed during the Great Recession and following the Brexit referendum relative to the European Sovereign Debt Crisis.

Our research agenda aims to investigate the relationship between invoicing currencies and exchange rate pass-through from a number of different perspectives. First, we wish to explore the role of firm-level characteristics. Second, we intend to merge the export and import data sets by firm, which will allow us to examine whether invoicing currencies are in any specific way related to the pricing behavior of exporters who are simultaneously importers.

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A Export Prices

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

A.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 2013 for non-EU transactions only (above £100,000). In our data set, non-EU exports represent 54 percent of total UK exports. Export unit values are measured by dividing the transaction value in sterling by the mass in kilograms at a quarterly frequency.

Compared to our sample for imports, Table A1 shows that for exports we observe fewer firms (29,495 exporters) and products (6,971) but more destination countries (144), with a total of 639,015 observations.[42] On average, these firms export 2.9 different products to 2.9 destination countries (at the 5^{th} and 95^{th} percentiles, the products per exporter are 1 and 8, while the destinations per exporter are 1 and 10). Exporters charge on average 282,578 pound sterling in each quarter, or 2,286.20 pound sterling per kilogram. The mean change in export unit values is equal to 0.54 percent per quarter (at the 5^{th} and 95^{th} percentiles, the mean changes are -154.6 and 155.9 percent).

Table A1: Summary Statistics

	Mean	Median	Std. dev.	5^{th} percentile	95^{th} percentile
Exporters	29,495	–	–	–	–
Products	6,971	–	–	–	–
Destination countries	144	–	–	–	–
Products per exporter	2.9	1	11.80	1	8
Destinations per exporter	2.9	1	4.37	1	10
Unit values (sterling/kg)	2,286.20	56.63	165,738.11	1.72	2,425.24
Change in log unit values (%)	0.54	0.06	0.98	-154.65	155.96
Transaction values (sterling)	282,578	14,477	4,039,375	1,208	636,393

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 market of the UK is the US (34.7 percent of total non-EU exports between 2011 and 2013), followed by China (8.9 percent), the United Arab Emirates (4.3 percent), Hong Kong (4.2 percent), India (4.0 percent), Japan (3.8 percent), and Singapore (3.5 percent).

Table A2 reports descriptive statistics for exports by invoicing currency. The largest share of exports is invoiced in producer currency (sterling) at 46.99 percent, followed by 33.00 percent in vehicle currency, and 20.01 percent in local currency. A total of 39 different vehicle currencies are used. Similar to what is the case for imports, 86.06 percent of the value of the transactions priced in a vehicle currency is in US dollars and 13.29 percent in euros. In terms of transaction counts, these

[42] In our sample, the UK exports to, but does not import from, Anguilla, Benin, Bhutan, the Central African Republic, Chad, Guinea-Bissau, Montserrat, and Timor-Leste.

correspond to shares of 75.69 and 22.70 percent. Unit values are the highest for vehicle currency priced goods at 2,624.76 pound sterling per kilogram.

Table A2: Descriptive Statistics by Invoicing Currency

	Obs.	Firms	Products	Dest.	Products per firm	Dest. per firm	Unit value	Export value	Export share
LCP	79,922	8,030	3,957	50	2.46	1.22	2,595.07	451,502	20.01
PCP	350,028	25,904	6,536	143	2.53	2.49	1,953.70	242,714	46.99
VCP	209,065	9,712	4,802	138	2.69	2.90	2,624.76	285,232	33.00
VCP (USD)	158,249	7,322	4,159	133	2.75	2.88	3,307.94	324,505	86.06
VCP (Euro)	47,453	4,649	3,162	128	1.98	1.98	417.53	166,506	13.29
VCP (Other)	3,363	476	623	73	1.92	1.62	1,324.59	114,283	0.65

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 A3 reports export shares by invoicing currency and industry (at the 1-digit SITC level). With the exception of "Manufactured goods" which are largely invoiced in vehicle currencies, producer currency pricing (sterling) is the dominant strategy for all industries, consistent with Table A2. Its share varies from 42.24 percent for "Chemicals" to 78.41 percent for "Animal and vegetable oils." The right panel of the table splits the data by region of destination. Producer currency pricing is the most widely used strategy for exports to China and Europe (excluding the EU), whereas vehicle currency pricing dominates for Asia, other Americas, and other regions.

Table A3: Invoicing Currency by Industry and Region

Industry (SITC)	PCP	LCP	VCP	Share	**Destination**	PCP	LCP	VCP	Share
Food, live animals	54.53	14.83	30.64	1.37	US	47.57	48.77	3.65	34.55
Beverages, tobacco	43.33	36.48	20.19	3.84	China	52.41	0.50	47.10	8.43
Crude materials	57.27	2.08	40.65	3.07	East/S. East Asia	40.09	7.38	52.53	24.34
Mineral fuels	61.58	23.87	14.54	4.66	Europe excl. EU	64.15	4.84	31.01	10.10
Animal, vegetable oils	78.41	7.34	14.25	0.03	Other Americas	35.85	10.58	53.57	7.76
Chemicals	42.24	29.94	27.82	18.72	All others	40.70	2.80	56.49	14.82
Manufactured goods	38.12	10.37	51.52	11.74					
Machinery	46.84	17.46	35.69	45.54					
Miscellaneous manuf.	56.28	22.26	21.46	11.04					

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 %).

Finally, export prices tend to be stickier in their currency of invoicing. If we calculate the shares of unit value changes falling below a threshold value of one percent (Fabling and Sanderson, 2015), 7.41 percent of the unit values priced in the producer's currency (sterling) are sticky when measured in the producer's currency, compared to 5.78 percent when converted to the local currency. Similarly, for the unit values priced in local currency, 4.72 percent of them are sticky when measured in local currency, versus 3.08 percent when converted to the producer's currency (sterling). Finally, for the goods priced in a third currency, 7.16 percent of the unit values are sticky when measured in the vehicle currency, versus 7.06 and 5.23 percent when expressed in producer or local currencies, respectively.

A.2 Exchange Rate Pass-Through

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

$$\Delta \ln UV_{ijk,t} = \sum_{n=0}^{N} \gamma_n \Delta \ln e_{j,t-n} + \sum_{n=0}^{N} \delta_n \pi^*_{j,t-n} + \sum_{n=0}^{1} \varrho_n Y^*_{j,t-n} + D_{i,t} + D_{jk} + \xi_{ijk,t}, \tag{A1}$$

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 of 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). 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 product-destination fixed effects, D_{jk}. Short-run pass-through is given 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-quarter level.

As we did for imports, we estimate equation (A1) on the full sample of exports, and then separately on 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 (A1) as:

$$\Delta \ln e_{j,t} \equiv \Delta \ln e_{ORIG/DEST_t} = \Delta \ln e_{ORIG/VCP_t} + \Delta \ln e_{VCP/DEST_t}, \tag{A2}$$

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

$$\begin{aligned}\Delta \ln UV^{VCP}_{ijk,t} \quad = \quad & \sum_{n=0}^{N} \vartheta_n \Delta \ln e_{ORIG/VCP_{t-n}} + \sum_{n=0}^{N} \zeta_n \Delta \ln e_{VCP/DEST_{t-n}} + \sum_{n=0}^{N} \varkappa_n \pi^*_{j,t-n} \\ & + \sum_{n=0}^{1} \varpi_n Y^*_{j,t-n} + D_{i,t} + D_{jk} + \eta_{ijk,t}, \end{aligned} \tag{A3}$$

where we allow for separate coefficients ϑ_n and ζ_n on the two exchange rates with the vehicle currency. Due to space constraints, we estimate equations (A1) and (A3) but only report and discuss the contemporaneous exchange rate elasticities. The long-run elasticities are available upon request.

Column (1) of Table A4 reports the results of estimating equation (A1) on the full sample of exports. The coefficient on the contemporaneous change in the exchange rate is equal to 0.123, and is significant at the five percent level. In response to a ten percent depreciation of sterling, exporters raise their export prices (in sterling) by 12.3 percent. Therefore, pass-through into import prices is large at 87.7 percent.

Columns (2) to (4) report the results of estimating equation (A1) separately for the transactions invoiced in producer, local, and vehicle currencies. As was the case for imports, exchange rate pass-through 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,

Table A4: Pass-Through into Export Prices

	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \ln e_{ORIG/DEST}$	0.123^{b} (0.063)	0.164 (0.105)	1.132^{b} (0.504)	0.083 (0.103)	–	–
$\Delta \ln e_{ORIG/VCP}$	–	–	–	–	0.859^{b} (0.423)	0.797^{c} (0.415)
$\Delta \ln e_{VCP/DEST}$	–	–	–	–	0.069 (0.102)	–
Invoicing currency	All	PCP	LCP	VCP	VCP	VCP
Observations	639,015	350,028	79,922	209,065	209,065	209,065
R-squared	0.289	0.430	0.539	0.339	0.339	0.339

Notes: Firm-quarter and destination country-product fixed effects are included. Contemporaneous and eight lags of the destination country's quarterly inflation rates, 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-quarter level are reported in parentheses. ^{b} and ^{c} indicate significance at the five and ten percent levels, respectively. The dependent variable is the quarterly log change export unit value (in sterling per kilogram).

and large at 1.132 for the ones in local currencies (column 3). As a result, pass-through into import prices is large for producer and vehicle currencies, and low for local currencies.

For the subsample of vehicle currency priced transactions, we then regress equation (A3) and decompose the bilateral exchange rate according to equation (A2). Consistent with our findings for imports, column (5) shows that export unit values react strongly to changes in the sterling to vehicle currency exchange rate, and do not change when the vehicle to destination country's currency exchange rate fluctuates. These findings are again consistent with prices being sticky in their currency of invoicing. By comparing columns (4) and (5), it can be seen that using the bilateral rather than the sterling to vehicle currency exchange rate underestimates the exchange rate response of export prices in third currencies by 77.6 percentage points. 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 remains large at 0.797.

In results available upon request, we show that our results remain consistent if we let the pass-through elasticities vary across industries. For the vehicle currency priced transactions, the elasticities of export unit values with respect to changes in the sterling to vehicle currency exchange rate are large, and the ones with respect to the vehicle to destination country's currency exchange rate are insignificant. Our results also remain similar if we estimate a specification similar to equation (4) using the full sample of export unit values and including interactions between exchange rate changes and dummies for invoicing currency choices.

B Import and Export Quantities

The regressions for trade quantities take the same form as the pass-through regressions (1) and (3) for imports, and (A1) and (A3) for exports, except that the dependent variable is the log change of import or export quantities (in kilograms), and the contemporaneous and lagged foreign inflation rates are omitted.[43]

For both export and import quantities, it turns out that the contemporaneous and lagged coefficients on the exchange rate changes are erratic and mostly insignificant. As a result, Table B1 only reports, for both exports and imports, the cumulative exchange rate estimates over eight quarters, which are insignificant. We therefore conclude that although trade prices tend to be sensitive to changes in exchange rates, trade quantities are not. This result holds across currency of invoicing choices. 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 and including interactions between changes in exchange rates and dummies for invoicing currency choices.

Table B1: Import and Export Quantities: Cumulative Estimates

	(1)	(2)	(3)	(4)	(5)	(6)
Imports						
$\Delta \ln e_{DEST/ORIG}$	0.143 (0.402)	0.176 (0.480)	−0.369 (0.864)	0.065 (0.380)	–	–
$\Delta \ln e_{DEST/VCP}$	–	–	–	–	1.521 (2.559)	1.499 (2.615)
$\Delta \ln e_{VCP/ORIG}$	–	–	–	–	0.063 (0.393)	–
Observations	2,641,208	732,020	595,997	1,313,191	1,313,191	1,313,191
R-squared	0.230	0.342	0.324	0.270	0.270	0.270
Exports						
$\Delta \ln e_{ORIG/DEST}$	0.292 (0.624)	0.207 (0.620)	−1.310 (2.911)	0.814 (0.741)	–	–
$\Delta \ln e_{ORIG/VCP}$	–	–	–	–	−1.054 (3.731)	−1.811 (3.786)
$\Delta \ln e_{VCP/DEST}$	–	–	–	–	0.820 (0.738)	–
Invoicing currency	All	PCP	LCP	VCP	VCP	VCP
Observations	639,015	350,028	79,922	209,065	209,065	209,065
R-squared	0.269	0.444	0.602	0.323	0.323	0.323

Notes: Firm-quarter and origin/destination country-product fixed effects are included. The table reports the cumulative effects of the contemporaneous and eight lags of the log change in each exchange rate. 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-quarter level are reported in parentheses. The dependent variable is the quarterly log change of import or export quantities (in kilograms).

[43] The results remain similar if we control for the foreign inflation rates.

C Pass-Through into Consumer Prices

In this appendix we describe how we calculate the back-of-the-envelope estimates of how exchange rate movements affect UK consumer price inflation in the short and the long run. We assume that the import component of the UK consumer price index is 30 percent (Forbes et al., 2015). This reflects that consumer prices contain a higher non-traded component compared to import prices, due for instance to local distribution costs, and also include the prices of non-traded and of traded goods which are only sold domestically.

Currency of Invoicing Shares for World Imports In our data set, we only observe the currency of invoicing shares for non-EU imports. To derive the shares for world imports, we rely on aggregate data from Gopinath (2016) which indicate that in 2015 total UK imports were priced in euros (14.78 percent), US dollars (47.16 percent), sterling (31.73 percent), and undefined currencies (6.33 percent). We assume that these shares do not change over time, and therefore apply them to the 2010 to 2013 period we focus on.[44] 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.

To derive 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.[45] In our full sample (i.e., including the "Not classified" industries that we exclude from our regressions), imports from the US in US dollars represent 14.17 percent of total non-EU imports. As non-EU imports amount to 51.92 percent of total UK imports between 2010 and 2013 (Direction of Trade Statistics of the International Monetary Fund), the share of US imports in US dollars in total UK imports is 7.36 percent ($0.1417 \times 0.5192 = 0.0736$). The total VCP share in US dollars is therefore equal to 39.79 percent ($47.16 - 7.36 = 39.79$). Second, we observe that 5.06 percent of non-EU imports are in euros. It follows that the total VCP share in euros is equal to 2.63 percent ($0.0506 \times 0.5192 = 0.0263$).[46] The total VCP share for the UK is therefore assumed to equal 42.42 percent ($39.79 + 2.63 = 42.42$).

Next, we define the total PCP share as the import share from the US in US dollars (7.36 percent), plus the import share from the EU in euros (i.e., 14.78 percent less 2.63 percent), or 19.52 percent. We then allocate the 6.33 percent of world imports invoiced in undefined currencies to either the VCP or PCP shares, and therefore consider two alternative scenarios for the magnitude of the PCP and VCP import shares, as reported in Table C1.

Exchange Rate Changes To measure the average appreciation or depreciation of sterling in each of the three quarterly episodes of large sterling fluctuations, we proceed in two steps. First, we calculate the log change of all sterling bilateral exchange rates (with the UK's importing partners),

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

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

[46] For simplicity, 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 2013, the import shares of the UK from the EU and from the Eurozone are equal to 48.08 and 41.13 percent, respectively (Direction of Trade Statistics of the International Monetary Fund).

Table C1: 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	25.85%	PCP	19.52%
VCP	42.42%	VCP	48.75%

Source: authors' calculations.

and of the sterling to vehicle currencies exchange rates, between the quarter where the exchange rate shock took place and the previous quarter. Second, we calculate weighted averages of these exchange rate changes, where the weights are 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 currencies exchange rate changes weighted by the imports in each vehicle currency as a share of total VCP imports. To assess the individual effects of the US dollar and of the euro, we calculate weighted exchange rate changes for the two currencies only.

To calculate the import weights by invoicing currency, we multiply the non-EU invoicing shares of each country by 0.5192 (the UK's import share from non-EU countries between 2010 and 2013) to get the shares out of total UK imports, and we then divide by the invoicing shares (two different scenarios) reported in Table C1 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 then obtained by subtracting from 100 percent the sum of the shares for the other countries. For the import shares by vehicle currency, 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 Consumer 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 Brexit 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 0.251, we calculate that the 7.13 percent average bilateral depreciation of sterling increases domestic inflation by 0.536 percentage points on impact. The effect is calculated as $(0.0713 \times 0.251 \times 0.3) = 0.536$ percentage points where 0.0713 is the average bilateral depreciation, 0.251 is the pass-through elasticity, and 0.3 is the import component of the consumer price index. After eight quarters, the pass-through elasticity increases to 0.422, implying that inflation rises by 0.902 percentage points.

Once we allow for the currency of invoicing, our point estimates reported in column (3) of Table 6 imply that the depreciation of sterling increases domestic inflation by 0.918 percentage points on impact, and by 1.566 percentage points after eight quarters. The contemporaneous effect is calculated as $[(0.0754 \times 0.006 \times 0.3173) + (0.0729 \times 0.618 \times 0.2585) + (0.0644 \times 0.689 \times 0.4242)] \times 0.3 = 0.918$ percentage points where 0.0754 and 0.0729 are the average bilateral depreciations of sterling for the LCP and PCP transactions while 0.0644 is the average depreciation of sterling against vehicle currencies for the VCP flows, respectively, 0.006, 0.618, and 0.689 are their respective pass-through

Table C2: UK Consumer 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	0.536^a (0.097)	0.902^a (0.290)	0.257^a (0.046)	0.432^a (0.139)
	USD	0.038^a (0.007)	0.064^a (0.021)	0.040^a (0.007)	0.068^a (0.022)
	Euro	0.293^a (0.053)	0.493^a (0.158)	–	–
Bilateral/vehicle rates	All currencies	0.911^a (0.119)	1.624^a (0.409)	0.518^a (0.065)	0.924^a (0.233)
	USD	0.689^a (0.086)	1.256^a (0.329)	0.430^a (0.051)	0.759^a (0.191)
	Euro	0.176^a (0.034)	0.283^a (0.086)	0.042^a (0.006)	0.080^a (0.022)
All currencies against sterling (weighted)		+7.13%		+6.58%	
US dollar against sterling		+6.34%		+6.34%	
Euro against sterling		+7.66%		+7.66%	
Great Recession (2008M11–2009M1)					
Bilateral rates	All currencies	0.953^a (0.172)	1.604^a (0.515)	0.509^a (0.092)	0.856^a (0.275)
	USD	0.117^a (0.021)	0.197^a (0.063)	0.124^a (0.022)	0.208^a (0.067)
	Euro	0.472^a (0.085)	0.795^a (0.255)	–	–
Bilateral/vehicle rates	All currencies	2.482^a (0.315)	4.463^a (1.134)	1.473^a (0.180)	2.615^a (0.657)
	USD	2.110^a (0.265)	3.846^a (1.007)	1.317^a (0.156)	2.325^a (0.586)
	Euro	0.283^a (0.054)	0.456^a (0.138)	0.067^a (0.009)	0.128^a (0.036)
All currencies against sterling (weighted)		+12.68%		+13.03%	
US dollar against sterling		+19.43%		+19.43%	
Euro against sterling		+12.34%		+12.34%	
EU Debt Crisis (2015M1–2015M3)					
Bilateral rates	All currencies	-0.227^a (0.041)	-0.382^a (0.123)	0.012^a (0.002)	0.021^a (0.007)
	USD	0.029^a (0.005)	0.048^a (0.015)	0.030^a (0.005)	0.051^a (0.016)
	Euro	-0.239^a (0.043)	-0.402^a (0.129)	–	–
Bilateral/vehicle rates	All currencies	0.377^a (0.055)	0.720^a (0.213)	0.293^a (0.035)	0.513^a (0.128)
	USD	0.516^a (0.065)	0.941^a (0.247)	0.322^a (0.038)	0.569^a (0.144)
	Euro	-0.143^a (0.027)	-0.230^a (0.070)	-0.034^a (0.005)	-0.065^a (0.018)
All currencies against sterling (weighted)		-3.02%		+0.31%	
US dollar against sterling		+4.76%		+4.76%	
Euro against sterling		-6.24%		-6.24%	

Notes: All estimates are reported in percentage points. The estimates reported in the rows "Bilateral rates" are obtained based on the pass-through regression of column (1) in Table 5. The estimates reported in the rows "Bilateral/vehicle rates" are obtained using the pass-through regression of column (3) in Table 6. ^{a} indicates significance at the one percent level.

elasticities, 0.3173, 0.2585, and 0.4242 are their invoicing shares for world imports (scenario 1), and 0.3 is the import component of the consumer price. The individual effects of the US dollar and of 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 to consumer prices.

Table 8 in the main text reports our estimates based on scenario 1 for the currency of invoicing shares, while columns (1) and (2) of Table C2 rely on scenario 2. Overall, the two alternative scenarios yield very similar results (notice that the estimates with bilateral exchange rates only are identical for scenarios 1 and 2).

Columns (3) and (4) of Table C2 report our estimates for non-EU imports. The estimates are calculated in the same way as for world imports, with two differences. First, we use the currency of invoicing shares that we directly observe in our sample for non-EU imports, and compute the corresponding weighted averages of exchange rate changes with non-EU trading partners only. Second, all estimates are further multiplied by 0.5192 which is the UK import share from non-EU countries between 2010 and 2013. As a result, the response of inflation to changes in exchange rates is smaller in magnitude for non-EU than for world imports.

Overall, for non-EU imports our results can be interpreted in the same way as for world imports, with a few differences. First, notice that for the specification with bilateral exchange rates only, the euro plays no role. Second, once we allow for the effect of vehicle currencies, the contribution of the euro is modest as it is only used as a vehicle currency in non-EU imports. Third, in the specification that considers the role of vehicle currencies, Table C2 shows that the contribution of the US dollar in columns (1) and (2) for world imports is larger than in columns (3) and (4) for non-EU imports. This reflects that 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 shows that exchange rate movements increase inflation as the appreciation against the euro is not accounted for. When we consider vehicle currencies, fluctuations in exchange rates also increase 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.

D Robustness

Table D1: Robustness for Import Prices

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\Delta \ln e_{DEST/ORIG} \times D_{PCP}$	0.567^{a}	0.610^{a}	0.613^{a}	0.628^{a}	0.738^{a}	0.603^{a}	0.500^{c}
	(0.092)	(0.084)	(0.113)	(0.087)	(0.134)	(0.144)	(0.277)
$\Delta \ln e_{DEST/ORIG} \times D_{LCP}$	0.008	0.006	0.043	0.052	0.006	0.022	−0.126
	(0.066)	(0.055)	(0.056)	(0.057)	(0.098)	(0.056)	(0.224)
$\Delta \ln e_{DEST/VCP}$	0.618^{a}	0.684^{a}	0.658^{a}	0.857^{a}	0.797^{a}	0.624^{a}	0.518
	(0.113)	(0.098)	(0.104)	(0.097)	(0.126)	(0.129)	(0.418)
Sample	Manuf.	Excl. raw	Excl. US	Origin	Interm.	Final	Capital
Observations	2,234,346	2,597,109	2,010,226	1,764,341	1,099,500	1,147,230	389,224
R-squared	0.240	0.235	0.264	0.318	0.288	0.308	0.350

Notes: Firm-quarter and origin country-product fixed effects are included. Contemporaneous and eight lags of the origin country's quarterly inflation rates, 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-quarter level are reported in parentheses. [a] and [c] indicate significance at the one and ten percent levels, respectively. The dependent variable is the quarterly log change import unit value (in sterling per kilogram).

Table D2: Robustness for Import Prices: Firm Size

	(1)	(2)	(3)	(4)
$\Delta \ln e_{DEST/ORIG} \times D_{PCP}$	0.594^{a}	0.627^{a}	0.464^{a}	0.656^{a}
	(0.111)	(0.113)	(0.171)	(0.085)
$\Delta \ln e_{DEST/ORIG} \times D_{LCP}$	−0.037	0.026	−0.060	0.019
	(0.069)	(0.062)	(0.114)	(0.054)
$\Delta \ln e_{DEST/VCP}$	0.762^{a}	0.598^{a}	0.625^{a}	0.704^{a}
	(0.117)	(0.141)	(0.192)	(0.105)
Sample	Excl. top 1% firms	Top 1% firms only	Excl. top 5% firms	Top 5% firms only
Observations	1,707,310	933,898	936,442	1,704,766
R-squared	0.346	0.082	0.499	0.110

Notes: Firm-quarter and origin country-product fixed effects are included. Contemporaneous and eight lags of the origin country's quarterly inflation rates, 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-quarter 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 D3: Robustness for Import Prices: Annual Frequency

	(1)	(2)	(3)	(4)
$\Delta \ln e_{DEST/ORIG}$	0.376^a (0.062)	–	–	–
$\Delta \ln e_{DEST/ORIG} \times D_{PCP}$	–	0.818^a (0.117)	0.820^a (0.103)	0.797^a (0.095)
$\Delta \ln e_{DEST/ORIG} \times D_{LCP}$	–	0.192^a (0.063)	0.223^a (0.056)	0.167^a (0.060)
$\Delta \ln e_{DEST/ORIG} \times D_{VCP}$	–	0.208^a (0.066)	–	–
$\Delta \ln e_{DEST/VCP}$	–	–	0.773^a (0.198)	0.624^a (0.193)
$\Delta \ln e_{VCP/ORIG}$	–	–	0.171^a (0.056)	–
Observations	1,108,007	1,108,007	1,108,007	1,108,007
R-squared	0.217	0.217	0.217	0.217

Notes: Firm-year and country-product fixed effects are included in (1). Firm-year, 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 rates, 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] indicates significance at the one percent level. The dependent variable is the annual log change import unit value (in sterling per kilogram).

E Theory

We set up and solve the optimization problem described in Section 6.1.1. Similar to Engel (2006), the firm maximizes the twice-differentiable concave profit function $\pi\left(p_v^*, \mathbf{x}\right)$, where $\mathbf{x}$ is a cost vector of variables including the exchange rate that affect the firm's profits but are exogenous to the firm. This cost vector $\mathbf{x}$ may include the exchange rate $e_{m/v}$. The firm has to choose the price for its product 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 $1-\widehat{\mu}^v$, where $\widehat{\mu}^v$ is the coefficient on the projection of $\tilde{p}_v^*$ on the exchange rate $e_{m/v}$. The result is given by

$$\widehat{\mu}^v = \frac{\pi'_{px}\left(\tilde{p}_v^*, \bar{\mathbf{x}}\right)}{\pi_{pp}\left(\tilde{p}_v^*, \bar{\mathbf{x}}\right)} \frac{cov\left(e_{m/v}, \mathbf{x}\right)}{var\left(e_{m/v}\right)}, \tag{E1}$$

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

The proof of the result in expression (E1) is as follows. We have the first-order condition $\pi_p\left(p_v^*, \bar{\mathbf{x}}\right) = 0$, and $\tilde{p}_v^*$ 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:

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

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

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

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

Replacing p_v^* with $p_0^v - \mu^v e$ (and dropping the subscript of e for simplicity), we find the first-order conditions for choosing p_0^v and μ^v, respectively:

$$\begin{aligned}
\pi_{pp}\left(\tilde{p}_v^*, \bar{\mathbf{x}}\right)\mathrm{E}\left(p_0^v - \widehat{\mu}^v e - \tilde{p}_v^*\right) &= 0, \\
\pi_{pp}\left(\tilde{p}_v^*, \bar{\mathbf{x}}\right)\mathrm{E}\, e\left(p_0^v - \widehat{\mu}^v e - \tilde{p}_v^*\right) + \pi_{px}\left(\tilde{p}_v^*, \bar{\mathbf{x}}\right)'\mathrm{E}\, e\left(\mathbf{x}-\bar{\mathbf{x}}\right) &= 0,
\end{aligned}$$

where $\widehat{\mu}^v$ is the value of μ^v that maximizes the objective function Π.

From the first condition above, we have $p_0^v = \widehat{\mu}^v \bar{e} + \tilde{p}_v^*$, where $\bar{e}$ is the mean of e. Substituting this into the second condition we obtain

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

Solving for $\widehat{\mu}^{v}$ we obtain equation (E1) as

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

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

Similar to expression (E1), the coefficient on the projection of $\tilde{p}_{v}^{*}$ on the exchange rate $e_{m/j}$ in Section 6.1.2 follows as

$$\widehat{\mu}^{bil}=\frac{\pi_{px}'\left(\tilde{p}_{v}^{*},\bar{\mathbf{x}}\right)}{\pi_{pp}\left(\tilde{p}_{v}^{*},\bar{\mathbf{x}}\right)}\frac{cov\left(e_{m/j},\mathbf{x}\right)}{var\left(e_{m/j}\right)}. \tag{E2}$$

This gives rise to the bilateral pass-through elasticity $1-\widehat{\mu}^{bil}$. Analogously, the coefficient on the projection of $\tilde{p}_{v}^{*}$ on the exchange rate $e_{v/j}$ in Section 6.1.3 follows as

$$\widehat{\mu}^{exp}=\frac{-\pi_{px}'\left(\tilde{p}_{v}^{*},\bar{\mathbf{x}}\right)}{\pi_{pp}\left(\tilde{p}_{v}^{*},\bar{\mathbf{x}}\right)}\frac{cov\left(e_{v/j},\mathbf{x}\right)}{var\left(e_{v/j}\right)}. \tag{E3}$$