BANK OF ENGLAND

Staff Working Paper No. 868

Non-linearities, asymmetries and dollar currency pricing in exchange rate pass-through: evidence from the sectoral level

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June 2020

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Abstract

We investigate pass-through of exchange rate changes into UK import prices for 55 sectors using sector-specific exchange rate indices. Estimating a separate error correction model for each sector, we document substantial sectoral variation in pass-through, but find that compositional effects have not generated much variation in aggregate pass-through over time. Aggregating our sectoral results, we find that 74% of exchange rate changes are passed through to aggregate import prices in the long run. Pass-through is faster for larger exchange rate changes than smaller ones; and for movements driven by the US dollar than for broader based exchange rate changes. This greater sensitivity to the dollar exchange rate changes suggests the US dollar is used as a vehicle currency for invoicing some imports from non-US countries. We find no evidence of a comparable role for the euro nor for asymmetries in pass-through at the aggregate level.

Key words: Exchange rate pass-through, import prices, vehicle currencies, non-linearities.

JEL classification: E31, E44.

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The authors would like to thank Michel Ghasssibe, Robert Zymek, Andrea Šiško, participants at the Bank of Brazil Conference on Inflation Targeting and participants at the Bank of Canada Seminar Series for useful comments on the paper. Any remaining errors are our own. The views expressed are those of the authors and not necessarily those of the Bank of England or any of its policy committees.

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ISSN 1749-9135 (on-line)

1 Introduction

How do changes in the exchange rate feed through to import prices? Typically, the recent empirical literature seeks to answer this question in one of two ways. One approach is to use aggregate import price series regressed on some aggregate exchange rate measure which has the advantage of yielding results expressed in terms of the aggregate variable of interest to macroeconomists. An alternative approach is to use microeconomic data, typically at the shipment or firm level. This has the twin advantages of providing more datapoints, and providing a unit of observation which corresponds more closely to the economic decision making unit. But the corresponding disadvantage is that it doesn't yield results in terms of aggregate variables. To the extent that responses differ between cross sectional units, and/or non-linearities are present, it is not straightforward to map over from one to the other.

This paper seeks to bridge the two approaches by using sectoral level data. We take sectoral level import price indices for 55 sectors, and construct our own sector-specific exchange rate indices based on sector-specific country weights computed using data on bilateral trade flows. Estimating a set of sector-specific error correction models (ECMs) for the UK over the period 1998-2018, we find evidence of considerable heterogeneity in the speed and extent of pass-through across sectors. Aggregating these using sector shares in total imports, we find that long-run pass-through is relatively high, but not complete: around 74% of an exchange rate change is ultimately passed through to import prices. We find that because the composition of imports has not changed substantially between high and low pass-through sectors, aggregate long run pass-through remains broadly stable over our sample period.

We exploit the richness and heterogeneity in our data to investigate for signs of short-run non-linearities, asymmetries or the presence of vehicle currency invoicing (where exporters from outside the US or euro area price in dollars or euros). We find that many sectors exhibit at least one of these phenomena.

In aggregate, the sectoral asymmetries largely cancel out, such that appreciations and depreciations are passed through at similar speed in aggregate. But non-linearities are significant at the aggregate level: with larger changes being passed through more quickly than smaller ones. In addition, movements in the exchange rate index driven by the US dollar are passed through more quickly than equivalent sized moves where sterling moves uniformly against all other currencies. For these dollar-led ERI changes, instantaneous pass-through is almost double.

Relative to the existing literature, our sector-level approach has several advantages. First, this is to our knowledge the first attempt to utilise sector-specific exchange rate indices, as opposed to applying a common index to all sectors. To the extent that the country composition of imports (and the associated bilateral exchange rate movements) differ across sectors, a common exchange index for all sectors will mis-specify exchange rate changes faced by individual sectors.

Second, our sectoral data allows us to investigate and quantify differences in pass-through across sectors. Various factors such as substitutability of imports with domestic production, length of the distribution/supply chain domestically, competitiveness of the sector and transit/production lags might generate differences in the speed and extent of pass-through across sectors. As Mumtaz, Oomen and Wang (2011) and Pesaran and Smith (1995) have shown, this heterogeneity can lead to a bias in the estimation of coefficients if estimated as a panel.[1]

Third, using sectoral as opposed to aggregate data and computing sector-specific exchange rates significantly increases the number of observations in our sample. In our dataset, utilising 55 sectors means our dataset is correspondingly expanded 55-fold. Exploiting cross sectional variation in both import prices and exchange rates, this greatly enhances our ability to test for non-linearities, asymmetries, and dollar/euro invoicing effects in the data.

Our paper sits between the empirical macro-level and micro-level literatures on exchange rate pass-through.

The modern macro-level literature traces its origins back to Campa and Goldberg (2005), which estimated exchange rate pass-through for a sample of 23 OECD countries by performing log difference regressions of aggregate import prices on lags of the exchange rate. This literature seeks to explain cross-country differences in pass-through by looking at various structural characteristics. It has evaluted the role of factors such as monetary policy (Gagnon and Ihrig, 2004), exchange rate volatility (Berger and Vavra, 2013) and trade integration (Gust, Leduc and Vigfusson, 2010) in influencing pass-through.

A recent strand of the macro-level literature has documented time-variation of exchange rate pass-through to import and consumer prices. This literature includes papers focusing on trends in exchange rate pass-through such as Selin Özyurt (2016), Marazzi and Sheets (2007) and Jašová, Moessner and Takáts (2016) who document an apparent fall in pass-through over time, as well as papers documenting variation in exchange rate pass-through over shorter time spans. Forbes, Hjortsoe and Nenova (2018) document that exchange rate pass-through to aggregate UK import prices varies over shorter time periods and shows that part of that variation can be explained by variation in the shocks affecting the UK exchange rate. Using a similar framework, Comunale and Kunovac (2017) and Corbo and Di Casola (2018) find similar results for selected euro area countries

[1]Elsewhere, Imbs et al. (2005) have made a similar point about aggregation bias in the context of estimating the speed with which deviations from purchasing power parity are eliminated

and for Sweden. In line with these papers focusing on individual countries, Forbes, Hjortsoe and Nenova (2017) document that exchange rate pass-through varies over time in numerous advanced and developed economies, and they show that that variation can be partly explained by variation in shocks as well as by changes in structural characteristics. We add to this literature by investigating other sources of time-variation of exchange rate pass-through, focusing on the role of non-linearities, asymmetries and vehicle currency pricing.

On the micro side, Gopinath and Rigobon (2008) and Gopinath, Itskhoki and Rigobon (2010) initiated a rich literature using goods-level data for the US. This literature focuses on the effects of dollar pricing and uncovers evidence of differential pass-through between imports priced in dollars versus those priced in exporters currency, even when conditioned on a price change. In this case aggregate import price pass-through would then depend on the relative weights of the two types of imports. Similarly, Devereux, Tomlin and Dong (2015) for Canada, find a similar split between pass-through to imports invoiced in domestic vs foreign currency, and of higher pass-through where competition is greater. Whilst the detailed nature of their datasets has obvious attractions, there may be questions as to whether the results regarding the role of the dollar as an invoicing currency generalise to other importing countries, where the US is neither the importer nor principal exporter.

This is an especially interesting question for small open economies such as the UK, where the use of the domestic currency as an invoicing currency has been found to be much lower (see for example, Gopinath, 2015; or Goldberg and Tille, 2008). In an important recent contribution, Novy, Chen and Chung (2019) considers this question using UK firm level micro-data for unit values. They uncover a significant role for vehicle currency pricing, predominantly the US dollar. Our results based on exchange rate pass-through to import prices (as opposed to unit values) are qualitatively similar, but we find a greater long-run pass-through, and one which is closer to that implied by aggregate data. Moreover, they don't consider explicitly the role of non-linearities, which we find to be important.

The presence of non-linearities in exchange rate pass-through has been documented in a couple of recent studies using micro-level data: Bonadio, Fischer and Sauré (2018) finds evidence of non-linearities in pass-through following a shift in exchange rate policy in 2015 in Switzerland; and Lewis (2016) finds evidence of non-linear pass-through to unit values for goods in the UK, whereby smaller exchange rate changes are subject to much lower pass-through, but shows that this disappears at the macro level because of aggregation effects.

A common feature of all these works is that they don't directly allow for or investigate the possibility that pass-through coefficients differ across industries. Accordingly, our work aims to fill that gap.[2]

To our knowledge, the only attempt to estimate pass-through using sectoral import price indices for the UK is Mumtaz, Oomen and Wang (2011). An important difference with respect to our work is that they use a homogenous, economy-wide exchange rate index, which takes no account of the potential heterogeneity in exchange rates arising from the fact that the composition of countries from which imports originate may differ across sectors. Yang (1997) performs a similar exercise for the US, but also uses a homogenous rather than an industry specific exchange rate as an explanatory variable. In addition, both papers impose a common lag structure on their models, whereas our approach allows for heterogeneity across industries. And crucially, neither paper seeks to test for asymmetries or non-linearities.

Finally and most importantly, our paper contributes directly to the new and growing literature on the role of vehicle currencies for invoicing in international trade.[3] We find strong evidence of dollar currency pricing by non-US exporters. UK import prices are responsive to US dollar movements by far more than would be implied by the US's trade weight in sectoral ERIs. This result is all the more striking because the US accounts for only 8% of total UK imports. This suggests widespread use of the dollar as a vehicle currency for invoicing exports from "third countries" to the UK.

The remainder of the paper is organised as follows. Section 2 describes our dataset and details our empirical methodology, section 3 outlines our baseline results and section 4 explores the role of non-linearities, asymmetries and dollar currency pricing. Section 5 concludes.

[2]Our work also has links to an earlier trade literature which used sectoral data to test the extent to which *exporters* discriminate across destinations, including by responding to bilateral exchange rate or tariff changes. For example Knetter (1993), which aims to understanding pricing to market behaviour, using export rather than import prices, or Feenstra (1989) which looks at pass-through of tariffs into import prices for a narrow set of Japanese goods imports into the US, or Gross and Schmitt (2000) for imports of cars into Switzerland. In contrast to this strand of the literature, our work focusses on imports, and seeks to provide insights into the aggregate economy-wide pass-through rather than analyse a specific sector or goods type.

[3]For more on this "dominant currency paradigm" see for example Plagborg-Møller, Gopinath and Boz (2017), Gopinath et al. (2016) or Gopinath (2015)

2 Empirical Methodology

2.1 Data

2.1.1 Import prices

The import price index (IPI) is collected by the ONS from the Monthly Survey for Index Numbers of Producer Prices. Each month approximately 2144 quotes are collected from a sample of UK import agents and manufactures, and some prices are collected from published and other sources. Prices are collected on a Standard Industrial Classification 2007 (SIC2007) basis, at the 6 HS digit level. Monthly import price series exist for 106 sectors[4] of goods covering the period 1998m1 to 2017m6.[5] These record the import prices of goods in a particular sector from EU countries, and from non-EU countries, though for some sectors only one of the two is reported. The series include sectors such as *"processed and preserved meat"*, *"textile, yarn and thread"* and *"paper stationery"*.

We clean the data in the following way. First, we exclude 42 series with missing observations during our sample period from 1998m1 to 2018m12. We are thus left with a sample of 64 series.[6] Visual inspection reveals that some series have large jumps in levels, indicative of a structural break. We test formally for structural breaks as follows: first, we defined a structural break to be any absolute month-on-month change which was unusual (more than three standard deviations from the average for that sector), sizeable (was bigger than 5% month on month), and isolated (was more than three deviations larger in size than any other change in the three months before and after.)[7] Any series with more than three such structural breaks was discarded.[8] For series with one or two structural breaks, we adjusted the data to account for these level shifts. We regressed the changes in import prices on a time trend and spike dummies equal to one the period of the structural break and equal to zero otherwise. The value of the coefficient on the spike dummy was taken as our estimate of the levels shift induced by the structural break, and the raw import price index was adjusted by that amount for all subsequent periods. This procedure was applied to 25 series. Finally, we also excluded the sectors "Other non-ferrous metal" and "Computers" from our

[4] In official terminology, these series are called groups" within the SIC 2007 classification, as opposed to the so-called "divisions" which are higher levels of aggregation. We use the term "sector" throughout for ease of reading

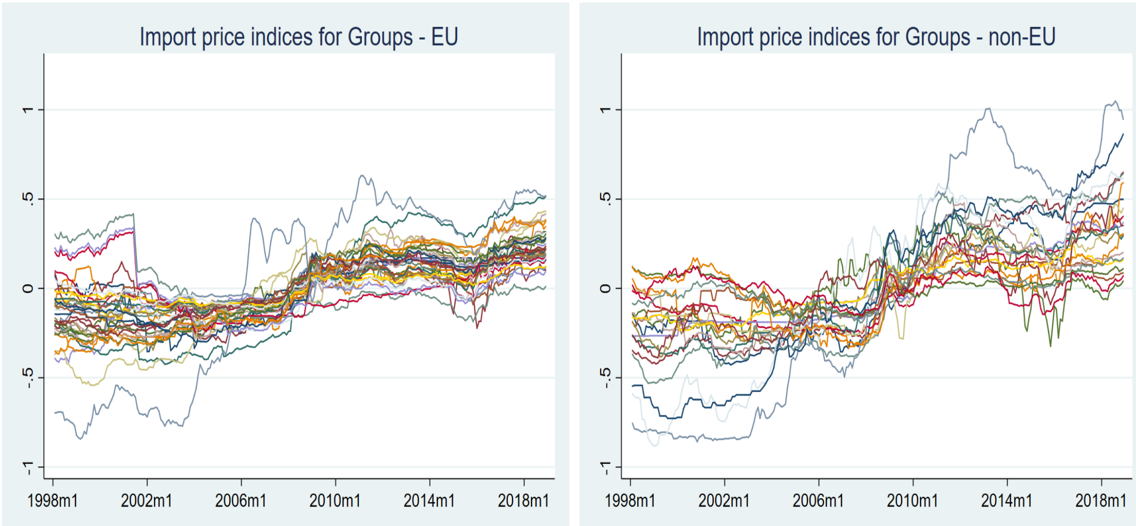
[5] Prior to 1998, the methodology used to derive import price indices differed, and in particular, was more heavily dependent on data collected in foreign currency.

[6] The series discarded due to missing data are series with data starting only after 2009 or series with missing data around 2009, for several months.

[7] This requirement ensures that large import price changes are not identified as structural breaks e.g. after a large depreciation such as the one experienced in the UK in 2008-9, as the adjustment would generally be spread over several months and not happen in an isolated month.

[8] We discarded 2 series because they had more than two structural breaks.

Figure 1: Import price indices for groups of goods



Note: These figures show the normalised level of import price indices.

sample given issues with quality-adjustment of prices related to the latter category of goods.

A list and description of the remaining 55 series can be found in Table 1. Figure 1 shows the logged import price indices of each of these series, for EU and non-EU imports respectively. The import price indices vary substantially, both across sectors and over time.[9]

2.1.2 Sector-specific exchange rate indices

We build sector-specific exchange rate indices whose country weights mirror the shares of imports from each country in a given sector.

We construct our index using chain weighting, where the change in the exchange rate index for sector i at time t, ΔER_t^i, is constructed as a weighted sum of sterling bilateral exchange rate changes:

[9]Despite our efforts to exclude series with structural breaks (without excluding those with large changes that aren't structural breaks), it looks like three of the series were adjusted at the end of 2001. These series are *"8231200100: Shaped and Processed Flat Glass - EU Imports"*, *"8231300100: Hollow Glass - EU Imports"* and *"8237000100: Cut, Shaped and Finished Stone - EU Imports"*, as as robustness check we re-ran the regressions without them, but our results do not change significantly if they are excluded.

Table 1: Groups of goods in final dataset

Description	EU	Non-EU
Processed and preserved meat	Y	Y
Meat and poultry meat	Y	
Processed and preserved fish, crustraceans and molluscs	Y	Y
Fruit and vegetable juices	Y	
Processed and preserved fruit and vegetables		Y
Processed tea and coffee		Y
Textile, yarn and thread	Y	Y
Woven textiles	Y	Y
Made-up textile articles, except apparel		Y
Cordage, rope, twine and netting	Y	
Wood, sawn and planed	Y	
Veneer sheets and wood-based panels		Y
Paper and paperboard	Y	
Paper stationary	Y	Y
Other inorganic basic chemicals	Y	Y
Other organic basic chemicals	Y	Y
Plastics in primary form	Y	Y
Perfumes and toilet preparations	Y	
Other chemical products n.e.c.	Y	
Rubber tires or tubes; retreading and rebuilding of rubber tires	Y	Y
Other rubber products	Y	Y
Plastic plates, sheets, tubes and profiles	Y	
Other plastic products	Y	
Shaped and processed flat glass	Y	
Hollow glass	Y	
Cut, shaped and finished stone	Y	
Basic iron and steel and of ferro-alloys		Y
Tubes, pipes, hollow profiles and related fittings, of steel	Y	Y
Aluminium	Y	Y
Copper	Y	
Electric motors, generators and transformers	Y	
Electricity distribution and control apparatus	Y	
Wiring devices	Y	
Electric domestic appliances	Y	Y
Other electrical equipment	Y	Y
Other pumps and compressors	Y	
Agricultural and forestry machinery	Y	Y
Machinery for mining, quarrying and construction	Y	
Other special-purpose machinery	Y	Y

$$\Delta ER_t^i = \sum_j \left[w_t^{i,j} \Delta S_t^j \right]$$

where S_t^j denotes the bilateral exchange rate between sterling and country j's currency and the weights, $w_t^{i,j}$, are defined as the share imports of sector i from country j in the previous year: $w_t^{i,j} \equiv (m_{t-1y}^{i,j})/(\sum_j m_{t-1y}^{i,j})$, where $m_{t-1y}^{i,j}$ denotes sector i imports from country j in the previous calendar year.

We use month average spot exchange rates against sterling from the Bank of England's Statistical Interactive Database. We use data for the 42 countries reported in Table 2.[10]

Table 2: Countries

Australia	Hong Kong	Philippines
Austria	Hungary	Poland
Belgium	Indonesia	Portugal
Brazil	India	Russia
Canada	Ireland	Singapore
China	Israel	Slovakia
Cyprus	Italy	Slovenia
Czech Republic	Japan	South Africa
Denmark	South Korea	Spain
Estonia	Malta	Sweden
Finland	Netherlands	Switzerland
France	New Zealand	Thailand
Germany	Norway	Turkey
Greece	Pakistan	USA

To construct the weights, we use data from the UN Comtrade database on trade flows at the goods level, on an annual basis. We construct annual weights for each sector as described above and use those in all months of the next year. The weights are thus exogenous to any simultaneous changes in the trade composition.

There is no official concordance between the SIC 2007 sectors for which we have import price data and the SITC sectors reported in the UN Comtrade database. We therefore carefully match the SITC sectors in the UN Comtrade database with the SIC 2007 sectors. An example of our

[10]While we have exchange rate data for 48 countries we do not use the exchange rate data for Egypt, Iran, Kuwait, Malaysia, Saudi Arabia and Taiwan, as we do not have import data for these countries.

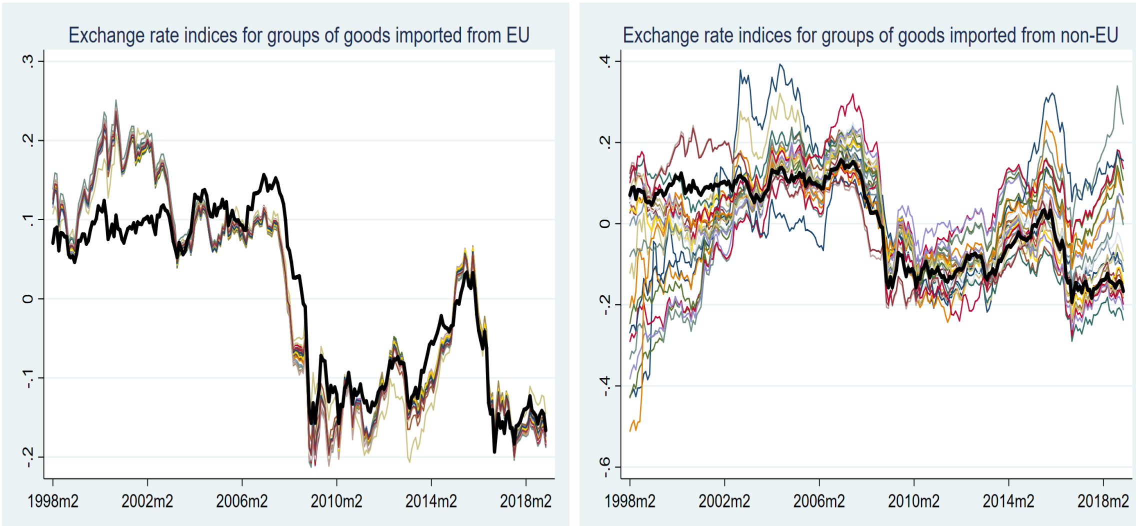
concordance figures in Table 3. A complete table showing which SITC (Rev 3) codes correspond to each of the 55 SIC2007 sectors can be obtained from the authors upon request.

Table 3: Example of concordance between SIC2007 sectors and SITC Rev 3 sectors

Division 10: Manufacture of food products	
SIC2007 code	SITC Rev 3 code(s)
Processed and preserved meat	**Group 017:** Meat and edible meat offal, prepared or preserved
Meat and poultry meat	**Group 011:** Meat of bovine animals, fresh, chilled or frozen **Group 012:** Other meat and edible meat offal, fresh, chilled or frozen (except meat and meat offal unfit/unsuitable for human consumption) **Group 016:** Meat and edible meat offal, salted, in brine, dried or smoked; edible flours and meals of meat and meat offal
Processed and preserved fish, crustaceans and molluscs	**Group 035:** Fish, dried, salted or in brine; smoked fish (whether or not cooked before or during the smoking process); flours, meals and pellets of fish, fit for human consumption **Group 036:** Crustaceans, molluscs and aquatic invertebrates, whether in shell or not, fresh (live or dead), chilled, frozen, dried, salted or in brine; crustaceans, in shell, cooked by steaming or boiling in water, whether or not chilled, frozen, dried, salted or in brine; flours, meals and pellets of crustaceans or of aquatic invertebrates, fit for human consumption **Group 037:** Fish, crustaceans, molluscs and other aquatic invertebrates, prepared or preserved, n.e.s.
Fruit and vegetable juices	**Group 059:** Fruit juices (including grape must) and vegetable juices, unfermented and not containing added spirit, whether or not containing added sugar or other sweetening matter

Figure 2 shows these sector-specific exchange rate indices, constructed as described above. These exhibit substantial variation across time and some variation across sectors, especially for non-EU imports. Note that the series is defined in the European style, so a rise denotes an appreciation of sterling.

Figure 2: Exchange rate indices for groups of goods



Note: The figures show the normalised log of the exchange rate indices for each of the groups of goods. The black line is the sterling exchange rate index, computed by the Bank of England.

2.1.3 Control variables

An extensive literature studying exchange rate pass-through across countries and over time has pointed out that import prices are a function of the exchange rate, but also respond to other variables, in particular foreign marginal costs. Estimates of exchange rate pass-through could be biased if foreign marginal costs are correlated with the exchange rate but not included in the regression. To avoid this, Campa and Goldberg (2005) for example use a framework in which import prices are a function of exchange rates as well as foreign exporters' wages and destination market demand conditions proxied by GDP.[11] Corsetti, Dedola and Leduc (2008) show that including those control variables help reduce the potential bias of estimates of exchange rate pass-through. Burstein and Gopinath (2014) also point out that pass-through regressions generally include a measure of exporters' cost of production, such as wages or producer prices, and sometimes a measure of competitive pressures in the destination market, such as producer prices, and demand conditions, proxied e.g. by GDP in the destination market. In line with this strand of literature, we control for foreign costs of production as well as for domestic competitive pressures and demand conditions.

To control for the bias which could arise if foreign costs of production and the exchange rate

[11] Mumtaz, Oomen and Wang (2011) also control for foreign exporters' unit labour costs and for domestic GDP in their sectorial analysis of exchange rate pass-through. Our analysis differs from theirs in that we have more sectors, monthly (rather than quarterly) data and most importantly construct sector-specific exchange rate indices (rather than using the ERI for all industries).

are correlated we include sector-specific measures of world prices in our regressions. World price inflation of sector i imports is constructed using aggregate export price inflation weighted by country import shares:

$$\Delta P^{f}_{i,t-p} = \sum_{j} w^{i,j}_{t} \Delta P^{j}_{t},$$

where $P^{f}_{i,t-p}$ denotes country j's export price inflation and the weights, $w^{i,j}_{t}$, are identical to those used to construct sector-specific exchange rate indices. To get as reliable export price data for as many countries as possible, we use quarterly data on export price deflators or on export price indices, and interpolate monthly data using linear interpolation.[12] While the sector-specific world prices reflect the composition of countries from which imports in sector i originate, they do not reflect otherwise industry-specific changes in costs of production. However, to reduce any bias from such industry-specific changes in costs of production, we also control for oil prices and non-energy commodity prices, as these input prices might be particularly important in some of the manufacturing sectors in our sample. In particular, we use the price of crude oil (Brent Dated) in US dollars per Barrel from the International Commodity Information Services, London Oilreport as provided by Datastream, and the Standard and Poors Goldman Sachs Non-Energy Spot Commodity Index. Moreover, to the extent that these sector-specific changes in foreign costs are worldwide and also affect UK costs, they should be picked up by domestic sector-specific PPI which we also include as a control.

To control for domestic competitive pressures and global sector-specific changes in costs, we include domestic PPI output prices for each of the sectors considered. We use the ONS indices of output prices which are collected according to the same sectorial classification as import prices. We correct for structural breaks in the output price series using the same methodology as for import prices.[13] Finally, we control for the effect of domestic demand conditions on import prices by including the relevant monthly indices of production. These indices of production are not available on as granular a level as the price indices, they are available for 13 broader manufacturing industries to which the divisions and groups in our data set belong. For each division and group, we use as a control variable the index of production of the broader manufacturing industry to which it belongs.

[12] A few countries (China, Hong Kong, India and Russia) do not collect the data required, or does not have it going back very far. For those countries we use unit value indices instead. We have no data for South Africa. We use national sources or Eurostat.

[13] We use the PPI output prices for the sectors considered, except for some groups with missing data where we use the output price of the broader division it belongs to. For the division '*'Beverages"*, we use an average of three groups that belong to *"beverages"*, namely *"Soft drinks, mineral waters and other bottled waters"*, *"Cider and other fruit wines"* and *"Beer"*.

2.1.4 Co-integration relations

An ECM is appropriate to study the link between exchange rates and import prices if these series are co-integrated i.e. have a common stochastic trend and a linear combination of them is I(0). We first test whether the series have a unit root and whether they are co-integrated.

We use unit root tests which allow for heterogeneity in the autoregressive parameters across industries such as the Im, Pesaran and Shin (2003) test and the Fisher test.[14] The null hypothesis is that all industries contain unit roots while the alternative in both tests is that at least one sector does not contain a unit root. The test results are reported in Table 4. None of the five tests we run are able to reject that all the panels of import prices and exchange rates contain unit roots. The evidence regarding the export price series is different: All five tests we run indicate that at least one panel does not have a unit root. To further check the robustness of the results for the main variables of interest, namely exchange rates, import prices and export prices, we ran augmented Dickey-Fuller unit root tests on all the series individually. We found strong support for the presence of a unit root in all individual import price series and in all but one of the exchange rate series and of the export prices series.

Table 4: Unit root test results

	Import prices		**Exchange rates**		**World export prices**	
	Statistic	P-value	Statistic	P-value	Statistic	P-value
Im-Pesaran-Shin unit root test						
	-1.5021	0.0665	-1.2324	0.1089	-4.3030	0.0000
Fisher unit root test						
Inverse chi-squared	128.9117	0.1051	108.7617	0.5155	167.4784	0.0003
Inverse normal	-1.1834	0.1183	-0.5175	0.3024	-3.9952	0.0000
Inverse logit t	-1.2389	0.1082	-1.0481	0.1478	-3.8362	0.0001
Modified inverse chi-squared	1.2750	0.1011	-0.0835	0.5333	3.8752	0.0001

We then test whether the variables to enter the long-run relationship that have a unit root are also co-integrated. We use the Westerlund error-correction-based panel cointegration tests described in Persyn and Westerlund (2008) which is robust to correlation in the cross-sectional units.[15] All

[14]We allow for panel-specific means and time trends. We also subtract the cross-sectional averages from the series. In the Im-Pesaran-Shin test, we allow the number of lags to be determined by the Akaike criteria, and in the Fisher test we use the cross-sectional average of those number of lags chosen by the Akaike criteria. Our results for import prices and world export prices are robust to refraining from subtracting the cross-sectional means from the data, while one of the tests then allow us to reject the hypothesis of a unit root in all exchange rate series. Ahn, Park and Park (2016) use the same unit root tests as we do, while Caselli and Roitman (2016) use a broader range of unit root tests, including those used here.

[15]We again allow for a constant and a trend in the co-integration relationship, and let the Akaike information criterion determine the number of lags.

four of the tests reject the hypothesis of no co-integration at the 5% level and three do so at 1% level. We therefore assume the panel does exhibit a cointegrating relationship.

We find that 22 of our series have a co-integrating rank of zero, implying that there is no evidence of a co-integrating relationship. But for the other 33 series, there is evidence of a co-integration relationship.[16] We conclude from this that there seems to be a co-integration relationship between the variables, at least for the majority of the series. As a result, the ECM model seems appropriate.

2.2 The model

2.2.1 Baseline model

Our empirical analysis uses a single-equation error correction model for each sector i based on the assumption that there is a long-run relationship between the import price in sector i and its relevant exchange rate and foreign export price. This assumption is consistent with the evidence that these prices exhibit a co-integration relationship. Because import prices in some of the sectors in our sample may be affected by oil and commodity prices, we allow the long-term relationship to include oil prices (P_i^{oil}) and non-oil commodity prices (P_i^{com}).[17] The ECM for sector i takes the form:

$$\begin{aligned} \Delta P_{i,t}^{M} =& \beta_i^0 + \beta_i^1 [P_{i,t-1}^{M} - (\alpha_i^1 S_{i,t-1} + \alpha_i^2 P_{i,t-1}^{F} + \alpha_i^3 P_{i,t-1}^{oil} + \alpha_i^4 P_{i,t-1}^{com})] \\ &+ \sum_{p=0}^{Le1} \beta_{i,p}^2 \Delta S_{i,t-p} + \sum_{p=0}^{Le2} \beta_{i,p}^3 \Delta P_{i,t-p}^{F} + \sum_{p=1}^{Ld} \beta_{i,p}^4 \Delta P_{i,t-p}^{M} + \sum_{p=1}^{Nex} \sum_{p=0}^{Lex(Nex)} \beta_{i,p}^{Nex} \Delta X_{i,t-p}^{Nex} + \epsilon_{i,t} \end{aligned} \quad (1)$$

Given that the long-run coefficients are not restricted to sum to unity, our model is consistent with parts of the literature, e.g. Atkeson and Burstein (2008) or Burstein and Gopinath (2014) which argue that firms change their optimal price mark-ups over marginal costs in response to cost shocks such as shocks to the exchange rate.[18]

[16]We use the stata "vecrank" command to test the rank of the co-integration relationship.

[17]That is, if an F-test finds the coefficients $\alpha_{i,p}^3$ and/or $\alpha_{i,p}^4$ to be significant for sector i, then oil prices and/or commodity prices are included in sector i's ECM. Otherwise, we exclude them from the long-run relationship. We also include a trend to account for any trends in import prices which are independent of exchange rates or foreign prices.

[18]If e.g. a firm's mark-up varies in response to changes in its market share as argued in Atkeson and Burstein (2008) then a measure of market share in the long-run equation may be desirable. That market share would possibly depend on the import price relative to the price of competitors. To the extent that these competitors are domestic producers, PPI could be a good proxy and it may be desirable to include it in the long-run relationship. However, given that PPI will, by definition, be affected by an exchange rate change, including it in the long-run relationship may bias the long-run estimates. We therefore exclude it from the long-run relationship, but include it (and its

The short-run dynamics of import prices are determined by the same variables which affect the long-run level, plus a set of exogenous (or control) variables, denoted $X_{i,t}^{Nex}$. Nex denotes the number of exogenous control variables in the equation. The control variables we include in our regressions are: oil prices, commodity prices and sector-specific PPI output prices and industrial production.[19] $Le1$ and $Le2$ refer to the lag length of the endogenous variables whereas Ld refers to the lag length of the dependent variable and $Lex(Nex)$ denotes the lag length of the exogenous variable number Nex. Of course, the lag length is important and, in the first stage, we therefore use the Akaike information criteria to find the optimal lag length for the dependent variable, $\Delta P_{i,t}^{M}$, as well as for the exogenous variables, $\Delta S_{i,t}$ and $\Delta P_{i,t}^{F}$, and the controls, allowing each of the optimal lag lengths to differ across variables and across sectors. The estimation methodology is described in Appendix A.

Finally, we also add terms to investigate the roles of non-linearities, asymmetries and vehicle currency pricing.

2.2.2 Non-linearities, asymmetries and dollar currency pricing in exchange rate pass-through

Non-linearities arise if firms respond differently to large exchange rate movements than to small ones. For example, if there are "menu costs" associated with changing prices, companies may be more reluctant to adjust prices in response to small changes in the exchange rate, implying less pass-through in these circumstances. Previous literature, such as Caselli and Roitman (2016), has found some evidence of non-linearities in pass through to import prices at the aggregate level in emerging economies, but not to UK import prices, see e.g. Bussiere (2013). However, there is some evidence of non-linearities in pass-through at the goods level: Lewis (2016) finds a higher degree of pass-through for large exchange rate moves than for small ones at the goods level in the UK.[20]

Our data is particularly well suited to study the extent of non-linearities in pass-through. Indeed, one advantage of constructing exchange rates for each sector is the additional cross sectional exchange rate variation that we can exploit. Studies which consider only changes in the sterling exchange rate index may only have seen two large movements in the exchange rate index over the time period we consider: a depreciation during the financial crisis and one around the EU referendum. These two episodes will therefore heavily influence any study of non-linearities in

lags) as a control variable.

[19] We also experienced with including a measure of sector-specific productivity as an exogenous control but that did not have any material effect on the estimation.

[20] This is in line with Pollard and Coughlin (2004) who finds that some US industries pass through exchange rate changes more quickly when these are above a certain threshold.

pass-through following moves in the sterling exchange rate index. By contrast at the sectoral level, there are more instances of larger changes because of differences in country weights across sectors.

There could also be asymmetries: firms could respond differently to to an appreciation than to a depreciation. For example, if wages are downwardly rigid, companies may be more reluctant to reduce their prices after appreciations than they are to increase their prices after depreciations, implying less pass-through following appreciations than following depreciations. The evidence for asymmetries in pass-through is mixed: while Berger and Vavra (2013) find no evidence of asymmetries in the extent of pass-through to US goods level import prices, Bussiere (2013) finds weak and mixed evidence of asymmetries for some G7 countries using aggregate data (but not for UK import prices), while Caselli and Roitman (2016) find evidence of asymmetries in aggregate pass-through in emerging markets. Using industry level data for the US, Pollard and Coughlin (2004) found mixed evidence of asymmetric exchange rate pass-through, with the direction varying across industries.

Finally, the currency of invoicing of imported goods could determine the degree of exchange rate pass-through. The importance of the currency of invoicing in the presence of price rigidities has been emphasised in the open economy macroeconomic literature, including by Betts and Devereux (2000) and Engel (2000). Gopinath, Itskhoki and Rigobon (2010) show using US import prices for goods that, even when firms change their price, the currency of invoicing matters: exchange rate pass-through to US import prices is much higher for goods priced in foreign currency relative to those priced in US dollars. This could result from differences in desired exchange rate pass-through rates across goods priced in foreign and local currencies, or it could be a bi-product of the special role played by the US dollar in the global trade and financial systems. Gopinath (2015) argues that the US dollar plays the role of vehicle currency and thus has a special impact on prices across the world. If the US dollar is used as a vehicle currency in the UK, then we would expect any changes in the sterling US dollar exchange rate to have an impact on import prices over and above that explained by the US' share of UK imports. Novy, Chen and Chung (2019) find evidence that vehicle currencies are used for pricing UK imports. We therefore consider whether the use of the US dollar as a vehicle currency affects exchange rate pass-through to UK import prices.[21]

We test whether there are non-linearities, asymmetries and effects related to dollar currency pricing in the short-run by including coefficients relating to each of these phenomena in the short-run dynamics. In particular, we include an interaction variable $\Delta S_{i,t}|\Delta S_{i,t}|$ in our error correction models for each sector i. If this variable is negative, it indicates greater passthrough of larger sized exchange rate changes. To test for short run asymmetries in exchange rate pass-through in

[21] We also considered whether the euro was used as a vehicle currency and whether that affected exchange rate pass-through, but we did not find evidence to support that.

sector i, we interact the exchange rate change with a dummy variable for depreciations ($Depr_{i,t}$).[22] And finally, we consider the role of US dollar currency pricing by including in our model a term accounting for the difference between the change in the Sterling - US dollar exchange rate and the exchange rate index computed for sector i, $\Delta S_{i,t} - \Delta S_t^{USD}$.

The model we estimate, for each sector i is then:[23]

$$\begin{aligned}
\Delta P_{i,t}^M = & \beta_i^0 + \beta_i^1 [P_{i,t-1}^M - (\alpha_i^1 S_{i,t-1} + \alpha_i^2 P_{i,t-1}^F + \alpha_i^3 P_{i,t-1}^{oil} + \alpha_i^4 P_{i,t-1}^{com})] \\
& + \sum_{p=0}^{Le1} \beta_{i,p}^2 \Delta S_{i,t-p} + \sum_{p=0}^{Le2} \beta_{i,p}^3 \Delta P_{i,t-p}^F + \sum_{p=1}^{Ld} \beta_{i,p}^4 \Delta P_{i,t-p}^M + \sum_{p=1}^{Nex} \sum_{p=0}^{Lex(Nex)} \beta_{i,p}^{Nex} \Delta X_{i,t-p}^{Nex} \\
& + \sum_{p=0}^{Le1} \beta_p^5 \Delta S_{i,t-p} |\Delta S_{i,t-p}| + \sum_{p=0}^{Le1} \beta_p^6 \Delta S_{i,t-p} Depr_{i,t-p} + \sum_{p=0}^{Le1} \beta_p^7 (\Delta S_{i,t-p} - \Delta S_{t+p}^{USD}) + \epsilon_{i,t}
\end{aligned} \tag{2}$$

Given the number of variables and their lags in our model specification, we face a trade-off between maximising the explanatory power of our model and minimising the presence of insignificant variables. We therefore proceed in the following way: First, we run the model shown above for each sector, with all potential explanatory variables included, using an ARDL test to determine the appropriate lag length of our short-run variables, testing for a maximum of up to 6 month lags. We then run F-tests for significance for the oil and commodities terms in the long run equation, dropping them for a given sector if insignificant. Second, we then re-run the model for each sector using the long run specification obtained from step 1, using an ARDL test again, to determine the optimal lag length of short-run variables. Third, if we are allowing for the presence of non-linearities, asymmetries or dollar currency pricing, we test sequentially for the joint significance of all the included lags of each of the three variables ($Depr$), ($\Delta S - \Delta S^{USD}$), ($\Delta S_{i,t-p}|\Delta S_{i,t-p}|$) dropping any variable whose lags are not jointly significant. This ensures that we do not use up any degrees of freedom by including any insignificant non-linearity, asymmetry or dollar pricing terms for any sector. It also means that we don't impose any of these effects on a given sector, including them only if the data confirm the presence of statistically significant effect.

Finally, having determined the appropriate inclusion of variables for each sector, we then run another ARDL test to identify the appropriate lag structure. The results of the final ARDL test determine our specification for each sector.

[22]Our focus on the short run is consistent with Delatte and López-Villavicencio (2012) who find that there are short run asymmetries in exchange rate pass-through to consumer prices for the UK but do not find any evidence of asymmetries in the long run, using a similar econometric approach to ours.

[23]For further details, see Appendix B

This approach allows for a substantial amount of heterogeneity across sectors, not only in terms of variable inclusion, but also lag length of coefficient estimates.

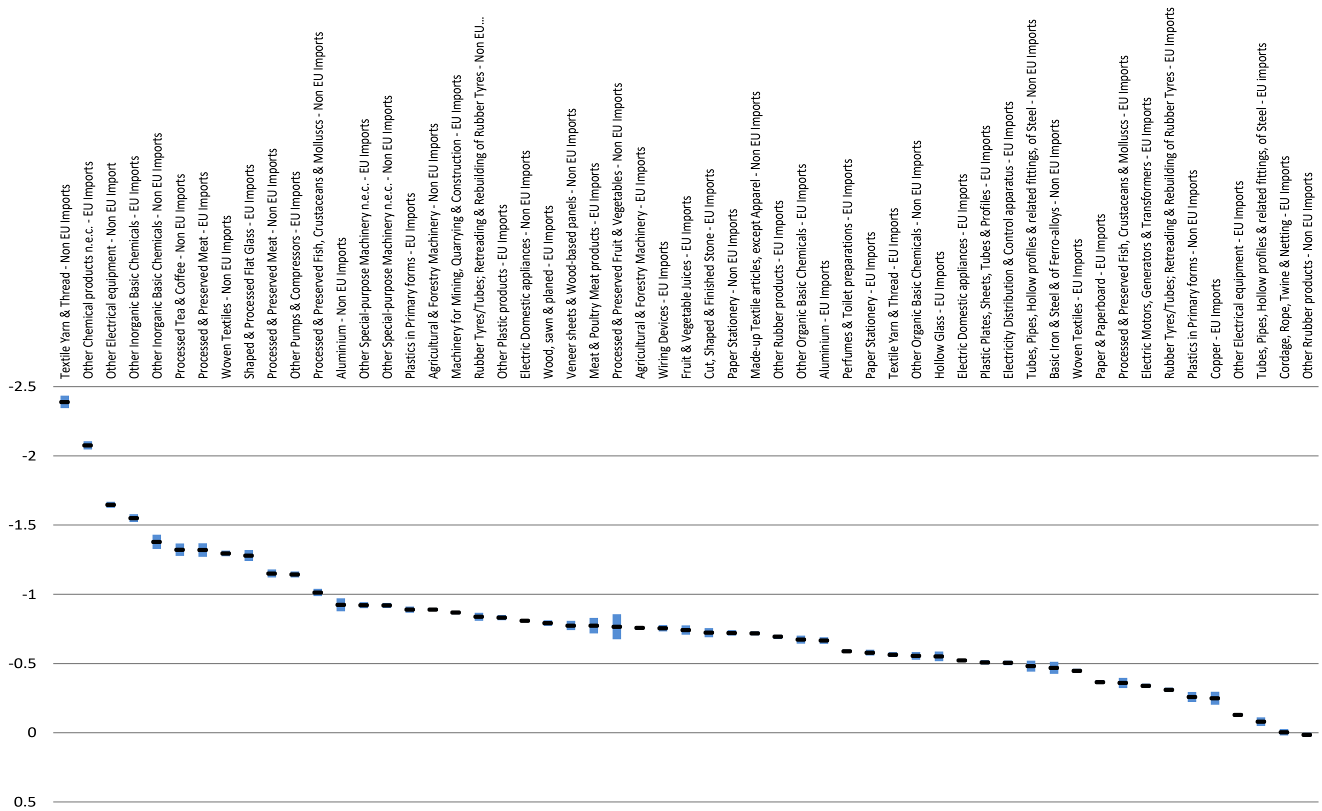
3 Exchange rate pass-through estimates

3.1 Sector-specific long-run exchange rate pass-through

We run the ECM model described above for each sector in our sample. We investigate the results in order to get a sense of how different sectors behave when faced with a change in their exchange rate. A first sign of the heterogeneity across sectors is that the optimal lag length of the dependent variables, the endogenous variables and the exogenous variables vary considerably across sectors. We also find a considerable amount of heterogeneity across sectors when it comes to the degree of exchange rate pass-through.

The figures below show our baseline results based on the ECM specified in equation (**??**) for each of the 55 series in our sample. The first chart shows that the long-run exchange rate pass-through coefficients for the groups are estimated to be between 0 and -2.4. While these ranges are large, most divisions have estimates between -0.5 and -1, and the average is -0.78. Aggregating up using sectoral weights long-run pass-through is -0.74.

Figure 3: Long-run exchange rate pass-through to import prices

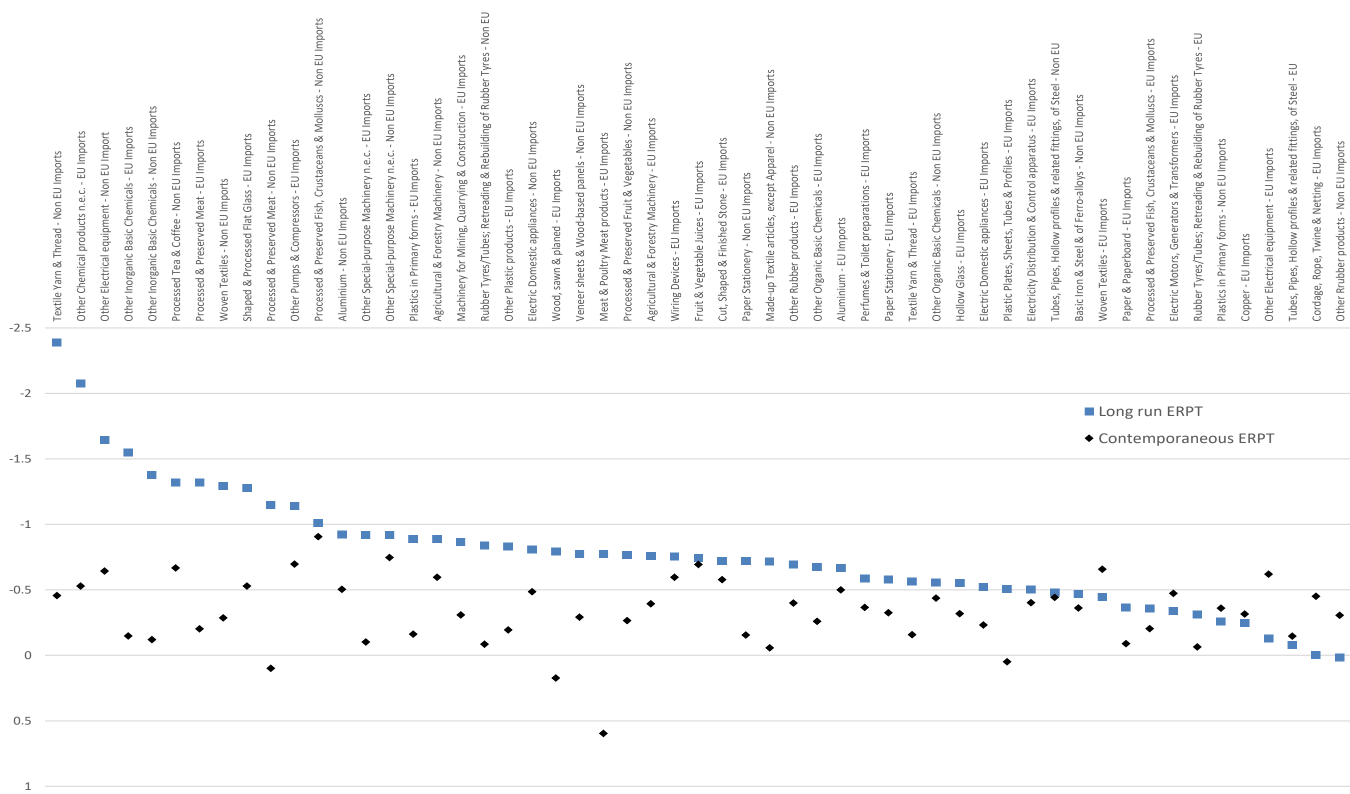


This figure shows the point estimates in black and the 95% confidence intervals around those esimates in light blue.

The contemporaneous exchange rate pass-through estimates also vary considerably across sectors, ranging from around 0 to -0.78.[24] There is no clear relationship between the contemporaneous and the long-term pass-through estimates, as shown in Figure 4.

[24] This excludes one series which we find to have a contemporaneous exchange rate pass-through coefficient of +0.6.

Figure 4: Contemporaneous and long-run exchange rate pass-through to import prices



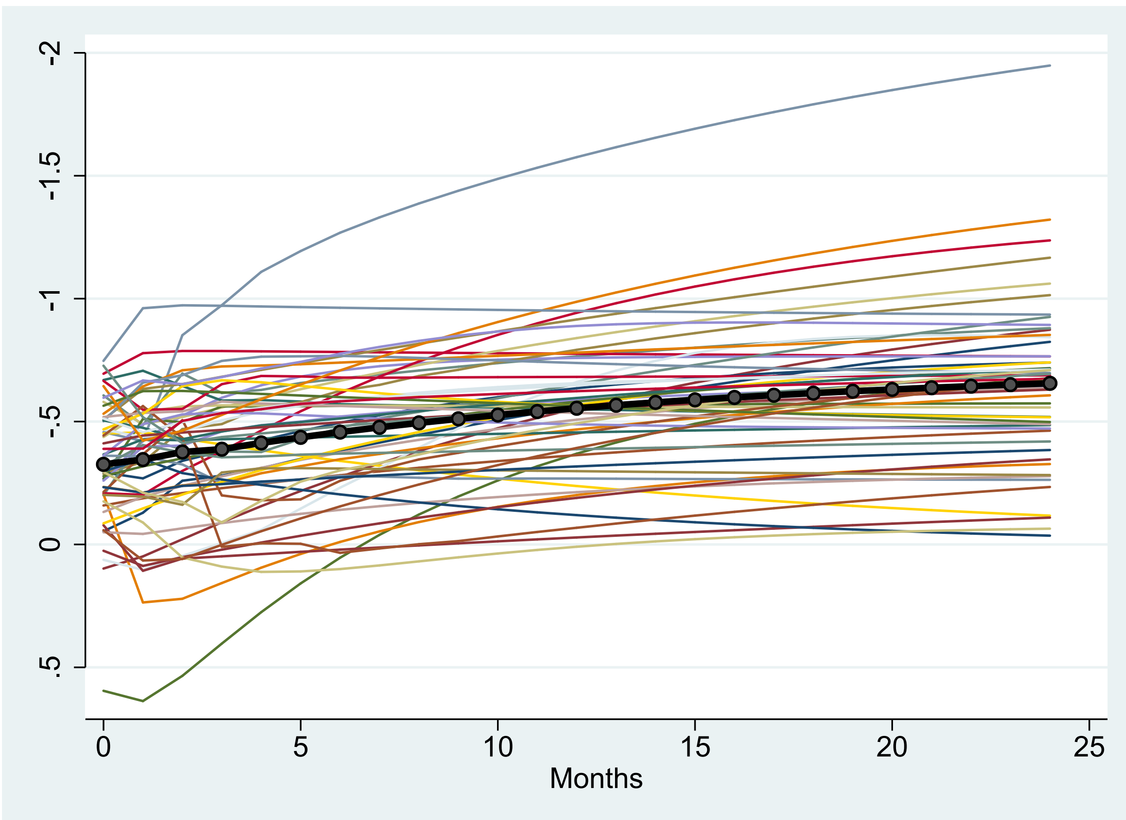
Point estimates of contemporaneous exchange rate pass-through in black and those of long-run exchange rate pass-through in blue.

For 16 out of our 39 sectors, we have data for both EU and non-EU imports. By comparing our estimates of exchange rate pass-through for EU and non-EU imports in the same sectors, we can check whether there are systematic differences across EU and non-EU imports. There is some tentative but not overwhelming evidence that this is the case: the average (median) long run exchange rate pass-through in the 16 sectors is -0.65 (-0.62) for EU imports and -0.95 (-0.91) for non-EU imports. In 12 of the 16 sectors, our estimates imply a higher contemporaneous degree of pass-through into non-EU import prices than EU import prices, while the same is true for 11 sectors with regards to estimates of long run exchange rate pass-through.

3.2 Sector-specific exchange rate pass-through dynamics

To get further insight into the dynamics of exchange rate pass-through, we compute the sector-specific month by month profiles of exchange rate pass-through for a 2% appreciation.[25] The speed of pass-through also differs across sectors as shown in Figure 5. However, on average, more than 75% of the estimated long-run change in import prices is completed in the first 6 months following an exchange rate change, and more than 80% in the first 12 months.

Figure 5: Exchange rate pass-through to import prices



Note: The figure depicts the accumulated degree of exchange rate pass-through over time, for each of the 55 sectors in our sample. The black line shows the weighted average of those profiles.

[25]Because of asymmetries, non-linearities and dollar pricing effects, profiles will also vary with the size, sign and composition of the exchange rate change. For ease of viewing, we always present the results of our baseline scenario: a uniform 2% exchange rate move against all currencies, and then compare alternative scenarios with that.

3.3 Aggregate pass-through Profiles

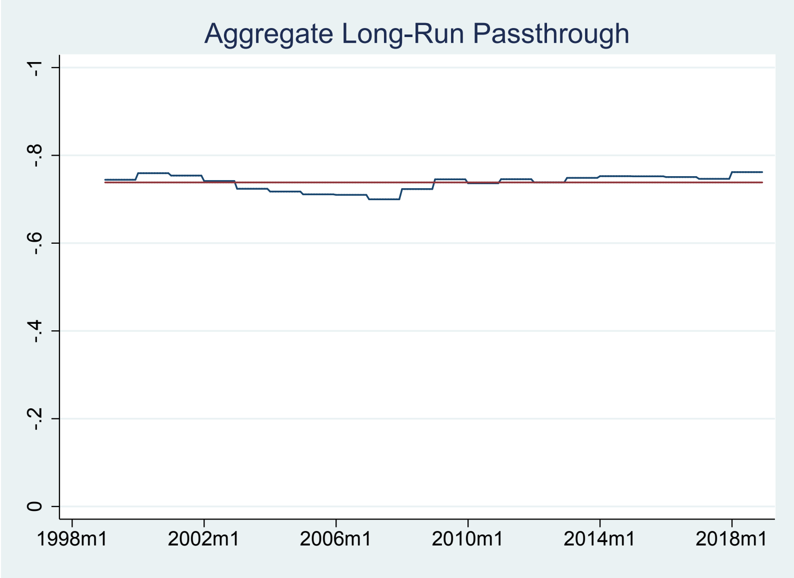
We can aggregate the sectoral pass-through coefficients and profiles to yield an estimate of what the model implies for aggregate pass-through. To do this, we weight up each sector according to its share of total imports. Because of the incomplete coverage of our dataset however, we don't simply obtain weights by dividing each sector's imports by total imports, because this could lead to weights which are out of line with sectoral and country composition of all imports. Instead, we implement an approach which ensures our aggregate weights imply the same EU vs non-EU and broad sectoral split as the aggregate UN Comtrade imports data reveals.

To do this, we split the sectors along two dimensions: EU vs non-EU, and then four broad sectors (Food and Drink; Manufactured Goods; Chemicals; and Machinery and Equipment). That gives us eight categories in total. We impose on each category the share implied by aggregate data, and then compute the shares of each sector using our micro data. More formally, if S_c is the share of category c in the aggregate trade data, and V_i is the value of imports in sector i then the weight of each sector i ω_i is given by:

$$\omega_{it} = S_c \frac{V_{it}}{\sum_{i,i \subset c} V_{it}} \tag{3}$$

Because import values are only measured yearly, this measure doesn't exhibit within year variation. The chart below shows the aggregate long-run pass-through for sample average weights and time-varying weights. Overall, our model estimates that with constant weights, pass-through is -0.74. Allowing for time-varying weights produces only very small changes around this number. We therefore conclude that the changing composition of imports over our sample period has not generated any significant time variation in long-run pass-through.

Figure 6: Non-linear pass-through



Note: The red line shows aggregate passthrough using sample average sectoral weights, the blue line shows aggregate passthrough using time-varying sectoral weights

We now turn to the issue of the profile of pass-through over time, and how the size, sign and composition of exchange rate changes affect that profile. In what follows, we use the time-varying weights ω_{it} when conducting forecast exercises, and we use sample average weights $\bar{\omega}_i$ when reporting pass-through profiles.[26]

4 The role of non-linearities, asymmetries and dollar currency pricing

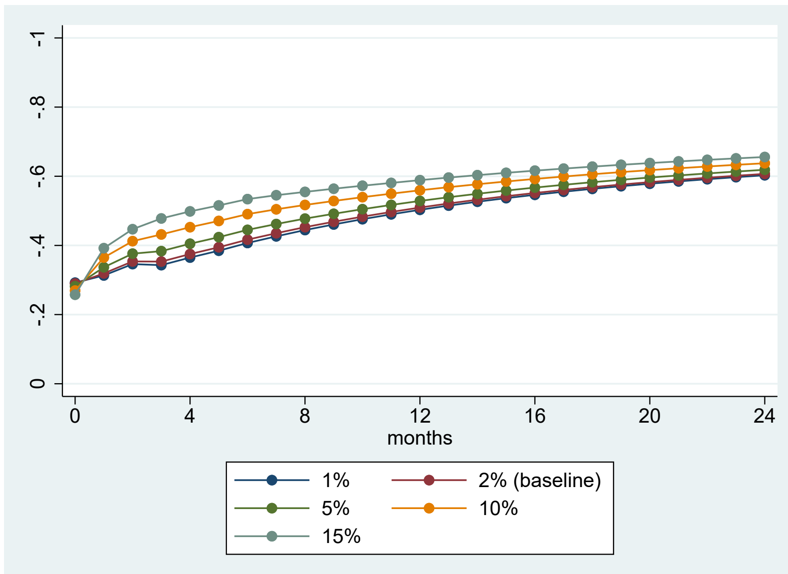
4.1 Non-linearities

At least one of the (lagged) quadratic exchange rate terms is significant for 32 of our 55 groups, i.e. over half the groups exhibit significant non-linearities in pass-through. The vast majority of

[26]To check whether our results were driven by outliers we also computed two alternative aggregate passthrough profiles using unweighted mean, and the median value across sectors. These results are shown in the appendix. These make clear that the median profile is very close to the aggregate profile, indicating that the results are not driven by outliers.

those significant non-linear terms imply that the larger is an exchange rate change, the higher will be pass-through to import prices in the short run. The results, aggregated across sectors according to their import share, are summarised in Figure 7. Instantaneous pass-through is more or less identical regardless of the size of changes. The real difference comes over the subsequent few months. The figure shows that while a 1% change in the exchange rate leads to 40% pass-through after three months, a 10% change leads to more than 60% pass-through within 3 months.[27]

Figure 7: Non-linear pass-through

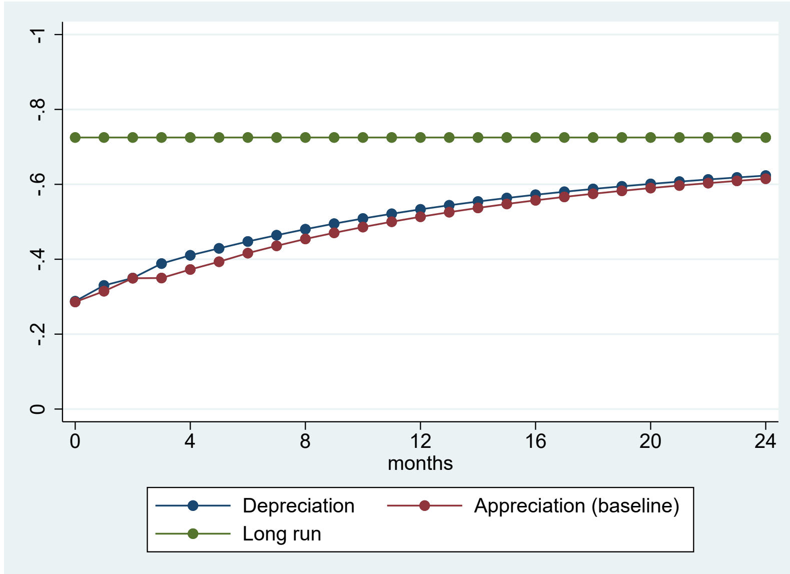


4.2 Asymmetries

Our results show that the coefficients relating to the asymmetric terms are significantly different for some sectors. In particular, for 25 of the series considered, there's a significant asymmetry between at least one of the terms (whether contemporaneous or lagged). But the direction of these is mixed. The weighted average of our results lead to the exchange rate profile depicted in Figure 8. Across the industries this coefficient has both signs, and roughly speaking these cancel out in aggregate, such that the profile of depreciations looks very similar to that of appreciations.

[27] These results are not dependent on a particular sector as shown in Appendix C.

Figure 8: Asymmetric pass-through

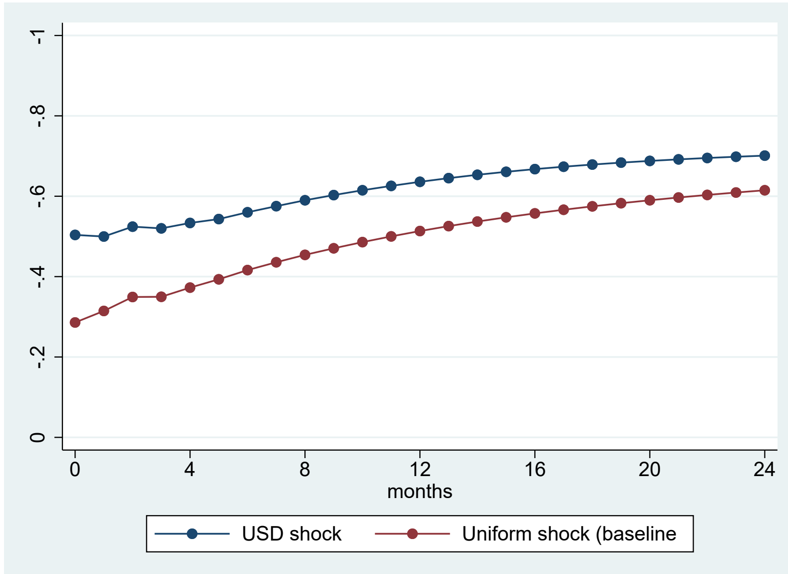


4.3 Dollar Currency Pricing

In 39 out of 55 sectors, the dollar pricing term is statistically significant, almost always with a negative sign. That means that movements in the US dollar exert an additional effect on pass-through profiles, above and beyond their effect on the exchange rate index.

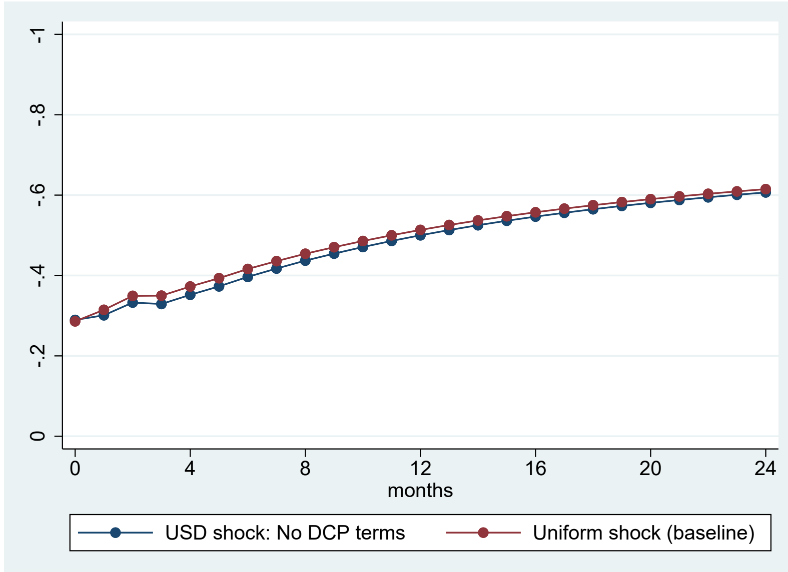
To gauge the magnitude of these effects, we compute aggregated impulse responses to two equivalent sized shocks to the aggregate exchange rate index - corresponding to a 2% appreciation - using our baseline model, but where the shocks are either driven entirely by a movement in the US dollar or result from a uniform move against all currencies. A 2% appreciation of the aggregate exchange rate index which is caused entirely by a move against the dollar implies that sterling's appreciation against the dollar is roughly 24%, with sterling remaining unchanged against all other currencies. We then work out the sector-specific exchange rate changes under this assumption of a 24% appreciation of the dollar and, using the sector-specific dollar currency pricing terms, we perform our simulation for each sector. The sectoral impulse responses are then aggregated up using the average weight of each sector in total imports over the sample period. This aggregate impulse response is shown below in figure 9 along with the equivalent response to a uniform change in all exchange rates.

Figure 9: Dollar Pricing



A 2% appreciation in the aggregate exchange rate index caused solely by a movement against the US dollar has a much faster pass-through profile than that from a uniform 2% appreciation against all currencies. The instantaneous pass-through is nearly double. This is particularly striking because the weight of the US in imports is under 10%. Even if there was full instantaneous pass-through to all imports from the US, that market share would imply an instantaneous pass-through of 0.1. The fact that instantaneous pass-through is estimated to be over four times as large suggests widespread use of the US dollar as a vehicle currency.

One possibility however, is that this result may be (partially) driven by the fact that sectors with a larger share of US imports happen to have higher pass-through coefficients. To check that this result was not driven or biased by sectors with a larger share of US imports having a higher pass-through, we also computed the pass-through with the dollar currency pricing coefficients set to zero. In this alternative profile, compositional effects would be the only source of difference in pass-through profiles. The profiles are shown below:



Switching the dollar currency pricing coefficients off produces an almost identical pass-through profile to the baseline case, indicating that the gap between profiles in Figure 9 is accounted for entirely by the operation of the DCP terms, and not due to sectoral differences in other coefficients. This means that dollar pricing effects account for the entirity of our finding.

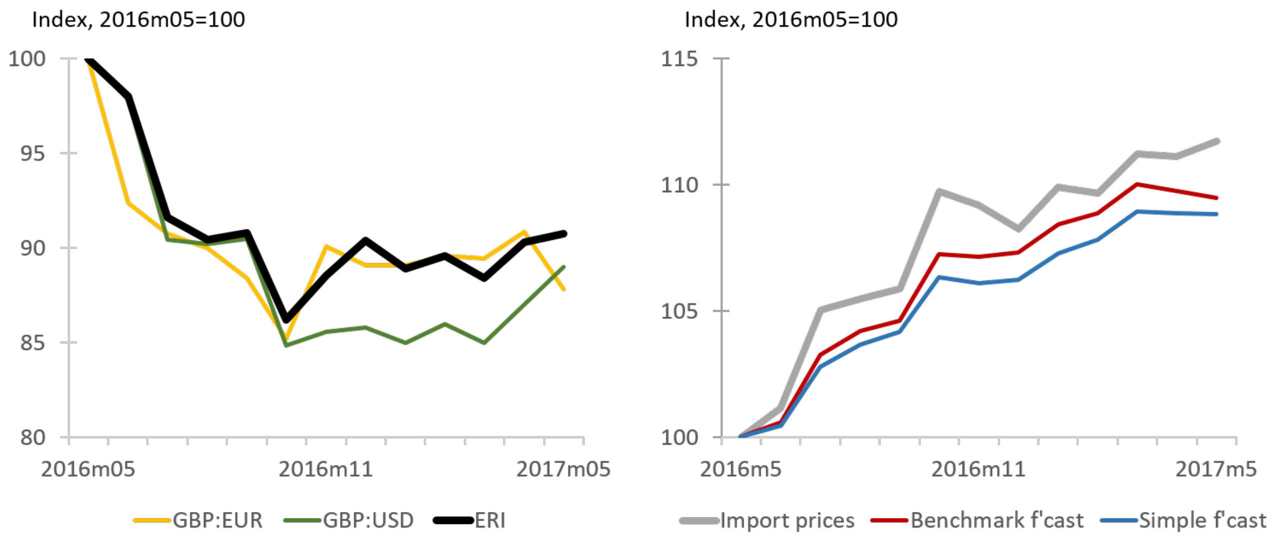
4.4 In-sample dynamic forecasts

To illustrate the magnitude of the non-linearity and dollar currency pricing effects above, we conduct in sample dynamic forecast exercises at two points in time. Our goal here is not to present a new tool for real-time forecasting, rather the purpose of this exercise is to provide a quantification of the dollar currency pricing and non-linear effects in two recent episodes.[28] We compare the dynamic forecast performance of our model over a 12 month horizon with that of a simpler model which has no role for asymmetries, non-linearities or dollar currency pricing effects, but is otherwise identical.

Our first exercise is the large fall in sterling in June 2016, when sterling fell by around 10% on the night of the EU referendum itself, the largest month on month change in our sample period by a considerable margin, followed by a fall of about 5% between September and October of that year. The second half of 2016 is a good test-bed to isolate the effects of non-linearities as sterling's fall was broadly uniform against all other currencies during this period. This is shown below in the

[28] As an in-sample forecast, this couldn't have been used in real time to forecast the future path of import prices, because the coefficients are based on estimates over the whole sample period.

Figure 10: Forecast exercise: May 2016



first panel of Figure 10.

The second panel of Figure 10 shows that the forecast based on our model which allows for the non-linearity generates a faster rise in import prices than the simple model, eliminating between a third and a half of the gap between actual and forecast values.

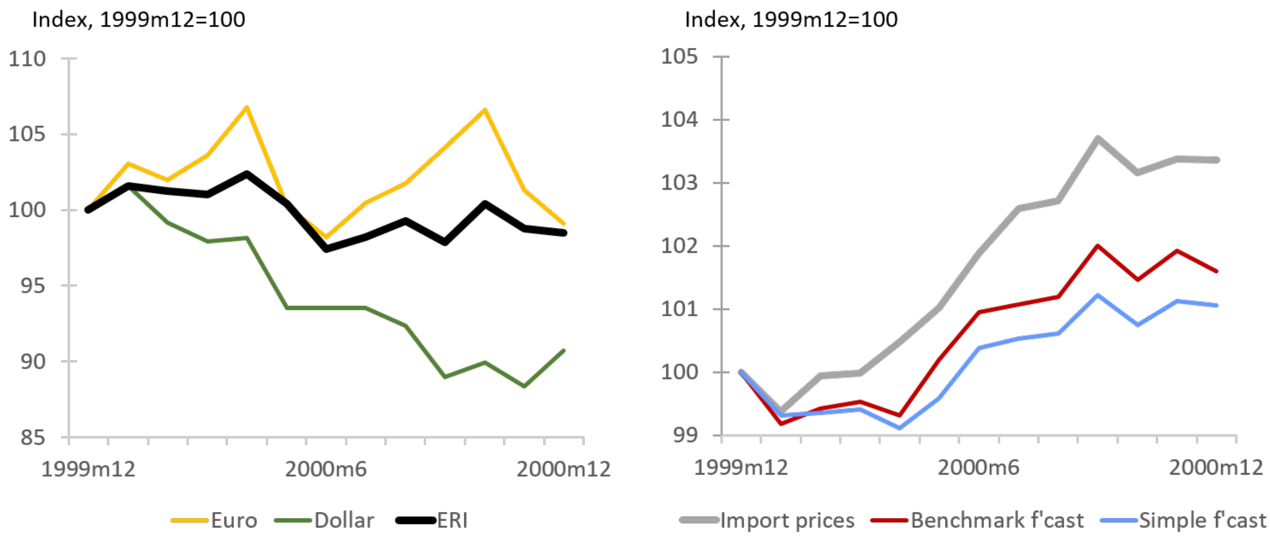
Our second exercise is based on a differential movement in sterling against the dollar and the euro at the end of 1999. As shown in the first panel of Figure 11, sterling experienced a decline of over 10% against the dollar, but the overall ERI remained broadly stable. The in sample forecasts of our model alongside that from a simpler model not including dollar currency pricing terms are shown below in the second panel of Figure 11.

Our benchmark model which allows for a differential impact of dollar moves generates a stronger forecast profile for import prices, which tracks the actual path of import prices more closely. Relative to the simple model, this adds about 1pp to the forecast profile, showing the importance of the role of dollar currency pricing.

5 Conclusions

We study exchange rate pass-through using sectoral data for 55 different sectors. We construct our own, sector-specific exchange rate indices using bilateral trade data from UN Comtrade. We

Figure 11: Forecast exercise: December 1999



identify several advantages of the sectoral-based approach. First, it allows us to account for heterogeneity across sectors. Second, we demonstrate that we are able to find cointegrating relations. Third, the greater number of datapoints facilitates the identification of asymmetries and non-linearities, which may be difficult to detect with conventional aggregate time series methods.

Our results indicate that (on a sector size weighted measure) aggregate long run exchange rate pass-through is 0.74. Further, we show that the bulk of this occurs within about 12 months. We also find evidence for statistically significant non-linearities, whereby larger exchange rate changes are passed through more quickly than smaller ones, and this effect is primarily driven by differences at 1 to 3 months rather than instantaneous pass-through. At the sectoral level there is some evidence for the differential pass-through of appreciations and depreciations, but these effects essentially cancel out at the macro level. Finally, we find that the changes to the US dollar exchange rate affects pass-through by much more than its effect on the trade-weighted exchange rate index would suggest. Pass-through of US dollar driven moves to the exchange rate index is about twice as fast as those driven by a uniform movement against all currencies. This suggests widespread use of the dollar as a vehicle currency for UK imports from non-US countries.

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Appendix A. Estimation methodology

Estimating equation (1) would allow us to compute estimates of the long-run relationship between import prices, relevant exchange rates and prices, but we would not be able to extract the associated standard errors. In order to estimate the standard errors of the long-run coefficient, we use a transformation proposed by Bewley (1979). Specifically, we rewrite the single equation error correction model (simplified to exclude oil and commodity prices in the long run relationship) in the following way:

$$
\begin{aligned}
P^M_{i,t} =& \beta^0 + (1+\beta^1)P^M_{i,t-1} - \beta^1\alpha^1 S_{i,t-1} - \beta^1\alpha^2 P^F_{i,t-1} + \beta^2(S_{i,t} - S_{i,t-1}) + \beta^3(P^F_{i,t} - P^F_{i,t-1}) \\
&+ \sum_{p=1}^{Le1} \beta^2_p \Delta S_{i,t-p} + \sum_{p=1}^{Le2} \beta^3_p \Delta P^F_{i,t-p} + \sum_{p=1}^{Ld} \beta^4_p \Delta P^M_{i,t-p} + \sum_{p=1}^{Nex} \sum_{p=0}^{Lex(Nex)} \beta^{Nex}_p \Delta X^{Nex}_{i,t-p} + \epsilon_{i,t} \\
-\beta^1 P^M_{i,t} =& \beta^0 - (1+\beta^1)\Delta P^M_{i,t} + (\beta^1\alpha^1 + \beta^2)\Delta S_{i,t} - \beta^1\alpha^1 S_{i,t} + (\beta^1\alpha^2 + \beta^3)\Delta P^F_{i,t} - \beta^1\alpha^2 P^F_{i,t} \\
&+ \sum_{p=1}^{Le1} \beta^2_p \Delta S_{i,t-p} + \sum_{p=1}^{Le2} \beta^3_p \Delta P^F_{i,t-p} + \sum_{p=1}^{Ld} \beta^4_p \Delta P^M_{i,t-p} + \sum_{p=1}^{Nex} \sum_{p=0}^{Lex(Nex)} \beta^{Nex}_p \Delta X^{Nex}_{i,t-p} + \epsilon_{i,t} \\
P^M_{i,t} =& -\frac{\beta^0}{\beta^1} + \frac{1+\beta^1}{\beta^1}\Delta P^M_{i,t} - \frac{\beta^1\alpha^1 + \beta^2}{\beta^1}\Delta S_{i,t} + \alpha^1 S_{i,t} - \frac{\beta^1\alpha^2 + \beta^3}{\beta^1}\Delta P^F_{i,t} + \alpha^2 P^F_{i,t} \\
&- \frac{1}{\beta^1}\sum_{p=1}^{Le1} \beta^2_p \Delta S_{i,t-p} - \frac{1}{\beta^1}\sum_{p=1}^{Le2} \beta^3_p \Delta P^F_{i,t-p} - \frac{1}{\beta^1}\sum_{p=1}^{Ld} \beta^4_p \Delta P^M_{i,t-p} + \sum_{p=1}^{Nex} \sum_{p=0}^{Lex(Nex)} \beta^{Nex}_p \Delta X^{Nex}_{i,t-p} + \epsilon_{i,t}
\end{aligned}
\tag{4}
$$

In the transformation above, the long-run relationship between import prices and associated exchange rates and prices are summarised by α^1, α^2 and α^3. Estimating this transformation thus allows for the direct estimation of not only those long-run coefficients but also their standard errors. We thus want to estimate the following equation:

$$
\begin{aligned}
P^M_{i,t} =& \phi^0 + \phi^1\Delta P^M_{i,t} + \phi^2\Delta S_{i,t} + \phi^3 S_{i,t} + \phi^4\Delta P^F_{i,t} + \phi^5 P^F_{i,t} \\
&+ \sum_{p=1}^{Le1} \phi^6_p \Delta S_{i,t-p} + \sum_{p=1}^{Le2} \phi^7_p \Delta P^F_{i,t-p} + \sum_{p=1}^{Ld} \phi^8_p \Delta P^M_{i,t-p} + \sum_{p=1}^{Nex} \sum_{p=0}^{Lex(Nex)} \beta^{Nex}_p \Delta X^{Nex}_{i,t-p} + \epsilon_{i,t}
\end{aligned}
\tag{5}
$$

But because $\Delta P^M_{i,t}$ contains our dependent variable, OLS estimates would be biased. To obtain unbiased estimates, we instrument for that variable. We therefore proceed with our estimation in two steps:

In a first stage, we estimate the following equation using OLS techniques:

$$
\begin{aligned}
\Delta P^M_{i,t} =& \gamma^0 + \gamma^1 P^M_{i,t-1} + \gamma^2\Delta S_{i,t} + \gamma^3 S_{i,t} + \gamma^4\Delta P^F_{i,t} + \gamma^5 P^F_{i,t} \\
&+ \sum_{p=1}^{Le1} \gamma^6_p \Delta S_{i,t-p} + \sum_{p=1}^{Le2} \gamma^7_p \Delta P^F_{i,t-p} + \sum_{p=1}^{Ld} \gamma^8_p \Delta P^M_{i,t-p} + \sum_{p=1}^{Nex} \sum_{p=0}^{Lex(Nex)} \gamma^{Nex}_p \Delta X^{Nex}_{i,t-p} + \epsilon_{i,t}
\end{aligned}
\tag{6}
$$

From this first stage, we get the contemporaneous impact of a change in the exchange rate on import prices, equal to $\gamma^2 + \gamma^3$.

We then include the fitted values of this regression, $\Delta\widehat{P^M_{i,t}}$, into the Bewley transformation, and, in a second stage, estimate the following regression:

$$\begin{aligned} P^M_{i,t} =& \phi^0 + \phi^1 \Delta\widehat{P^M_{i,t}} + \phi^2 \Delta S_{i,t} + \phi^3 S_{i,t} + \phi^4 \Delta P^F_{i,t} + \phi^5 P^F_{i,t} \\ &+ \sum_{p=1}^{Le1} \phi^6_p \Delta S_{i,t-p} + \sum_{p=1}^{Le2} \phi^7_p \Delta P^F_{i,t-p} + \sum_{p=1}^{Ld} \phi^8_p \Delta P^M_{i,t-p} + \sum_{p=1}^{Nex} \sum_{p=0}^{Lex(Nex)} \phi^{Nex}_p \Delta X^{Nex}_{i,t-p} + \epsilon_{i,t} \end{aligned} \tag{7}$$

In this estimation step, we obtain the long-run exchange rate pass-through coefficient, ϕ^3. We can also compute its standard error. We can also deduct the error correction term, as $\phi^1 = (((1+\beta^1))/(\beta^1))$, so that $\beta^1 = (1/(\phi^1 - 1))$.

We now compute the change in import prices following a 1% permanent exchange rate change in period 0 and thereafter (in percent).

$\Delta P^M_{i,t=0} = \gamma^2 \Delta S_{i,0} + \gamma^3 S_{i,0} = \gamma^2 + \gamma^3$

$\Rightarrow P^M_{i,0} = \gamma^2 + \gamma^3$

$\Delta P^M_{i,t=1} = \beta^1[P^M_{i,0} - \alpha^1 S_{i,0}] + \beta^2_1 \Delta S_{i,0} + \beta^4_1 \Delta P^M_{i,0} = \dfrac{1}{\hat{\phi}^1 - 1}[P^M_{i,0} - \hat{\phi}^3] + \hat{\gamma}^6_1 + \hat{\gamma}^8_1 \Delta P^M_{i,0}$

$\Rightarrow P^M_{i,1} = P^M_{i,0} + \Delta P^M_{i,t=1}$

$\Delta P^M_{i,t=2} = \beta^1[P^M_{i,1} - \alpha^1 S_{i,1}] + \beta^2_2 \Delta S_{i,0} + \beta^4_1 \Delta P^M_{i,1} + \beta^4_2 \Delta P^M_{i,0} = \dfrac{1}{\hat{\phi}^1 - 1}[P^M_{i,1} - \hat{\phi}^3] + \hat{\gamma}^6_2 + \hat{\gamma}^8_1 \Delta P^M_{i,1} + \hat{\gamma}^8_2 \Delta P^M_{i,0}$

$\Rightarrow P^M_{i,2} = P^M_{i,1} + \Delta P^M_{i,t=2}$

$\Delta P^M_{i,t=3} = \beta^1[P^M_{i,2} - \alpha^1 S_{i,2}] + \beta^2_3 \Delta S_{i,0} + \beta^4_1 \Delta P^M_{i,2} + \beta^4_2 \Delta P^M_{i,1} + \beta^4_3 \Delta P^M_{i,0}$

$= \dfrac{1}{\hat{\phi}^1 - 1}[P^M_{i,2} - \hat{\phi}^3] + \hat{\gamma}^6_3 + \hat{\gamma}^8_1 \Delta P^M_{i,2} + \hat{\gamma}^8_2 \Delta P^M_{i,1} + \hat{\gamma}^8_3 \Delta P^M_{i,0}$

$\Rightarrow P^M_{i,3} = P^M_{i,2} + \Delta P^M_{i,t=3}$

For $t = j$ larger than the maximum lag length permitted, we have:

$\Delta P^M_{i,t=j} = \beta^1[P^M_{i,j-1} - \alpha^1 S_{i,j-1}] + \beta^4_1 \Delta P^M_{i,j-1} + \beta^4_2 \Delta P^M_{i,j-2} + \beta^4_3 \Delta P^M_{i,j-3}$

$= \dfrac{1}{\hat{\phi}^1 - 1}[P^M_{i,j-1} - \hat{\phi}^3] + \hat{\gamma}^8_1 \Delta P^M_{i,j-1} + \hat{\gamma}^8_2 \Delta P^M_{i,j-2} + \hat{\gamma}^8_3 \Delta P^M_{i,j-3}$

To get the impulse responses we accumulate those import price changes computed above.
After the maximum number of lags is reached, then

$$\Delta P^M_{i,t} = \beta^1 \left[\sum_{s=0}^{t-1} \Delta P^M_{i,s} - \alpha^1 \right] \tag{8}$$

Using the regression results, we can rewrite this as:

$$\Delta P^M_{i,t} = (1/(\phi^1 - 1)) \left[\sum_{s=0}^{t-1} \Delta P^M_{i,s} - \phi^2 \right] \tag{9}$$

Appendix B. ECM with non-linear, asymmetric and dollar currency pricing terms

We test whether there are non-linearities, asymmetries and dollar currency pricing in the short-run coefficients by running the ECM below for each sector i.[29]

$$
\begin{aligned}
\Delta P^M_{i,t} = & \beta^0 + \beta^1[P^M_{i,t-1} - (\alpha^1 S_{i,t-1} + \alpha^2 P^F_{i,t-1})] \\
& + \sum_{p=0}^{Le1} \beta^2_p \Delta S_{i,t-p} + \sum_{p=0}^{Le2} \beta^3_p \Delta P^F_{i,t-p} + \sum_{p=1}^{Ld} \beta^4_p \Delta P^M_{i,t-p} + \sum_{p=1}^{Nex} \sum_{p=0}^{Lex(Nex)} \beta^{Nex}_p \Delta X^{Nex}_{i,t-p} \\
& + \sum_{p=0}^{Le1} \beta^5_p \Delta S_{i,t-p} |\Delta S_{i,t-p}| + \sum_{p=0}^{Le1} \beta^6_p \Delta S_{i,t-p} Depr_{i,t-p} + \sum_{p=0}^{Le1} \beta^7_p (\Delta S_{i,t-p} - \Delta S^{USD}_{t+p}) + \epsilon_{i,t}
\end{aligned} \tag{10}
$$

The Bewley transformation is as follows:

$$
\begin{aligned}
P^M_{i,t} = & -\frac{\beta^0}{\beta^1} + \frac{1+\beta^1}{\beta^1} \Delta P^M_{i,t} - \frac{\beta^1 \alpha^1 + \beta^2}{\beta^1} \Delta S_{i,t} + \alpha^1 S_{i,t} - \frac{\beta^1 \alpha^2 + \beta^3}{\beta^1} \Delta P^F_{i,t} + \alpha^2 P^F_{i,t} \\
& - \frac{1}{\beta^1} \sum_{p=1}^{Le1} \beta^2_p \Delta S_{i,t-p} - \frac{1}{\beta^1} \sum_{p=1}^{Le2} \beta^3_p \Delta P^F_{i,t-p} - \frac{1}{\beta^1} \sum_{p=1}^{Ld} \beta^4_p \Delta P^M_{i,t-p} + \sum_{p=1}^{Nex} \sum_{p=0}^{Lex(Nex)} \beta^{Nex}_p \Delta X^{Nex}_{i,t-p} \\
& - \frac{1}{\beta^1} \sum_{p=0}^{Le1} \beta^5_p \Delta S_{i,t-p} |\Delta S_{i,t-p}| - \frac{1}{\beta^1} \sum_{p=0}^{Le1} \beta^6_p \Delta S_{i,t-p} Depr_{i,t-p} - \frac{1}{\beta^1} \sum_{p=0}^{Le1} \beta^7_p (\Delta S_{i,t-p} - \Delta S^{USD}_{t+p}) + \epsilon_{i,t}
\end{aligned} \tag{11}
$$

In a first stage, we estimate the following equation using OLS techniques:

$$
\begin{aligned}
\Delta P^M_{i,t} = & \gamma^0 + \gamma^1 P^M_{i,t-1} + \gamma^2 \Delta S_{i,t} + \gamma^3 S_{i,t} + \gamma^4 \Delta P^F_{i,t} + \gamma^5 P^F_{i,t} \\
& + \sum_{p=1}^{Le1} \gamma^6_p \Delta S_{i,t-p} + \sum_{p=1}^{Le2} \gamma^7_p \Delta P^F_{i,t-p} + \sum_{p=1}^{Ld} \gamma^8_p \Delta P^M_{i,t-p} + \sum_{p=1}^{Nex} \sum_{p=0}^{Lex(Nex)} \gamma^{Nex}_p \Delta X^{Nex}_{i,t-p} \\
& + \sum_{p=0}^{Le1} \gamma^9_p \Delta S_{i,t-p} |\Delta S_{i,t-p}| + \sum_{p=0}^{Le1} \gamma^{10}_p \Delta S_{i,t-p} Depr_{i,t-p} + \sum_{p=0}^{Le1} \gamma^{11}_p (\Delta S_{i,t-p} - \Delta S^{USD}_{t+p}) + \epsilon_{i,t}
\end{aligned}
$$

We then include the fitted values of this regression, $\widehat{\Delta P^M_{i,t}}$, into the Bewley transformation, and,

[29] In this exposition, we exclude oil and commodity prices from the long run relationship for simplicity.

in a second stage, estimate the following regression:

$$\begin{aligned}
P^M_{i,t} =& \phi^0 + \phi^1 \Delta \widehat{P^M_{i,t}} + \phi^2 \Delta S_{i,t} + \phi^3 S_{i,t} + \phi^4 \Delta P^F_{i,t} + \phi^5 P^F_{i,t} \\
&+ \sum_{p=1}^{Le1} \phi^6_p \Delta S_{i,t-p} + \sum_{p=1}^{Le2} \phi^7_p \Delta P^F_{i,t-p} + \sum_{p=1}^{Ld} \phi^8_p \Delta P^M_{i,t-p} + \sum_{p=1}^{Nex} \sum_{p=0}^{Lex(Nex)} \phi^{Nex}_p \Delta X^{Nex}_{i,t-p} \\
&+ \sum_{p=0}^{Le1} \phi^9_p \Delta S_{i,t-p} |\Delta S_{i,t-p}| + \sum_{p=0}^{Le1} \phi^{10}_p \Delta S_{i,t-p} Depr_{i,t-p} + \sum_{p=0}^{Le1} \phi^{11}_p (\Delta S_{i,t-p} - \Delta S^{USD}_{t+p}) + \epsilon_{i,t}
\end{aligned}$$

As before, this estimation step allows us to obtain the long-run exchange rate pass-through coefficient, ϕ^3 and its standard error. We can also deduct the error correction term, as $\phi^1 = (((1 + \beta^1))/(\beta^1))$, so that $\beta^1 = (1/(\phi^1 - 1))$. And finally, we can deduct the marginal non-linear, asymmetric and dollar currency pricing impacts by noting that $\phi^9_p = -\frac{\beta^5_p}{\beta^1}$, $\phi^{10}_p = -\frac{\beta^6_p}{\beta^1}$ and $\phi^{11}_p = -\frac{\beta^7_p}{\beta^1}$.

Appendix C. Robustness

The chart below compares the weighted and unweighted means with the median sectoral passthrough at every time horizon: