Intertemporal pass-through

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Abstract

Forward-looking pricing is at the core of modern macroeconomics, yet a gap remains between its theoretical microfoundations and their empirical validation. To bridge this gap, we study *intertemporal pass-through* (iPT): the sensitivity of firms' desired prices to changes in their *expected* future marginal costs. On the empirical side, we estimate iPT by combining UK firm-level survey data with a quasi-natural experiment: the 2019 announcement of a *future* tariff schedule in the event of a No-Deal Brexit. In line with conventional pricing models, we find iPT to be largest among firms with the lowest frequency of price adjustment and those expecting the cost shock to arrive earlier. In addition, we estimate iPT to be smaller among firms with state-dependent pricing and for larger shocks. On the theory side, we assess the general equilibrium consequences of micro heterogeneities in iPT. To do that, we derive theoretical iPT in a multi-sector model with heterogeneous adjustment frequencies and perceived shock horizons. We show that the sensitivity of *aggregate* inflation to changes in future costs is *convex* in non-adjustment frequencies and in the perceived shock horizons. As a result, heterogeneity in firm-level iPTs *amplifies* the degree of forward-lookingness of macroeconomic aggregates. Overall, our results imply that announcements of future policies can have contemporaneous effects, and heterogeneities in price setting amplify their magnitude.

Keywords: price-setting, survey data, firms, tariffs, Brexit

JEL Codes: C83, D25, D84, E31

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1 Introduction

Much of the monetary economics literature is based on the premise that firms are – at least to some extent – forward-looking in their price-setting due to nominal rigidities (Woodford, 2003; Gali, 2015). Firms' forward-looking pricing decisions underpin many fundamental objects in macroeconomics, such as the New Keynesian Phillips Curve (NKPC). Furthermore, they form the basis of key macroeconomic policies, such as the forward guidance measures implemented by many central banks during the low interest rate period after the 2008 Global Financial Crisis. The microeconomic foundations of forward-looking pricing are characterised by how individual firms adjust their *current* prices in response to changes in *expected* future marginal costs, a concept we define as *intertemporal pass-through* (iPT). Obtaining empirical iPT estimates is challenging, since it requires plausibly exogenous variation in firms' own cost expectations that is orthogonal to general equilibrium forces. In this paper, we estimate iPT using a quasi-natural experiment in the UK and data on firm pricing from a large economy-wide survey.

We focus on the period leading up to the United Kingdom's departure from the European Union's Single Market. As a quasi-natural experiment, we exploit the unexpected announcement by the UK government in March 2019 that in the event of a "No-Deal" outcome, import tariffs will be temporarily and unilaterally substantially reduced, relative to the Most Favoured Nation (MFN) tariff rate that UK firms would otherwise face. Such an announcement generates sectoral variation in expected future tariffs, depending on the industrial composition of imported intermediate inputs. We combine the sector-level variation in effective tariff changes with UK firm survey data to create firm-level exogenous shifters in expected marginal costs. To do that, we exploit firm-level heterogeneity in (i) the perceived probabilities of a "No-Deal" outcome, and (ii) the cost share of intermediate inputs imported from the EU. We then estimate the pass-through of expected marginal cost shocks to firm prices. The estimates can be mapped to the theoretical partial equilibrium responses of desired prices to future marginal costs. This is because our econometric specification features fixed effects and firm-level controls, which absorb aggregate and local general equilibrium forces.

The empirical section yields the following key findings. First, iPT is statistically insignificant from zero for firms with higher frequencies of price adjustment, indicating that their prices react only contemporaneously when the shocks happen. In contrast, price responses are economically and statistically significant for firms with stickier prices, which are firms who have to be very forward-looking. Second, we show that the estimated iPT decreases with the ex-

pected horizon of the cost shock. Specifically, firms which expect Brexit to occur at a later date respond less to the expected tariff shock. In our empirical estimates, we also show that the responsiveness of prices rises less than proportionately with the size of the shocks. We also show that the response is stronger for firms which set prices in a time-dependent manner (as opposed to state-dependent price-setters), even after controlling for the average price stickiness across sectors.

To assess the implications of the empirical results on iPT, we construct a multisector New Keynesian model with heterogeneous price adjustment frequencies and heterogeneity in the expected cost shock horizons. A key result in the literature is that heterogeneity in price rigidities across sectors dampens the contemporaneous price response (Carvalho, 2006). However, this is a special case. More generally, across time, we show that heterogeneity in sectors' price stickiness parameters *amplifies* the price responses to expected future shocks (iPT). Therefore, while firm-level iPT is low, *in aggregate*, prices become quite forward-looking. We also show that heterogeneity in the expected shock horizons also *amplifies* the forward-lookingness of aggregate inflation. However, quantitatively, the heterogeneity in price stickiness is a more important driver of the amplification, when matched to the data.

Literature review Our paper is most closely related to the literature on the forward-lookingness of price setting and the use of survey data – dating back to Galí and Gertler (1999) and Mavroeidis et al. (2014) using aggregate macroeconomic data, and more recently using microdata – noting that firms do monitor, but likely seems to be far from perfectly forward-looking (from the full information rational expectations benchmark) but nevertheless their forward-lookingness do affect their economic decisions (Coibion et al., 018a,b, 2020; Candia et al., 2023; Weber et al., 2023; Candia et al., 2024).

Recent studies have also advanced our understanding of (the dynamics of) pass-through of costs to price. Godl-Hanisch and Menkhoff (2024) highlight the gradual pass-through due to nominal and micro real rigidities, Nakamura and Zerom (2010) attribute incomplete pass-through to markup adjustments and Bunn et al. (2024) . [galina cristina paper] [DMP cost price pass-through]

We also contribute to the literature on price rigidity heterogeneity and cost-price pass-through.[1] Carvalho (2006); Fougère et al. (2007); Pasten et al. (2020) explore the heterogeneity in price stickiness across different sectors, emphasizing that this variation can significantly im-

[1]There is also a related literature on the heterogeneity of marginal propensities to consume across households, which matter for aggregate outcomes. See, for example, Auclert et al. (2024); Bilbiie (2020); Boehm et al. (2025).

pact aggregate economic outcomes, with Gorodnichenko and Weber (2016) showing price rigidity can explain the heterogeneity of stock market outcomes to monetary policy shocks. Dedola et al. (2021) identify heterogeneities in the response to import and energy costs (with an emphasis of the intensive vs extensive margins of price adjustment). Relatedly, Gopinath and Itskhoki (2010) examine the propagation of cost shocks in a multi-sector economy, revealing that sectors/firms with higher price rigidity tend to have lower pass-through rates of contemporaneous shocks (which contrasts to our findings with *news* shocks).

Thus, this paper is also related to the large literature on how news shocks play a key role in economic fluctuations and policy responses, which includes the following papers (amongst others). Theoretically, Beaudry and Portier (2006) and Jaimovich and Rebelo (2009) highlight how anticipated changes in future productivity drive business cycles and shape consumption and investment decisions. While empirically, Barsky and Sims (2011); Schmitt-Grohé and Uribe (2012); Kurmann and Mertens (2014); Forni et al. (2014); Crouzet and Oh (2016) provide evidence on the effects of news shocks on macroeconomic variables and monetary policy, while Cascaldi-Garcia and Vukotić (2022) examine sectoral co-movement. Görtz and Tsoukalas (2017); Görtz et al. (2022); Cascaldi-Garcia and Galvão (2021) analyse the role of financial frictions and expectations of news shocks. While this literature tends to focus on news shocks on productivity, there are also a variety of different news shocks (such as government spending (Ramey, 2011), oil supply (Känzig, 2021), forward guidance (McKay et al., 2016; Del Negro et al., 2023) or depreciation (Delgado et al., 2024)).

Exchange-rate pass-through is a related topic with a large literature (as it forms part of import costs): Nakamura and Steinsson (2010) delve into the mechanisms of illustrating how firms' pricing strategies influence the transmission of these cost shocks to prices, as do various heterogeneities (Gopinath et al., 2010, 2020; Auer et al., 2021). Breinlich et al. (2022); Graziano et al. (2023); Hobijn et al. (2021); Corsetti et al. (2022) are also closely associated, though they examine the inflation impacts of the 2016 post-referendum exchange rate depreciation, rather than changes in trading arrangements.

Our quasi-natural experiment also links this paper to the broader literature on the macroeconomic/inflation implications of trade frictions (eg. introduction of tariffs). Cavallo et al. (2024) provide evidence from US trade policy, showing mixed retail price impacts while Amiti et al. (2019) find complete pass-through to domestic prices. Barattieri et al. (2021) and Jacquinot et al. (2022) analyse the broader macroeconomic impacts of trade restrictions. Our paper complements this literature by focusing on the impacts of anticipated future changes in

trade restrictions (in contrast to realised changes) – a valuable exercise as changes in trade restrictions tend to be announced well in advance of the actual changes. Bakker et al. (2022);

The paper is organised as follows. Section 2 describes the data and institutional context. Section 3 outlines the empirical strategy and highlights the key empirical results from the survey data, including robustness. Section 4 outlines the theoretical model and matches it to the reduced-form empirical results. Section 5 concludes.

2 Data

We begin by providing a detailed decription of our data construction strategy. First, we introduce the institutional context behind the quasi-natural experiment we are exploiting: the March 2019 announcement of a reduced tariff schedule in the event of a No-Deal Brexit. Second, we augment the sectoral variation in expected future tariff generated by the unexpected policy announcement with confidential UK survey data to construct firm-level shifters in expected future marginal costs.

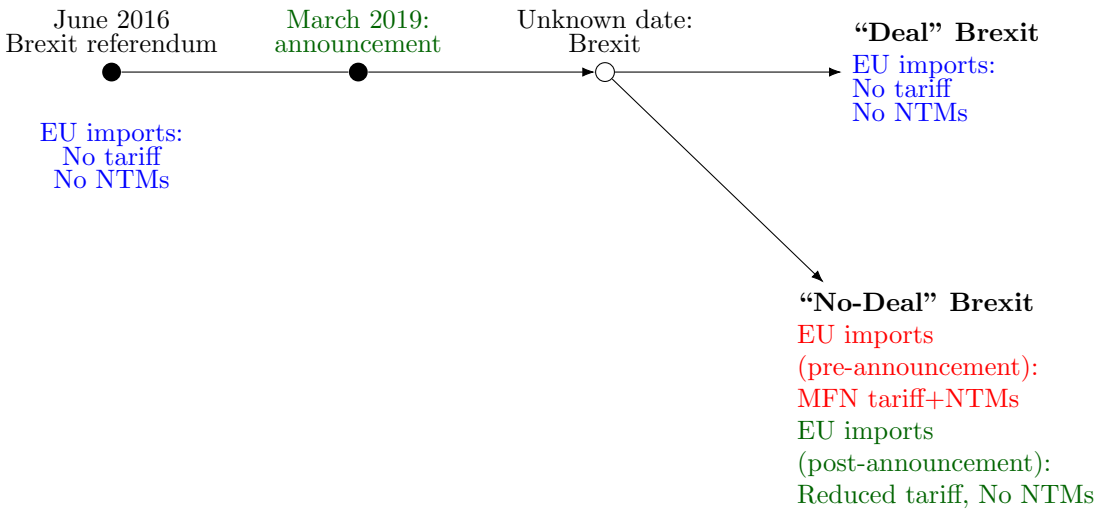
2.1 Institutional Context

A 'no-deal' outcome meant that the UK would be treated as a third country under the EU's Most Favoured Nation (MFN) rules. If the UK retaliates and applies its (and the EU's) MFN external tariff regime to EU imports - which is a significant change from the tariff-free trade - this would impose new tariffs on EU imports, and would therefore disrupt supply chains. In contrast, if the UK maintained zero tariffs on EU imports, under WTO MFN rules, it would also be forced to extend it to the rest of the world. Correspondingly, the UK may wish to impose tariffs on EU imports. Furthermore, the UK would also lose access to trade agreements as previously negotiated by the EU. Therefore, similarly to EU imports, the UK could impose tariffs on non-EU imports from countries that it did not negotiate an equivalent or similar trade agreement with prior to its exit from the EU.

On 13 March 2019, the UK Government announced details of the temporary tariff regime in such a no-deal outcome.[2] There is significant heterogeneity across sectors: 87% of imports (by value) would be eligible for tariff-free access, while the remaining 13% would remain subject to tariffs, primarily in protected industries such as the agriculture and automotive sectors. For most sectors, but not all, the announced temporary tariff regime has tariffs lower than the

[2] https://www.gov.uk/guidance/check-temporary-rates-of-customs-duty-on-imports-after-eu-exit

Figure 1: Timeline of key Brexit tariff scenarios



previously known EU MFN tariffs (if the UK reciprocated the EU MFN tariffs). In effect, this led to an announced disinflationary 'news' cost shock. The announcement was highly detailed, at a HS 8-digit level. Therefore, firms would be able to figure out from this announcement how their import costs change, depending on the sectors that they import from. This is the key quasi-natural experiment that we use as a laboratory to study firms' forward-lookingness.

The various 'deals' that were feasible at the time of the sample (2019) largely varied across some implementation of remaining in the European Economic Area (EEA) or a customs union. But in large, this would retains tariff-free trade between the UK and EU, with varying degrees of trade frictions such as checks on goods to ensure compliance with regulations.[3] Thus, we interpret in the next subsection as a 'deal' having a continuation of zero-tariff goods trade.

2.2 A firm-specific tariff shock measure

To create a *firm-specific* tariff shock measure based on this quasi-natural experiment, we proceed in the following steps. First, we use the trade micro-data on 9,533 products p supplied by His Majesty's Revenue & Customs (HMRC) to construct product-level changes in effective tariff rates, for **two** scenarios. The first scenario is that there is no announcement by the Government, and tariffs following a no-Deal Brexit adjust to the MFN rates. These are denoted by τ_p^{MFN}. The second scenario is what *was* announced as the potential tariff rates in the case of a no-Deal Brexit by the Government in March 2019. We denote these by τ_p^{M19}.

[3]See **?**. The small exception is the 'Canada-style' deal where will be tariffs on a small handful of food products, but in large, broader goods trade would remain tariff-free.

For each one of these two scenarios, the change in tariff rates is given by:

$$\Delta\tau_p^k = \left[\tau_p^k - \left(\frac{M_p^{EU}}{M_p} \times 0 + \frac{M_p^{non-EU}}{M_p} \times \tau_p^{MFN}\right)\right], \qquad \forall p, \forall k \in \{MFN, M19\} \tag{1}$$

We define our main tariff shock measure, $\Delta\tau_p$ as the difference between the change in effective tariff rates across two scenarios. In other words,

$$\Delta\tau_p = \Delta\tau_p^{M19} - \Delta\tau_p^{MFN} = \tau_p^{M19} - \tau_p^{MFN} \tag{2}$$

Secondly, these aggregate product-level changes in effective tariffs are then mapped to two-digit SIC 2007/CPA 2008 level, k, using relative product import weights. This is done with UK Input-Output accounts published by the Office for National Statistics (ONS).

Third, in addition to the announced tariffs, we also include the disruption from Brexit due to non-tariff measures (NTMs) in our shock construction. To do this, we follow Bakker et al. (2022) and use ad-valorem equivalents (AVEs) of non-tariff measures from the World Bank.[4] We include both estimates of technical and non-technical NTMs. Technical non-tariff measures capture sanitary and phytosanitary measures as well as labelling and certification requirements. Non-technical measures include contingent trade measures, quantitative restrictions, price controls, and finance measures. These are available at the HS6 digit product level, and are mapped to the sectoral level following the same approach above. Finally, we note that these NTMs are only available for the EU as an importing country. Hence, the assumption is that the NTMs are mirrored for the UK after Brexit.

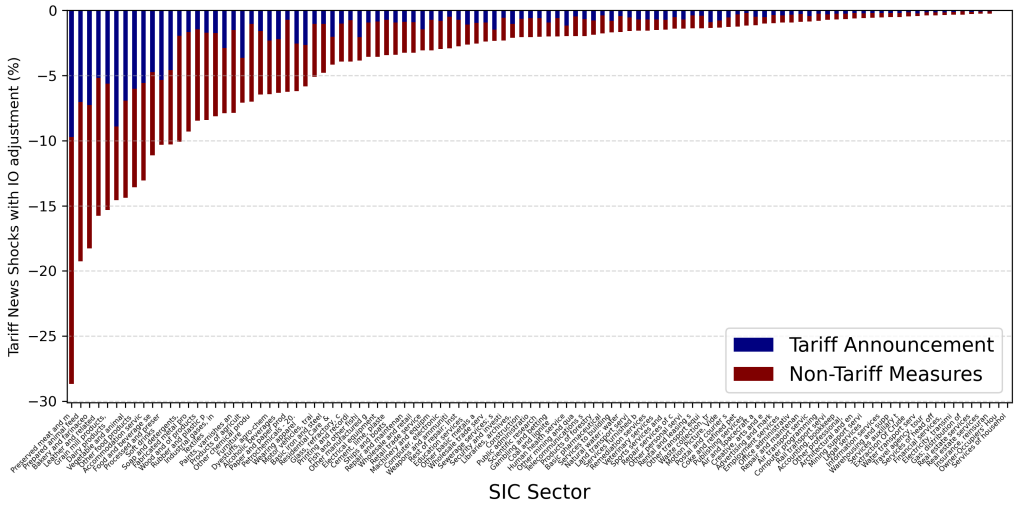
Fourth, we account for the exposure of each sector, k, to imported intermediates from any other sector, r. This is denoted by $\overline{\omega}_{kr}$. Thus, with $\overline{\omega}_{kr}$ and the proposed changes in effective sectoral tariffs $\Delta\tau_k$, we compute the changes in sector-specific relevant tariff rate:

$$\Delta T_k = \sum_r \overline{\omega}_{kr} \Delta\tau_r, \quad \forall k \tag{3}$$

Figure 2 shows the estimated *sectoral* tariff shocks based on the steps described above for each SIC2 sector. All the estimates are negative, as this is a deflationary news cost shock.

[4]The data can be accessed here: https://datacatalog.worldbank.org/search/dataset/0040437/Ad-Valorem-Equivalent-of-Non-Tariff-Measures

Figure 2: Sectoral tariff news shocks



Notes: The figure shows the sectoral tariff news cost shocks. These shocks account for technical and non-technical tariff measures and include an input-output table adjustment.

Furthermore, there is substantial heterogeneity across sectors. The three sectors with the largest sectoral estimates are preserved meat and meat products (-28%), prepared animal feeds (-19%), and Bakery and farinaceous products (-18%).

Finally, we use *firm-level* responses on the perceived probability of no-deal (Figure A3), cost share of imported intermediate inputs $\delta_{i,k}$ (Figure A5), and *sector-level* estimated fixed cost shares, fc_k, to construct firm-level tariff shocks:

$$\Delta\boldsymbol{\tau}_{i,k} = Pr(\text{no-deal})_{i,k} \times \delta_{i,k} \times \frac{1}{1 - fc_k} \times \Delta T_k, \quad \forall i, k \tag{4}$$

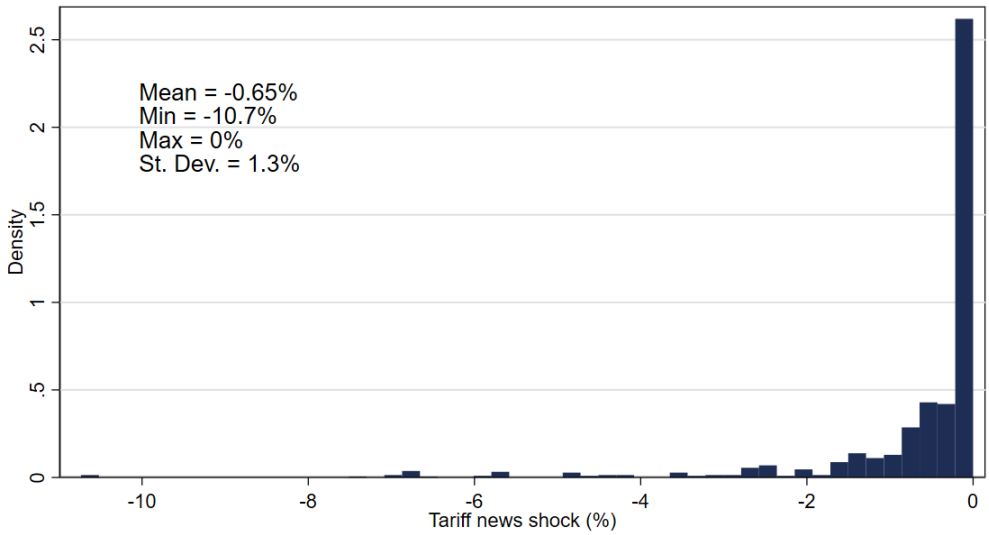
For the firm-level data to assess how firms respond to the $\Delta\boldsymbol{\tau}_{i,k}$ shocks, we use UK firm-level responses underlying the Decision Maker Panel (DMP) survey, jointly constructed and maintained by the Bank of England, University of Nottingham, and King's College London.[5] Launched in 2016, the panel comprises Financial Officers from small, medium and large UK companies operating in a broad range of industries and is designed to be representative of the population of UK businesses. Approximately 10,000 businesses were part of the panel as of September 2022. We are specifically interested in the following firm-level responses:

- Firm-level price index, year-ahead expected price index (quarterly frequency)[6]

[5] https://decisionmakerpanel.co.uk/

[6] Because firms are only asked about 12-month own-price *growth* (for both past realised prices and expected

Figure 3: Distribution of firm-level tariff news shock



Notes: The figure shows the distribution of the firm-level tariff news shock in the main regression sample.

- Firm-level employment, sales and year-ahead expectations (quarterly frequency)
- Firm-level cost share of imported intermediate inputs
- Trading arrangement-specific questions: perceived probability of No-Deal, perceived date of No-Deal

Finally, we scale the tariff news shock by the sectoral variable cost share. We use data on sectoral fixed cost shares for UK firms.[7] This allows us to account for the fact that the tariff announcement will only affect the variable cost component of firms' costs. Figure A7 shows the distribution of these fixed cost shares in our estimation sample. The median fixed cost share is 37%.

Figure 3 shows the distribution of the firm-level tariff news shock based on Equation 4. As discussed previously, the shock is disinflationary in nature. The shock values range from -10.7% to 0, with an average of -0.65% and a standard deviation of 1.3%.[8]

Because of the Covid pandemic, we restrict our sample until end-2019 – which still allows us to study the firm-level price responses for three quarters after the March 2019 announcements.

future prices), we impute the price levels from this variable. We assume a uniform geometric price growth to fill in the price levels where necessary (e.g. at the beginning of the sample, or due to missing observations). We limit the maximum gap between observations to four quarters, so all price level data points are informed by at least one observation of price growth data.

[7] We thank Maria Ptashkina in particular for sharing this data with us.

[8] Figure A8 shows the equivalent distribution of non-zero firm-level tariff news shocks.

2.3 Sector-specific frequencies of price adjustment

To estimate the price stickiness of various sectors for both the empirical estimates and multi-sector DSGE model, we use the confidential micro-data that underpin the UK's Consumer Price and Producer Price Indices (CPI and PPI), as collected with the Office for National Statistics. The PPI data largely covers the manufacturing sector and is easily matched to the 4-digit SIC 2007/CPA 2008 sectors in both the DMP dataset and DSGE model (aggregated to 2-digit sectors using PPI/CPI weights available in the microdata). We further supplement the sectors by carefully hand-matching the various sectors that are more consumer-facing or have close counterparts in the CPI and PPI components, also at a 2-digit level, to the best of our ability.[9]

For example, the price stickiness of the energy sectors was matched to the average price duration energy parts of the CPI basket. Not all sectors would be covered, however, as some of these sectors do not have a suitable CPI and PPI counterpart – and thus are omitted from our analysis. To estimate the Calvo parameter for each 2-digit SIC 2007/CPA 2008 sector, we then follow Gorodnichenko and Weber (2016) to construct frequency of price non-adjustment:

$$\hat{\alpha}_p = \frac{NM_p^{\text{no change}}}{NM_p}, \qquad \forall p. \tag{5}$$

Figure A9, shows the distribution of price adjustment frequencies based on this approach. We convert the frequencies of non-adjustment α to average price durations using the formula: $-1/\ln(\alpha)$. The median price duration we estimate is 5.8 months. In the estimation, we split the average durations into four bins: 0-5 months, 5-10 months, 10-20 months, and 20+ months. Figure 4 shows the distribution of firms in these four bins. Around 45% are in the first bin with the shortest price durations. But over one-third of firms are in sectors with a price duration longer than ten months.[10]

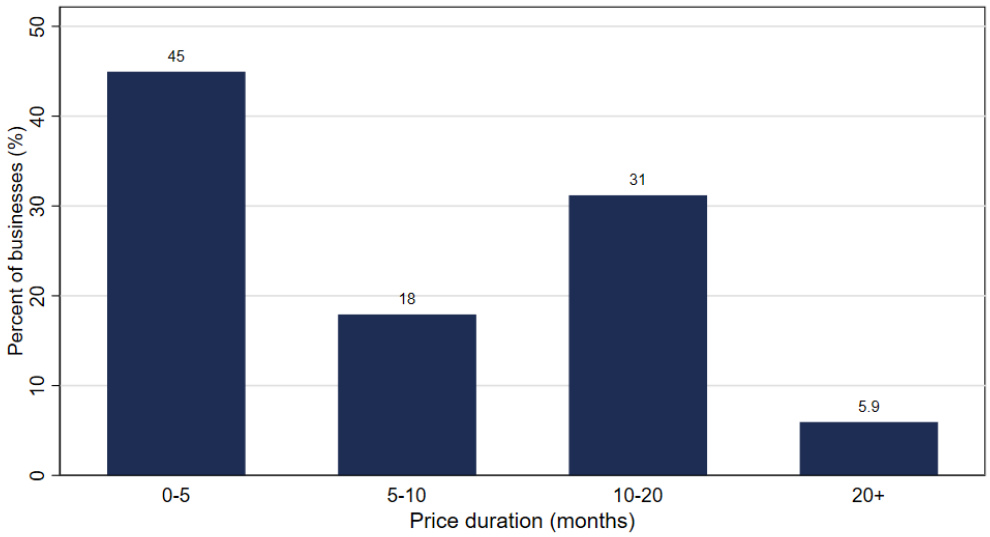
3 Econometric Strategy and Estimation Results

Having constructed the dataset, we now introduce our econometric strategy and describe our key estimation results. Our specification captures possibly heterogeneities in the frequency of price

[9] Most of the missing sectors largely lie in the business-to-business services. For these sectors, we set it to the average price duration of the whole PPI. The matched price durations at a sector-level are available from authors upon request.

[10] In Figure A10 we also compare our estimate sectoral price adjustment parameters to firms' reported frequencies of price adjustment. The two measures are positively correlated.

Figure 4: Frequency of price adjustment in main estimation sample



Notes: the figure shows the distribution of estimated duration of prices.

adjustment, perceived horizon of the shock, time- or state-dependent pricing, as well as the size of the shock. In line with conventional pricing models, we find that the iPT is largest for firms with stickiest prices and short perceived shock horizons. Moreover, we find the pass-through to be lower for firms with state-dependent pricing, as well as for large shocks.

3.1 Econometric specification

In this section, we outline our empirical strategy for estimating the effects of tariff news shocks on firm price inflation. Specifically, we estimate the following specification for firm i in industry k for horizon H (where the horizons are the three quarters between 2019Q2 to 2019Q4):

$$\boldsymbol{p}_{i,k,H} = \phi \Delta \boldsymbol{\tau}_{i,k} + \gamma_H + \varphi \boldsymbol{X}_{i,k} + \varepsilon_{i,k,H} \tag{6}$$

The dependent variable is the *cumulative* log change in the price level between the quarter prior to the March 2019 announcement (i.e. based on data between December and February) and quarter H post-announcement. In other words, $\boldsymbol{p}_{i,k,H} \equiv (\ln P_{i,k,H} - \ln P_{i,k,-1})$. In addition, in our regression estimates we drop firms for which the change in the price level is 0 for a given horizon. In the main estimation sample, the average change in the price level is 1%, with a standard deviation of 4.2%.

On the right-hand side of Equation 6, the main object of interest is ϕ, which captures the

effect of a tariff news shock on firm price growth. In addition to the average effect across all firms, we consider several dimensions of heterogeneity in these estimates. First, we analyse how the pass-through of the expected tariff shock depends on price stickiness. We estimate price stickiness as the frequency of price non-adjustment at the industry level using CPI microdata (as defined above). In the regressions, we convert the price non-adjustment frequencies to *durations* of price non-adjustment. Furthermore, we split this measure into categories ranging from 0-5 months of price duration to 20+ months of price duration. Our hypothesis is that firms with higher price stickiness would respond more strongly to a given tariff shock.

The second dimension of heterogeneity we consider is the date when the UK is expected to leave the EU. This is estimated at the firm level using questions asked in the DMP. Our hypothesis is that the effect of the tariff shock on price growth would be stronger when the expected Brexit date is closer to the announcement.

In addition, all the empirical specifications include a set of controls and fixed effects. We control for quarter fixed effects, which capture aggregate trends in price growth across all firms. In addition, we control for employment, capital expenditure, and exporter status at the firm level (all measured using DMP data). We also include controls for the perceived probability of no-deal Brexit, the import cost share from the EU, and the sectoral fixed cost share, which are components of the tariff news shock.

3.2 Main results

Table 1 presents our main results on the pass-through of tariff news cost shocks on firm prices. Column 1 shows that, on average, there is no significant pass-through across all firms. This is perhaps not surprising. Firms which normally update their prices at a higher frequency would not be expected to react to this announcement on impact. Our main hypothesis is that it is only firms with stickier prices which should react to this news shock, as they would be sufficiently forward-looking.

In Column 2, we add an interaction for whether firms expect Brexit to happen in 2020 (as opposed to 2019, the base category). To estimate this, we use questions asked to firms about the year they expect the UK to leave the EU. Firms are asked to assign probabilities to each year between 2019 and 2022 (as well as a 2023+ option). We construct a 'modal expected exit year' variable based on the year to which firms assign the highest probability.[11] We also

[11] In the regression, we only present results for modal exit years 2019 and 2020, as there are very few observations for the years beyond 2020.

Table 1: Impact of tariff news shock on prices: Interaction with price durations and expected Brexit duration

	(1)	(2)	(3)	(4)	(5)
Dependent variable:	$100 \times \Delta \ln$(Price Level)				
Sample:	2019Q2 - 2019Q4				
Tariff news shock$_{i,k}$	-0.107	0.051	0.060	0.054	-0.020
	(0.080)	(0.081)	(0.126)	(0.125)	(0.108)
Tariff news shock$_{i,k}\times$ Modal Brexit Year=2020$_i$		-0.416***	-0.449***	-0.445***	-0.482***
		(0.124)	(0.160)	(0.162)	(0.139)
Tariff news shock$_{i,k}\times$ Price Duration 20+M$_k$		0.357***	0.498**	0.481**	
		(0.108)	(0.218)	(0.221)	
Tariff news shock$_{i,k}\times$ Price Duration 5-10M$_k$					0.138
					(0.185)
Tariff news shock$_{i,k}\times$ Price Duration 10-20M$_k$					0.435**
					(0.171)
Tariff news shock$_{i,k}\times$ Price Duration 20+M$_k$					0.616***
					(0.224)
Quarter fixed effects	No	No	No	Yes	Yes
Additional firm controls	No	No	Yes	Yes	Yes
Mean of Dependent Variable	1.078	1.078	1.078	1.078	1.078
R^2	0.002	0.012	0.022	0.032	0.036
Observations	1,010	1,010	1,010	1,010	1,010

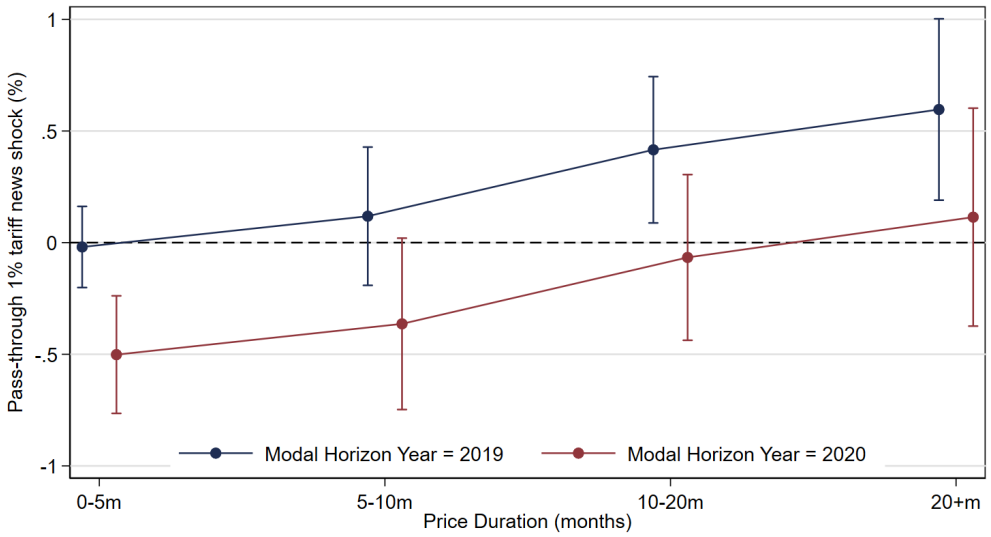
Notes: The dependent variable is winsorised at the 5th and 95th percentiles. Additional controls include: Perceived probability of No Deal Brexit; Import cost share; Exporter status; Sectoral fixed cost share; Natural logarithms of employment and capital expenditure in March 2019. Standard errors are clustered at the industry (SIC2) level and reported in parentheses, stars indicate *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

add an indicator for whether firms are the most price-sticky sectors – those with an average price duration above 20 months.[12] These are our two main dimensions of heterogeneity, which follow from the theory on price-setting with nominal rigidities. The results show that (1) firms which expect Brexit to happen further in the future have a lower estimated pass-through and (2) firms with a higher average price duration have a stronger inter-temporal pass-through to the expected tariff shock. The coefficients are also quantitatively meaningful. Among firms which have a 2019 modal Brexit horizon, there is no pass-through for price-flexible firms but for price-sticky firms the pass-through is around 0.4, or roughly a 40% iPT.

In Columns 3 and 4 of Table 1, we show that the main results are robust to adding more controls and fixed effects. In Column 3 we add controls for the perceived probability of no-Deal Brexit, the import cost share from the EU, the sectoral fixed cost share, a dummy for exporter status, and controls for firm employment and capital expenditure in March 2019. Our main results remain highly significant, and the estimated iPT increases for the more price-sticky sectors. In Column 4 we also add quarter fixed effects to capture average trends in price growth

[12]To do this, we convert the industry-level estimates of price non-adjustment frequency into approximate durations of non-adjustment. Specifically, if the frequency of price non-adjustment is α, the average duration of non-adjustment is $-1/\ln(\alpha)$.

Figure 5: Impact of tariff news shock on prices: Interaction with price durations and expected Brexit date



Notes: This figure presents the effect of the tariff import cost shock on firm prices, with interactions for average price duration and expected Brexit date. Standard errors are clustered at the SIC2 level and 90% confidence intervals are reported. The regression results are reported in Column 5 of Table 1.

across all firms. These also do not affect our main results.

In Columns 2-4 we compare firms with price duration between 0-20 months with those with 20+ months duration. This is a very extreme distinction, and indeed only a small percentage of firms have price duration above 20 months. In Column 5 of Table 1, we provide a further breakdown of the price duration variable into four categories: 0-5 months (the base category); 5-10; 10-20; and 20+ months. The results suggest that the iPT is increasing monotonically with price duration, and the interactions are statistically significant for the 10-20 month and 20+ month categories.

In Figure 5, we present the main empirical results from Column 5 of Table 1 on the effect of the firm-level tariff news shock on price inflation.

As seen in the chart, the effect of the tariff news shocks is not significant for low price stickiness (up to 10 months) for firms that have a modal Brexit horizon of 2019 (blue coefficient plot). Nevertheless, the point estimates are increasing in the price durations, and for firms with price durations above ten months, the effect is large, positive, and statistically significant. The coefficient for firms with a price duration above 20 months (who also expect Brexit in 2019) suggests that a 1% expected tariff cost shock leads to a 0.6% increase in the price level (or a 60% intertemporal pass-through). The red coefficients in the figure show the estimated iPT

for firms with a modal Brexit horizon of 2020. Following the regression results, these are lower across all levels of price duration. We do not find a positive and significant iPT for any firms with this expected shock horizon.

Table A2 presents the main results from Table 1 as well as the coefficients on the additional control variables. In addition, in Column 5 we add industry fixed effects to the main specification. The estimated coefficients remain statistically significant, but the magnitudes become very large. For example, the estimated iPT is now above 1 for firms with the highest price durations. This is likely because our sample is not very large (around 1,000 observations), and the amount of within-industry variation is limited. We therefore present the results without industry fixed effects as our main specification.

Non-linearity of iPT In Table 2, we analyse whether the pass-through of the tariff news shock varies with the size of the shock. In Column 1, we add an interaction which captures separates tariff shocks at the 25th percentile (i.e. most negative shocks) versus the rest. We find that iPT is lower for these large negative shock. Column 2 confirms this when isolating just the bottom 15th percentile of shocks, and Column 3 shows that this remains the case even when introducing the additional interactions with expected shock horizon and price duration. Both of these remain statistically significant as in Table 1.

In Column 4, we add an interaction with the absolute value of the tariff news shock. This allows us to flexibly test whether the estimated iPT is non-linear. We find a negative statistically significant coefficient on the absolute value of the tariff shock measure. This suggests that firms are less than proportionately responsive to larger tariff shocks (in absolute value). Overall, the results in Table 2 could be consistent with state-dependent price-setting behaviour, if larger expected shocks are more uncertain and therefore firms react contemporaneously by less.

In Figure 6, we provide a quantification exercise based on the coefficient estimates in Column 4 of Table 2. Specifically, we show what the estimated iPT would be, depending on the linear vs. nonlinear specification, for the tariff news shocks in our sample. In this exercise, we focus on firms with a price duration above 20 months and with a 2019 modal Brexit horizon. For smaller shocks, there is little difference. But for the largest shocks, the difference is meaningful. For the largest shock in our sample (around 10% in absolute value), the linear estimated pass-through to prices is around 9% (a 90% pass-through), whereas the non-linear iPT is around 3.5% (a 35% pass-through).

State- vs. time-dependent price-setting In Table 3, we test whether there is a different iPT for sectors with more 'time-dependent' vs. 'state-dependent' price setters. In 2023 and

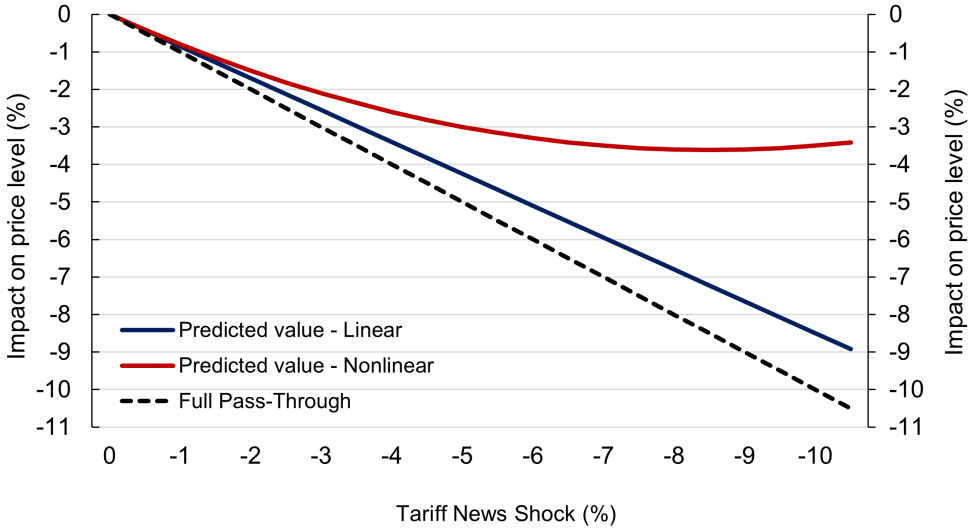
Table 2: Impact of tariff news shock on prices: Nonlinearity of tariff news shock

	(1)	(2)	(3)	(4)
Dependent variable:	$100 \times \Delta \ln$(Price Level)			
Sample:	2019Q2 - 2019Q4			
Tariff news shock$_{i,k}$	1.089**	0.638	0.859*	0.451
	(0.474)	(0.469)	(0.502)	(0.283)
Tariff news shock$_{i,k}$× Tariff news shock < 25 Pctile	-1.185**			
	(0.446)			
Tariff news shock$_{i,k}$× Tariff news shock < 15 Pctile		-0.721*	-0.842*	
		(0.408)	(0.433)	
Tariff news shock$_{i,k}$ × | Tariff news shock$_{i,k}$|				-0.047*
				(0.026)
Tariff news shock$_{i,k}$× Modal Brexit Year=2020$_i$			-0.478**	-0.528**
			(0.181)	(0.197)
Tariff news shock$_{i,k}$× Price Duration 20+M$_k$			0.402*	0.400*
			(0.236)	(0.226)
Quarter fixed effects	Yes	Yes	Yes	Yes
Additional controls	Yes	Yes	Yes	Yes
Mean of Dependent Variable	1.078	1.078	1.078	1.078
R^2	0.027	0.025	0.036	0.034
Observations	1,010	1,010	1,010	1,010

Notes: The dependent variable is winsorised at the 5th and 95th percentiles. Additional controls include: Perceived probability of No Deal Brexit; Import cost share; Exporter status; Sectoral fixed cost share; Natural logarithms of employment and capital expenditure in March 2019. Standard errors are clustered at the industry (SIC2) level and reported in parentheses, stars indicate *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

2024, the DMP survey asked firms how they set their prices: by time-dependence (and how frequently) or state-dependence. Based on these responses, we create a measure at the SIC2 level for whether there are more state-dependent or time-dependent firms. The theoretical prediction from standard state-dependent menu cost type models would be that firms change their prices when the cost shock happens – and thus, for a news cost shock, they would not act until the cost shock is in the vicinity of transpiring. Matching this prediction, Table 3 shows that these state-dependent firms have significantly lower pass-through of the news cost shock relative to other time-dependent firms (of which, the sticky firms have to be more forward-looking). This is true when using a continuous measure of state/time dependence (Column 1), and also with discrete splits at the 66th, 50th, and 33rd percentiles in Columns 2-4, respectively. Importantly, in Column 5 we show that this result also holds conditional on the price duration of sectors and the expected shock horizons, bothe of which remain statistically significant. This is also consistent with the predictions of Auclert et al. (2024) that the Phillips curve of a menu cost model looks like one derived from Calvo pricing, but with a higher price flexibility (and thus, lower pass-through of news cost shocks).

Figure 6: Impact of tariff news shock on prices: Linear vs. non-linear effects



Notes: This figure presents the linear and nonlinear predicted effect of the tariff import cost shock on firm prices. The results are based on Column 4 from Table 2. The predicted values are for firms who have a modal expected Brexit year of 2019.

Additional outcome variables In Table A4, we analyse the effect of the tariff news shocks on several additional outcome variables. Specifically, we test for the effects on employment, capital expenditure, and real sales, using data from the DMP survey. The dependent variable is the natural logarithm of these responses, and we flexibly control for level in March 2019 in each specification. In addition, we present the results by estimation quarter. We find that for price sticky firms, there is a negative effect of the tariff shock on employment (particularly in 2019Q3) and on real sales (in 2019Q2 and Q4). We also find negative coefficients for capital expenditure in 2019Q2 and Q3, but these are not statistically significant. This suggests positive cost shocks lead to higher prices and lower employment and lower real sales for these price-sticky firms, consistent with a negative supply shock. In general we find that expecting the shock to be further in the future has a positive effect on these outcome varibles.

Estimation by sample quarters To check the robustness of our empirical results, we perform some sensitivity checks. First, we split the sample by the different quarters of their response through 2019 (after the tariff announcement) (Figure A15). Panel A shows the result for firms with a modal Brexit horizon of 2019; Panel B shows the results with a modal Brexit horizon of 2020. Three findings stand out. First, across both panels, we find stronger responses for price-sticky firms (red coefficients). Second, the effects are stronger for firms with a 2019 modal Brexit horizon (Panel A). Third, the positive iPT are concentrated in the first two

Table 3: Impact of tariff news shock on prices: Interactions with state/time dependent pricing

	(1)	(2)	(3)	(4)	(5)
Dependent variable:	$100 \times \Delta \ln$(Price Level)				
Sample:	2019Q2 - 2019Q4				
Tariff news shock$_{i,k}$	0.519*	0.251**	0.185**	0.147	0.253*
	(0.270)	(0.105)	(0.090)	(0.103)	(0.126)
Tariff news shock$_{i,k}\times$ State-dependent$_k$	-0.860**				
	(0.404)				
Tariff news shock$_{i,k}\times$ State-dependent$_k^{p66}$		-0.441***			
		(0.096)			
Tariff news shock$_{i,k}\times$ State-dependent$_k^{p50}$			-0.342***		
			(0.089)		
Tariff news shock$_{i,k}\times$ State-dependent$_k^{p33}$				-0.259**	-0.228*
				(0.117)	(0.130)
Tariff news shock$_{i,k}\times$ Price Duration 20+M$_k$					0.443*
					(0.223)
Tariff news shock$_{i,k}\times$ Modal Brexit Year=2020$_i$					-0.436***
					(0.151)
Quarter fixed effects	Yes	Yes	Yes	Yes	Yes
Additional controls	Yes	Yes	Yes	Yes	Yes
Mean of Dependent Variable	1.087	1.087	1.087	1.087	1.087
R^2	0.025	0.031	0.027	0.024	0.034
Observations	1,000	1,000	1,000	1,000	1,000

Notes: The dependent variable is winsorised at the 5th and 95th percentiles. Additional controls include: Perceived probability of No Deal Brexit; Import cost share; Exporter status; Sectoral fixed cost share; Natural logarithms of employment and capital expenditure in March 2019. Standard errors are clustered at the industry (SIC2) level and reported in parentheses, stars indicate *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

quarters following the announcement. By 2019Q4, we no longer find a positive iPT. Table A5 shows the estimated coefficients for this figure.

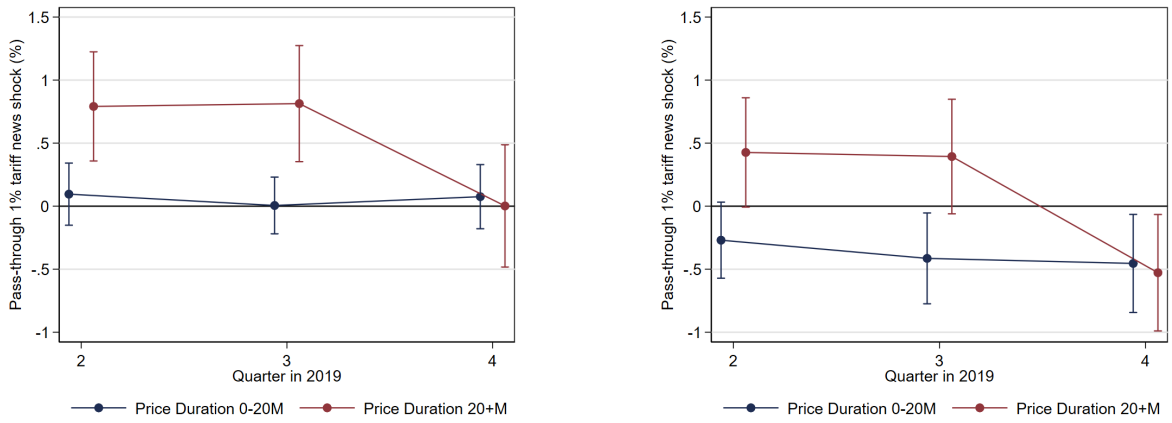
Pre-trends test In Table A6 we show that the main results are absent in the four quarters before the tariff shock announcement (2018Q1-2018Q4). This serves as a valuable robustness check of our main estimation.

Placebo tests We also construct two placebo tests. The first attempts to identify whether the assignment of a firm in the most price-sticky category happens by chance that leads to the significant result. Therefore, the first placebo randomly assigns firms the status of being in the most price-sticky category (the number of firms in this category being the same as in the sample), at a firm-level. The second randomises the assignment of the expected Brexit horizon at the firm level in the same was as the first placebo test, and analyses the interaction with the tariff news shock. In both cases, we also randomise the tariff news shock at the firm level as well. The results in Figures A16 and A17 indicate that it is highly unlikely that we observe the statistically significant results by chance.

Overall, in this section we have shown that the tariff news shock had an effect on price-

Figure 7: Impact of tariff news shock on prices: Effects by estimation quarter

(a) Modal Horizon = 2019 (b) Modal Horizon = 2020



Notes: The results are based on Column 3 of Table A5. Standard errors are clustered at the industry (SIC2) level.

setting behaviour of firms. This was highly significant for those firms with the highest price stickiness and for those which expected Brexit to happen sooner. We also find evidence that firms with highest price stickiness experience lower employment following the tariff news shock. In the next section, we show that we find very similar effects in a theoretical framework with price stickiness.

4 General equilibrium setup

We now turn to theoretical analysis of iPT in the conext of a general equilibrium model that captures the empirically-relevant dimensions of heterogeneity. Moreover, we study how micro iPT heterogeneity affects the forward-lookingness of macroeconomic aggregates, such as CPI inflation. We find that heterogeneities in adjustment frequencies and perceived shock horizons amplify the degree of aggregate forward-lookingness.

4.1 Model overview

Time is discrete, with outcomes in $t = 0$ exogenously given, and outcomes in $t \geq 1$ determined by agents' decisions. There are three types of agents in the model. First, a continuum of infinitely lived households. Second, a continuum of monopolistically competitive firms, owned by the households, where each firm belongs to one, and only one, of the K sectors; let the set of all firms in sector k be $\Phi_k, \forall k = 1, 2, ..., K$. Third, a government, comprising of a central

bank which sets the level of money supply in the economy, and a fiscal authority which collects taxes from firms and rebates them to households as a lump-sum transfer. Below we describe the problem solved by each type of agents.

4.2 Demand side and monetary policy

Households A continuum of infinitely lived households populates the economy and owns all the firms. The representative household makes choices to maximize the lifetime utility:

$$\max_{\{C_{t+s},N_{t+s},B_{t+s+1}\}_{s\geq 0}} \sum_{s\geq 0} \beta^s \left[\log C_{t+s} - N_{t+s}\right] \tag{7}$$

subject to

$$P_t^c C_t + \left[F_{t,t+1} B_{t+1}\right] \leq B_t + W_t N_t + \sum_{k=1}^{K} \int_{j\in\Phi_k} \Pi_{kt}(j) dj + T_t, \quad \forall t \tag{8}$$

where C_t is aggregate consumption, P_t^c is consumption price index (defined below), N_t is labor supply, B_{t+1} is the payoff of securities purchased at time t, $F_{t,t+1}$ is the stochastic discount factor between periods t and $t+1$, $\Pi_{kt}(j)$ denotes nominal profits of firm j in sector k, β is the discount factor for future utility and T_t are lump-sum transfers from the government.

The households' maximization problem yields standard aggregate first-order conditions, namely an equation for the stochastic discount factor $F_{t,t+s} = \beta^s \left(\frac{C_{t+s}}{C_t}\right)^{-1} \frac{P_t^c}{P_{t+s}^c}$, and the labor supply equation $P_t^c C_t = W_t$.

Monetary policy Purchases of final goods are subject to a cash-in-advance constraint, so that $P_t^c C_t = M_t$. Agents know the initial level of money supply M_0, and at $t = 0$ anticipate it to stay at that level forever. In period $t = 1$ they discover the future path of money supply $\{M_t\}_{t=1}^{\infty}$ and therefore any $M_t \neq M_0$ constitutes a monetary shock at time t to the agents.

Combining the cash-in-advance constraint with the households' consumption-labour supply condition implies that $M_t = W_t$. Therefore, by setting money supply the central bank controls the aggregate nominal wage in the economy.

4.3 Full setup of the supply side

On the production side, our economy consists of K sectors, indexed by $k \in \{1, 2, ..., K\}$, and a continuum of monopolistically competitive firms, indexed by j, that each belongs to one sector.

The production function of firm j that operates in sector k is given by:

$$Y_{kt}(j) = A_{kt}N_{kt}(j), \tag{9}$$

where $Y_{kt}(j), N_{kt}(j)$ and A_t are, respectively, total output, labour input and aggregate exogenous productivity at time t.

Given the nominal wage W_t, firms choose $N_t(j)$ in order to minimize their total inputs cost subject to the production function. The latter delivers the following expression for the nominal marginal cost, common to all firms within a given sector:

$$MC_{kt}(j) = MC_{kt} = \frac{1}{A_{kt}}W_t. \tag{10}$$

Price stickiness in our economy is modelled as in Calvo (1983), although the probability of price adjustment is allowed to vary across sectors. More precisely, in any period a firm in sector k has probability $(1-\alpha_k)$ of setting its price equal to its optimal value. The optimal price at time t is chosen to maximize expected future discounted nominal profits:

$$\max_{P_{kt}(j)} \sum\nolimits_{s\geq 0} \alpha_k^s F_{t,t+s} \left[P_{kt}(j)\tilde{Y}_{k,t+s}(j) - (1+\tau)MC_{k,t+s}\tilde{Y}_{k,t+s}(j) \right], \tag{11}$$

where $\tilde{Y}_{k,t+s}(j) = \left[\frac{\hat{P}_{kt}(j)}{P_{t+s}}\right]^{-\theta} Y_{k,t+s}$, $\theta > 1$ is the within-sector elasticity of substitution; τ is a tax imposed by the government, revenue from which is rebated to households as a lump-sum transfer.

The first order condition for the optimal reset price for any firm in sector k, P_{kt}^* is given by

$$P_{kt}^* = (1+\tau)\frac{\theta}{\theta-1}\frac{\sum_{s\geq 0}\alpha_k^s F_{t,t+s}P_{k,t+s}^{\theta}Y_{k,t+s}MC_{k,t+s}}{\sum_{s\geq 0}\alpha_k^s F_{t,t+s}P_{k,t+s}^{\theta}Y_{k,t+s}}. \tag{12}$$

We set $1+\tau = \frac{\theta-1}{\theta}$ in order to remove the steady-state distortion associated with market power.

Given that the optimal reset price is identical for all firms within a sector, sectoral price index can be obtained by simple aggregation:

$$P_{kt} = \left[\alpha_k P_{k,t-1}^{1-\theta} + (1-\alpha_k)(P_{kt}^*)^{1-\theta}\right]^{\frac{1}{1-\theta}}. \tag{13}$$

4.4 Market clearing and equilibrium

In addition to the optimality conditions, budget constraints and the policy rule above, equilibrium in my economy is characterized by market-clearing conditions in the asset market: $B_t = 0$; the labour market: $N_t = \sum_{k=1}^{K} \int_{j \in \Phi_k} N_{kt}(j) dj$; and the goods markets: $Y_{kt}(j) = C_{kt}(j) + \sum_{r=1}^{K} \int_{j' \in \Phi_r} Z_{rkt}(j', j) dj', \quad \forall k, \forall j \in \Phi_k$.

4.5 Log-linearized equilibrium

We log-linearize the equilibrium conditions from the previous subsections around an efficient, symmetric zero-inflation steady-state. Let the lower case letters denote log-deviations from the steady state.

The expression for the optimal reset price in sector k is given by:

$$p^*_{kt} = (1 - \beta\alpha_k) \sum_{s \geq 0} (\beta\alpha_k)^s mc_{k,t+s}. \tag{14}$$

Consider a common shifter to future marginal costs of all firms, allowing for heterogeneity in the **perceived horizons** of the shifter. In particular, the shifter lasts for D periods for all firms, but firms in sector k believe that it occurs in d_k periods.

Proposition 1 (Micro iPT) *The iPT of a firm in sector k after a unit shifter in future marginal costs between periods d_k and $d_k + D$ is:*

$$\phi_{k,d_k|d_k+D} = (\beta\alpha_k)^{d_k} - (\beta\alpha_k)^{d_k+D+1}.$$

Further, it follows that:

$$\frac{\partial \phi_{k,d_k|d_k+D}}{\partial d_k} < 0 \qquad \frac{\partial^2 \phi_{k,d_k|d_k+D}}{\partial d_k^2} > 0 \tag{15}$$

$$\frac{\partial \phi_{k,d_k|d_k+D}}{\partial \alpha_k} > 0, \quad \alpha_k < \overline{\alpha}_k \qquad \frac{\partial^2 \phi_{k,d_k|d_k+D}}{\partial \alpha_k^2} > 0, \quad \alpha_k < \tilde{\alpha}_k \tag{16}$$

where $\overline{\alpha}_k \equiv \frac{1}{\beta}\left[\frac{d_k}{d_k+D+1}\right]^{\frac{1}{D+1}}$ *and* $\tilde{\alpha}_k \equiv \frac{1}{\beta}\left[\frac{d_k(d_k-1)}{(d_k+D+1)(d_k+D)}\right]^{\frac{1}{D+1}}$.

4.6 Micro to macro intertemporal pass-through

Next, we study the behaviour of *aggregate* price indices following a common shifter to the expected future marginal cost. In particular, a first-order change in the consumption price

Table 4: Calibration of the model (UK, monthly data)

Parameter	Description	Value	Source/Target
N	Number of sectors	63	Data availability
β	Discount factor	0.997	Real rate of 3.6%
D	Duration of news shock	12	Temporary cost shifter
$\{d_k\}_k$	Horizon of news shock		DMP Brexit horizon
$\{\alpha_k\}_k$	Sectoral Calvo parameters		UK PPI microdata
$\{\omega_{ck}\}_k$	Steady-state final consumption shares		ONS IO Tables

index can be written as:

$$\pi_t^C = \sum_i \omega_{ck} p_{k,t} = \sum_i \omega_{ck}(1-\alpha_k)\left[(\beta\alpha_k)^d - (\beta\alpha_k)^{\bar{d}+1}\right]. \tag{17}$$

The above gives a measure of aggregate forward-lookingness of prices in our economy. We can now formally establish that heterogeneity in perceived shock horizons amplifies the forward-lookingness of aggregate CPI:

Proposition 2 *Heterogeneity in perceived horizons* ***amplifies*** *the contemporaneous response of aggregate CPI to a common shifter in expected future marginal costs.*

In the limit of a permanent shifter to expected future marginal costs ($\bar{d} \to \infty$), one can formally establish the condition under which heterogeneity in price rigidity at the sector level amplifies aggregate forward-lookingness:

Proposition 3 *Suppose* $D \to \infty$ *and* $\alpha_k \in \left(0, \frac{d_k-1}{d_k+1}\right), \forall k : \omega_{ck} > 0$. *Then heterogeneity in adjustment frequencies* ***amplifies*** *the contemp. response of aggregate CPI to a common shifter in expected future marginal costs.*

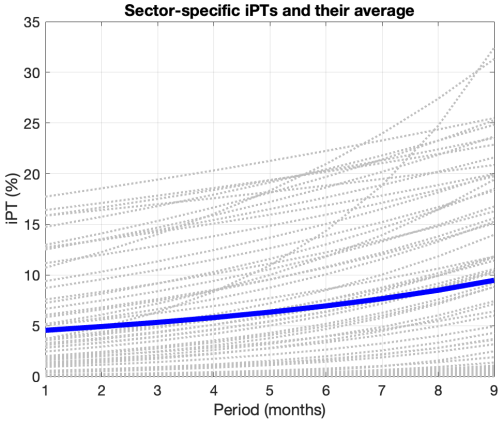
4.7 Quantitative exercises

In order to quantify our key results, we calibrate our model to monthly UK data. Table 4 summarizes our calibration strategy.

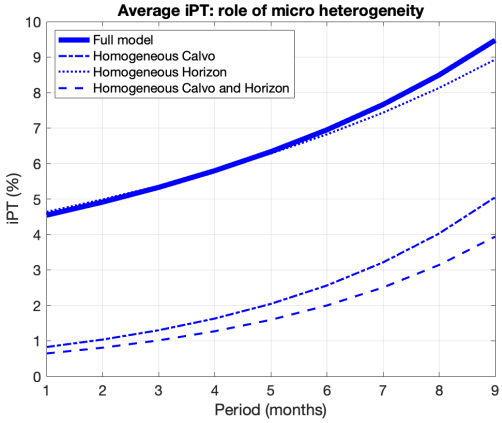
In Figure 8(a) we show the micro iPT for the 63 sectors of our economy. As one can see, there is wide heterogeneity in the responses, with the average iPT given by 5% on impact. In Figure 8(b) we quantify the role of heterogeneity in frequencies of price adjustment the perceived shock horizons. It follows that an otherwise identical economy with homogeneous frequencies of adjustment has iPT that is lower by a factor of five. At the same time, heterogeneity in the perceived horizons has a minor quantitative role.

Figure 8: Heterogeneity in micro iPT estimates

(a) Sector-specific iPT and their average



(b) Role of micro heterogeneity for average iPT



Notes: These figures show results from the model as described in Section 4

In Figure 9(a) we show the responses of sectoral price indices, as well as the aggregate CPI, of our economy to the expected future cost shifters. As one can see, there is wide heterogeneity in the responses, with the average sectoral price index response given by 0.5% on impact. In Figure 9(b) we quantify the role of heterogeneity in frequencies of price adjustment the perceived shock horizons. It follows that an otherwise identical economy with homogeneous frequencies of adjustment has iPT that is lower by a factor of two. At the same time, heterogeneity in the perceived horizons has a minor quantitative role.

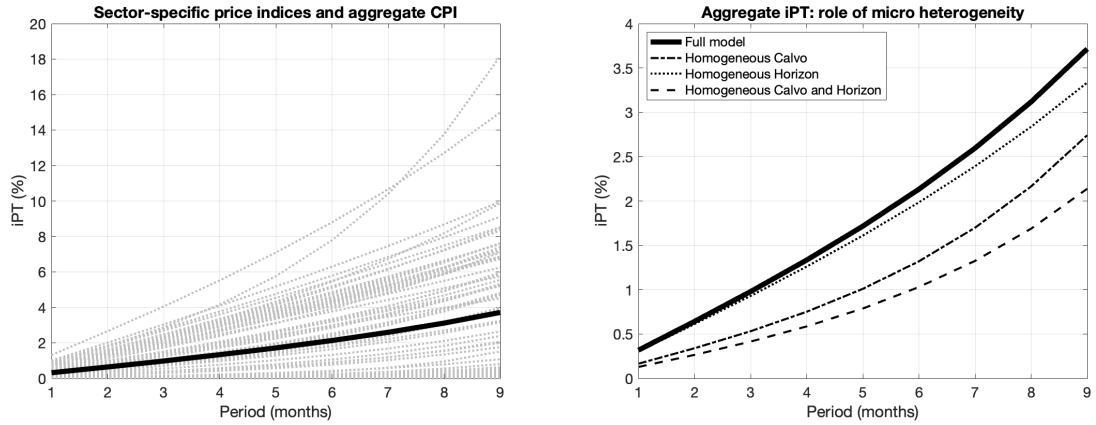
5 Conclusion

We study intertemporal pass-through: the sensitivity of firm prices to changes in their future expected costs. We identify exogenous firm-level variation in firms' expected future costs by using a novel and unique quasi-natural experiment of heterogeneous information treatment as a laboratory – the announcement of a tariff schedule – in combination with firm-level confidential survey data that elicits firms' beliefs on the probability distribution and time horizon of the tariff schedule taking effect. We provide evidence that intertemporal pass-through is economically and statistically highest in firms with the most sticky prices. The effect is even more pronounced in firms that expect the tariff schedule to take effect sooner. From a standard theoretical Calvo (1983) perspective, it is exactly these firms which should be most forward-looking.

To understand the aggregate general equilibrium effects of our empirical findings, we then construct a multi-sector New Keynesian general equilibrium model with heterogeneous price

Figure 9: Aggregate iPT

(a) Sector-specific iPT and aggregate CPI (b) Role of micro heterogeneity for aggregate iPT



Notes: These figures show results from the model as described in Section 4

rigidities and heterogeneous shock horizons. We identify a key role for the heterogeneity in price rigidities across sectors in the transmission of anticipated shocks to prices. Carvalho (2006) finds that heterogeneity in price stickiness dampens the price response to *contemporaneous* cost shocks. Because the price response to *news* cost shocks is convex across degrees of price rigidities (the Calvo parameter), via Jensen's inequality, this implies a stronger price response relative to a homogeneous price rigidity model that simply uses the average price duration. With a very similar logic, we also show that heterogeneity in the expected shock horizons also *amplifies* the forward-lookingness of aggregate inflation. However, quantitatively, we show that the heterogeneity in price stickiness is a more important driver of the amplification, when matched to the data.

The primary policy implication of these results is to underscore the importance of modelling heterogeneity in (nominal) rigidities when designing policies that affect economic agents' individual expectations of the future. Examples could include the design of forward guidance monetary policies (that rely on convincing agents that monetary policy commits to a lower path of interest rates), the pre-announcement of fiscal policies of future spending/taxation pledges, and more recently, climate policies such as the future path of carbon prices that attempt to encourage firms' green investment over a long transition horizon that can last many decades. As our results imply that the price response in a (more realistic) heterogeneous price stickiness environment is stronger than the baseline homogeneous environment, this may inadvertently amplify or dampen the desired effects of the aforementioned policies, and thus should be incor-

porated into the calibration of such policies.

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Online Appendix

Intertemporal Pass-Through

Mishel Ghassibe, *CREi, UPF & BSE*
Boromeus Wanengkirtyo, *Bank of England*
Ivan Yotzov, *Bank of England*

A Figures

Figure A1: Effective tariff rates under two main scenarios by sector

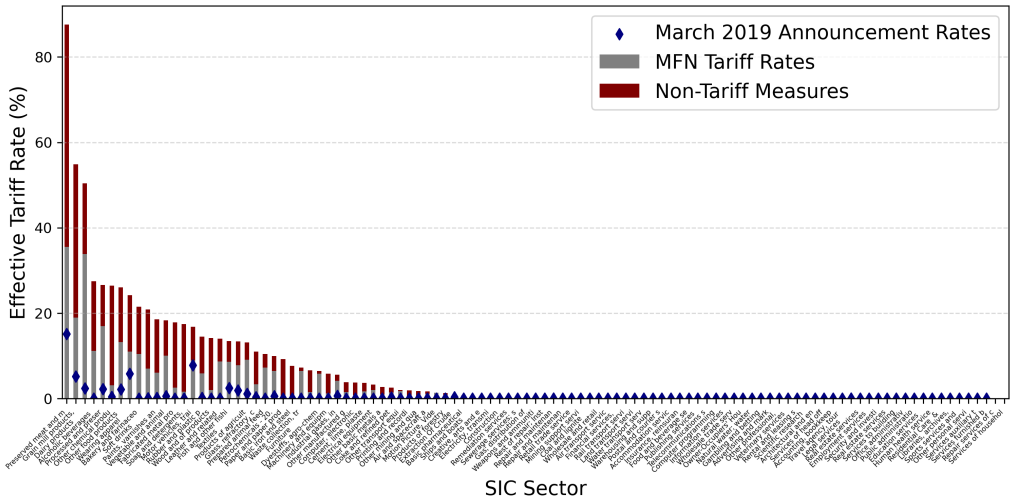


Figure A2: Sectoral tariff news shocks before input-output adjustment

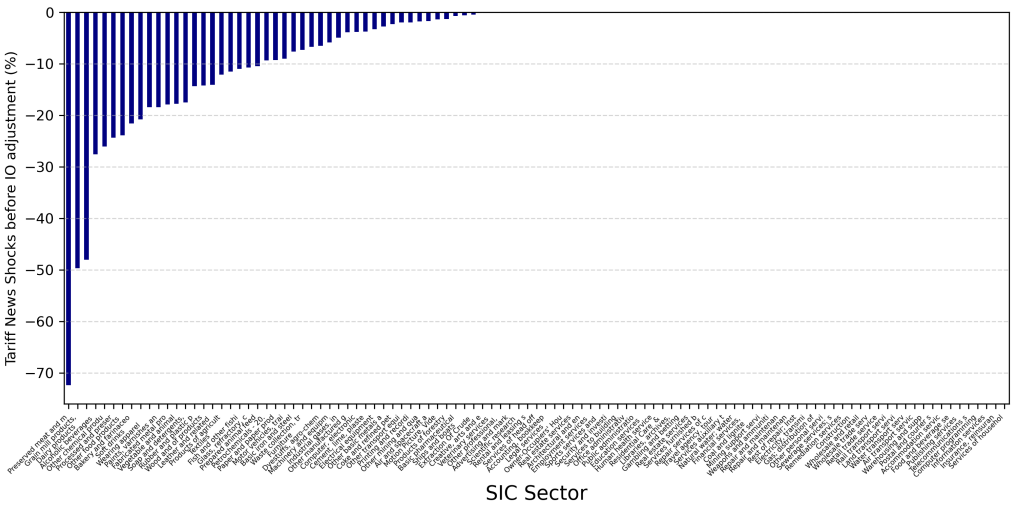
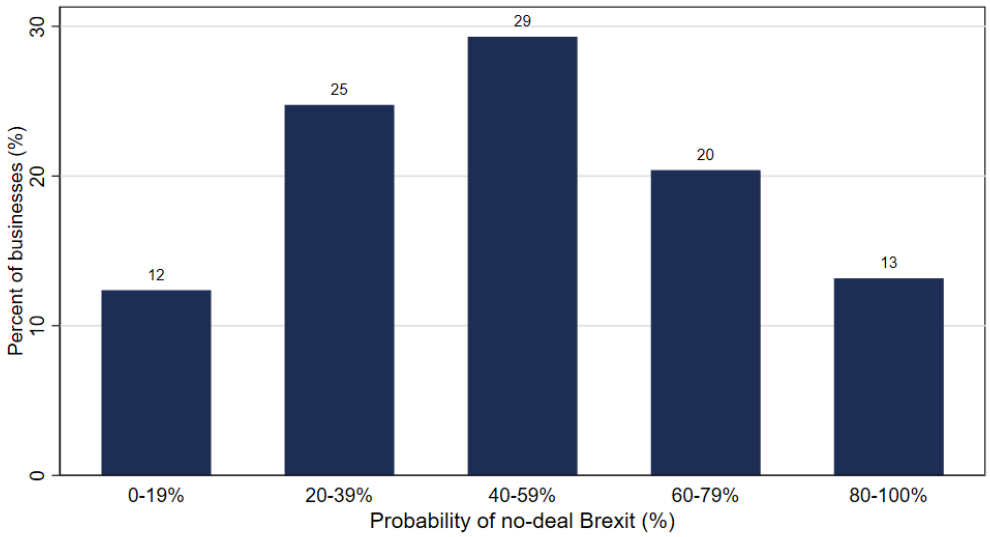
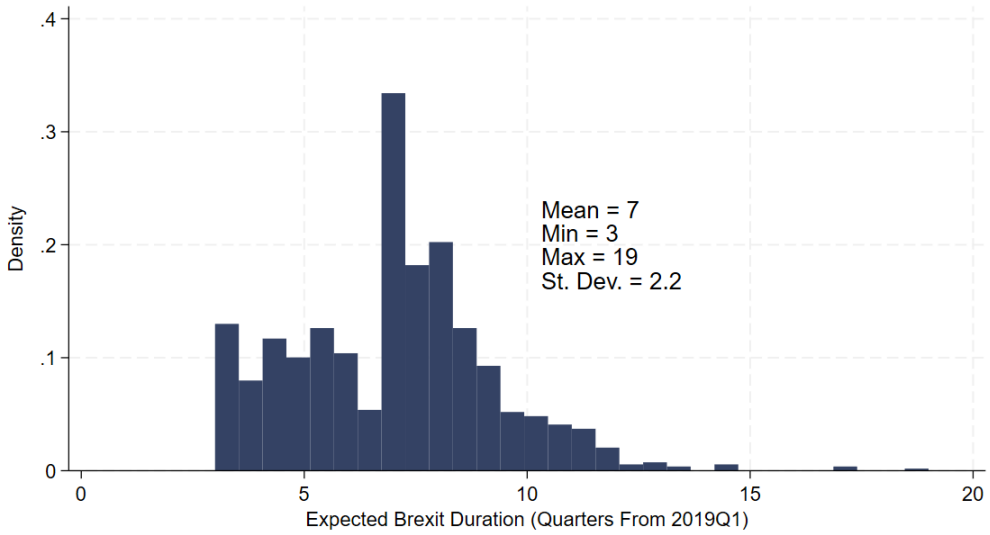


Figure A3: Probability of no-deal Brexit in main estimation sample



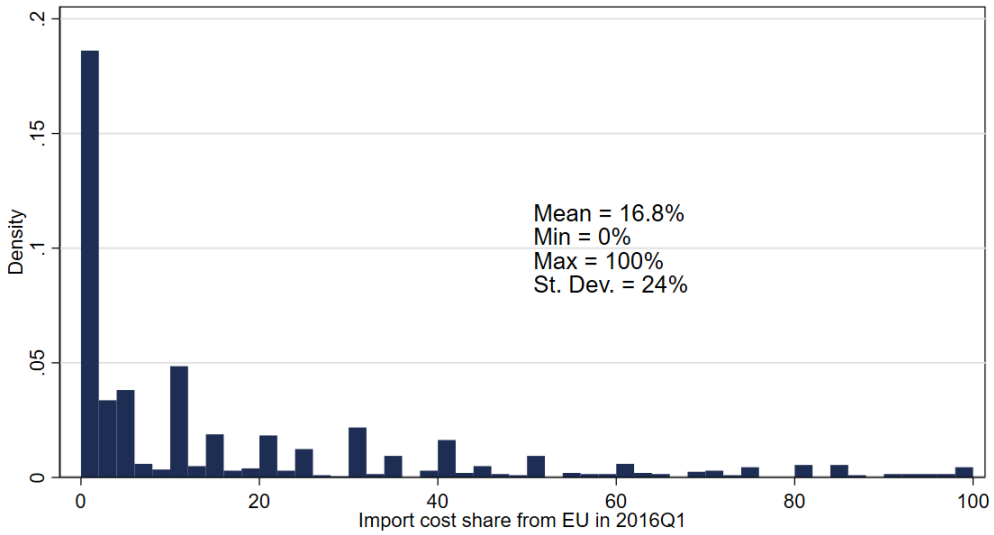
Notes: This figure shows the distribution of perceived probabilities of a No-Deal Brexit across firms in the Decision Maker Panel (DMP).

Figure A4: Expected Brexit Duration (quarters)



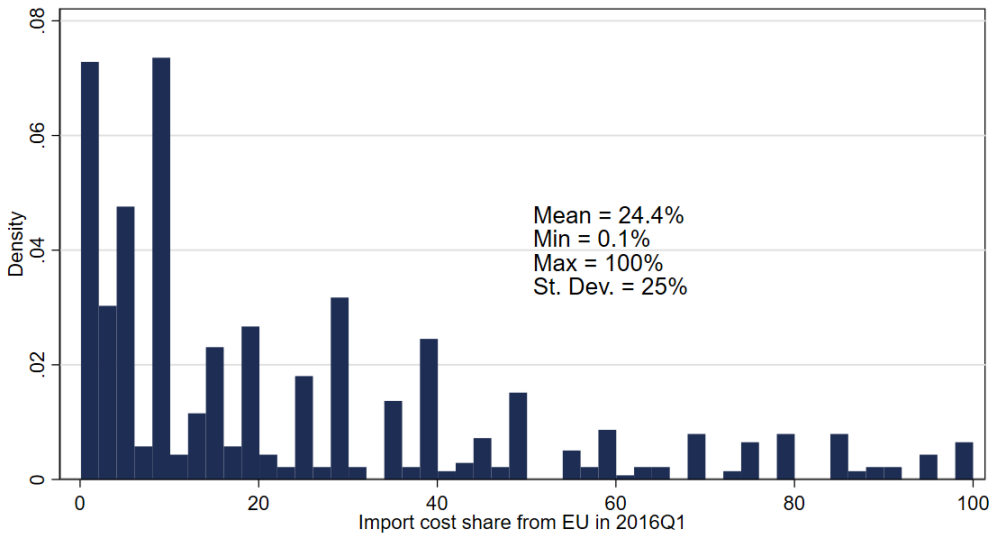
Notes: The figure shows the distribution of the expected duration, presented as quarters from 2019Q1, constructed using survey responses in the Decision Maker Panel (DMP).

Figure A5: Histogram of import cost shares from EU in main regression sample



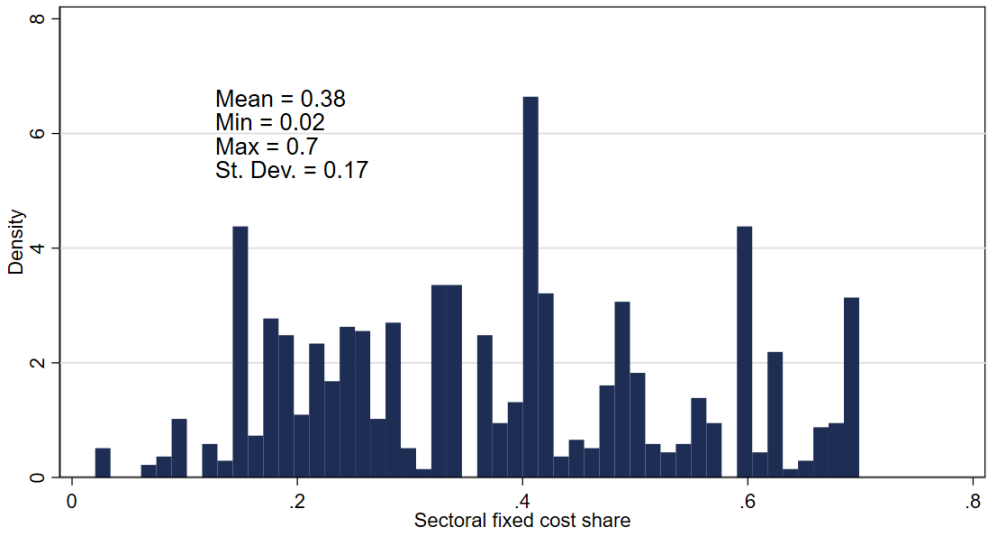
Notes: This figure presents the distribution of firm-level cost shares of intermediate inputs from the EU, as reported in the Decision Maker Panel (DMP).

Figure A6: Histogram of import cost shares from EU in main regression sample (excluding zeros)



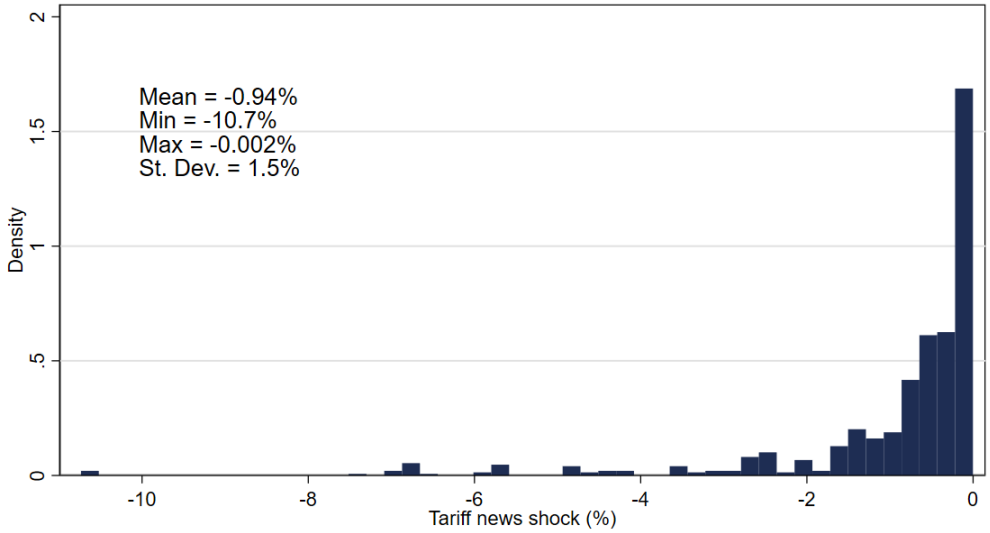
Notes: This figure presents the distribution of non-zero firm-level cost shares of intermediate inputs from the EU, as reported in the Decision Maker Panel (DMP).

Figure A7: Histogram of sectoral fixed cost shares in main regression sample



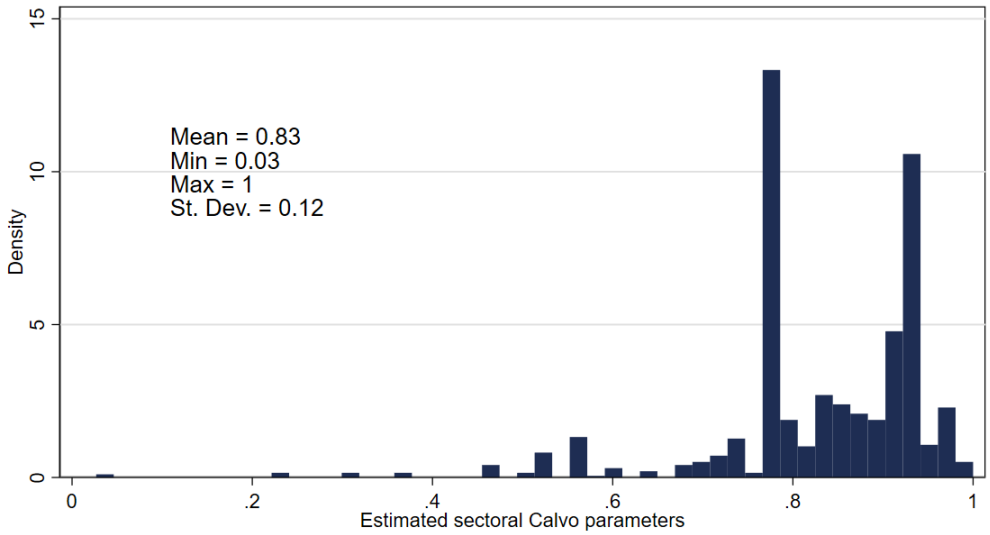
Notes: This figure presents the distribution of sectoral fixed cost shares in the main estimation sample.

Figure A8: Distribution of (non-zero) firm-level tariff news shock



Notes: This figure presents the distribution of (non-zero) firm-level tariff news shocks in the main estimation sample.

Figure A9: Histogram of estimated Calvo parameters in main estimation sample



Notes: This figure presents the distribution of estimated frequencies of non-adjustment.

Figure A10: Comparison of price duration estimates: PPI/CPI micro data vs. DMP survey responses

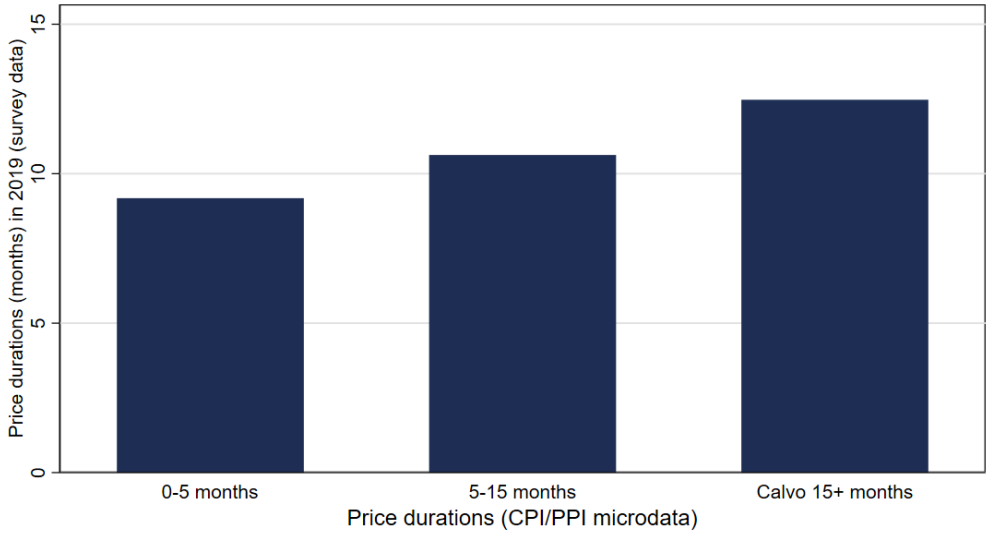
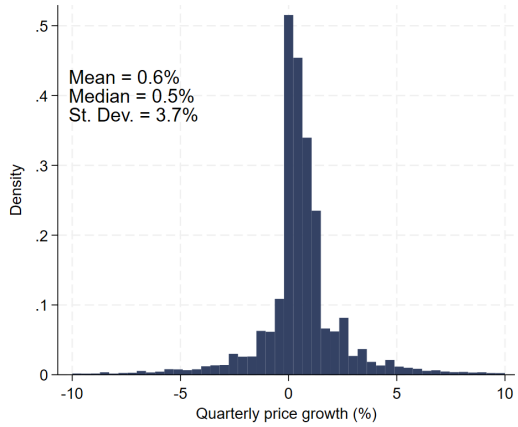


Figure A11: Distribution of quarterly firm price growth

(a) Full Sample



(b) Full Sample excl. zeros

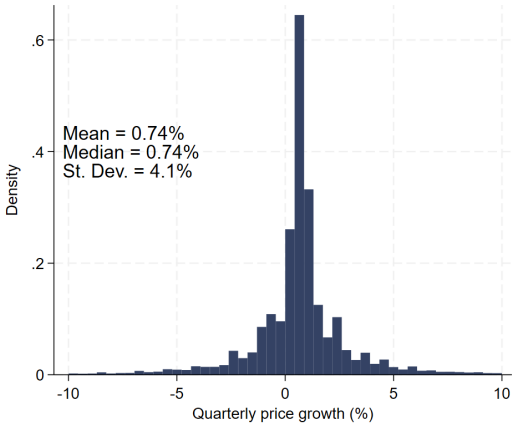


Figure A12: Share of state-dependent firms by SIC2 sector

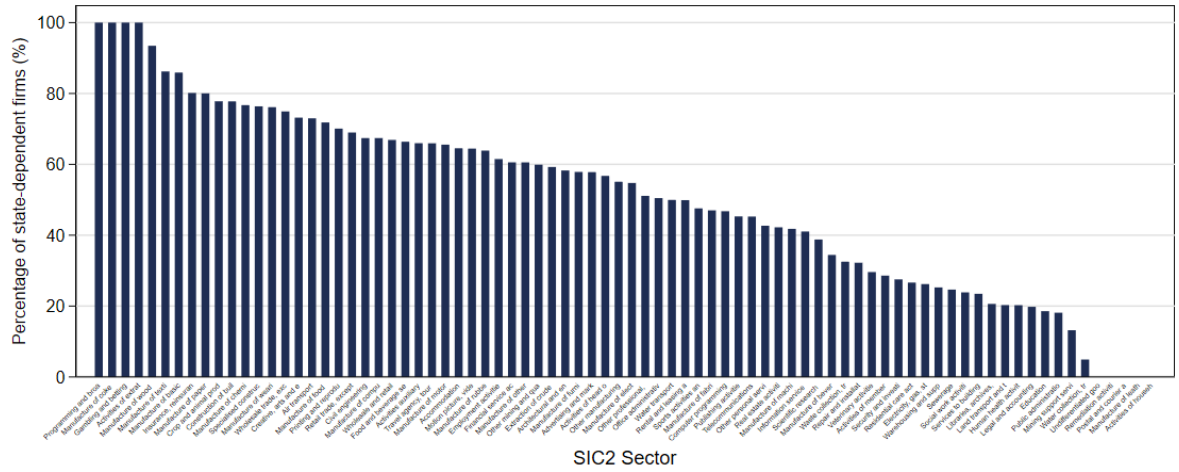
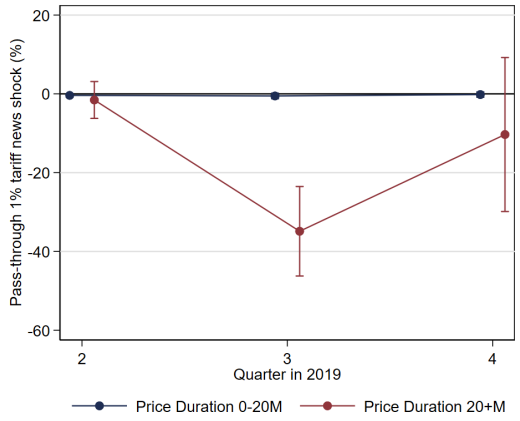
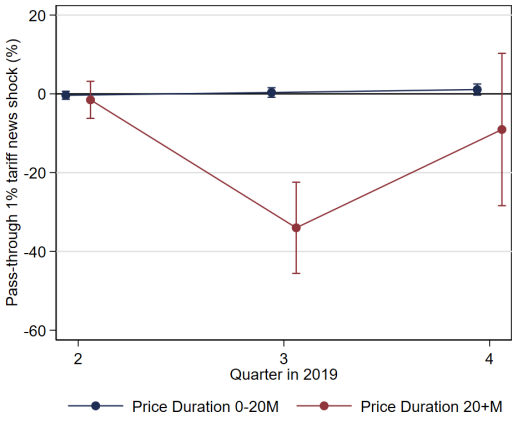


Figure A13: Impact of tariff news shock on employment: Effects by estimation quarter

(a) Modal Horizon = 2019



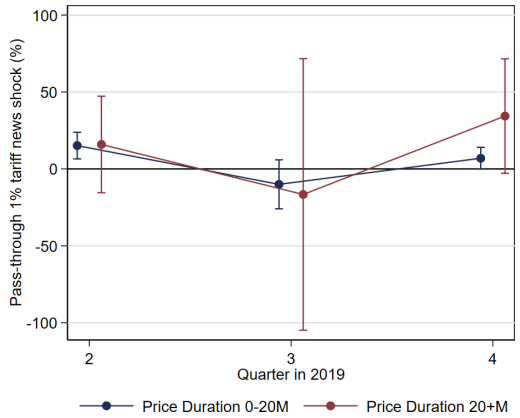
(b) Modal Horizon = 2020



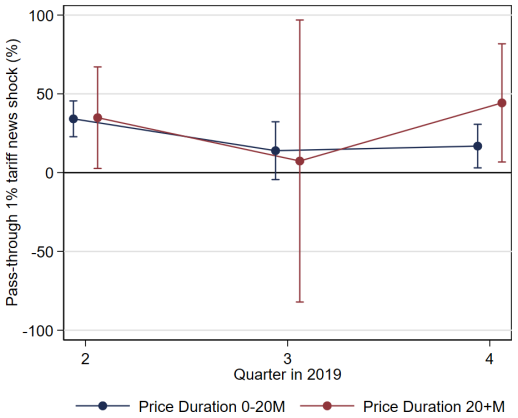
Notes: The results are based on Column 1 of Table A4. Standard errors are clustered at the industry (SIC2) level.

Figure A14: Impact of tariff news shock on capital expenditure: Effects by estimation quarter

(a) Modal Horizon = 2019



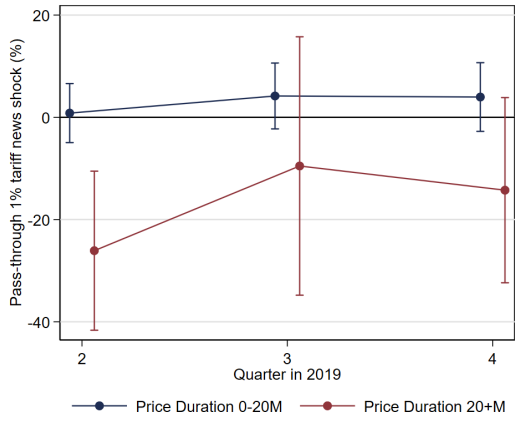
(b) Modal Horizon = 2020



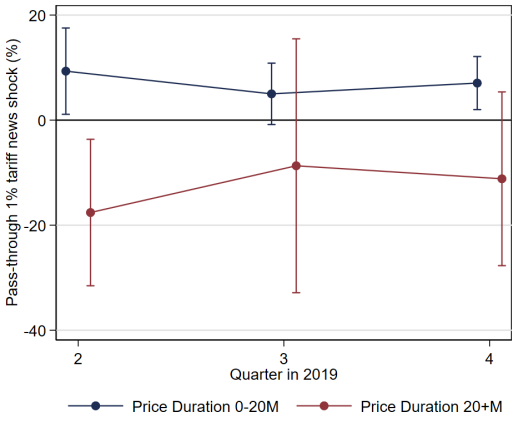
Notes: The results are based on Column 2 of Table A4. Standard errors are clustered at the industry (SIC2) level.

Figure A15: Impact of tariff news shock on real sales: Effects by estimation quarter

(a) Modal Horizon = 2019



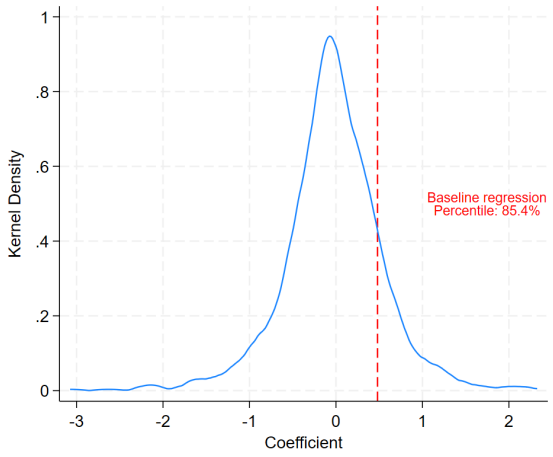
(b) Modal Horizon = 2020



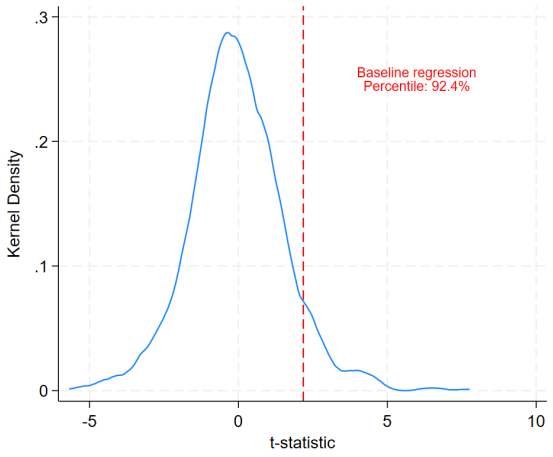
Notes: The results are based on Column 3 of Table A4. Standard errors are clustered at the industry (SIC2) level.

Figure A16: Placebo tests: Randomised tariff news shock and sticky price indicator

(a) Coefficient

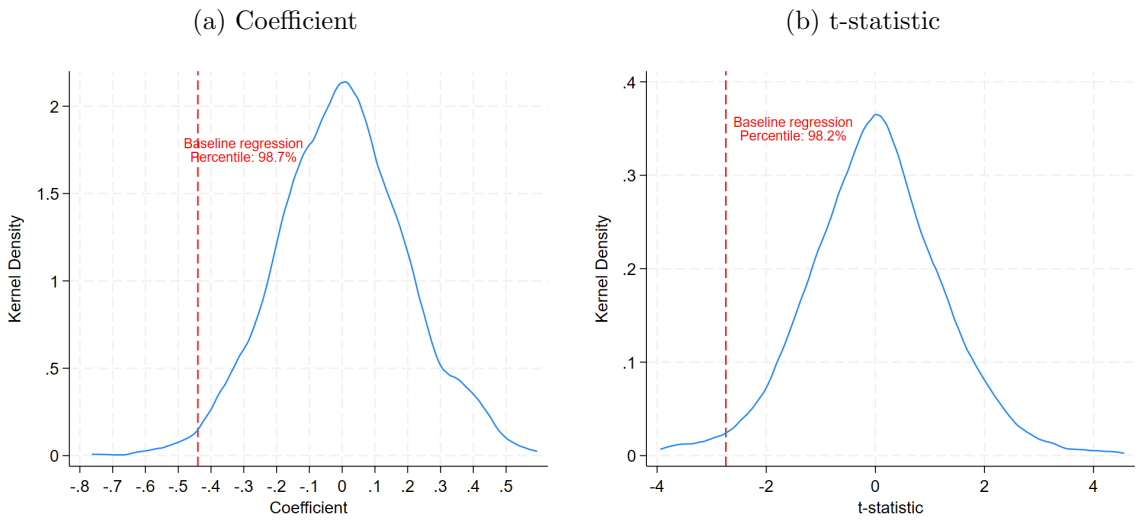


(b) t-statistic



Notes: For the placebo tests, we use the regression specification in Column 4 of Table 1 (sticky prices defined as longer than 20 months price duration). Standard errors are clustered at the industry (SIC2) level. We take 1000 replications and plot the kernel density of the estimated coefficients across replications.

Figure A17: Placebo tests: Randomised tariff news shock and shock horizon indicator



Notes: For the placebo tests, we use the regression specification in Column 4 of Table 1 (Modal Brexit year = 2020). Standard errors are clustered at the industry (SIC2) level. We take 1000 replications and plot the kernel density of the estimated coefficients across replications.

B Tables

Table A1: Key (non-exhaustive) relevant dates and official date of UK's departure from the EU

Date	Event	Official Departure Date
23/06/2016	UK referendum on EU Membership	-
29/03/2017	UK PM formally triggers Article 50	29/03/2019
28/02/2018	Draft Withdrawal Agreement published (transition period ends 31/12/2020)	29/03/2019
25/11/2018	EU27 leaders re-confirm endorsement of Withdrawal Agreement	29/03/2019
13/03/2019	*Announcement of temporary tariff regime*	29/03/2019
14/03/2019	House of Commons vote to extend Article 50, granted by EU27 the next day	30/06/2019
05/04/2019	UK PM requests European Council to extend Article 50	30/06/2019
10/04/2019	EU27 agree to extend Article 50	31/10/2019
19/10/2019	Proposed Brexit deal lost on amendment in the House of Commons	31/10/2019
29/10/2019	European Council agree to UK PM request to extend	31/01/2020
31/01/2020	UK formally leaves the EU, enters a transition period	31/01/2020
31/12/2020	UK leaves EU Single Market and customs union	-

Notes: House of Commons Research Briefing and European Council

Table A2: Impact of tariff news shock on prices: Interaction with price durations and expected Brexit duration

Dependent variable:	(1)	(2)	(3)	(4)	(5)	(6)
	$100 \times \Delta \ln$(Price Level)					
Sample:	2019Q2 - 2019Q4					
Tariff news shock$_{i,k}$	-0.107	0.051	0.060	0.054	-0.135	-0.020
	(0.080)	(0.081)	(0.126)	(0.125)	(0.294)	(0.108)
Tariff news shock$_{i,k}\times$ Modal Brexit Year=2020$_i$		-0.416***	-0.449***	-0.445***	-0.684**	-0.482***
		(0.124)	(0.160)	(0.162)	(0.259)	(0.139)
Tariff news shock$_{i,k}\times$ Price Duration 20+M$_k$		0.357***	0.498**	0.481**	1.221**	
		(0.108)	(0.218)	(0.221)	(0.585)	
Tariff news shock$_{i,k}\times$ Price Duration 5-10M$_k$						0.138
						(0.185)
Tariff news shock$_{i,k}\times$ Price Duration 10-20M$_k$						0.435**
						(0.171)
Tariff news shock$_{i,k}\times$ Price Duration 20+M$_k$						0.616***
						(0.224)
Probability No-Deal Brexit$_i$			-0.009*	-0.009*	-0.014*	-0.008*
			(0.005)	(0.005)	(0.007)	(0.005)
Import Cost Share EU$_i$			0.004	0.004	-0.010	0.005
			(0.006)	(0.006)	(0.010)	(0.005)
Industry Fixed Cost Share$_k$			0.478	0.472		0.384
			(0.518)	(0.514)		(0.520)
=1 Exporter$_i$			-0.164	-0.160	0.467	-0.129
			(0.262)	(0.264)	(0.292)	(0.331)
ln(Capex)$_{i,M19}$			0.053	0.055	0.012	0.060
			(0.045)	(0.044)	(0.055)	(0.045)
ln(Employment)$_{i,M19}$			0.023	0.020	0.158	0.002
			(0.112)	(0.110)	(0.140)	(0.112)
Industry (SIC4) fixed effects	No	No	No	No	Yes	No
Quarter fixed effects	No	No	No	Yes	Yes	Yes
Mean of Dependent Variable	1.078	1.078	1.078	1.078	1.081	1.078
R^2	0.002	0.012	0.022	0.032	0.325	0.036
Observations	1,010	1,010	1,010	1,010	1,003	1,010

Notes: The dependent variable is winsorised at the 5th and 95th percentiles. Standard errors are clustered at the industry (SIC2) level and reported in parentheses, stars indicate *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A3: Impact of tariff news shock on employment, capital expenditure, and real sales: Interaction with price durations and expected shock horizon

	(1)	(2)	(3)
Dependent variable:	ln(Employ)	ln(CapEx)	ln(Real Sales)
Sample:	2019Q2 - 2019Q4		
Tariff news shock$_{i,k}$	-0.004	0.033	0.031
	(0.003)	(0.048)	(0.036)
Tariff news shock$_{i,k}$× Modal Horizon 2020$_i$	0.009	0.182**	0.040
	(0.007)	(0.070)	(0.027)
Tariff news shock$_{i,k}$× Price Duration 20+M$_k$	-0.069	0.154	-0.195*
	(0.081)	(0.180)	(0.101)
ln(CapEx)$_{i,M19}$	0.007***	0.443***	0.060***
	(0.002)	(0.057)	(0.019)
ln(Employment)$_{i,M19}$	0.973***	0.630***	0.437***
	(0.010)	(0.105)	(0.064)
ln(Real Sales)$_{i,M19}$			0.398***
			(0.070)
Quarter fixed effects	Yes	Yes	Yes
Additional controls	Yes	Yes	Yes
Mean of dependent variable	4.810	4.681	3.823
R^2	0.978	0.503	0.692
Observations	946	865	938

Notes: The dependent variable is winsorised at the 5th and 95th percentiles. Additional controls include: Perceived probability of No Deal Brexit; Import cost share; Exporter status; Sectoral fixed cost share; Natural logarithms of employment, capital expenditure, and real sales in March 2019. Standard errors are clustered at the industry (SIC2) level and reported in parentheses, stars indicate *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A4: Impact of tariff news shock on employment, capital expenditure, and real sales: Interaction with price durations, expected shock horizon, and quarter dummies

Dependent variable:	(1) ln(Employ)	(2) ln(CapEx)	(3) ln(Real Sales)
Sample:	2019Q2 - 2019Q4		
Tariff news shock$_{i,k}$	-0.004	0.152***	0.008
	(0.002)	(0.051)	(0.034)
Tariff news shock$_{i,k}$× 2019Q3	-0.001	-0.252**	0.033
	(0.003)	(0.113)	(0.022)
Tariff news shock$_{i,k}$× 2019Q4	0.002	-0.082	0.031**
	(0.003)	(0.059)	(0.015)
Tariff news shock$_{i,k}$× Price Duration 20+M$_k$× 2019Q2	-0.012	0.007	-0.269***
	(0.027)	(0.190)	(0.094)
Tariff news shock$_{i,k}$× Price Duration 20+M$_k$× 2019Q3	-0.343***	-0.065	-0.137
	(0.069)	(0.511)	(0.140)
Tariff news shock$_{i,k}$× Price Duration 20+M$_k$× 2019Q4	-0.101	0.274	-0.182*
	(0.115)	(0.220)	(0.100)
Tariff news shock$_{i,k}$× Modal Horizon 2020$_i$× 2019Q2	0.000	0.190***	0.085**
	(0.006)	(0.055)	(0.034)
Tariff news shock$_{i,k}$× Modal Horizon 2020$_i$× 2019Q3	0.009	0.240*	0.008
	(0.007)	(0.133)	(0.039)
Tariff news shock$_{i,k}$× Modal Horizon 2020$_i$× 2019Q4	0.013	0.099	0.031
	(0.009)	(0.078)	(0.039)
ln(CapEx)$_{i,M19}$	0.007***	0.444***	0.060***
	(0.002)	(0.057)	(0.019)
ln(Employment)$_{i,M19}$	0.973***	0.625***	0.438***
	(0.010)	(0.105)	(0.064)
ln(Real Sales)$_{i,M19}$			0.398***
			(0.070)
Quarter fixed effects	Yes	Yes	Yes
Additional controls	Yes	Yes	Yes
Mean of dependent variable	4.810	4.681	3.823
R^2	0.978	0.506	0.692
Observations	946	865	938

Notes: The dependent variable is winsorised at the 5th and 95th percentiles. Additional controls include: Perceived probability of No Deal Brexit; Import cost share; Exporter status; Sectoral fixed cost share; Natural logarithms of employment, capital expenditure, and real sales in March 2019. Standard errors are clustered at the industry (SIC2) level and reported in parentheses, stars indicate *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A5: Impact of tariff news shock on prices: Interaction with price durations, expected shock horizon, and quarter dummies

	(1)	(2)	(3)
Dependent variable:	$100 \times \Delta \ln$(Price Level)		
Sample:	2019Q2 - 2019Q4		
Tariff news shock$_{i,k}$	0.123	0.095	0.095
	(0.146)	(0.146)	(0.146)
Tariff news shock$_{i,k}\times$ 2019Q3	-0.110	-0.090	-0.090
	(0.088)	(0.093)	(0.093)
Tariff news shock$_{i,k}\times$ 2019Q4	-0.085	-0.019	-0.020
	(0.110)	(0.131)	(0.132)
Tariff news shock$_{i,k}\times$ Price Duration 20+M$_k\times$ 2019Q2	0.741***		0.696***
	(0.239)		(0.244)
Tariff news shock$_{i,k}\times$ Price Duration 20+M$_k\times$ 2019Q3	0.823***		0.808***
	(0.253)		(0.264)
Tariff news shock$_{i,k}\times$ Price Duration 20+M$_k\times$ 2019Q4	-0.118		-0.074
	(0.219)		(0.234)
Tariff news shock$_{i,k}\times$ Modal Horizon 2020$_i\times$ 2019Q2		-0.357*	-0.365*
		(0.185)	(0.183)
Tariff news shock$_{i,k}\times$ Modal Horizon 2020$_i\times$ 2019Q3		-0.409**	-0.420**
		(0.177)	(0.179)
Tariff news shock$_{i,k}\times$ Modal Horizon 2020$_i\times$ 2019Q4		-0.545**	-0.530**
		(0.254)	(0.254)
Tariff news shock$_{i,k}\times$ Price Duration 20+M$_k$		0.473**	
		(0.221)	
Tariff news shock$_{i,k}\times$ Modal Horizon 2020$_i$	-0.444***		
	(0.163)		
Quarter fixed effects	Yes	Yes	Yes
Additional controls	Yes	Yes	Yes
Mean of dependent variable	1.078	1.078	1.078
R^2	0.033	0.033	0.033
Observations	1,010	1,010	1,010

Notes: The dependent variable is winsorised at the 5th and 95th percentiles. Additional controls include: Perceived probability of No Deal Brexit; Import cost share; Exporter status; Sectoral fixed cost share; Natural logarithms of employment and capital expenditure in March 2019. Standard errors are clustered at the industry (SIC2) level and reported in parentheses, stars indicate *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A6: Impact of tariff news shock on prices: Interaction with price durations and expected shock horizon (placebo test)

	(1)	(2)
Dependent variable:	$100 \times \Delta \ln$(Price Level)	
Sample:	2019Q2 - 2019Q4	2018Q1 - 2018Q4
Tariff news shock$_{i,k}$	0.054	-0.080
	(0.125)	(0.089)
Tariff news shock$_{i,k}\times$ Modal Brexit Year=2020$_i$	-0.445***	-0.342
	(0.162)	(0.212)
Tariff news shock$_{i,k}\times$ Price Duration 20+M$_k$	0.481**	0.403
	(0.221)	(0.342)
Quarter fixed effects	Yes	Yes
Additional controls	Yes	Yes
Mean of Dependent Variable	1.078	-1.198
R^2	0.032	0.076
Observations	1,010	1,212

Notes: The dependent variable is winsorised at the 5th and 95th percentiles. Additional controls include: Perceived probability of No Deal Brexit; Import cost share; Exporter status; Sectoral fixed cost share; Natural logarithms of employment and capital expenditure in March 2019. Standard errors are clustered at the industry (SIC2) level and reported in parentheses, stars indicate *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A7: Determinants of perceived no Deal Brexit probability

Dependent variable:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Perceived No Deal Brexit Probability									
Sample:	2019Q2 - 2019Q4									
Import Cost Share EU$_i$	0.046									0.055
	(0.037)									(0.038)
=1 Exporter$_i$		0.109								-1.146
		(1.581)								(1.723)
=1 Price Duration 5-10M$_k$			1.897							1.682
			(2.214)							(2.307)
=1 Price Duration 10-20M$_k$			1.388							1.706
			(1.828)							(2.107)
=1 Price Duration 20+M$_k$			-3.141							-4.995
			(3.640)							(3.596)
=1 State-dependent$_k^{p33}$				-2.761						-4.201**
				(1.688)						(1.775)
=1 Expected Brexit Date 2020$_i$					-2.298					-2.397
					(1.596)					(1.592)
Industry Fixed Cost Share$_k$						-1.791				-5.697
						(4.815)				(5.206)
Price Growth$_{i,M19}$							0.655***			0.657***
							(0.200)			(0.209)
ln(Employment)$_{i,M19}$								-3.053***		-2.392**
								(0.875)		(1.052)
ln(Capex)$_{i,M19}$									-1.089***	-0.654
									(0.326)	(0.401)
Mean of Dependent Variable	46.811	46.811	46.811	46.811	46.811	46.811	46.811	46.811	46.811	46.811
R^2	0.002	0.000	0.002	0.003	0.002	0.000	0.012	0.013	0.011	0.041
Observations	1,010	1,010	1,010	1,010	1,010	1,010	1,010	1,010	1,010	1,010

Notes: The dependent variable is the perceived no-deal Brexit probability in the main estimation sample. Robust standard errors are reported in parentheses, stars indicate *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A8: Determinants of expected Brexit horizon

Dependent variable:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	=1 Expected Brexit Date 2020									
Sample:	2019Q2 - 2019Q4									
Import Cost Share EU_i	0.000									0.001
	(0.001)									(0.001)
=1 $Exporter_i$		-0.098***								-0.088**
		(0.031)								(0.034)
=1 Price Duration 5-10M_k			-0.062							-0.035
			(0.044)							(0.046)
=1 Price Duration 10-20M_k			0.075**							0.077*
			(0.036)							(0.041)
=1 Price Duration 20+M_k			-0.059							-0.069
			(0.069)							(0.073)
=1 State-dependent$_k^{p33}$				0.006						0.012
				(0.033)						(0.037)
No Deal Brexit Probability					-0.001					-0.001
					(0.001)					(0.001)
Industry Fixed Cost $Share_k$						0.021				-0.018
						(0.092)				(0.099)
Price $Growth_{i,M19}$							-0.000			-0.001
							(0.004)			(0.004)
$\ln(\text{Employment})_{i,M19}$								0.021		0.024
								(0.016)		(0.019)
$\ln(\text{Capex})_{i,M19}$									-0.004	-0.012
									(0.007)	(0.008)
Mean of Dependent Variable	0.568	0.568	0.568	0.568	0.568	0.568	0.568	0.568	0.568	0.568
R^2	0.000	0.010	0.011	0.000	0.002	0.000	0.000	0.002	0.000	0.024
Observations	1,010	1,010	1,010	1,010	1,010	1,010	1,010	1,010	1,010	1,010

Notes: The dependent variable is a dummy variable for the expected modal Brexit date being 2020. in the main estimation sample. Robust standard errors are reported in parentheses, stars indicate *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.