Trade and Worker Deskilling

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Abstract

This paper presents new evidence on international trade and worker outcomes. It examines a big world event that produced an unprecedentedly large shock to the UK exchange rate. In the 24 hours in June 2016 during which the UK electorate unexpectedly voted to leave the European Union, the value of sterling plummeted. It recorded the biggest depreciation that has occurred in any of the world's four major currencies since the collapse of Bretton Woods. Exploiting this variation, the paper studies the impact of trade on wages and worker training. Wages and training fell for workers employed in sectors where the intermediate import price rose by more as a consequence of the sterling depreciation. Calibrating the estimated wage elasticity with respect to intermediate import prices to theory uncovers evidence of a production complementarity between workers and intermediate imports. This provides new direct evidence that, in the modern world of global value chains, it is changes in the cost of intermediate imports that act as a driver of the impact of globalization on worker welfare. The episode studied and the findings add to widely expressed, growing concerns about poor productivity performance relating to skills and to patterns of real wage stagnation that are plaguing contemporary labour markets.

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1 Introduction

Recently, and especially in the wake of the Great Recession, real wages and productivity have stagnated across the developed world. Some commentators have argued that globalization has been systematically connected to this worsening of economic performance (see, for example, Mishel 2015 and De Long 2017). Empirical studies in international trade and labour economics have attempted to connect the two, via a number of research areas studying the impact of import competition on manufacturing jobs and wages, the differential evolution of skilled versus unskilled wages in response to offshoring, labour reallocation due to trade and the changing employment shares of skilled workers over time.[1] While much progress has been made, a number of fundamental questions - like the impact of offshoring on domestic workers and how trade can causally impact upon worker outcomes - remain far from resolved.[2]

This paper offers complementary new evidence on connections between international trade and the labour market. It approaches the question by studying a big world event that sent shock waves globally about the future of international trade and trade policy. More specifically, the empirical approach adopted looks at what happened to trade and worker outcomes in the UK before and after the Brexit referendum vote of June 23, 2016. The focus is on trade and worker outcome responses to the sizable depreciation of sterling that arose because of the unanticipated vote result.

The UK electorate's vote to leave the EU came as a big surprise to almost all observers. It exerted large and quickly realised effects on foreign exchange markets. Sterling suffered its biggest one day loss since the introduction of free-floating exchange rates in the 1970s. In 24 hours, the pound-dollar exchange rate fell by a massive 8 percent to $1.33 on June 24, 2016. This was a much larger drop than the one on Black Wednesday when the UK withdrew from the Exchange Rate Mechanism and more sizable than its drop during the height of the financial crisis in 2008.[3] In fact, the Brexit vote induced sterling drop is the biggest one day fall that has ever occurred in any of the world's four major currencies that make up the bulk of global hard cash reserves since the collapse of Bretton Woods.[4]

[1] See, *inter alia*, Feenstra (1999), Trefler (2004), Autor et al. (2013), Pierce and Schott (2016), Hakobyan and McLaren (2016). For recent surveys, see Goldberg and Pavcnik (2016) and Helpman (2017).

[2] For example, in developed countries, the usual sources of exogenous variation, like economic policy shocks, are scarce as trade policies have recently remained fairly stable. In their Handbook chapter, Goldberg and Pavcnik (2016) very much stress the limits to knowledge arising from endogeneity of trade policy and anticipation, arguing they are "first-order" concerns for identifying credible causal effects of globalisation on workers.

[3] https://www.theguardian.com/business/2016/jun/23/british-pound-given-boost-by-projected-remain-win-in-eu-referendum

[4] https://uk.reuters.com/article/us-britain-markets-sterling/sterlings-post-brexit-fall-is-biggest-loss-in-a-hard-currency-idUKKCN0ZN1R0

Importantly, the pound depreciated to different degrees against different world currencies. For example, for the UK's two major trade partners (the US and the EU) the pound-dollar exchange rate fell by 8 percent overnight on June 23/24 while the pound-euro exchange rate fell by 6 percent. Because imports and exports differ in their source and destination countries, industries trading in different world markets faced a different sterling depreciation. The differential cost and revenue shocks from these country specific variations in the unexpected sterling depreciation therefore induced industries to respond to different degrees along various possible margins of adjustment, including worker outcomes.

According to international trade theory, a rise in exports typically benefits workers through an increase in economic activity. The impact of a rise in imports on workers is less clear cut. This ambiguity is reflected in how evidence on import effects has evolved over time. Early studies tended to report a negative impact of imports on workers (Grossman 1987, Revenga 1992). This is consistent with the traditional theoretical literature that highlights detrimental import-competing effects on domestic firms. But a key development in trade patterns in the last few decades has been the huge rise of trade in intermediate goods and services, commonly referred to as offshoring. Intermediate inputs today account for two thirds of international trade and imported content is estimated to make up 30 percent of world exports (Johnson and Noguera 2012, Datt et al. 2011). Trade in intermediates changes the possible effects of trade and trade policy – for example, import tariffs need not protect domestic producers when they rely on imports as intermediate inputs into their production (Antras and Staiger 2012).

As a consequence, conclusions for the impacts of trade on worker outcomes are no longer as straightforward as they were when the earlier literature studied final goods trade arising from factor price differences across countries. As in that work, imports may have negative impacts on domestic workers when they have to compete with offshored sources of supply of tasks they perform. But domestic workers can also benefit from cheaper foreign inputs when cost savings from abroad raise the productivity or scale of domestic production. These two opposing forces from trade in intermediates imply that its impacts on workers have become increasingly nuanced and depend on various factors such as the costs of offshoring, the mix of trade partners and the extent of scale economies (Grossman and Rossi-Hansberg 2008, 2012).

The question of how trade in intermediate inputs affects workers therefore requires careful empirical examination. The empirical research pioneered by Feenstra and Hanson (1999), more recent research on exchange rates and the now quite sizable body of research on offshoring all very much confirm this, with results emerging that show the impact of imports

on worker outcomes may prove positive in some settings and negative in others.[5] A critical feature of this sign variation is whether workers and intermediate imports are complements or substitutes in production.

This paper offers new evidence on trade and the labour market that is in line with these developments. It presents findings that depreciation induced increases in intermediate import prices hurt workers. The sizable depreciation of sterling following the EU referendum vote made intermediate imports more expensive and the mode of adjustment to this cost shock was lower wages and reduced worker training. At the same time there was no benefit to offset this for exports, so the depreciation imposed extra costs on firms. Workers experienced a significant economic hit from this cost shock. Empirical estimates show that a 1 percent increase in the price of intermediate imports of an industry lowered wages by somewhere between 0.32 and 0.53 percent. The results are from a different setting, but resonate with some of the more recent offshoring work that finds evidence of complementarities between labour and intermediate imports.[6]

Negative effects on wages were further compounded by a cutback in job-related education and training. This loss of future earnings potential via lower training has important implications for future wage and productivity growth.[7] Beyond its contribution to economic growth,

[5]Feenstra and Hanson (1999) reported that real wages of production workers were largely unaffected by offshoring activities of US firms while the real wages of non-production workers increased with the share of imports in intermediate inputs. Sitchinava (2008) updates and extends the Feenstra and Hanson paper to find that most of the increase in relative wages can be explained by technical change (see also Harrison et al. 2011). Newer exchange rate work by Campa and Goldberg (2001) expands the analysis of Revenga (1992) to intermediate imports, continuing to find similarly signed wage elasticities. Similarly, Goldberg and Tracy (2001) estimates a negative, but statistically insignificant, wage elasticity with respect to import-weighted exchange rate depreciation. The recent literature on offshoring and the labour market is reviewed in the comprehensive survey by Hummels et al. (2018).

[6]A few recent studies provide some evidence suggestive of complementarity between imports and workers. In a rare study of services, Criscuolo and Garicano (2010) report substantial complementarity between imports of services and those in licensed occupations dedicated to the production of those services. In related work to ours using exchange rate movements, Sethupathy (2013) finds that after the Mexican peso crisis of 1994, average domestic wages of US manufacturing multinational firms that already offshored to Mexico rose more than other firms in the US, suggesting complementarity between domestic workers and offshoring. Using country-year variation in economic activity to construct Bartik instruments, Desai et al. (2009) find a positive relationship between earnings of domestic and foreign employment outcomes of US multinational firms. Kovak et al. (2017) find a positive employment elasticity at the US parent firm with respect to a Bilateral Tax Treaty-induced increase in foreign affiliate employment, albeit in just the high differentiation industries where BTTs provide a first stage for foreign affiliate employment.

[7]A substantial fraction of investment in skills takes place through job-related education and training of workers, which is an important contributor to wage and productivity growth (for example, Lynch 1992, or Dearden et al. 2006). Although internationally comparable statistics are scarce, the OECD estimated that, on average, over a third of employed adults participate in job-related training, with countries like the UK, US and New Zealand showing much higher rates (OECD 1998). In many developed countries, training makes up the single-largest component of investments in intangibles, higher than software and databases, R&D or brand equity (example, van Ark et al. 2009).

job-related education and training is an important lever to cushion workers during changes in their economic environment. Whilst rarely offering direct evidence, the offshoring literature frequently has recognised the importance of training in redistributing the gains from globalization to workers who are hurt by it. Displaced individuals need skills to transition into better jobs, and this is particularly important for workers who are hurt by offshoring (Hummels et al. 2012). Yet empirical research connecting trade and training remains scarce, at least in part because the data requirements - observing wages, training and offshoring shocks together - have been said to be "onerous" (Hummels et al. 2018). Consequently, most papers rely on data from public training programmes for displaced workers to shed light on the prospects for future earnings of workers impacted by trade.[8]

The focus on a large, unexpected exchange rate depreciation facilitates study of an exogenous variation that impacts worker outcomes through trade price movements.[9] Other economic shocks that move exchange rates are less plausibly exogenous than the referendum induced exchange rate depreciation of the pound studied here. One example would be if an exchange rate depreciates due to oil price shocks, so that changes in worker outcomes incorporate the direct substitution effects between energy and labour along with indirect impacts through changes in trade. Another example is if exchange rate movements were driven by monetary policy actions, which are often adopted to bolster employment outcomes.

This paper advances trade and labour market research in several other noteworthy directions. First of all, the available data and setting enable study of the impact of trade on all workers in the economy (i.e. not just in manufacturing), as the UK has high quality (and relatively scarce in international terms) services trade data.[10] Second, as trade policy in

[8] What little empirical work exists on training and trade comprises a few recent papers that find a link between rise in imports and training in the manufacturing sector. Kosteas (2017) finds US workers in industries with rising import penetration were less likely to enroll in career advancement training. Hogrefe and Wrona (2015) finds instead that workers in industries with rising imports from low-income countries were more likely to enrol in training in Germany, where these investments have risen during the crisis period (unlike many other advanced countries). Cross-sectional evidence from Norway shows that manufacturing firms that report facing high competition in international markets invest more in training their workers, but this is not true for non-manufacturing firms (Schone 2007). Looking at training provided by Brazil's national services, Bastos et al. (2016) finds that manufacturing firms that are induced to export from exchange rate movements, have higher shares of low-skilled workers in training.

[9] The focus on sizable exchange rate movements has some commonalities with the emerging literature on exchange rates that examines large depreciation episodes, often arising from currency devaluations during large declines in output, consumption and imports. See for example, Cravino and Levchenko (2017) which examines the price impacts of an unexpected Mexican peso crisis, and the price evolution studies of Burstein et al. (2005), Burstein and Gopinath (2005), Auer et al. (2018).

[10] A few papers have moved beyond manufacturing and find workers benefit from trade in intermediate goods and services, but the effects are small even over long periods of time (example, Amiti and Wei 2009, Liu and Trefler 2008, Liu and Trefler 2011). Harrison et al. (2011) in their survey discuss the notion that, complementarity between workers and intermediate imports could be masked by a stronger negative labour supply effect of offshoring, especially as many studies focus on offshoring to low-wage-countries like China and India.

most developed countries has remained relatively stable this means that variations in tariffs and exchange rate movements are usually too small to study causal effects of trade, because instruments for imports are hard to come by, especially in services (Liu and Trefler 2011, Ebenstein et al. 2014, Hummels et al. 2018). The UK experience around the referendum therefore provides a unique setting in the developed country context to utilise the large currency depreciation to lever plausible exogenous variation.

Finally of relevance is the growing body of research on the potential and actual impacts of recent surges in nationalist politics. The dominant approach to date has been to infer the impact of leaving the EU on national GDP and on the household income distribution using standard models and estimated elasticities from international trade (for example, Dhingra et al. 2017, or the surveys by Van Reenen 2016 and Sampson 2017 for Brexit). In related work constructing counterfactuals, Auer et al. (2018) model the distributional effects of revoking NAFTA on US workers and at the same time note that the impact on industry-specific workers through the intermediate imports channel is quantitatively important. Looking at the Trump trade war of 2018, Fajgelbaum et al. (2019) estimate the impact of US tariff policy on trade outcomes, and use that to model the implied impact on workers. Amiti et al. (2019) estimate the losses in consumer welfare arising from the Trump trade war. Grossman and Helpman (2018) cast these political changes in light of the dislocation between personal identities and political loyalties. Speaking to this nascent literature, and to the best of our knowledge, this paper provides the first evidence on actual worker-level outcomes being adversely affected as populist politics has been on the rise.[11]

The remainder of the paper is structured as follows. Section 2 details the context of the sterling depreciation that occurred as the unexpected Leave vote came about. Section 3 presents the theoretical framework and section 4 describes the research design that is adopted along with the data sources. Section 5 presents the main statistical results. Section 6 offers a number of extensions and probes of robustness. Section 7 discusses and interprets the key findings more broadly and by means of a calibration exercise that links back to the theory. Section 8 concludes.

2 The EU Referendum Vote

The United Kingdom is one of the most open economies in the world. Its trade to GDP share is over 60 per cent. The European Union (EU) is the UK's largest trade partner. Prior

[11] More recently, a few studies have started to look at post-referendum data on stock market valuations of firms, prices, entry and exit of exporters of merchandise goods, economic uncertainty and trade policy uncertainty (Davies and Studnicka 2018, Breinlich et al. 2017, Crowley et al. 2018, Bloom et al. 2018, and Graziano et al. 2018 respectively).

to the UK joining the European Economic Community (EEC) in 1973, around one third of UK trade was with the EEC. In 2014, the 27 other EU members accounted for 45 percent of exports and 53 percent of imports (Dhingra et al. 2017).

Whilst a member of the EU, the UK has been in a customs union and a single market. The customs union eliminated tariff barriers within the EU and coordinated trade policies of member states with countries outside the union. Member states pursue trade policies through the EU, and not independently. Importantly, EU membership implies the existence of a 'single market' that reduces non-tariff barriers to trade such as border controls, cross-country differences in regulations over rules like product standards and safety, and threats of anti-dumping duties.

Membership lowers the costs of doing business between member states, who are required to coordinate on trade policy, including tariffs and non-tariff barriers and other trade-related policies like migration, foreign investment and related regulations. Over time, some political groups in the UK came to view this as a constraint on national sovereignty, and this was one of the motivating calls for a referendum to allow the UK electorate to vote on whether to remain in the EU or to leave. This campaign was heavily stepped up by Nigel Farage, leader of the UK Independence Party (UKIP), then a single issue party campaigning for Britain's exit from the EU. UKIP started to see electoral gains from its campaign and this put political pressure on the main parties. Consequently, UK Prime Minister David Cameron pledged to hold an in or out referendum if his Conservative Party won the May 2015 election.

After the party's win, June 23, 2016 was set as the date for a referendum on "Should the United Kingdom remain a member of the European Union or leave the European Union?". The possible answers were: "Remain a member of the European Union" or "Leave the European Union" (Baldwin 2016). When the referendum took place, 72% of eligible voters cast a ballot and 52% of these chose 'Leave'. Few had expected this result, especially in the foreign exchange and betting markets. In the run-up to the referendum, most polls and bookmakers had predicted a win for the Remain campaign, albeit with a small margin. Even up to polling day, Nigel Farage admitted that Remain was likely to edge a win. The forex market exhibited similar expectations over the result of the Brexit vote. A full timeline of the events of June 23/24 is given in Appendix B, and next the main episodes are summarised.

Polling stations across the country closed at 10pm on June 23. A YouGov opinion poll released at the same time suggested Remain were on course for victory with 52 percent and Leave on 48 percent. By 10.15pm, UK Independence Party's Nigel Farage conceded the Brexit campaign may be beaten and said Remain "will edge it." Sterling surged against the US dollar on the back of the favourable opinion poll for Remain and Farage's comments, rising to 1.5 dollars, its strongest performance in 2016. Figure 1 shows this rise (which is

actually dwarfed by the scale of what was to follow in the early hours of the 24th) by plotting the value of the pound compared to the dollar, euro and yen between 6 PM on the day of the vote and 8 AM the next day. The three exchange rates are indexed to 1 at 10 PM when the polls closed so as to clearly show the before/after shifts.

Shortly after midnight the first big result was declared. It was a narrow win in Newcastle for Remain with 50.7 percent against Leave on 49.3 percent. It was an expected win in Newcastle, but not by anywhere near the margin many thought would occur, and shortly afterwards the odds of Leave winning the vote were cut by bookmakers. But the big upset came at 12.20am. Sunderland voted to Leave by a significant margin, with 61 percent in the Tyne and Wear town in favour of Brexit compared with 39 percent backing Remain. By 12.30am, sterling had tumbled against the US dollar, as Figure 1 shows with an instantaneous near 4.7 percent drop - greater than the Black Wednesday crash in 1992.

People started to feel that Leave could be winning, and it showed in their Google searches after an hour. Bookmakers changed their odds in favour of Leave winning the referendum. Other Brexit wins followed and by 2.17am, Nigel Farage tweeted that he is "so happy with the results in North East England".[12] A few big wins went to Remain subsequently, but in the next couple of hours the Leave campaign enjoyed more and more gains across Wales, Northern Ireland, Yorkshire and the Midlands to outweigh the majority of Remain's support in Scotland and London.

Sterling's slide against the dollar continued, and the pound dropped to 1.37 dollars, down from its high of the previous night of just over 1.5 dollars. Investors reacted by moving away from sterling, as reflected in its value against major foreign currencies shown in Figure 1. Table 1 gives more detail on the quite wide discrepancies in the percentage fall that sterling experienced against a bigger range of 26 currencies (the Bank of England's official set of currencies) in the 24 hour period surrounding the referendum.

After 7am on June 24, the Leave campaign had officially won. The empirical work in this paper uses this overnight exchange rate drop to capture the unanticipated depreciation shock to the pound against other currencies. Sterling depreciated most against the Japanese Yen and the US dollar which were considered safe haven assets in this event window by forex traders and analysts.[13] In contrast, sterling depreciated relatively less against EU currencies like the Euro and the Polish Zloty, which were perceived to be more exposed to the political and economic fallout of the Brexit vote. Being one of the major currencies of the world, the flight from sterling also changed the value of a whole host of other more minor currencies as

[12] https://www.bbc.co.uk/news/uk-politics-eu-referendum-36598599

[13] https://www.cnbc.com/2016/06/22/if-uk-votes-leave-in-brexit-referendum-pound-sterling-will-likely-tumble-dollar-surge.html and https://www.cnbc.com/2016/06/26/pound-sterling-set-to-fall-further-as-brexit-uncertainty-continues.html

forex traders looked for new avenues and trades.[14]

That the relative depreciation was driven by a flight into safe haven assets is also reflected in the subsequent rise in the price of gold and the stock market valuations of commodity firms. The day after the Brexit vote saw a gold price rise of over 5 percent - the highest surge since the depth of the 2008 financial crisis. The Royal Mint reported a 550 percent increase in traffic on its online purchase site compared to the same time the previous day.[15] Within a day, prices of other safe assets like silver, precious metals and 10-year US Treasury bonds rose sharply.[16]

While sterling continued to decline in subsequent months, the analysis uses just the overnight decline to minimise endogeneity concerns arising from subsequent actions taken by the Bank of England (very soon after) and other market players in hedging economic losses and bolstering the UK economy. This is borne out by observing the pattern of exchange rate movements that later occurred. The two charts in Figure A1 of Appendix A show this for the three main currencies over windows of 7 and 15 days after the referendum. The 7-day window does not show much difference, but (unsurprisingly) more discrepancies start to arise relative to the 24 hour movements for the 15 day window. As with event studies looking at exchange rate movements more generally (and indeed event studies looking at stock price movements) this is obviously because other news that occurs shapes the subsequent observed shifts.

Clearly the use of a wider window begins to raise endogeneity concerns not present for the 24 hour window that measures exchange rate shifts that pre-date the several news and announcements following the referendum result that could be seen as direct reactions to the exchange rate drop. Some of these are listed in the Brexit timetable in Appendix B. The first is the Governor of the Bank of England Mark Carney's 8:50am statement on June 24 about the readiness on the part of the Bank of England to use monetary policy to support the UK economy. And soon after this, the Bank of England strengthened its position and started some quantitative easing operations. The extent to which these operations could have been targeted to industries with higher trade exposure and/or larger exchange rate drops makes the movements in exchange rates past the 24 hour window potentially endogenous.

Exchange rate movements after the referendum are clearly driven by other factors too, but it is noteworthy that the sterling depreciation turned out to be a largely permanent one that strongly persists for at least two years after. This is shown in Figure A2 of Appendix A

[14] https://www.euromoney.com/article/b12kpbtwmrnrp7/fx-traders-pick-through-brexit-wreckage

[15] https://www.coinworld.com/news/precious-metals/2016/06/brexit-vote-european-union-gold-price-surge-kitco.all.html

[16] https://www.forbes.com/sites/maggiemcgrath/2016/06/24/global-markets-in-turmoil-after-the-u-k-votes-to-leave-the-european-union/#76b991053994

which plots the real effective exchange rate for the entire estimation period that is considered below, namely quarterly data for four years before the referendum (starting in 2012 Q3) and two years after (ending in 2018 Q2). The key feature of relevance is the permanence of the post-referendum evolution: the trade weighted exchange rate falls by 8.1 percent in 2016 Q3 relative to the previous pre-referendum quarter, dropping a little further to a cumulative 10.7 percent lower by 2016 Q4, to 9.8 percent lower by 2017 Q4 and ending up being 8.2 percent lower in 2018 Q2 relative to 2016 Q2.[17]

3 Theoretical Framework

This section presents a theoretical framework to guide the research design used in the empirical model for study and interpretation of the connections between worker outcomes, trade and exchange rates. The starting point is a description of the economy and the market equilibrium, after which the exposition proceeds to the empirical set up and discussion of the possible impacts of the sterling depreciation.

Model Structure

UK firms produce in output industries, indexed by o, to sell in destination countries indexed by d (including the UK). They buy intermediate inputs from industries, indexed by i, which are supplied from source countries indexed by s. Their production and sales decisions, which determine input and output prices, are discussed first, followed by the wages that they face.

Intermediate Input Prices

Suppliers of intermediate goods and services combine C_{s0} and C_0 units of the numeraire good from the source country and the UK (the location of the output industry) to provide a unit of their intermediate. It is assumed that $C_0 > 0$ as this is a standard way of adding distribution costs in the exchange rate literature. The unit cost of providing the intermediate is therefore $C_{si} = P_{0s}C_{0s} + E_sC_0$ where P_{0s} is the price of the numeraire good in the foreign source country. E_s is the cost of the numeraire good in the UK in terms of source country currency.

As is standard, intermediate suppliers are assumed to be able to price discriminate across locations but not across buyers within a location. They are monopolistically competitive and

[17] A regression of the log(real effective exchange rate) on a simple post-referendum dummy variable produced an estimated coefficient (and associated standard error) of -0.101 (0.017), again re-iterating the permanent nature of the drop in the exchange rate that occurred following the vote.

choose prices to maximize profits, taking their derived demand M_{si} from all industries in the UK as given. Their optimal sterling price is $P_{si} = \mu^M \tau_{si} C_{si}/E_s$ where $\tau_{si} \geq 1$ are iceberg trade costs and $\mu^M \equiv 1/\left(1 + 1/\left(\partial \ln M_{si}/\partial \ln P_{si}\right)\right)$ is the inverse derived demand elasticity of intermediates which we assume is constant.[18]

Output Prices

Firms in output industry o have a homothetic production function with unit cost C_o. Production requires workers L, intermediate inputs M from different industries and the numeraire good. Workers are industry-specific, at least in the short run and W_o denotes the wage rate of workers who are employed in output industry o. The unit cost function can be written as $C_o = C\left(W_o, P_o^M\left(P_i\left(P_{si}\right)\right)\right)$ where P_i summarizes the import price index from intermediate industry i and P_o^M summarizes the import price index across all intermediates used in o.[19]

As earlier, firms can price discriminate across locations but not within locations, and they are monopolistically competitive. Following Burgess and Knetter (1998) and Campa and Goldberg (2001), firms face destination-specific inverse demand $P\left(Q_{od}, A_d\right) = A_d Q_{od}^{-1/\sigma}$ where Q_{od} denotes the units of output o consumed in destination d, A_d is an aggregate demand shifter for destination d, and $\sigma > 1$ is the elasticity of demand.[20]

When firms sell their output abroad, they incur iceberg transport costs $\tau_{od} \geq 1$ in destination d. They must also pay for distribution costs in the foreign destination, which require C_{0d} units of the numeraire good from the foreign destination. Therefore, the unit cost of selling in foreign markets is $\tau_{od}\left(C_o + P_{0d} C_{0d}/E_d\right)$ where P_{0d} is the price of the numeraire in the destination market and E_d is the exchange rate that converts destination d prices into sterling. Firms therefore choose $P_{od} = \frac{\sigma}{\sigma - 1}\tau_{od}\left(C_o + P_{0d} C_{0d}/E_d\right)$ and foreign consumers are charged $E_d P_{od}$ in their own currency.

Industry Wage

Labour market clearing sets the industry-specific wage rate. In equilibrium, the industry-specific supply of labour in the UK, $\bar{L}_o$, exactly equals the demand for labour from that

[18] Constant markups are assumed since we will not be able to empirically decompose prices into markups and costs. More generally, under variables markups, estimated coefficients would incorporate the elasticity of markups to expenditures. Under oligopolistic competition, they would include the sensitivity of the aggregate price index to own prices. For a detailed exposition of such price effects in a general framework, see Amiti et al. (forthcoming).

[19] Specifically, the cost function is $C_o = C\left(W_o, P_o^M\left(P_i\left(P_{si}\right)\right), P_o^D\left(P_i\left(1\right)\right), 1\right)$ where P^D denotes domestic inputs and 1 denotes the price of the numeraire good which for brevity, is written without the third and last arguments because they stay the same.

[20] In the baseline, A_d summarizes other prices, tastes or incomes in the destination country, which do not vary with the exchange rate. This can be easily generalized to allow for explicit dependence of A_d on the destination exchange rate, as discussed in Appendix C.

industry, $\sum_d L_{od}$. By Shephard's lemma, $\bar{L}_o = C_W\left(W_o, P_o^M\right)\sum_d \tau_{od} Q_{od}$ where $C_W > 0$ is the partial derivative of unit costs C with respect to the wage rate. Having specified the market equilibrium, how equilibrium outcomes change with a depreciation of the exchange rate can next be considered.

Impacts of the Referendum Sterling Depreciation

This sub-section starts with a discussion of the Brexit news shock and the exchange rate, and then determines how it could impact on trade prices and wages.

Sterling Depreciation

The international finance literature (for example, as summarized in Engel 2015), examines exchange rate changes over very short time intervals following news announcements. Over these intervals, the economic fundamentals that determine exchange rates do not change much or at all, so that the primary driver of the exchange rate change is the news itself. The approach here also takes this line, by looking at the narrow window of the Brexit referendum night to determine the news shock from the EU referendum results.

The key news that is announced during the 24 hour window from 8am on June 23, 2016 to 8am on June 24, 2016 is the news of the Brexit referendum. As in Faust et al. (2007), let $\mathscr{S}$ be the vector describing all variables in the economy that can be viewed as fixed in the time period of the results announcement. Then let $\tilde{\mathscr{S}}$ be the public's best estimate of $\mathscr{S}$. The equilibrium exchange rate of the pound with respect to country currency c can be written as $E_c = \phi_c\left(\mathscr{S}, \tilde{\mathscr{S}}\right)$ where the c subscript allows the exchange rate to depend on various factors like trade costs, prices, the state of the aggregate world economy.

Linearising and time differencing the result during the 24 hour window gives $\Delta E_c = \phi_{1c}\Delta\mathscr{S} + \phi_{2c}\Delta\tilde{\mathscr{S}}$, where Δ is the 24 hr difference operator and ϕ_{1c}, ϕ_{2c} are the partial derivatives. Assuming the state variable does not change in this narrow window (when most markets except the forex market in London were closed), $\Delta\mathscr{S} = 0$ and $\phi_{2c}\Delta\tilde{\mathscr{S}}$ gives the marginal effect on the currency of a change in the public's perception of the state variable. Conditional on information at the beginning of the window $\tilde{\mathscr{S}}$ and the Brexit referendum news B, the estimate of the state variable changes by $\Delta\tilde{\mathscr{S}} = gB$. Therefore, the depreciation from the Brexit referendum news can be summarized by $\Delta E_c = \phi_{2c} gB$.

Trade Impacts

The trade price impact can be analysed by solving for how the equilibrium outcomes change as a result of the vote-induced sterling depreciation. Following the exchange rate

literature, let κ denote the probability that a firm can adjust its price following an exchange rate shock. Incorporating this sticky price mechanism, changes in equilibrium outcomes are discussed here. For notational purposes for a given variable Z, let $\hat{Z}$ denote the log change in Z with respect to the 24-hour exchange rate depreciation ΔE.

From the supplier's optimal price equation, the change in the price of intermediates from industry i in source country s is $\hat{P}_{si} = \kappa^M \left(\hat{C}_{si} - \hat{E}_s\right)$ where κ^M is the probability of adjustment for suppliers of intermediate imports. Let $\delta^M \equiv P_{0s}C_{0s}/\left(P_{0s}C_{0s} + E_sC_0\right)$ denote the share of source country costs in the total costs of the intermediate supplier. Assuming the UK is a small open economy, the price of the numeraire good in foreign countries is unchanged by the Brexit news. Then the price of imported intermediates in the UK increases by $\hat{P}_{si} = -\delta^M \kappa^M \hat{E}_s$. A sterling depreciation ($\hat{E}_s < 0$) works like an increase in trade costs and so raises the prices of imported intermediates.

The change in the intermediate import price index is a weighted average of all intermediate prices from various foreign source countries, $\hat{P}_o^M \equiv \sum_i \sum_{s \neq uk} S_{sio} \hat{P}_{si}$. The shares $S_{sio} \equiv S_{P_iP_o^M} S_{P_{si}P_i}$ are the shares of intermediates of industry i from source county s in the factor expenditures of output industry o. $S_{P_{si}P_i}$ and $S_{P_iP^M}$ are the shares of source s and intermediate i in the relevant intermediate costs of the industry, P_i and P^M respectively.

From the output unit cost function, $\hat{C}_o = S_{WC}\hat{W}_o + S_{P^MC}\hat{P}_o^M$ where S_{WC} and S_{P^MC} are the shares of labour and imported intermediates in the industry's factor costs C_o. Incorporating into the optimal price equation, output prices change by $\hat{P}_{od} = \kappa\left(\delta\hat{C}_o - (1-\delta)\hat{E}_d\right)$ where $\delta \equiv C_o/\left(C_o + P_{0d}C_{0d}/E_d\right)$ is the share of UK-based costs in total unit costs of the output industry.

Defining S_{dxo} as the share of destination d in exports of UK firms in output industry o. The export price index for UK firms can be written as $\hat{P}_o^X \equiv \sum_{d \neq uk} S_{dxo}\hat{P}_{od}$. Substituting for the change in output prices, $\hat{P}_o^X = \kappa\delta S_{P^MC}\hat{P}_o^M + \kappa\delta S_{WC}\hat{W}_o - \kappa(1-\delta)\sum_{d\neq uk} S_{dxo}\hat{E}_d$. Holding all else fixed, a sterling depreciation ($\hat{E}_d < 0$) raises the export price that UK firms charge on account of the destination-specific costs, but lowers the export price in terms of the foreign consumer's currency.

Wage Impacts

To determine the before/after change in wages, let σ_{XY} denote the Allen-Uzawa elasticities of substitution (AES) between factors with prices X and Y. Specifically, σ_{WW} is the own elasticity of labour demand which is less than zero for downward sloping demand, and equals $\sigma_{WW} \equiv \varepsilon_{WW}/S_{WC}$ where $\varepsilon_{WW} \equiv C_{WW}W/C_W$ and $C_{WW} < 0$ is the second order partial derivative of the unit cost function with respect to wage. Similarly, $\sigma_{WP^M} \equiv \varepsilon_{WP^M}/S_{P^MC}$ is the Allen-Uzawa elasticity of substitution between workers and imported intermediates.

From Shephard's lemma, the elasticity of labour demand with respect to the price of imported intermediates is $\varepsilon_{WP^M} \equiv C_{WP^M} P^M / C_W$ which is less than zero (greater than zero) for Allen-Uzawa complements (substitutes).

From labour market clearing, the change in wages is given by

$$-\sigma_{WW} S_{WC} \hat{W}_o = \sigma_{WP^M} S_{P^M C} \hat{P}_o^M + \sum_d S_d \hat{Q}_{od} \tag{3.1}$$

where $\sum_d S_d \hat{Q}_{od}$ is the change in scale of UK firms across all destinations and S_d is the share of sales to destination d in total sales of UK firms. The sum of the two terms on the RHS of equation 3.1 determines whether workers and intermediate imports are gross substitutes or complements. The first term on the RHS determines the net complementarity or substitutability of workers with imported intermediates. When $\sigma_{WP^M} < 0$, an increase in the price of imported intermediates drives down the wage rate of workers in the industry and also has the direct effect of reducing the absolute cost share of workers (because $\partial \ln S_{WC} / \partial \ln P^M = -S_{P^M C}(1 - \sigma_{WP^M}) < 0$ iff $\sigma_{WP^M} < 1$). The second term on the RHS determines the wage response to the scale of production. An increase in the scale of production raises the wage rate and the gross substitutability or complementarity between workers and imported intermediates depends on the relative strength of the direct substitution effect and the indirect scale effect. Solving further for the change in scale in terms of price changes in equation 3.1, enables us to arrive at the estimating equations in the next sub-section.[21]

Structural and Reduced Form Relationships

The structural and reduced form equations for the empirical application to the Brexit news shock can now be derived. Here the emphasis is placed on highlighting the structural relationship in terms of changes in wages, intermediate import prices and export prices that can be taken to the data with an appropriate empirical model.

The trade measures used in the empirical work are an intermediate import price index and an export price index. The focus on prices is based on the reasoning by Grossman (1987) that, if available, they are preferable to other commonly used measures of trade like the share of intermediate imports in domestic consumption because the latter captures changes

[21] For simplicity, we do not have a dynamic model that builds in the exact exchange rate determination rule. The framework can be extended to multiple periods to illustrate that, in the presence of some degree of stickiness in wage and price adjustment, they are likely to respond to changes in the expectations about the future state of the economy induced by the Brexit vote news. The change in expectations could reflect trade policy uncertainty and economic uncertainty arising from the vote (as suggested in Handley and Limao 2015, 2017 and Pierce and Schott 2016, Bloom et al. 2018). In the extreme case when prices cannot be re-adjusted even after the actual Brexit event, then the responses could already reflect the expected changes in economic variables from leaving the EU, and not just the associated uncertainty and transition phases induced by the news.

in domestic supply and not just changes in foreign supply conditions. Feenstra et al. (2010) explain further that prices are important for better capturing shifts in source countries by firms and for covering services inputs, which are often difficult to measure as trade flows. We therefore focus on deriving estimating equations using prices. In many contexts, price data are scarce and therefore much of the literature uses import shares, but we are fortunate in our setting to have access to good trade price data, as will be discussed below.[22]

From the inverse demand function, the change in quantity $\hat{Q}_{od} = -\sigma\hat{P}_{od} + \sigma\hat{A}_d$ can be substituted for in the wage equation with price changes $\hat{P}_{od}$ and aggregate demand shifters $\hat{A}_d$ (which are zero for foreign markets $d \neq uk$ when the UK is a small open economy). Foreign quantity and price data are readily available through customs and trade-in-services data. But as in many countries, domestic quantity or price data are less complete in the UK (largely because domestic prices for domestically available goods and services are often collected in differing ways). Therefore, the change in domestic sales is substituted in terms of the corresponding cost changes and the aggregate demand shifters: $\hat{Q}_{o,uk} = -\sigma\kappa\delta\hat{C}_o + \sigma\hat{A}_{uk}$. Then the change in wage rate from equation 3.1 in terms of the import price index, the export price index and the aggregate demand shifters is

$$\begin{aligned}(\sigma_{WW} - \delta S_{uk}\kappa\sigma)\, S_{WC}\hat{W}_o = & -(\sigma_{WP^M} - \delta S_{uk}\kappa\sigma)\, S_{P^MC}\hat{P}_o^M \\ & -(1 - S_{uk})\,\sigma\hat{P}_o^X + \sigma S_{uk}\hat{A}_{uk}\end{aligned}$$

where S_{uk} is the share of sales at home in total sales of UK firms, which accounts for the indirect domestic price effects. Later the demand shifter is extended to explicitly include final import competition in the output industry.[23]

The structural equation that relates the post-pre referendum change in wages to changes in trade prices is:

$$\hat{W}_o = \alpha + \theta_{MW}\hat{P}_o^M + \theta_{XW}\hat{P}_o^X \tag{3.2}$$

and the underlying reduced forms for changes in wages and trade prices with respect to the

[22] Parallel results using the quantities of imports are also shown as an extension in the empirical work.

[23] The trade and exchange rate literature rarely considers all three channels (intermediate imports, exports and final imports) at the same time, reflecting well-known multicollinearity problems (between exports and final imports). This does not turn out to be a problem in our setting, because we are using industry-country trade shares to weight the industry specific exchange rate movements and because most of our focus is on intermediate import and export weighted measures of the sterling depreciation. In the extensions section reported below, an import competition (i.e. final imports) weighted depreciation measure is also considered, making little difference to the main results of the paper.

sterling depreciation are:

$$\hat{W}_o = \alpha_W + \beta_{MW}\hat{E}_o^M + \beta_{XW}\hat{E}_o^X \tag{3.3}$$

$$\hat{P}_o^M = \alpha_M + \beta_{MM}\hat{E}_o^M \tag{3.4}$$

$$\hat{P}_o^X = \alpha_X + \beta_{XX}\hat{E}_o^X + \beta_{MX}\hat{E}_o^M \tag{3.5}$$

where α denote economy-wide shifters. The exchange rate changes, $\hat{E}_o^M \equiv \sum_i \sum_{s\neq uk} S_{sio}\hat{E}_s$ and $\hat{E}_o^X \equiv -\sum_{d\neq uk} S_{dxo}\hat{E}_d$, are respectively the intermediate import weighted exchange rate depreciation and the export weighted exchange rate appreciation for the industry. When used as instruments, this construction of exchange rate changes is similar to the input tariff changes that Goldberg et al. (2009) construct for their study of product adoption from reduction in intermediate input tariffs in India. The β and θ coefficients are respectively the relevant reduced form and structural form estimands of interest. How these relate to the model primitives is discussed next with empirical implementation and interpretation in mind, first for trade prices, then for wages.

As sterling depreciates, $\hat{E}_o^M < 0$ and prices of intermediate imports rise for $\beta_{MM} < 0$. The estimated exchange rate pass through to import prices is $\beta_{MM} \equiv -\delta^M \kappa^M$ which incorporates the share of source country resources used in the provision of the intermediate δ^M and the probability of price adjustment in importing κ^M. Note that only the intermediate import weighted sterling depreciation enters the RHS of equation 3.4, and not the export-weighted sterling depreciation. This is because theoretically UK firms and their suppliers do not negotiate on intermediate prices based on how much they sell in foreign markets. The intermediate import prices therefore do not depend on the export weighted sterling appreciation. Empirically, this provides a reasonable setting where firms incur a cost shock through a rise in intermediate import prices and this does not depend on the revenue shock that they receive from UK exports becoming cheaper for foreign consumers.

As sterling appreciates, $\hat{E}_o^X > 0$, the estimated pass-through of the exports-weighted appreciation to export prices that UK firms receive is $\beta_{XX} \equiv \kappa(1-\delta)\frac{\sigma_{WW}-\delta S_{uk}\kappa\sigma}{\sigma_{WW}-\delta\kappa\sigma} > 0$ (for downward sloping labour demand). The extent of the pass-through depends on the probability of price adjustment in the output market κ and the indirect price effects incorporated in σ_{WW} and $\delta S_{uk}\kappa\sigma$. Combining this with the direct effect of the sterling depreciation, export prices in foreign currency are lower.

But there may also be an offsetting effect as costs rise in the UK due to increases in the price of intermediate imports when $\beta_{MX} < 0$. The coefficient $\beta_{MX} \equiv \delta\kappa S_{P^M C}\beta_{MM}\frac{\sigma_{WW}-\sigma_{WP^M}}{\sigma_{WW}-\delta\kappa\sigma}$ is the exchange rate pass through of intermediate import costs to exports, and it incorporates the export price pass through $\delta\kappa$, the intermediate import price pass through $S_{P^M C}\beta_{MM}$ and

the indirect price effect is captured in the elasticities of substitution and demand. The sign of this coefficient depends on the difference in the elasticity of substitution of workers with respect to costs of intermediate imports relative to wages ($\sigma_{WP^M} - \sigma_{WW}$). When workers and intermediate imports are Allen-Uzawa substitutes, $\sigma_{WP^M} > 0 > \sigma_{WW}$, export prices rise with the sterling depreciation through the rise in intermediate import costs and increased substitution towards labour. Under complementarity, the relative magnitudes of the elasticities of substitution determine the direction of change in factor costs of UK firms and hence the cost channel through which the sterling depreciation affects exports. This is because the rise in intermediate import prices from the sterling depreciation also reduces the demand for labour and has a countervailing effect on firm's factor costs through reduced wages. It is reasonable to think that the cross elasticity of demand for labour is smaller in magnitude than the own elasticity of demand for labour. Then export prices would rise with the sterling depreciation on account of the cost channel, as workers and intermediates would not be complementary enough to reduce the total factor costs of exporters.

The sterling depreciation changes wages in the industry through its impact on the costs of intermediate imports and sales to export markets. Wages fall with an increase in the intermediate import price index when workers and intermediate imports are Allen-Uzawa complements. The coefficient $\theta_{MW} \equiv -\frac{(\sigma_{WP^M} - \delta S_{uk} \kappa\sigma) S_{P^M C}}{(\sigma_{WW} - \delta S_{uk} \kappa\sigma) S_{WC}}$ measures the elasticity of wages with respect to intermediate import prices. It incorporates Allen-Uzawa complementarity through σ_{WP^M}, the relative importance of workers and intermediates through their factor cost shares ($S_{P^M C}, S_{WC}$), and the pass-through to UK prices through $\delta S_{uk} \kappa\sigma$.

In the absence of pass-through of factor costs to UK domestic prices ($\delta S_{uk} \kappa\sigma = 0$), the coefficient is just the relative Allen-Uzawa elasticities of substitution and factor shares. In the presence of pass-through to UK domestic prices, the coefficient θ_{MW} captures the difference between the production elasticity and the demand elasticity (which determines the scale effects arising from domestic sales). This difference between the production side and demand side elasticities in θ_{MW} is similar to Alfaro et al. (forthcoming). They show that the difference between the output and the intermediate elasticities of substitution determines the sequential complementarity or substitutability of intermediate suppliers with earlier stages of the value chain of production. When workers and intermediate imports are Allen-Uzawa complements, $\sigma_{WP^M} < 0 < \delta S_{uk} \kappa\sigma$ and workers' wages are lowered through the intermediate import cost channel of the exchange rate depreciation ($\theta_{WM} < 0$).

While the first (non-constant) term in equation 3.2 is the intermediate import channel of the sterling depreciation, the other is the export channel which captures the effects of a rise in scale through foreign sales on wages. The coefficient $\theta_{XW} \equiv \frac{(1 - S_{uk})\sigma}{(\sigma_{WW} - \delta S_{uk} \kappa\sigma) S_{WC}}$ measures the pass through of higher export earnings into wages, which is positive for downward sloping

labour demand.

To sum up, the sterling depreciation raises intermediate import and export prices. When workers and intermediate imports are Allen-Uzawa complements, the sterling depreciation induced rise in intermediate import prices lowers wages in industries that experience a greater intermediate imports weighted depreciation. In contrast, the rise in (sterling) export prices induced by a sterling depreciation raises wages in industries that experience a greater exports weighted appreciation, but these may be mediated by any associated rise in import costs. Which effect dominates depends on the relativities between the revenue and cost shocks.

Empirical Model

In practical terms, these relationships from the reduced forms in equations 3.3 to 3.5 are empirically operationalised by means of difference-in-differences specifications that relate the outcomes of interest – wages and trade prices – before and after the EU referendum to the pre-referendum trade weighted industry-specific sterling shock. The reduced form approach for wages has some similarities to recent papers on trade and labour market outcomes, which typically examine employment changes from the event of interest across industries that differ in their initial trade structure or trade policy exposure (for example, Pierce and Schott 2016, Acemoglu et al. 2016). Specifically, Pierce and Schott (2016) examine US manufacturing employment before and after China received permanent most favored nation status across manufacturing industries based on differences in their pre-determined tariff cuts from permanent most favoured nation (MFN) status. The trade price reduced forms display similarities to the exchange rate pass through work already mentioned but rely on the exogenous exchange rate shock induced by the unexpected vote outcome, rather than general exchange rate movements that arise for a variety of reasons. As the referendum shock is measured in terms of the 24 hour window industry-specific exchange rate change, the research design in practice is set up in a difference-in-differences setting, which we turn to next.

To interpret the regression estimands of interest as elasticities, and where relevant for ease of comparison to draw with existing estimates, a double-log difference-in-differences specification is adopted. In terms of key independent variables, let $Log\left(\text{Depreciation}_o^M\right)$ denote the log of the import share weighted sum of the exchange rate E_s in the post-referendum period divided by its pre-referendum value. Similarly, $Log\left(\text{Appreciation}_o^X\right)$ is the log of the export share weighted exchange rate E_d in the post-referendum period divided by its pre-referendum value. The weights are the pre-referendum trade shares and the log depreciation/appreciation variables enter as independent variables interacted with a post-referendum dummy to pick up changes in the dependent variables before and after the referendum.

For the reduced forms of import and export prices – the first stage - the reduced form

changes of equations 3.4 and 3.5 can be estimated with industry-level quarterly panel data using the following differences-in-differences specification for industry o in quarter q of year t:

$$Log(P^M_{oqt}) = \alpha_o + \alpha_{qt} + \beta_{MM} Log\left(\text{Depreciation}^M_o\right) * Post_{qt} + \beta_{ZM} Z_{oqt} + \varepsilon^M_{oqt} \tag{3.6}$$

$$Log(P^X_{oqt}) = \alpha_o + \alpha_{qt} + \beta_{XX} Log\left(\text{Appreciation}^X_o\right) * Post_{qt} + \beta_{MX} Log\left(\text{Depreciation}^M_o\right) * Post_{qt} + \beta_{ZX} Z_{oqt} + \varepsilon^X_{oqt} \tag{3.7}$$

where P^M_{oqt} is the intermediate import price index of output industry o and P^X_{oqt} is its export price index. The pre-referendum values for the industry are subsumed in industry fixed effects α_o. The inclusion of output industry fixed effects α_o absorbs the time-invariant level of the trade-weighted exchange rate appreciation/depreciation, and so this is controlled for throughout in the empirical work. α_{qt} are quarter-year fixed effects, Z is a set of controls (comprising demographics and other characteristics of workers in the industry) and ε_{oqt} are error terms. The difference-in-differences estimands of interest in equations 3.6 and 3.7 are β_{MM}, β_{XX} and β_{MX}, the coefficients on the interaction between the relevant trade weighted appreciation or depreciation measures and the post-referendum dummy variable *Post*.

The reduced form for wages can also be operationalised in an analogous way to equations 3.6 and 3.7, other than we now have worker level data to work with. For worker j in output industry o in quarter q of year t,

$$Log(W_{joqt}) = \alpha_o + \alpha_{qt} + \beta_{MW} Log\left(\text{Depreciation}^M_o\right) * Post_{qt} + \beta_{XW} Log\left(\text{Appreciation}^X_o\right) * Post_{qt} + \beta_{ZW} Z_{joqt} + \varepsilon^W_{joqt} \tag{3.8}$$

where W_{joqt} is the wage rate and ε_{joqt} is an error term. In equation 3.8, the difference-in-differences estimands of interest are β_{MW} and β_{XW}. Of course, the key variation remains at the industry-level so all statistical inference from appropriately computed standard errors is conducted at this level.

The industry aggregated (or equivalently the individual-level industry weighted) reduced forms 3.6, 3.7 and 3.8 can be combined to estimate a structural form that identifies a causal effect of trade on wages. The precise specification is:

$$Log(W_{joqt}) = \alpha_o + \alpha_{qt} + \theta_{MW} Log(P^M_{oqt}) + \theta_{XW} Log(P^X_{oqt}) + \theta_{ZW} Z_{joqt} + \upsilon_{joqt} \tag{3.9}$$

with υ_{joqt} being the error term of the equation. The difference-in-differences instrumental

variable estimates are θ_{MW} and θ_{XW}. In terms of model parameters, $\theta_{MW} = \beta_{MW}/\beta_{MM} - \beta_{XW}\beta_{MX}/\beta_{MM}\beta_{XX}$ and $\theta_{XW} = \beta_{XW}/\beta_{XX}$, and these relations will be used in the model calibration presented after the statistical estimates.

Generalising to Other Adjustment Margins

The focus so far has been on inelastic labour supply to industries, thereby allowing for one single margin of adjustment in workers' outcomes - wage rates. When wages are downward sticky, the model estimates would still capture the impact on workers through slower wage growth when comparing across industries that are more or less exposed to the sterling depreciation. But when there is limited ability to change wages, adjustment could occur along other margins of labour costs. Firms cannot immediately hire and fire workers, but they can change their outlays along several possible adjustment margins. The one we mostly choose to focus upon is job-related education and training of workers.[24] This is, of course, a significant contributor to human capital investment of workers across their work lives.

To incorporate this channel of adjustment, the unit cost function includes training costs as $C = C\left(W_o, P_o^M\left(P_i\left(P_{si}\right)\right), R_o^T\right)$ where R_o^T is the per unit cost of providing job-related education and training to workers (in terms of the numeraire). Firms choose $T_o = C_{R^T}\sum_d \tau_{od} Q_{od}$ where C_{R^T} is the partial derivative of the unit cost function with respect to R_o^T. Training costs are assumed to not change with the Brexit news, though the model can be easily extended to accommodate them.

Proceeding as earlier for wages, the structural relationship for training responses is $\hat{T}_o = \alpha_T + \theta_{MT}\hat{P}_o^M + \theta_{XT}\hat{P}_o^X$, which is empirically operationalised as

$$T_{joqt} = \alpha_o + \alpha_{qt} + \theta_{MT} Log(P_{oqt}^M) + \theta_{XT} Log(P_{oqt}^X) + \theta_{ZT} Z_{joqt} + \eta_{joqt} \tag{3.10}$$

where T_{joqt} is a dummy variable indicating worker training receipt and η_{joqt} is an error term. The difference-in-differences instrumental variable estimates are θ_{MT} and θ_{XT}. In principle, firms can also respond along other margins of labour adjustment which can be determined analogously. More detail is given in Appendix C.

4 Data Description

A combination of individual-level and industry-level data sources from the UK, supplemented by trade data from various sources, are used.[25] Information on individual worker

[24] Other possibilities are overtime hours and hours worked, and we present some estimates briefly on this later in the paper.

[25] Detailed information on data sources and definitions are given in Appendix D.

outcomes comes from the quarterly Labour Force Survey (LFS), a large-scale representative survey of around 38,000 responding households in each quarter. The quarterly survey has a longitudinal design with households staying in the sample for five consecutive quarters, and a fifth of the sample replaced each quarter (which generates an 80% overlap in the samples for each successive survey). To cover a long enough pre-period before the referendum, LFS data was compiled for four full pre-referendum survey years, beginning in 2012 Q3, and two full post-referendum years, ending in 2018 Q2. The analysis therefore covers sixteen quarters pre-referendum (where the last quarter, 2016 Q2, includes the June 2016 referendum) and eight quarters post-referendum.

The two worker outcomes studied are hourly wages and job-related education and training. The hourly wage is defined for full-time private sector workers aged 22 to 65, based upon the wage questions asked in quarters 1 and 5 and the hours question asked in all quarters of the LFS. The survey also contains a series of questions on training, asked to individuals in all five quarters. The main one studied in this paper is whether individuals report that they received job related education and training in the four weeks preceding the survey.[26] There is also a longer window measure, which asks LFS respondents whether they have participated in training in the three months before the survey. Finally, LFS variables on gender, age, whether individuals have a degree, are natives, region and size of workplace are used as control variables in the empirical analysis.

Trade data was matched to the individual-level LFS data at the two-digit level of SIC 2007 classification, across the whole economy. This covers 85 industries, comprising 23 in manufacturing and 62 in services. This is the finest level of disaggregation at which supply-use tables are available for the UK, and for which there are reasonable sample sizes when matched to the Labour Force Survey. The trade measures come from the Office of National Statistics (ONS), including publicly available information on trade prices for manufacturing industries and from a freedom of information request we undertook to obtain trade prices for services. Two price indexes are produced by ONS, for export and import prices. An intermediate import price index is produced from the UK input-output structure.

The trade weights used to construct the intermediate import prices and the exchange rate measures are based on pre-referendum data combining goods trade from UN COMTRADE and services trade from ONS International Trade in Services (ITIS) for 2015. The shares S_{dxo} and S_{sio} for industry o are taken from the industry-country values of exports and imports reported in the ITIS by firms in each output industry. For goods, the UK does not conduct

[26]The four week aspect of the question does cause an issue in the weeks immediately following the referendum of June 23. The LFS survey is carried out in various weeks within the relevant quarter and so for the main analysis observations when individuals were surveyed on June 26, July 3, July 10 and July 17 of 2016 are omitted. This turns not to matter for the overall results, as discussed later.

a corresponding import use and export sales survey across firms. It is therefore necessary to use supply-use tables to construct $S_{sio} = S_{io}S_{si}$ for goods, where S_{io} is the share of imports of intermediate i used in output industry o from the UK Supply-Use tables and S_{si} is the share of source country s in UK imports of intermediate i in the pre-referendum period from UN COMTRADE data. As discussed above, and because it offers an exogenous currency shock, the exchange rate changes ΔE_c are measured for most of the analysis for the 24 hour window around the referendum date between June 23 and 24, 2016. In light of Borusyak et al. (2018), the empirical exercise benefits from a large number of exogenous shocks because the data cover 85 input/output industries which on average have non-zero imports from 146 countries (100 currencies) and non-zero exports to 177 countries (98 currencies).

Table 2 lists the top and bottom four industries of the depreciation/appreciation shock rankings. The upper panel shows these for the intermediate imports weighted depreciation and the lower panel for the exports weighted appreciation. The Table also reports relevant intermediate import and export shares of the three top partner currencies for the industries. It is very clear that the top four industries in both panels trade more with the US and the bottom four trade more with the EU. This strong variation across currencies is further confirmed by Appendix A Figures A3a and A3b which show the intermediate imports and exports trade weight composition by main trading partners for 11 broad industry categories, which are ranked by their depreciation (or appreciation) magnitude from left to right.[27] Figure A3a shows clearly how the country composition of industry trade with countries whose currency gained more ground against the pound (United States, Japan) maps into higher intermediate import weighted depreciation. The same is broadly true for the export counterpart, shown in Figure A3b, although in this case it is a little harder to see in the visual representation.

5 Results

This section reports the main findings of the paper. Following a discussion of the basic pre-post referendum features of the data, statistical results based on the trade and labour reduced forms are discussed first, after which the discussion moves to highlight how the reduced form findings can be combined to generate structural form estimates showing the causal impact of trade prices on worker outcomes.

[27]For disclosure reasons we are not able to provide trade weights and calculated depreciations at a more disaggregate level of industry or country of origin/destination.

Raw Difference-in-Differences

Table 3 shows what happened to the trade and worker outcome measures before and after the referendum by reporting changes between 2012 Q3 and 2016 Q2 (the before period) and 2016 Q3 and 2018 Q2 (the after period). The Table shows before/after referendum changes by quintiles of the exchange rate change measures, with panel A showing before/after changes by intermediate import weighted depreciation quintiles and panel B by exports weighted appreciation quintiles.

Considering first the before/after changes in trade prices with respect to the intermediate import weighted depreciation, columns (1) and (2) of panel A show clearly that higher depreciation industries experienced faster growth in intermediate import prices but not in export prices. On the former, the price of intermediate imports were 8.1 log points higher in the highest quintile depreciation industries in the post-referendum period, a higher growth rate than in the other quintiles, with the lowest increase of only 3.7 log points occurring in the lowest quintile. Growth in intermediate import prices in the middle three quintiles lies in between the two. The implied differences-in-differences between the top and bottom quintile is therefore 4.4 log points, reflecting a much bigger cost shock resulting from higher prices in the industries facing a higher exchange rate depreciation based on which countries they import intermediates from. The same is not true of export prices, which also rise in the post-referendum period albeit in a very neutral pattern with a highly similar rate of growth across quintiles.

There are also between-quintile depreciation differences in pre-post referendum changes in log(wages) and training receipt. These are shown in columns (3) and (4) of panel A of Table 3. Wage growth is seen to be lower in the relatively higher depreciation industries. In the highest fifth of industries ranked by depreciation, wages are around 5.5 percent higher, whereas in the bottom two quintiles they rise by nearly 8 percent. This corresponds to a highest-lowest quintile difference-in-differences of 2.5 log points. In qualitative terms, the same is true of training receipt. It falls by 0.8 of a percentage point in the upper quintile, and stays almost the same in the lowest quintile, again reflecting a statistically significant difference-in-differences of a -0.7 percentage point drop in training.

There is much less responsiveness – for all four outcomes variables – in the lower panel of Table 3 which considers pre-post referendum changes by quintiles of the exports weighted exchange rate appreciation. All of the highest-lowest quintile difference-in-differences are small in magnitude and statistically insignificant. In fact, the pre-post referendum changes are in all cases highly similar across all five quintiles for both trade price measures and both worker outcome variables.

The main action on changing trade price patterns and worker outcomes across industries

facing differential exchange rate shocks therefore very much comes about on the cost side of things, due to differences in intermediate imports weighted depreciations. This can be seen clearly in the scatter plots shown in Figures 2 and 3 that respectively chart the pre-post referendum changes for all 85 industries against the depreciation/appreciation measures for trade prices and worker outcomes.

Trade Prices

Table 4 shows results from estimating difference-in-differences reduced form specifications for prices of intermediate imports and exports. Results from log-log specifications are reported, with the coefficients on the depreciation/appreciation being elasticities that can be benchmarked against estimates from the exchange rate pass through literature. As the theoretical framework suggests, only the intermediate imports weighted depreciation is entered on the right hand side of the log(intermediate import prices) regression, whilst both this and the exports weighted appreciation are included regressors in the log(export prices) equation. Three specifications were estimated for each trade price, with the time period of estimation being different in each after a careful empirical examination of pre-referendum events and trade price trends.

The first specification, in column (1), reports estimates for the full sample of all 24 quarters between 2012 Q3 and 2018 Q2. In the case of intermediate import prices, shown in panel A, there is strong evidence that the exchange rate depreciation had a significant price raising impact, with an estimated elasticity of 0.38. This shows that industries with a higher sterling depreciation faced a bigger cost shock. A 10 percent higher depreciation (for example, a sterling depreciation of 6.6 percent as compared to the pound-euro fall of 6 percent) resulted in intermediate import prices going up by 3.8 percent. This is sizable, and in line with magnitudes seen in other work looking at price pass-through for imports. For example, in their study of large devaluations, Burstein and Gopinath (2014) estimate an exchange rate pass through of 0.37 (concurrent) to 0.87 (after two years) for import prices in the UK.

The full sample specification for export prices, shown in column (1) of panel B, however does not show responsiveness of export prices to either exchange rate measure. Both estimated coefficients are positive, but statistically insignificant.[28] In fact, the estimated price pass through from the exports weighted exchange rate appreciation is tiny at 0.006, and shows

[28]If the exports weighted appreciation variable was also entered into the intermediate imports price regressions, it always attracted a statistically insignificant coefficient and barely moved the estimated coefficient on the depreciation measure. For the column (1) panel A specification, the estimated coefficient (and associated standard error) was -0.007 (0.022) for the log(exports weighted appreciation) and 0.383 (0.100) for the log(intermediate imports weighted depreciation).

no pass through at all in sterling terms.[29] Maybe surprisingly, one cannot reject the null hypothesis that the Brexit vote induced exchange rate appreciation had no differential effect on industry export prices. Nonetheless, the column (1) specifications are suggestive that it is the cost channel that dominates in terms of reflecting effects of the referendum induced exchange rate shifts. It implies the main impact was to raise the price of intermediate imports, thus generating a cost shock that disproportionately hit industries more exposed to higher currency depreciations.

While some studies find high pass through of exchange rate shocks on export prices, the findings are more in line with the literature on global value chains where importing and exporting go hand in hand and access to intermediate inputs from abroad enables firms to export.[30] On first reflection, it might seem surprising that export prices do not move much despite the large exchange rate shock. But this is in fact consistent with a growing body of work that finds low exchange rate pass through on the exporting side (Amiti et al. 2014, Ahmed et al. 2015, de Soyres et al. 2018, Fauceglia et al. 2015). This literature on exchange rate disconnect identifies intermediate imports and global value chain participation as channels for low export responses due to rising import costs. Exports from OECD countries contain a large fraction of imported content, and this is true for the UK as well.

It is, however, premature to reach the conclusion that the key result is a depreciation induced cost shock to intermediate imports without first considering possible pre-referendum trend differences. This was explored carefully and quite extensively in various ways, looking at pre-trend differences in trade prices by depreciation (or appreciation) quintiles, and from including pre-trend quarter interactions in event study models. Figure 4 shows the issues of relevance in two related charts. The upper Figure 4a plots above/below median trends in log(intermediate import prices) for the 24 quarters of data used in the empirical analysis. It is clear that there are highly similar trends in intermediate import prices for the above and below median industries for the first nine quarters, after which there is some divergence as intermediate prices in the above median depreciation group of industries fall back. After another five quarters, the trends become similar again.

It turns out that two pre-trend events were behind these pre-referendum differences in the evolution of trade prices for higher and lower depreciation/appreciation industries. The lower Figure 4b shows dollar and euro exchange rate movements against the pound over the same period, highlighting the two pre-trend events of relevance. The first of these is the announcement that the referendum would take place, which was made on 22 February 2016. The second event generating a possible identification threat owing to differential pre-trends is

[29] The same is true if only the exports weighted appreciation variable was entered.

[30] See Berman et al. (2012) and Leigh et al. (2016) for export pass through.

potentially a more serious one, as there was a reasonably sustained exchange rate depreciation that occurred in the pre-referendum period which relates to when the United States stopped its quantitative easing (QE) programme and when the European Central Bank began theirs.

The two charts in Figure 4 are drawn to match on identical time scales and it is visually striking how closely they map on to one another. It is evident from looking at the two that differential trends in intermediate import prices for the above and below median industries were associated with pre-referendum exchange rate movements due to these events. First of all, consider the February 2016 announcement. Exchange rates did react to the news of this, albeit in a more muted aggregate manner when compared to the referendum result, as there was a drop in sterling on the day and the days that followed. One might therefore be concerned about the potential of this pre-referendum drop in exchange rates to influence pre-trends, especially since the structure of the exchange rate drop was very similar in terms of relative depreciations of sterling against different currencies, and because of possible hedging behaviour by firms.[31] Secondly, regarding the QE induced shifts, from 1 September 2014 to the announcement date there was a sharp drop in the pound-dollar exchange rate from 1.66 to 1.42, and a modest rise in the pound-euro exchange rate in the same period.[32]

The remainder of Table 4 therefore shows results when the time periods associated with these two events are excluded. Column (2) shows what happens to the trade price results if the time period of two quarters between the referendum announcement and the actual referendum is excluded. As one might surmise from closely inspecting Figure 4a, the results remain very much the same as in column (1) and the pass through to intermediate import prices actually rises a little, going up to 0.41 from 0.37. The exports price results are also highly similar. Results for trade prices with the QE depreciation quarters excluded from the estimation sample are shown in column (3).[33] The price pass through estimate actually rises again, going up to 0.53 from the column (1) estimate of 0.38. It thus seems that, if anything, the trade price responsiveness is underestimated owing to these pre-referendum trends, but that the evidence of a significant cost shock occurring due to the referendum induced exchange rate depreciation remains strong.[34]

[31]For the 26 currencies in Table 1, there is a Spearman rank correlation of 0.67 (with an associated p-value of 0.00) for the referendum date depreciation and the announcement depreciation (the latter being defined for a 7 day window around 22 February 2016).

[32]A significant correlation between the 24 hour referendum window and QE depreciation is clear for the 26 currencies in Table 1, with a Spearman rank correlation of 0.62 (with an associated p-value of 0.00) for the referendum date.

[33]Contrary to the significant correlation found between the 24 hour referendum window and QE depreciation, the Spearman rank correlation between the referendum drop in sterling and the change in the pre-QE period for the 26 currencies of Table 1 is of -0.006 (with an associated p-value of 0.98). This supports the idea that excluding the QE period helps to ensure the validity of parallel trends in the analysis.

[34]Results using the quantities of imports are shown in Table A1 of Appendix A. These confirm that the key

Wages

Table 5 reports estimates of reduced form difference-in-differences log(wage) equations and combines them with trade price first stages to report causal IV estimates of the impact of trade prices on wages. Estimates from four reduced forms are reported in the upper panel of the Table and are converted to their respective paired IV estimates in the lower panel of the Table. Estimates of two specifications, the first only including the intermediate imports weighted depreciation or prices and the second additionally including the exports based equivalents are shown for the full sample in columns (1) and (2). Columns (3) and (4) show equivalents of the first of these for the restricted samples already considered for the trade price results.

The full sample wages reduced form, shown in column (1) of the upper panel, shows a significant wage lowering effect of the intermediate imports weighted depreciation. The estimated elasticity is -0.19, showing that a 10 percent higher exchange rate depreciation was connected to a 1.9 percent fall in wages. The column (2) specification of the upper panel shows that it is the intermediate imports weighted depreciation effect that matters most as the exports weighted appreciation post-referendum effect is small and insignificant and leaves the baseline column (1) result almost unchanged - the coefficient on the intermediate imports weighted depreciation post-referendum effect remaining at -0.20.

The reduced form effect remains totally robust to the sample restrictions owing to the identification concerns raised by the referendum announcement and the earlier QE induced depreciation. When the announcement to referendum time periods are left out, the reduced form estimate shown in column (3) is -0.20 and when the QE period is omitted the estimate in column (4) is the same, again being -0.20. Thus the reduced form estimates are highly consistent and stable with the cost shock resulting from the referendum having a significant slowing impact on wage growth.

These strongly consistent reduced form impacts observed in the different comparison periods reflect that there are no significant issues on diverging pre-trends in wages before the referendum. This is confirmed by Figure 5 which shows remarkably parallel pre-referendum trends. The dotted gray and black lines showing mean wage growth before the vote are very close to each other, showing highly similar wage growth for high and low depreciation industries in the pre-referendum four year time period. Post-referendum the two lines diverge as wage growth is significantly lower for workers employed in the above median depreciation industries.

The lower panel of the Table shows the IV estimates. In column (1) the full sample re-

action in terms of responsiveness to the depreciation occurs in terms of prices.

duced form estimate of -0.19 is combined with the first stage trade price elasticity of 0.38 from Table 4 to produce a causal IV elasticity of -0.50. Thus, use of the referendum induced exchange rate depreciation as an instrumental variable for intermediate import prices uncovers a causal wage reducing impact from the trade induced cost shock. The reduced form and IV estimates pair in column (2) instrument both intermediate import and export prices using their respective trade weighted exchange rate changes. Not surprisingly given there is not a significant first stage for the export based measure, the results lose some precision but importantly the associated causal estimate remains highly robust, going to -0.53 from -0.50. However, because there was some degree of change in the first stage coefficients, the paired causal IV estimates shown in columns (3) and (4) do move somewhat. For the sample excluding the announcement to referendum time, the IV estimate gets a little smaller (in absolute terms) to -0.47; for the sample further excluding the QE depreciation period it becomes -0.32. Both estimates, however, show there to be a causal wage reducing impact of higher intermediate import prices. The quite tightly bound range is useful to demonstrate robustness of the key finding of a negative wage-intermediate import price elasticity, and for use as checks of sensitivity in the model calibration, which is presented later in section 7.

Training

An analogous set of results to the wage equations shown in Table 5 are given for worker training in Table 6. They further corroborate the negative effect of the cost shock induced by the exchange rate depreciation following the referendum vote on worker outcomes through an additional deskilling effect on top of the wage reductions. The results very clearly show that workers employed in higher depreciation industries experienced a significant fall in training. The reduced form impact is, as it was for wages, relatively stable across the four specifications reported in the upper panel (always being negative and statistically significant, and in the range from -0.052 to -0.073 showing that for a 10 percent higher intermediate imports weighted sterling depreciation the probability of training receipt was around 0.5 to 0.7 of a percentage point lower). The causal estimates of the impact of intermediate import prices, shown in the even numbered columns, is also negative. Thus, overall the cost shock from the referendum induced fall in sterling had both a wage lowering and a deskilling impact on UK workers.

6 Extensions

This section reports on further extensions, some of which emerge from the theoretical model, some pertain to related research and others focus on robustness of the main findings

reported to date. They are grouped under sub-sections for the three key empirical measures being studied in the paper - exchange rates, trade and worker outcomes.

Exchange Rates

Timing

For reasons already discussed in detail, the exchange rate variation exploited in the empirical work so far is the plausibly exogenous change that took place in between June 23 and 24 of 2016. Of course, exchange rate fluctuations that take place around a time window any longer than the information period reflecting the unexpected nature of the Brexit referendum shock may occur for reasons not to do with the shock itself. Looking at correlations with the 24 hour change and windows of 7 and 15 days reflects exactly this – the correlation is very strong for 7 days, but weakens as the window is widened. Tables A2 and A3 of Appendix A show comparable results to those using the 24 hour window measure, but by replacing the intermediate imports depreciation measure with one calculated in the same way for time windows of 7 and 15 days. The 7 day window results, shown in Table A2, prove very similar, albeit a little less precise in statistical terms. For the 15 day window, this imprecision becomes more marked. This is unsurprising, and in line with the argument that exchange rate movements are likely reflecting other information flows not related to the foreign exchange market's reaction to the unexpected referendum vote.

Currency of Invoicing

A growing literature has documented the prevalence of invoicing in currencies other than those of the source and destination countries. When prices are sticky ($\kappa^M < 1$), the estimated price pass through could be low in a given time period if some firms were not able to re-set their prices in that window (example, Gopinath, Itskhoki and Rigobon 2010). Then the estimated price pass through need not reflect its potential long-term import price rise.

To empirically examine the importance of this for our results, the depreciation measure can be adjusted for the shares of different types of invoicing across various source countries. As in most countries, the currency of invoicing is not recorded in the UK for services trade (and for goods trade with the EU). The exchange rate measure is therefore re-defined by using the aggregate goods-trade shares of currency of invoicing undertaken in local currency pricing (LCP), producer currency pricing (PCP) and vehicle currency pricing (VCP) across non-EU countries as reported in Chen et al. (2019). Specifically, the baseline exchange rate measure uses the source country's exchange rate E_s. The re-defined exchange rate measure instead uses $S_s^{PCP} E_s + S_s^{LCP} \cdot 1 + \left(1 - S_s^{PCP} - S_s^{LCP}\right) E_v$ where S_s^{PCP} is the share of producer

currency pricing in imports from country s and S_s^{LCP} is the share of local currency pricing in imports from source country s. The vehicle currency is the US Dollar for all countries except European countries (not in the EU) for which it is the Euro.[35] Appendix Table A4 shows for this redefined measure that the intermediate import price pass-through increases slightly to 0.42 (from 0.38) and the reduced form wage coefficient falls slightly (in absolute terms) to -0.13 (from -0.19), resulting in an IV estimate of -0.32. Thus the adjustment broadly leaves the results unchanged, and within the earlier bound. This is unsurprising in light of the highly disaggregate goods trade results of Chen et al. (2019), which also finds that the two-year import price pass-through elasticity barely changes (from 0.41 to 0.43) when the actual currency of invoicing is used instead of the source country currency over a two-year window.

Trade

Initial Trade and Cost Structure

One further question of interest is whether the initial trade structure also impacted upon trade changes, or whether it is the exchange rate impact upon intermediate prices that was the key outcome associated with the referendum induced exchange rate depreciation. Table 7 considers this by additionally entering the share of imported intermediates in total intermediates interacted with the post-referendum dummy into the estimating equations.[36] In undertaking this exercise, it is important to bear in mind that any levels effect of these variables are absorbed into the industry fixed effects that have been included in all the statistical specifications already reported. The estimated coefficients on the interacted initial trade structure measures themselves turn out to be statistically insignificant and do not affect the general tenor of the results. This suggests the country variations in depreciations are what matters for the overall findings, and not just the initial trade structure across industries.

To further explore heterogeneity based on differences in labour to intermediate import shares in costs across industries, Table A5 reports reduced form wage coefficients with inclusion of (S_{PMC}/S_{WC}) X Log(Intermediate Imports Weighted Depreciation) X Post-Referendum and (S_{PMC}/S_{WC}) X Log(Intermediate Imports Weighted Depreciation) X Post-Referendum. The magnitude of the reduced form wage coefficients barely change, again implying that the key driver is differences in depreciation rather than initial differences in factor shares across

[35] As invoicing shares are not available for the EU and Japan, they are assigned the shares of LCP, PCP and VCP in UK trade with the United States.

[36] Other trade variables were considered. For example, an interaction of the post-referendum dummy variable with the share of exports in final demand was additionally entered into the specifications. Its inclusion had no impact and since there is no first stage on the exports side of things, we did not pursue this any further.

industries.

Import Competition

Exchange rate depreciation could affect worker outcomes through competition in the output market, which is not picked up in the intermediate imports and the exports of the output industry. To capture all final, direct and indirect imports of an output industry, import competition in the output market is defined as total imports of industry *o* into the UK. The main results remained very robust to inclusion of a measure of the exchange rate depreciation weighted by import competition. Table 8 shows the reduced form coefficients on the Log(Intermediate Imports Weighted Depreciation) X Post-Referendum variable in the specifications for intermediate import prices, wages and training are comparable to those reported in column (1) of Tables 4, 5 and 6 respectively. The coefficients on the Log(Total Imports Weighted Depreciation) X Post-Referendum variable have the same sign as the coefficients on the Log(Intermediate Imports Weighted Depreciation) X Post-Referendum for intermediate import prices and training, but were imprecisely estimated for wages. Most importantly, inclusion of the import competition weighted variable makes no difference at all to the magnitudes and significance of the trade price and worker outcome reduced form coefficients.

Worker Outcomes

Margins of Labour Adjustment

To explore whether labour market adjustment occurred over other margins, estimates of an analogous form to the wages and training specifications were produced for: wages of all workers (rather than full-timers); individual hours worked; paid overtime hours worked; labor market flows (industry inflow and outflow rates); industry employment growth. Table 9 shows the estimates, with reduced form specifications in the upper panel, and paired IV estimates in the lower panel. The specification in column (1) shows that considering wages of all workers produces highly similar findings - the estimates turn out to be statistically a little bit stronger and the magnitudes of the causal IV estimates a little larger (in absolute terms) with the main result of wage falls being connected to the rise in the costs of intermediate inputs remaining strong. The different forms of possible employment adjustment are shown in columns (2) through (5). All bar one attract statistically insignificant coefficients, revealing that the key form of labour market adjustment to the depreciation induced cost shock was downward wage adjustment.

The one significant finding is for paid overtime hours, and this does uncover evidence of significant reductions, suggesting this is an additional margin by which employers were able

to adjust to the depreciation shock. However, this is not an especially important margin as paid overtime is very rare in the UK labour market. The qualitative nature of the paid overtime reduction does complement the training cutback evidence shown earlier, which suggests that it was not just wages that fell as a result of the depreciation induced cost shock that occurred. It is also consistent with Campa and Goldberg (2001) who find much higher magnitudes of overtime elasticities using two decades of US manufacturing data. This is suggestive that more easily adjustable flow variables (like training and overtime) that are often components of intangible capital can be studied to detect early signs of economic adjustments to shocks. They are likely to respond faster than stock variables like employment that are also subject to contractual obligations and search frictions.

Heterogeneity by Skill

Previous empirical work has found evidence of differential degrees of complementarity/substitutability between imports and workers of different skill levels. Table 10 shows estimates for full-time wages and training of high-skilled and low-skilled workers. The estimates are broadly robust across the different sample restrictions. There is evidence that high-skilled workers (defined as college graduates in the context of the analysis) have a higher degree of complementarity with intermediate imports than low-skilled workers. This is similar to the offshoring results of Hummels et al. (2014), which also suggests greater complementarity between intermediate imports and high-skilled workers, relative to intermediate imports and low-skilled workers.[37]

Measurement of Worker Outcomes

Further robustness checks, relating to the training and wage measures used, are reported in Appendix Table A6, first studying what happens when the observations that were previously excluded on the grounds of being within a four week window of the referendum are put back into the analysis, second looking at an alternative training measure from the Labour Force Survey. The first two columns of the Table also show that reinstating the previously excluded observations also does nothing to the basic IV results. The negative wage and training effects

[37]In terms of other aspects of heterogeneity, work by Ottaviano et al (2013) suggests migrant workers and offshoring have a higher degree of substitutability than do native workers in the context of manufacturing industries in the United States. Estimating the wage and training responses across nativity and skill dimensions of heterogeneity, wage estimates for migrant workers are lower in absolute magnitude than for native workers across skill groups. Wages and training of high-skilled migrants respond negatively to the rise in intermediate import prices, while low-skilled migrants actually show a positively signed (albeit statistically insignificant) wage effect, suggesting substitutability with respect to imported intermediate prices. The results are also robust to including the initial share of migrants interacted with the post-referendum dummy.

remain intact, and highly similar to the estimates reported in the earlier Tables 5 and 6. The final column (3) of the Table shows results for training receipt over a longer time period, the three months preceding the survey. This offers a useful counterpoint to the more commonly studied four week measure, in that it is likely to have a lower proportion of induction training for newly hired workers. The estimates prove robust and, if anything stronger in statistical terms, when using this measure.

7 Interpretation

This section offers an interpretation of the key findings. There are two main components. The first is a discussion of the nature of the Brexit news shock and the means by which this may have acted to induce adjustment in the labour market via changes in trade. The second is to calibrate the structural wage estimates to infer the Allen elasticity of substitution from the theory in an exercise that connects back to the model presented in section 3, and to consider implications of the findings in light of other related research.

Discussion

To more fully understand the impact of the Brexit news shock on both trade and worker outcomes, it is important to discuss the economic forces that underpinned the unexpected exchange rate variation that took place on the night of the referendum. According to the theoretical model presented earlier, and the main interpretation offered so far in the discussion of the empirical findings, it is the cost shock that raised the price of intermediate imports that, in turn, resulted in lower wage growth and training cutbacks in industries that faced a bigger shock.

One issue of direct relevance is that the exchange rate shock could, at least in part, be capturing differential changes in economic expectations associated with trading with different countries that occurred in the wake of the vote to leave. Measuring economic uncertainty and future expectations is notoriously difficult, even at the aggregate level (Baker et al. 2016, Bloom et al. 2018). However, the UK's premier business organisation, the Confederation of British Industry (CBI), conducts quarterly surveys of its member businesses to canvass their expectations over business conditions in their industry. Specifically, the survey asks each firm: "Are you more, or less, optimistic than you were three months ago about the general business situation of your industry?".[38] We have therefore looked at responses to the CBI survey before and after the referendum, both at the aggregate level and for industries broken

[38]The question is available for firms surveyed by the CBI in manufacturing, services and financial services sectors, but not in distributive trade services. See Appendix D for more details.

down into higher and lower depreciation industries.

Responses to the CBI survey reveal there to be a very sharp increase in the proportion of respondents saying they were less optimistic in the post-referendum period. In the quarter before the referendum took place, 21 percent stated they were less optimistic (and 23 percent that they were more, with 56 percent staying the same). In the quarter directly following the referendum, the percent less optimistic rose very sharply to 47 percent (with comparable percent numbers for more and same respectively being drops to 11 and 42). In quarters following this, however, the percentages were highly similar to pre-referendum responses. One way of thinking about this is that, in the wake of the unexpected leave vote, there was a sharp increase up in business uncertainty which stayed permanently higher in the post-referendum period.

This aggregate pattern is clear from Figure 6 which plots quarterly data on the proportion of CBI respondents stating they had become less optimistic about their business situation relative to the past three months for industries with above median and below median intermediate imports weighted depreciation. There is a very big spike up in 2016 Q3. However, this appears to be a common shock to high and low depreciation industries. The responses are extremely similar across these two groups of industries.

Thus, whilst a more uncertain business environment clearly seems to be a feature of what happened in the UK economy following the Brexit vote, this seems to apply in a highly similar manner in industries that faced bigger and smaller depreciation induced cost shocks that were driven by differential currency movements. The common shock is therefore not a confounder of the reported results, even though it is evidently a factor at work in the post-referendum economic landscape of the UK.

A further issue for interpreting the results concerns their timing. Looking closely at the above/below median difference-in-differences charts in Figure 4a for intermediate import prices and Figure 5 for wages reveals that the jump up in intermediate import prices took place almost straight away in the quarters following the referendum. Wage adjustment, however, was not so instantaneous and actually the wage disparities begin to emerge at the start of 2017. As such, it seems like the staggered timing of the trade price and worker outcome responses acts to reinforce the causal pattern of results that run in the direction of higher import prices reducing worker outcomes, as the model of section 3 suggested.

Calibration

The theoretical discussion of section 3 highlighted a number of key aspects of connections between trade and worker outcomes. The key empirical estimates can be tied back to the model predictions through a calibration exercise. The first issue of interest considers what the

reported results on wages have to say regarding the extent of substitutability/complementarity between labour and intermediates, including variations across different types of workers. The second is how the findings square up with estimates from related research. Lastly it is useful to consider how the findings on training being a notable margin of adjustment to a cost shock to trade operates.

The estimated wage elasticity with respect to intermediate import prices, $\hat{\theta}_{MW}$, is negative in all reported specifications and, depending on the sample, lies in a range from approximately -0.30 to -0.55. Returning to the theory, this corresponds to there being a gross complementarity between workers and intermediate imports in production. To understand what the elasticities imply about the Allen Uzawa elasticity of substitution, we can specify the parameters from data and the existing literature. The elasticity of labour demand is taken as -0.5 which is standard in the literature for short term labour market responses. Moving on to incorporate the indirect effects from domestic price, the estimated structural wage coefficient can be calibrated to the demand side of the model to arrive at the production elasticity of substitution. Then the probability of price adjustment with respect to factor costs is set to $\delta\kappa = 0.25$. The share of home sales in the UK is $S_{uk} = 0.7$ and the relative share of wages to intermediate import costs is $S_{WC}/S_{P^MC} = 0.4/0.1$ in the UK data. The output elasticity of substitution is varied between 1, 3 and 5, based on the literature. Then the range of Allen Uzawa elasticities is -1.54 to -3.80 in Table 11 which implies net complementarity for all of the configurations reported.

As stated earlier in the paper, in both the theoretical setup and in the empirical implementation, trade prices are used to compute the appropriate elasticities. To our knowledge, ours is the only study based upon recent data that uses prices, and that looks at intermediates. The much earlier work on the effect of import competition on wages and employment by Grossman (1987) and Revenga (1992) does study import prices and reports evidence of positive wage-import price elasticities in US manufacturing in the 1960s, 1970s and 1980s. For intermediate import prices, with UK data from 2012-18, our study finds the opposite sign for the wage-price elasticity. One way in which this apparent contradiction could be resolved is if the rising importance of intermediate imports over time has changed the nature of the relationship between imports and wages and they have shifted from being substitutes for labour in the past towards being complements more recently. This is in fact what Grossman and Rossi-Hansberg (2008) model as a labour-augmenting productivity effect that raises domestic wages through cost savings from offshoring, and is also raised in the more recent empirical work on offshoring. It is also in line with two empirical observations: first, that far more imports are now intermediates; and second, the well established finding of productivity

enhancing effects of intermediate imports.[39]

Rather than looking at trade prices, the newer research on offshoring and the labour market utilises trade value data (surveyed by Hummels et al. 2018). Because values contain both price and quantity components, this does not map well to the theoretical concept of an elasticity of substitution among factors. Moreover, it is often the case that value measures are expressed as the share of imports in total purchases and therefore also contain changes arising from domestic intermediate supply conditions (Feenstra et al. 2010). Nonetheless, and despite these reservations regarding value measures, the magnitudes of the wage-price elasticities that we have estimated and their implications for complementarity/substitutability can, with some appropriate assumptions about import demand elasticities, be compared with related work based on values. Specifically, if one is willing to assume an intermediate import demand elasticity in line with the literature of -4.8 (the median in Alfaro et al. forthcoming, based on further developing numbers from Broda and Weinstein 2006), an empirical wage elasticity with respect to import values can be calculated in the range 0.08 to 0.14.[40] This modestly sized, but positive elasticity reflects, on average, the complementarity between labour and intermediate imports.

Most of the wage elasticities with respect to intermediate import values reported in the offshoring literature are small and of varying sign across different papers (see the Hummels et al. 2018 survey). They also display heterogeneity across different worker types, in particular by skill. For example, the offshoring estimates for Danish manufacturing reported in Hummels et al. (2014) are in the range of 0.03 to 0.07 for high-skilled workers and -0.06 to -0.11 for low-skilled workers (in their Table A5). As Table 10 showed earlier the estimates also display heterogeneity by skill. Under the same assumption as made before regarding the import demand elasticity, the empirical wage-intermediate import value elasticities for graduates are around 0.16, to 0.17, a little higher than the Hummels et al. range. One cannot reject the null hypothesis of a zero elasticity for the non-graduate group (numerically the range runs from 0 to 0.05). This suggests complementarity with intermediates is confined to the graduate group.

The estimates, like those of Hummels et al (2014), show that, in relative terms, graduates are more complementary to intermediates than non-graduates. Therefore the finding that the graduate/non-graduate wage premium is increased by intermediate imports is also common to our study. Moreover, the wage premium impact has an implied magnitude that is highly similar to Hummels et al., with the estimates between 0.11 and 0.17 lying within their range

[39] See, inter alia, Amiti and Konings (2007), Kugler and Verhoogen (2009, 2012), Kasahara and Lapham (2013), Halpern et al. (2015).

[40] Specifically, it is computed as $\hat{\theta}_{MW} \cdot (1/(1-4.8))$.

of 0.09 to 0.18.[41]

The earlier analysis also reported significant training cutbacks connected to higher intermediate import prices. The IV specifications reported earlier were linear probability models with a binary dependent variable and so are semi-log estimates. The IV semi-elasticities range from -0.09 to -0.20. Converting to an elasticity produces estimates of the order of -0.88 to -1.81. These are evidently larger in absolute terms than the wage elasticities, intuitively suggesting a greater sensitivity of training to trade prices. As discussed in the introduction, there is little work on training responses to trade, despite the very obvious salience of training as a labour adjustment mechanism to globalization. Of the small body of research that does study training and trade, its focus is mostly on public training programs (for example, Hummels et al. 2012, Hyman 2018). Recently, a few papers have started to examine on-the-job training and its relationship with import penetration, typically from low-wage countries, and they find mixed results. In recent work using US Survey of Income and Program Participation (SIPP) data, Guner et al. (2018) find that the share of workers receiving job training dropped significantly more in occupations with growing import penetration. They model globalization as raising the returns to on-the-job training for high-skill workers, relative to low-skill workers, which is consistent with our finding of a negative training response for graduates after a rise in intermediate import prices.

8 Conclusions

This paper presents new evidence on empirical connections between trade and the labour market. It does so by considering what happened to both trade and worker outcomes in the face of a big world event that produced an unprecedentedly large negative shock to the UK exchange rate. In the 24 hours around the previously unexpected vote by the UK electorate to leave the European Union, the value of sterling fell massively against other nations' currencies. The empirical analysis exploits this currency depreciation and its variation by the different structure of trade partners across industries to look at the causal impact of trade on wages and future earnings potential measured by job related education and training. Intermediate import prices rose by more in sectors where the exchange rate depreciated by more and this exerted a negative effect on worker outcomes. Both training and hourly wages fell for workers employed in sectors where intermediate import prices rose by more due to the sterling depreciation.

The finding of falls in wages and training after the Brexit vote offers poignant evidence on

[41] In their pioneering work studying intermediates, Feenstra and Hanson (1999) also find higher shares of offshoring increase wages for non-production workers and to some degree for production workers (when offshoring occurs outside the main industry of activity).

how the recent surge in economic nationalism is taking its toll by adversely affecting workers.[42] Many have argued that the economic disparities of the last few decades have polarised people and contributed to the current rise in nationalist politics. A common rationale behind nationalist policies is that putting up protectionist barriers protects domestic production and would undo the economic damage suffered by those who lost out earlier. This reasoning very clearly does not account for trade no longer being dominated by final demand, nor recognise that the fragmentation of production into global value chains has changed the classic reasoning on protectionism. Calibrating the estimated wage elasticity with respect to intermediate import prices to theory reveals complementarity between workers and intermediate imports. Thus the cost shock that made intermediate imports more expensive required an adjustment by employers, and workers took a hit in the form of lower wages and training.

At the very least these results show that trade is no longer dominated by final demand, and that in the modern world of global value chains, the way in which trade impacts on worker welfare does not fit traditional conclusions. To reiterate the point, in a classic setting with just trade in final goods, the sterling depreciation from the Brexit vote would be expected to benefit UK exporters and increase demand for domestic workers. Instead, it seems to have had a relatively deskilling impact upon workers in industries that rely on specific foreign sources for their intermediate inputs, and it is this effect which dominates. This has scope to translate into a long-term negative impact on human capital and worker earnings — quite the opposite of what the leave vote was expected to deliver by some. Moreover, consumer price inflation rose after the Brexit vote, especially in product categories that had higher shares of imported products (as documented by Breinlich et al. 2017), and this has further ramifications for workers' living standards.

The paper therefore concludes by showing what happened to real wages following the referendum. Figure 7 recasts the earlier nominal wage chart in real terms and plots real wage growth for workers employed in above median versus below median depreciation industries. Because of the price inflation surge following the vote, in the post-referendum period real wages do not grow at all for either group. Prior to the vote they were on almost exactly the same trajectories of (by historical standards) weak real wage growth.[43] The post-referendum lack of real wage growth features essentially zero growth for two years for the below median depreciation group. Real wages fell significantly for the above median depreciation group. Thus the combined evidence on wage and price consequences of the Brexit vote shock shows there to have been an aggregate decline in real earnings for workers, with this featuring a

[42] This resonates with recent findings of Amiti et al. (2019) and Fajgelbaum et al. (2019) which examine the price and welfare effects of tariffs imposed by the Trump administration in 2018.

[43] See Blanchflower et al. (2017) for more detail on the UK's historical real wage movements.)

more pronounced decline for those facing a larger cost shock. This has acted to reinforce and exacerbate pre-existing trends of real wage stagnation that have already been particularly marked for UK workers in the past decade. Coupled with the deskilling that resulted from training cutbacks, UK workers have not fared well since the referendum. Over and above the Brexit din, and the key related issues about the future of trade, the episode studied therefore adds to widely expressed, growing concerns about poor productivity performance relating to skills and to patterns of real wage stagnation that are plaguing contemporary labour markets in many countries.

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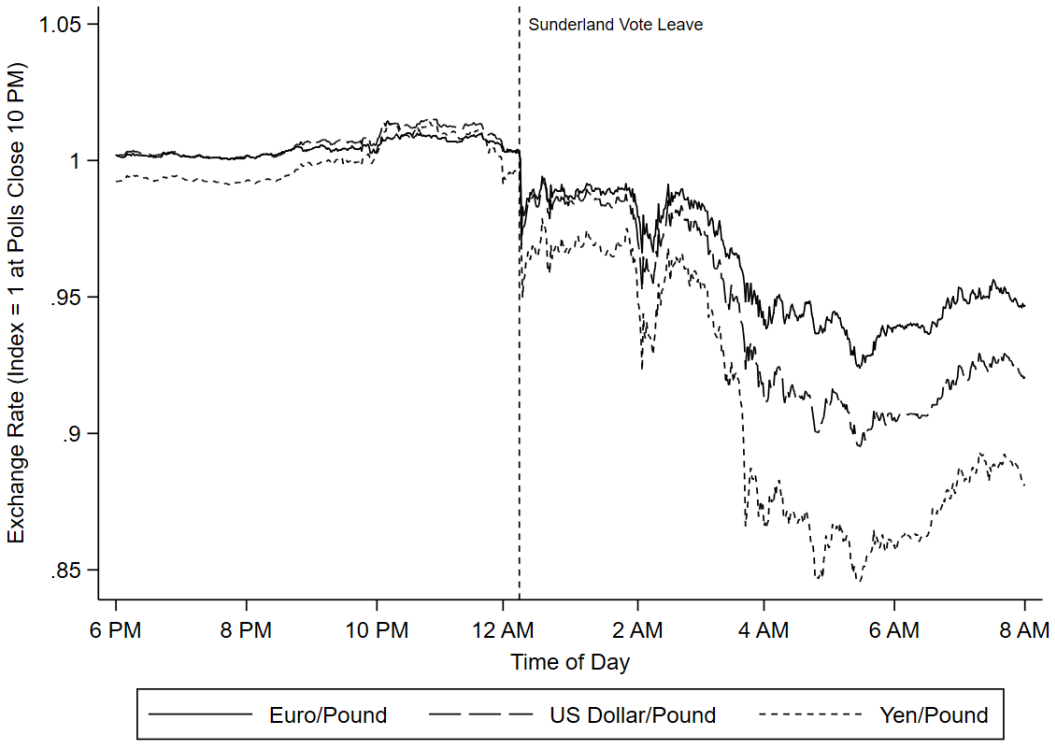
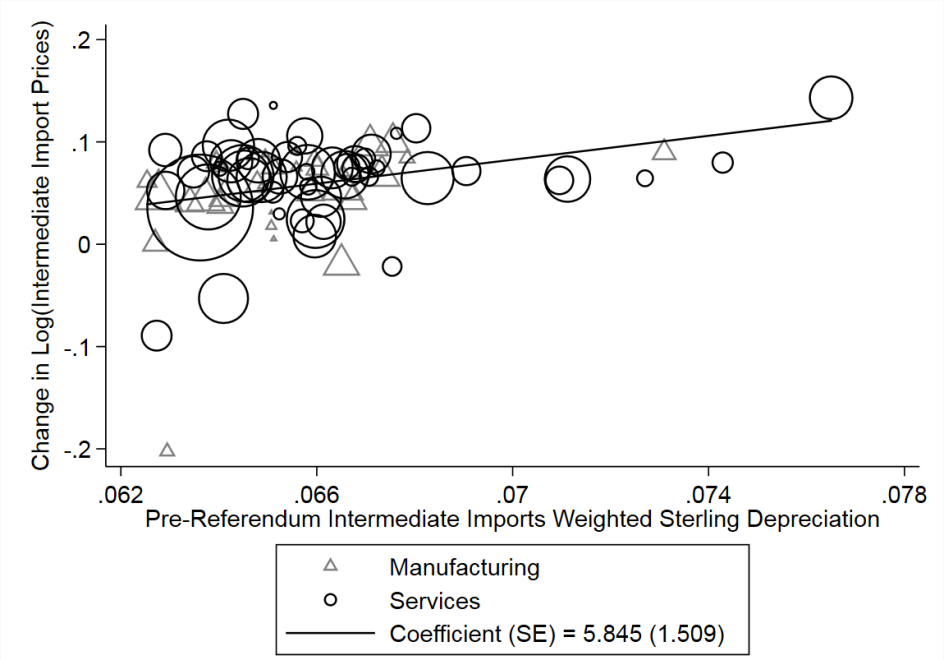
Figure 1: Exchange Rate Movements in the 6 PM to 8 AM Window



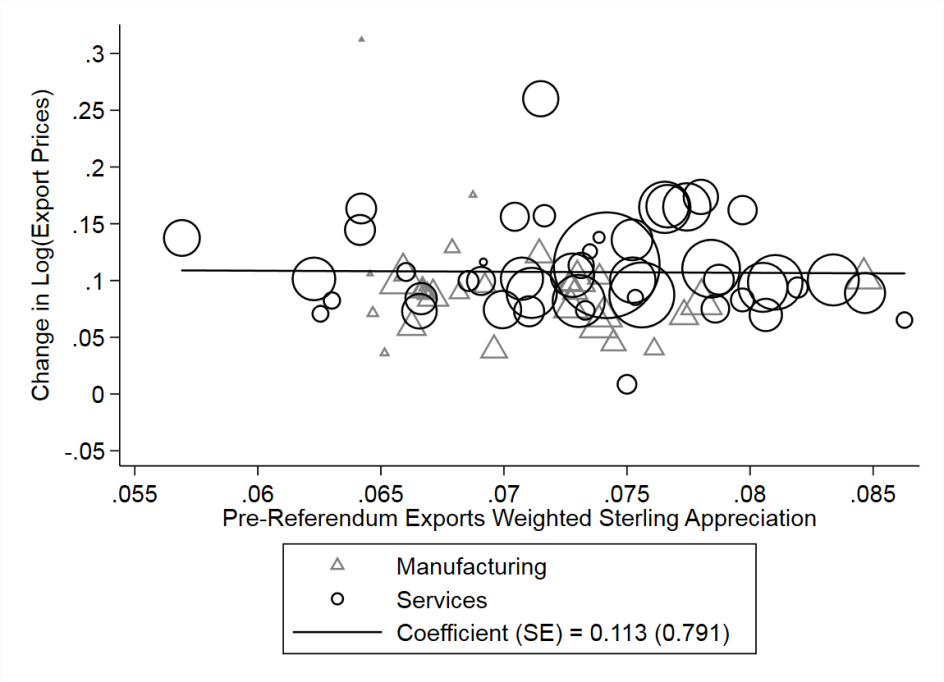
Notes: Exchange rates are taken from HistData (FOREX).

Figure 2: Post - Pre Referendum Changes in Trade Prices

(a) Intermediate Import Prices



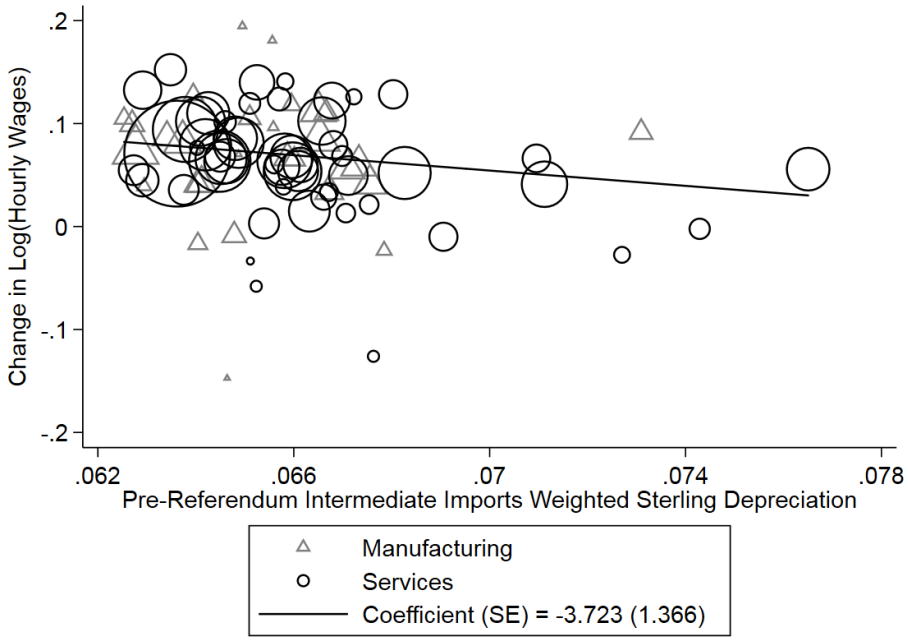
(b) Export Prices



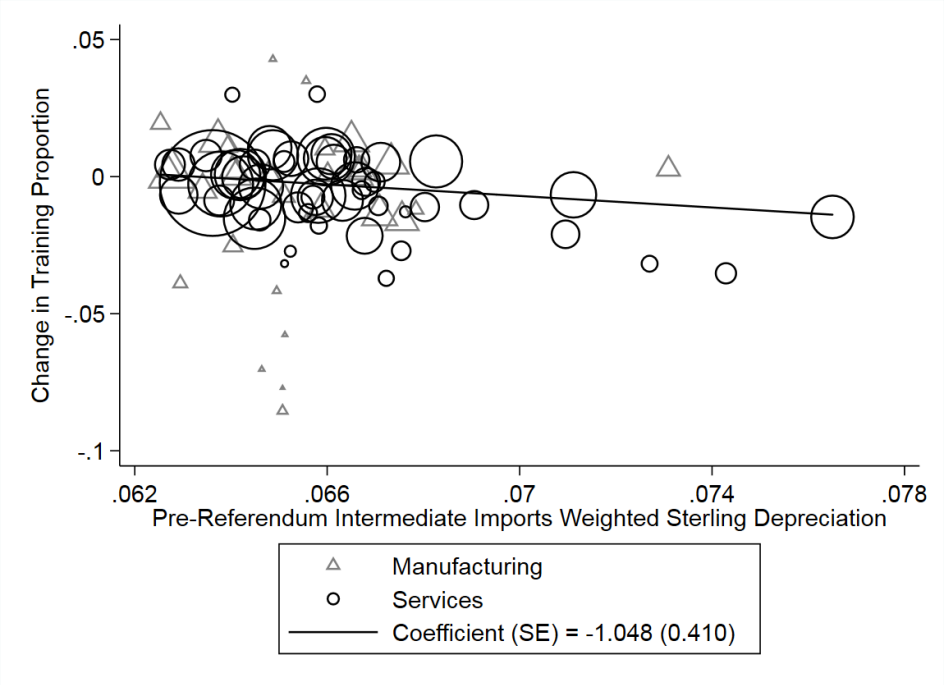
Notes: Size of the markers proportional to LFS industry weights.

Figure 3: Post - Pre Referendum Changes in Worker Outcomes

(a) Wages



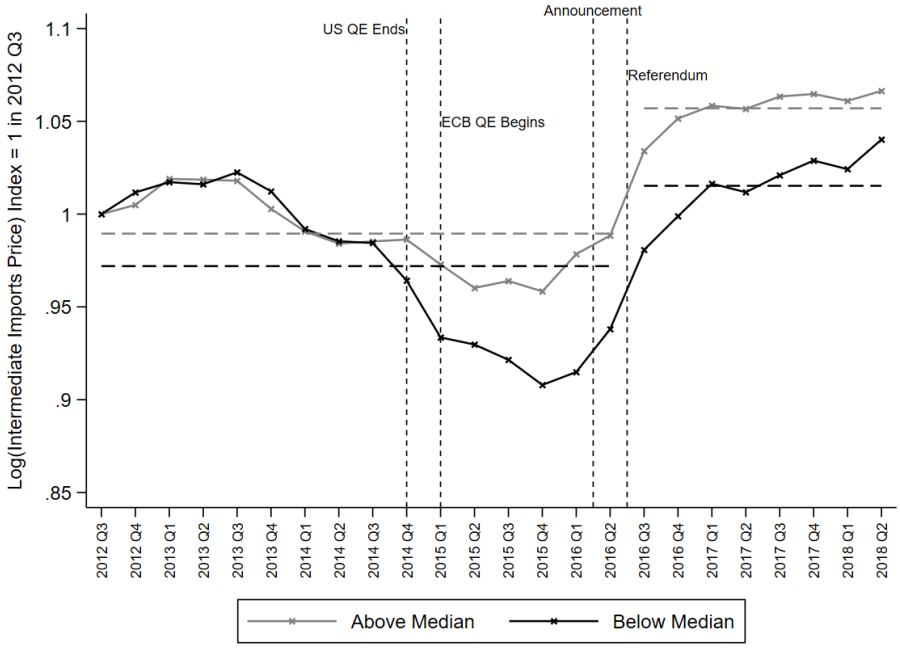
(b) Training



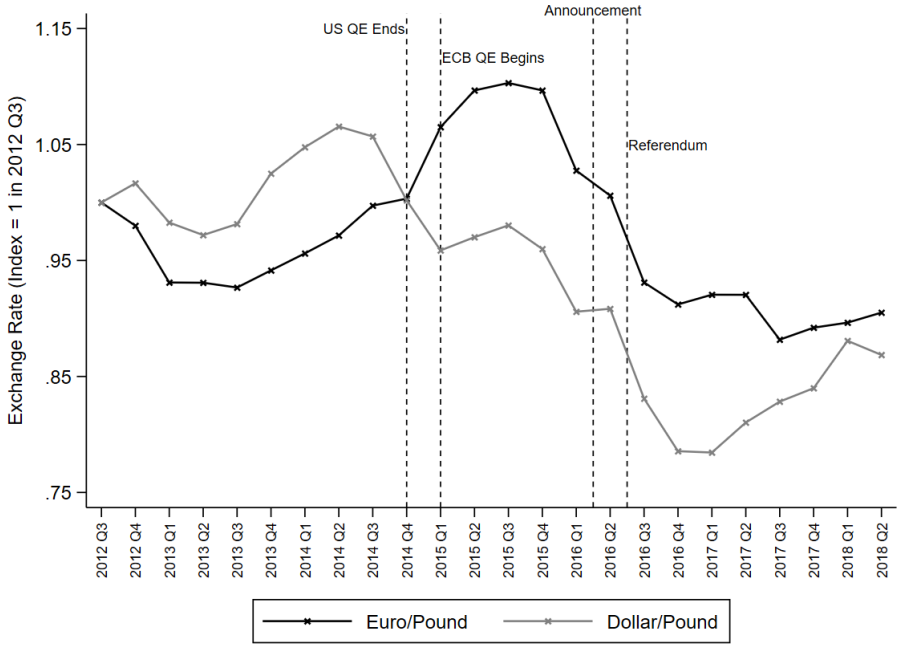
Notes: Size of the markers proportional to LFS industry weights.

Figure 4: Trends in Intermediate Import Prices

(a) Intermediate Import Prices

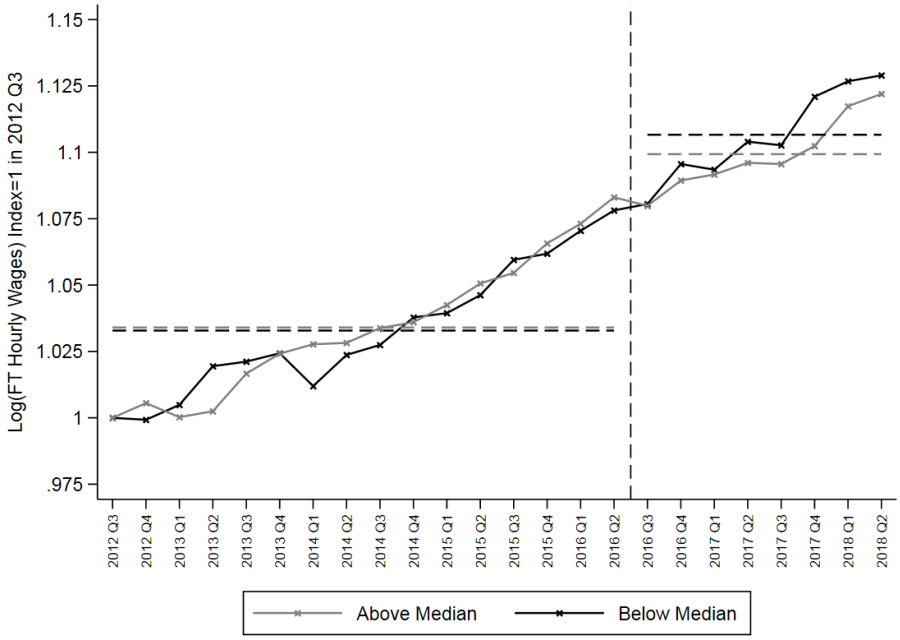


(b) Dollar and Euro Exchange Rates



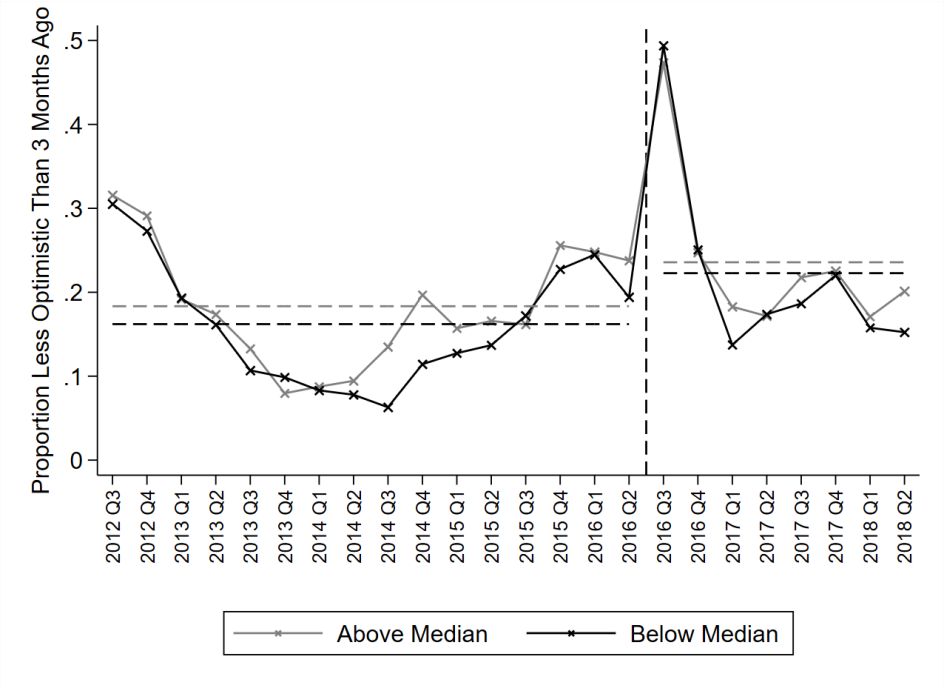
Notes: Log of average intermediate import prices calculated using LFS industry weights. In (a) the gap (and associated standard error) between the horizontal lines showing above/below median averages in the pre-referendum period is 0.016 (0.011) and 0.033 (0.007) in the post-referendum period. Daily exchange rates are from Reuters Datastream. Quantitative Easing (QE) episodes are marked at time of announcement from Federal Reserve Board and European Central Bank.

Figure 5: Trends in Wages



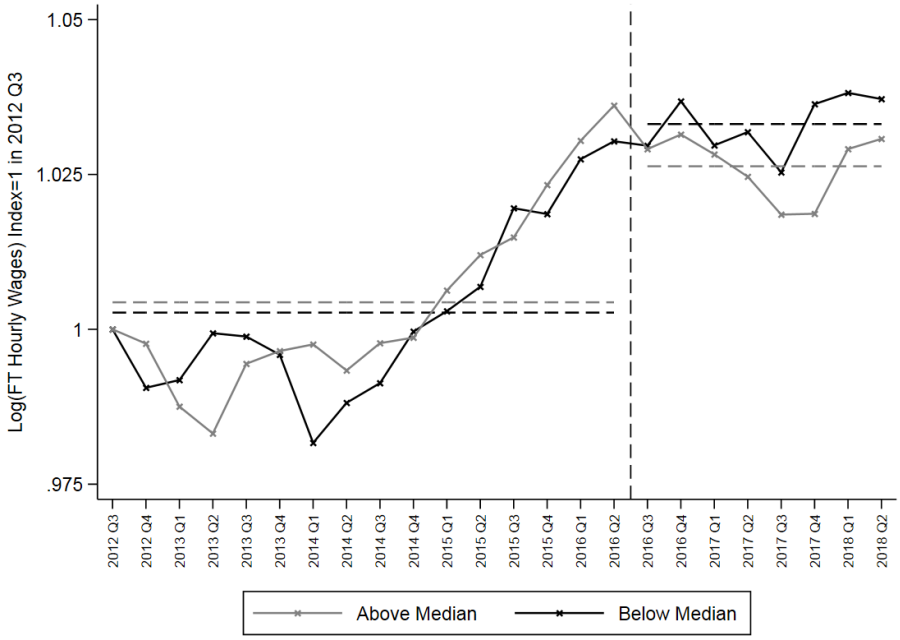
Notes: Log of average wages calculated using LFS industry weights. The gap (and associated standard error) between the horizontal lines showing above/below median averages in the pre-referendum period is 0.001 (0.005) and -0.007 (0.003) in the post-referendum period.

Figure 6: Trends in Business Optimism



Notes: Proportion responding that they are less optimistic from CBI respondents within the two industry groupings calculated using LFS industry weights. The gap (and associated standard error) between the horizontal lines showing above/below median averages in the pre-referendum period is 0.021 (0.026) and 0.013 (0.011) in the post-referendum period.

Figure 7: Trends in Real Wages



Notes: Log of average real wages calculated using LFS industry weights. The price deflator used is the CPIH. The gap (and associated standard error) between the horizontal lines showing above/below median averages in the pre-referendum period is 0.001 (0.005) and -0.007 (0.003) in the post-referendum period.

Table 1: Country-Specific Sterling Depreciations, 23 to 24 June 2016

	Currency	Percent Depreciation
Japan	Japanese Yen	11.1
United States	US Dollar	8.0
Saudi Arabia	Saudi Riyal	8.0
Hong Kong	Hong Kong Dollar	7.9
Thailand	Thai Baht	7.6
China	Chinese Yuan	7.5
Singapore	Singapore Dollar	7.4
Taiwan	Taiwan Dollar	7.2
Russia	Russian Ruble	7.2
India	Indian Rupee	7.1
New Zealand	New Zealand Dollar	7.1
Australia	Australian Dollar	6.9
Canada	Canadian Dollar	6.9
Israel	New Israeli Shekel	6.8
Switzerland	Swiss Franc	6.6
Turkey	Turkish Lira	6.5
Malaysia	Malaysian Ringgit	6.3
Denmark	Danish Krone	6.1
Euro Zone	Euro	6.0
Czech Republic	Czech Koruna	5.9
South Korea	Korean Won	5.7
South Africa	South African Rand	5.3
Hungary	Hungarian Forint	5.2
Norway	Norwegian Krone	5.2
Sweden	Swedish Krona	5.1
Poland	Polish Zloty	4.3

Notes: Exchange rate depreciations defined over 24-hour window for official set of currencies listed by the Bank of England.

Table 2: Currency Variations in Top and Bottom 4 Industries

(a) Intermediate Imports Weighted Depreciation

SIC	Industry	Import Shares of Top 3 Partner Currencies
A. Top Four Industries		
66	Security and Commodity Contracts and Fund Management	USD 44%, Euro 23%, Yen 6%
72	Biotech, R&D services	USD 47%, Euro 22%, Swedish Kr 10%
09	Mining Support Service Activities	SGD 29%, Euro 17%, USD 13%
60	Radio and TV Programming/Broadcasting	USD 47%, Euro 35%, Yuan 3%
B. Bottom Four Industries		
17	Manufacture of Paper and Paper Products	Euro 56%, Yuan 9%, USD 8%
24	Manufacture of Basic Metals	Euro 33%, USD 11%, CDN 10%
35	Electricity, Gas and Steam Supply	Nor. Kr 39%, Euro 12%, Alg. Dinar 7%
10	Manufacture of Food Products	Euro 53%, USD 7%, Yuan 5%

(b) Exports Weighted Appreciation

SIC	Industry	Export Shares of Top 3 Partner Currencies
A. Top Four Industries		
91	Libraries, Archives and Museums	USD 15%, Euro 17%, Yen 7%
52	Warehousing and Support for Transportation	USD 34%, Euro 30%, Yen 11%
33	Repair and Installation of Machinery and Equipment	USD 53%, Euro 12%, Saudi Riyal 8%
88	Social Work Activities Without Accommodation	USD 95%, Polish Zloty 3%, Euro 2%
B. Bottom Four Industries		
45	Wholesale and Retail Trade of Motor Vehicles	Euro 52%, Swedish Kr 34%, USD 6%
68	Real Estate and Leasing Activities	Euro 52%, GBP 14%, USD 12%
36	Water Collection, Treatment and Supply	Euro 53%, GBP 47%
92	Gambling and Betting Activities	GBP 54%, Euro 20%, USD 10%

Notes: Pre-referendum trade shares by industry and currency.

Table 3: Post - Pre Referendum Changes in Trade Prices and Worker Outcomes

	Post - Pre Referendum Changes			
	Intermediate Import Prices	Export Prices	Wages	Training
	(1)	(2)	(3)	(4)
A. Intermediate Imports Weighted Depreciation				
Highest Quintile	0.081	0.105	0.054	-0.008
	(0.008)	(0.010)	(0.007)	(0.003)
2nd Highest Quintile	0.043	0.118	0.067	0.003
	(0.009)	(0.009)	(0.009)	(0.002)
Middle Quintile	0.074	0.108	0.071	-0.002
	(0.004)	(0.012)	(0.008)	(0.003)
2nd Lowest Quintile	0.052	0.101	0.079	-0.003
	(0.015)	(0.013)	(0.007)	(0.003)
Lowest Quintile	0.037	0.102	0.079	-0.001
	(0.007)	(0.009)	(0.008)	(0.001)
Difference-in-Differences	0.044	0.003	-0.025	-0.007
(Highest - Lowest Quintile)	(0.010)	(0.012)	(0.010)	(0.003)
B. Exports Weighted Appreciation				
Highest Quintile	0.052	0.097	0.069	-0.004
	(0.017)	(0.004)	(0.008)	(0.003)
2nd Highest Quintile	0.062	0.125	0.073	-0.001
	(0.013)	(0.015)	(0.008)	(0.002)
Middle Quintile	0.047	0.108	0.057	-0.004
	(0.009)	(0.006)	(0.011)	(0.002)
2nd Lowest Quintile	0.070	0.107	0.070	0.002
	(0.007)	(0.013)	(0.008)	(0.002)
Lowest Quintile	0.051	0.096	0.078	-0.002
	(0.010)	(0.007)	(0.010)	(0.002)
Difference-in-Differences	0.001	0.001	-0.009	-0.003
(Highest - Lowest Quintile)	(0.020)	(0.008)	(0.012)	(0.003)

Notes: Changes in log of variables in columns (1) to (3) and of the proportion in column (4). Standard errors in parentheses. Weighted by LFS industry cell sizes.

Table 4: Trade Prices

	Full Sample	Restricted Samples	
		Excluding Announcement	Excluding QE
	(1)	(2)	(3)
A. Intermediate Imports			
Log(Intermediate Imports Weighted Depreciation) X Post-Referendum	0.375 (0.100)	0.411 (0.107)	0.589 (0.156)
B. Exports			
Log(Intermediate Imports Weighted Depreciation) X Post-Referendum	0.164 (0.111)	0.171 (0.114)	0.248 (0.143)
Log(Exports Weighted Appreciation) X Post-Referendum	0.006 (0.016)	0.007 (0.016)	0.011 (0.020)
Controls	Yes	Yes	Yes
Time Dummies	Yes	Yes	Yes
Industry Dummies	Yes	Yes	Yes
Sample Size	2040	1870	1445

Notes: The dependent variable is log of price of intermediate imports in panel A and log of price of exports in panel B. Standard errors clustered by industry in parentheses. Controls are LFS demographics of workers in the industry (age, gender, education, full-time, native, workplace size and region). Regressions are weighted by LFS industry cell sizes. Panel B specifications include a dummy for non-exporting industry interacted with post-referendum period. Full sample is from 2012 Q3 to 2018 Q2. Restricted sample excluding announcement is from 2012 Q3 to 2015 Q4 and from 2016 Q3 to 2018 Q2. Restricted sample excluding quantitative easing (QE) is from 2012 Q3 to 2014 Q3 and from 2016 Q3 to 2018 Q2.

Table 5: Wages

	Full Sample		Restricted Samples	
			Excluding Announcement	Excluding QE
	(1)	(2)	(3)	(4)
A. Reduced Form				
Log(Intermediate Imports Weighted Depreciation) X Post-Referendum	-0.193 (0.068)	-0.196 (0.067)	-0.198 (0.067)	-0.197 (0.076)
Log(Exports Weighted Appreciation) X Post-Referendum		-0.015 (0.014)		
B. IV				
Log(Intermediate Import Prices)	-0.497 (0.229)	-0.528 (0.205)	-0.465 (0.200)	-0.319 (0.137)
Log (Export Prices)		0.084 (0.096)		
First-Stage F Statistic	13.6	4.6	14.1	13.4
Controls	Yes	Yes	Yes	Yes
Time Dummies	Yes	Yes	Yes	Yes
Industry Dummies	Yes	Yes	Yes	Yes
Sample Size	123110	123110	117001	87339

Notes: The dependent variable is log of full time hourly wages. Standard errors clustered by industry in parentheses. Controls are LFS demographics of workers in the industry (age, gender, education, full-time, native, workplace size and region). Column (2) specifications include a dummy for non-exporting industry interacted with post-referendum period. Restricted sample definitions are as described in the notes to Table 4.

Table 6: Training

	Full Sample		Restricted Samples	
			Excluding Announcement	Excluding QE
	(1)	(2)	(3)	(4)
A. Reduced Form				
Log(Intermediate Imports Weighted Depreciation) X Post-Referendum	-0.069 (0.021)	-0.071 (0.022)	-0.073 (0.022)	-0.052 (0.027)
Log(Exports Weighted Appreciation) X Post-Referendum		-0.001 (0.007)		
B. IV				
Log(Intermediate Import Prices)	-0.184 (0.073)	-0.196 (0.076)	-0.177 (0.073)	-0.088 (0.057)
Log (Export Prices)		0.024 (0.044)		
First-Stage F Statistic	14.1	4.9	14.8	14.3
Controls	Yes	Yes	Yes	Yes
Time Dummies	Yes	Yes	Yes	Yes
Industry Dummies	Yes	Yes	Yes	Yes
Sample Size	578282	578282	548079	411173

Notes: The dependent variable is a dummy for whether the individual received job-related education or training in the past 4 weeks. Standard errors clustered by industry in parentheses. Controls are LFS demographics of workers in the industry (age, gender, education, full-time, native, workplace size and region). Columns (2) specifications include a dummy for non-exporting industry interacted with post-referendum period. Restricted sample definitions are as described in the notes to Table 4.

Table 7: Pre-Referendum Intermediate Import Shares

	Intermediate Import Prices	Worker Outcomes	
	First Stage	Reduced Form	IV
	(1)	(2)	(3)
A. Wages			
Log(Intermediate Imports Weighted Depreciation) X Post-Referendum	0.382	-0.197	
	(0.107)	(0.066)	
Share of Imports in Intermediates X Post-Referendum	-0.035	-0.017	
	(0.037)	(0.025)	
Log(Intermediate Import Prices)			-0.428
			(0.195)
First-Stage F Statistic			8.3
Sample Size	2040	123110	123110
B. Training			
Log(Intermediate Imports Weighted Depreciation) X Post-Referendum	0.371	-0.068	
	(0.101)	(0.021)	
Share of Imports in Intermediates X Post-Referendum	-0.035	0.003	
	(0.035)	(0.009)	
Log(Intermediate Import Prices)			-0.177
			(0.068)
First-Stage F Statistic			8.5
Sample Size	2040	578282	578282
Controls	Yes	Yes	Yes
Time Dummies	Yes	Yes	Yes
Industry Dummies	Yes	Yes	Yes

Notes: The dependent variable is log of price of intermediate imports in Column (1), log of full time hourly wages in Columns (2) and (3) of panel A and a dummy for whether the individual received job-related education or training in the past 4 weeks in Columns (2) and (3) of panel B. Standard errors clustered by industry in parentheses. Controls are LFS demographics of workers in the industry (age, gender, education, full-time, native, workplace size and region).

Table 8: Import Competition Channel

	Full Sample			Restricted Samples	
				Excluding Announcement	Excluding QE
	(1)	(2)	(3)	(4)	(5)
A. Intermediate Import Prices					
Log(Intermediate Imports Weighted Depreciation) X Post-Referendum	0.375 (0.100)		0.350 (0.091)	0.383 (0.098)	0.548 (0.146)
Log(Total Imports Weighted Depreciation) X Post-Referendum		0.169 (0.050)	0.147 (0.046)	0.165 (0.048)	0.244 (0.065)
Sample Size	2040	2040	2040	1870	1445
B. Wages					
Log(Intermediate Imports Weighted Depreciation) X Post-Referendum	-0.193 (0.068)		-0.184 (0.070)	-0.189 (0.068)	-0.187 (0.078)
Log(Total Imports Weighted Depreciation) X Post-Referendum		-0.069 (0.039)	-0.060 (0.039)	-0.066 (0.038)	-0.066 (0.025)
Sample Size	123110	123110	123110	117001	87339
C. Training					
Log(Intermediate Imports Weighted Depreciation) X Post-Referendum	-0.069 (0.021)		-0.060 (0.020)	-0.065 (0.022)	-0.047 (0.028)
Log(Total Imports Weighted Depreciation) X Post-Referendum		-0.055 (0.017)	-0.051 (0.015)	-0.046 (0.017)	-0.030 (0.019)
Sample Size	578282	578282	578282	548079	411173
Controls	Yes	Yes	Yes	Yes	Yes
Time Dummies	Yes	Yes	Yes	Yes	Yes
Industry Dummies	Yes	Yes	Yes	Yes	Yes

Notes: The dependent variable is log of price of intermediate imports in panel A, log of full time hourly wages in panel B and a dummy for whether the individual received job-related education or training in the past 4 weeks in panel C. Standard errors clustered by industry in parentheses. Controls are LFS demographics of workers in the industry (age, gender, education, full-time, native, workplace size and region). Restricted sample definitions are as described in the notes to Table 4.

Table 9: Margins of Labour Adjustment

	Wages (All)	Hours	Overtime Hours	Inflow Rate	Outflow Rate	Employment Growth
	(1)	(2)	(3)	(4)	(5)	(6)
A. Reduced Form						
Log(Intermediate Imports Weighted	-0.237	-0.052	-0.147	-0.015	-0.001	0.022
Depreciation) X Post-Referendum	(0.074)	(0.032)	(0.049)	(0.009)	(0.012)	(0.040)
B. IV						
Log(Intermediate Import Prices)	-0.628	-0.137	-0.391	-0.038	-0.001	0.056
	(0.283)	(0.105)	(0.172)	(0.026)	(0.032)	(0.109)
First-Stage F Statistic	14.4	14.3	14.3	18.9	19.1	19.1
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Time Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Industry Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Sample Size	159394	571335	571335	2040	2040	2040

Notes: The dependent variable is log of hourly wages (all workers) in column (1), log of total weekly hours worked for all workers in column (2), a dummy for individuals doing paid overtime weekly hours in column (3), industry inflow rate in column (4), industry outflow rate in column (5) and difference in industry log of employment in column (6). Standard errors clustered by industry in parentheses. Controls are LFS demographics of workers in the industry (age, gender, education, full-time, native, workplace size and region).

Table 10: Heterogeneity By Skill

	Full Sample	Restricted Samples	
		Excluding Announcement	Excluding QE
	IV	IV	IV
	(1)	(2)	(3)
A. Wages			
Log(Intermediate Import Prices)			
× Graduates	-0.597	-0.590	-0.627
	(0.196)	(0.174)	(0.160)
× Non-Graduates	-0.194	-0.164	-0.004
	(0.227)	(0.199)	(0.161)
First-Stage F Statistic	6.8	7.3	23.8
Sample Size	123489	117380	87721
B. Training			
Log(Intermediate Import Prices)			
× Graduates	-0.205	-0.199	-0.144
	(0.067)	(0.067)	(0.067)
× Non-Graduates	-0.118	-0.124	-0.030
	(0.085)	(0.087)	(0.081)
First-Stage F Statistic	6.9	7.4	20.1
Sample Size	578282	548079	411173
Controls	Yes	Yes	Yes
Time Dummies	Yes	Yes	Yes
Industry Dummies	Yes	Yes	Yes

Notes: The dependent variable is log of full time hourly wages in panel A and a dummy for whether the individual received job-related education or training in the past 4 weeks in panel B. Standard errors clustered by industry in parentheses. Controls are LFS demographics of workers in the industry (age, gender, education, full-time, native, workplace size and region). Restricted sample definitions are as described in the notes to Table 4.

Table 11: Calibration

(a) Parameter Values for Calibration

	Notation	Value	Source
Ratio of imported intermediate costs to labour costs	$S_{P^M C}/S_{WC}$	0.1/0.4	ONS
Labour demand elasticity	ε_{WW}	-0.5	Hamermesh (1996)
Share of domestic sales in total sales	S_{uk}	0.70	ONS
Share of adjustment of prices	$\delta\kappa$	0.25	Itskhoki and Mukhin (2017)
Output elasticity of substitution	σ	1, 3, 5	Broda and Weinstein (2006)

(b) Estimates for Allen Uzawa Elasticities of Substitution (AES)

Estimated Wage Elasticity $\hat{\theta}_{MW}$	Implied AES between Workers and Intermediate Imports σ_{WP^M}		
	$\sigma = 1$	$\sigma = 3$	$\sigma = 5$
(1)	(2)	(3)	(4)
-0.30	-1.54	-1.61	-1.68
-0.35	-1.82	-1.96	-2.10
-0.40	-2.11	-2.32	-2.53
-0.45	-2.39	-2.67	-2.95
-0.50	-2.68	-3.03	-3.38
-0.55	-2.96	-3.38	-3.80

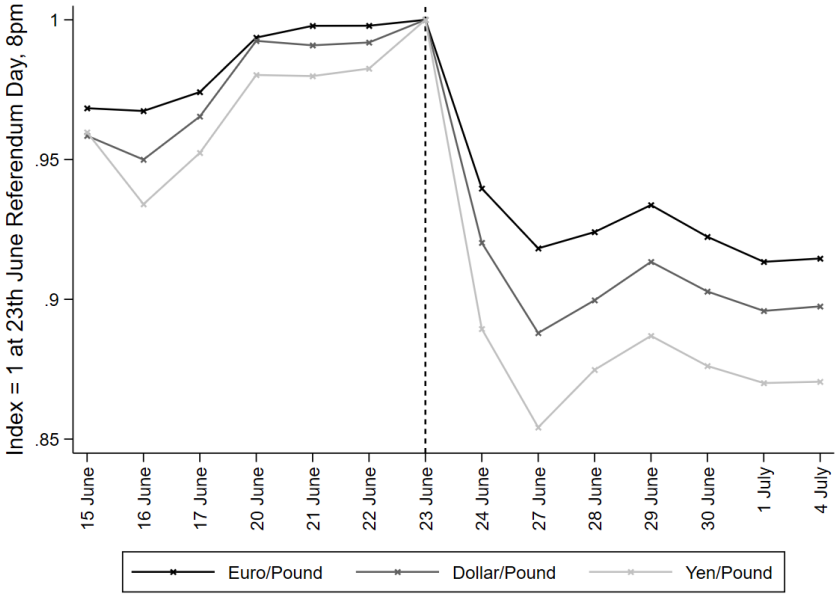
Notes: Estimated wage elasticities in column (1) of panel (b) are values within the range of the estimated IV coefficient $\hat{\theta}_{MW}$. To recover the AES between workers and intermediate imports in columns (2), (3) and (4), parameter values are taken from panel (a).

Appendices

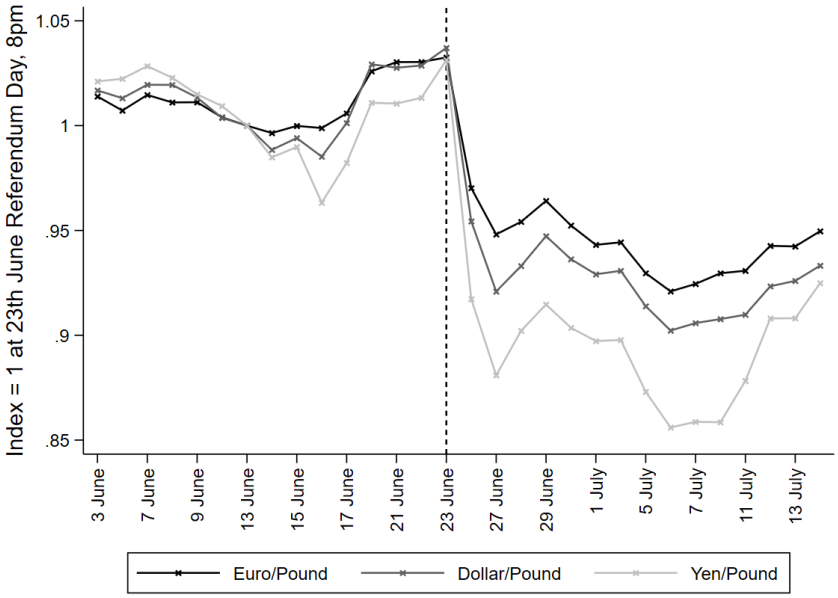
Appendix A: Additional Tables and Figures

Figure A1: Exchange Rate Movements, 7 and 15 Day Windows

(a) 7 Day Window

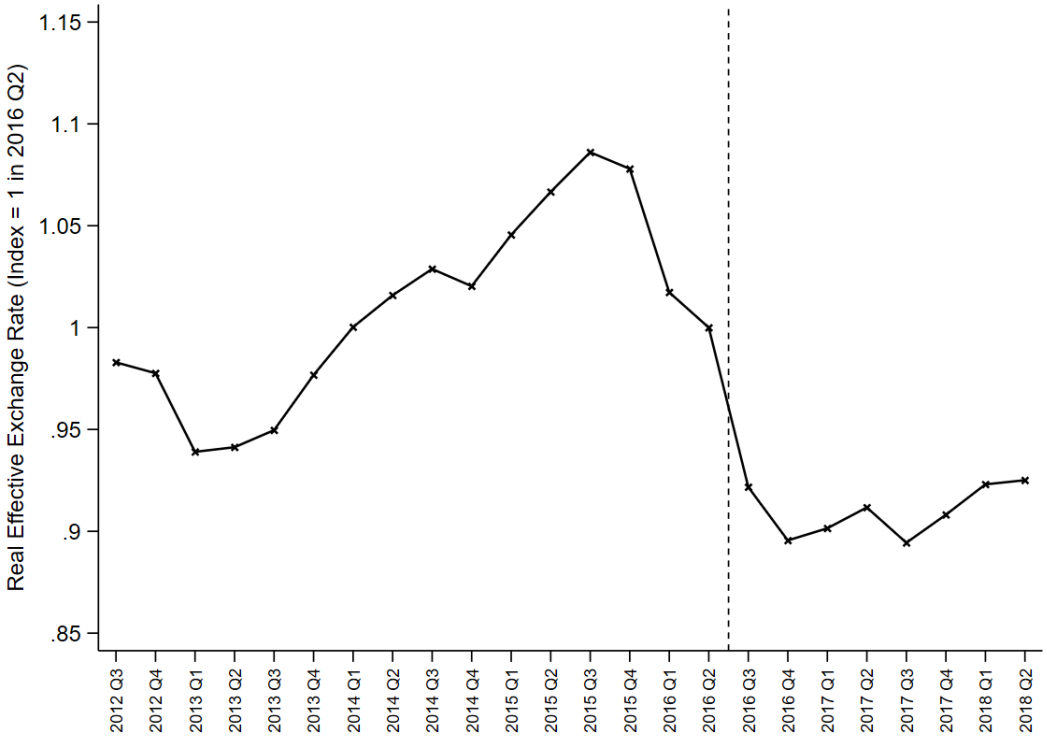


(b) 15 Day Window



Notes: Daily exchange rates from Reuters Datastream.

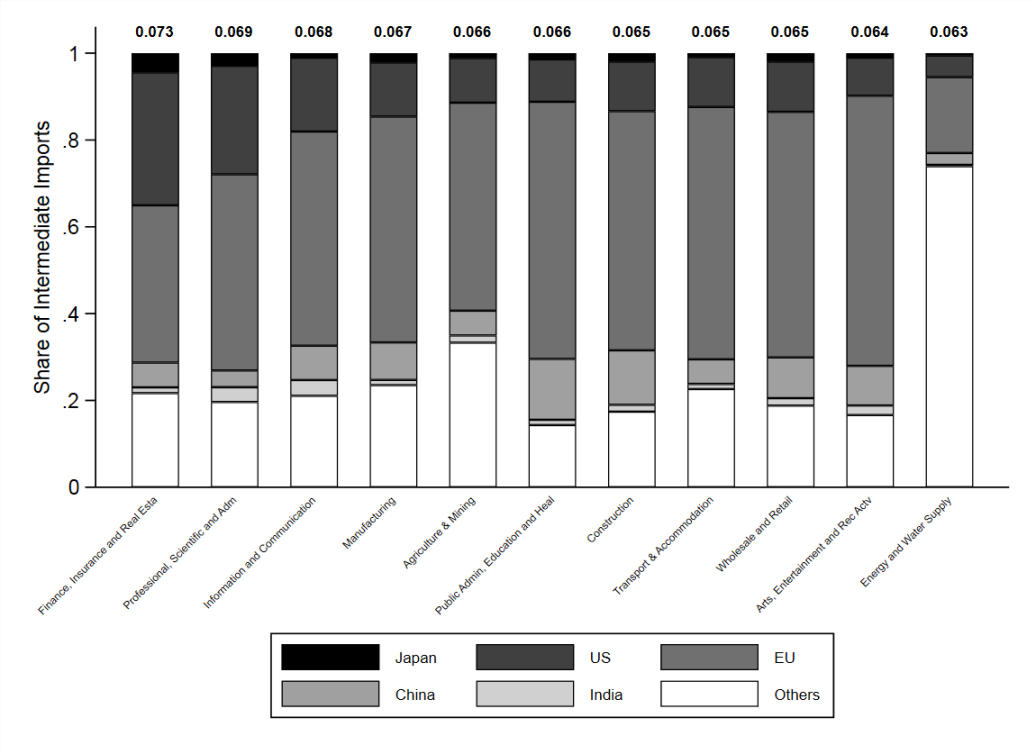
Figure A2: Real Effective Exchange Rate (Bank of England)



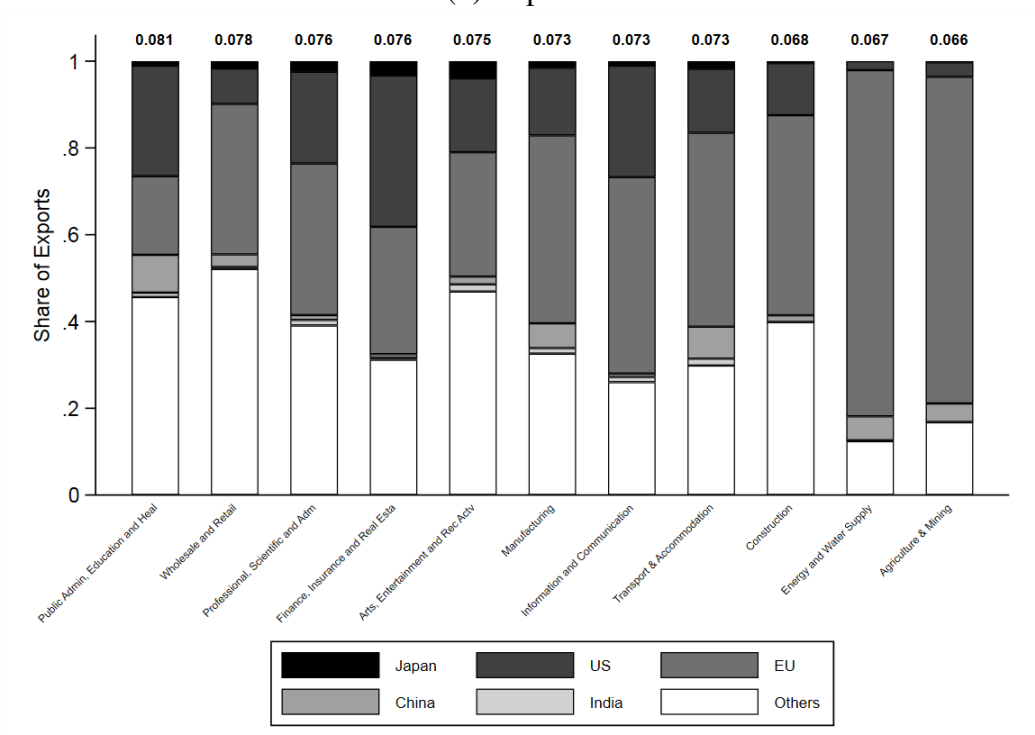
Notes: The real effective exchange rate published by the Bank of England, defined as a trade weighted average of the standard bilateral exchange rates corresponding to trade partners with at least 1% of trade share in imports or exports.

Figure A3: Trade Shares by Main Trading Partners in 2015

(a) Intermediate Imports



(b) Exports



Notes: Shares of trade are calculated based on the sum of trade in goods and services for each industry aggregate. The numbers at the top of the bars represent the weighted depreciation/appreciation calculated for each industry aggregate.

Table A1: Trade Quantities

	Full Sample	Restricted Samples	
		Excluding Announcement	Excluding QE
	(1)	(2)	(3)
A. Intermediate Imports			
Log(Intermediate Imports Weighted Depreciation) X Post-Referendum	0.072	0.088	0.145
	(0.079)	(0.085)	(0.122)
B. Exports			
Log(Intermediate Imports Weighted Depreciation) X Post-Referendum	-0.461	-0.493	-0.699
	(0.289)	(0.305)	(0.396)
Log(Exports Weighted Appreciation) X Post-Referendum	0.010	0.009	0.003
	(0.053)	(0.057)	(0.072)
Controls	Yes	Yes	Yes
Time Dummies	Yes	Yes	Yes
Industry Dummies	Yes	Yes	Yes
Sample Size	2040	1870	1445

Notes: The dependent variable is log of quantity (chained volume measure) of intermediate imports in panel A and log of quantity (chained volume measure) of exports in panel B. Standard errors clustered by industry in parentheses. Controls are LFS demographics of workers in the industry (age, gender, education, full-time, native, workplace size and region). Panel B specifications include a dummy for non-exporting industry interacted with post-referendum period. Restricted sample definitions are as described in the notes to Table 4.

Table A2: Estimates With 7 Day Exchange Rate Windows

	Intermediate Import Prices	Worker Outcomes	
	First Stage	Reduced Form	IV
	(1)	(2)	(3)
A. Wages			
Log(Intermediate Imports Weighted Depreciation) X Post-Referendum	0.383	-0.184	
	(0.116)	(0.067)	
Log(Intermediate Import Prices)			-0.481
			(0.248)
First-Stage F Statistic			10.9
Sample Size	2040	123110	123110
B. Training			
Log(Intermediate Imports Weighted Depreciation) X Post-Referendum	0.370	-0.073	
	(0.113)	(0.024)	
Log(Intermediate Import Prices)			-0.197
			(0.084)
First-Stage F Statistic			10.8
Sample Size	2040	578282	578282
Controls	Yes	Yes	Yes
Time Dummies	Yes	Yes	Yes
Industry Dummies	Yes	Yes	Yes

Notes: The dependent variable is log of price of intermediate imports in column (1), log of full time hourly wages in columns (2) and (3) in panel A and a dummy for whether the individual received job-related education or training in the past 4 weeks in columns (2) and (3) of panel B. Standard errors clustered by industry in parentheses. Controls are LFS demographics of workers in the industry (age, gender, education, full-time, native, workplace size and region).

Table A3: Estimates With 15 Day Exchange Rate Windows

	Intermediate Import Prices	Worker Outcomes	
	First Stage	Reduced Form	IV
	(1)	(2)	(3)
A. Wages			
Log(Intermediate Imports Weighted Depreciation) X Post-Referendum	0.402	-0.102	
	(0.129)	(0.049)	
Log(Intermediate Import Prices)			-0.255
			(0.154)
First-Stage F Statistic			9.2
Sample Size	2040	123110	123110
B. Training			
Log(Intermediate Imports Weighted Depreciation) X Post-Referendum	0.386	-0.052	
	(0.127)	(0.024)	
Log(Intermediate Import Prices)			-0.136
			(0.076)
First-Stage F Statistic			9.2
Sample Size	2040	578282	578282
Controls	Yes	Yes	Yes
Time Dummies	Yes	Yes	Yes
Industry Dummies	Yes	Yes	Yes

Notes: The dependent variable is log of price of intermediate imports in column (1), log of full time hourly wages in columns (2) and (3) of panel A and a dummy for whether the individual received job-related education or training in the past 4 weeks in columns (2) and (3) of panel B. Standard errors clustered by industry in parentheses. Controls are LFS demographics of workers in the industry (age, gender, education, full-time, native, workplace size and region).

Table A4: Wages With Currency of Invoicing Adjustment

	Intermediate Import Prices	Wages	
	First Stage	Reduced Form	IV
	(1)	(2)	(3)
Log(Intermediate Imports Weighted Depreciation) X Post-Referendum	0.418	-0.134	
	(0.151)	(0.074)	
Log(Intermediate Import Prices)			-0.321
			(0.183)
First-Stage F Statistic			7.6
Controls	Yes	Yes	Yes
Time Dummies	Yes	Yes	Yes
Industry Dummies	Yes	Yes	Yes
Sample Size	2040	123110	123110

Notes: The dependent variable is log of price of intermediate imports in column (1) and log of full time hourly wages in columns (2) and (3). Standard errors clustered by industry in parentheses. Controls are LFS demographics of workers in the industry (age, gender, education, full-time, native, workplace size and region).

Table A5: Wages With Ratio of Labour Costs to Intermediate Import Costs

	Wages	
	Reduced Forms	
	(1)	(2)
Log(Intermediate Imports Weighted Depreciation) X Post-Referendum	-0.192	-0.197
	(0.070)	(0.084)
(S_{PM_C}/S_{WC}) X Log(Intermediate Imports Weighted Depreciation) X Post-Referendum	-0.001	0.020
	(0.001)	(0.188)
(S_{PM_C}/S_{WC}) X Post-Referendum		0.056
		(0.519)
Controls	Yes	Yes
Time Dummies	Yes	Yes
Industry Dummies	Yes	Yes
Sample Size	123489	123489

Notes: The dependent variable is log of full time hourly wages. S_{PM_C}/S_{WC} is the ratio of labour share to intermediate import share in total costs. Standard errors clustered by industry in parentheses. Controls are LFS demographics of workers in the industry (age, gender, education, full-time, native, workplace size and region).

Table A6: Robustness of Worker Outcome Measures

	Excluding Observations Close to Referendum		Received training in Last Three Months
	Wages	Training	Training - 3 months
	IV	IV	IV
	(1)	(2)	(3)
Log(Intermediate Import	-0.471	-0.177	-0.321
Prices) X Post-Referendum	(0.231)	(0.071)	(0.138)
First-Stage F Statistic	13.5	13.9	14.1
Controls	Yes	Yes	Yes
Time Dummies	Yes	Yes	Yes
Industry Dummies	Yes	Yes	Yes
Sample Size	121575	571049	578282

Notes: The dependent variable is log of full time hourly wages in column (1), a dummy for whether the individual received job-related education or training in the past 4 weeks in column (2) and a dummy for whether the individual received job-related education or training in the past 3 months in column (3). Standard errors clustered by industry in parentheses. Controls are LFS demographics of workers in the industry (age, gender, education, full-time, native, workplace size and region).

Appendix B: Full Timeline

Thursday June 23, 2016:

- 10pm - The last votes are cast and polling stations across the country close at the end of a day on which a record 46.5 million people were eligible to have their say. Ballot boxes are sent to 382 counting centres nationwide.
- 10pm - A YouGov opinion poll released at the same time suggests Remain are on course for victory with 52% and Leave on 48%.
- 10.15pm - UKIP's Nigel Farage concedes the Brexit campaign may be beaten and Remain "will edge it" - but promises "UKIP and I are going nowhere".[44]
- 10.30pm - Sterling surges against the US dollar on the back of the favourable opinion poll for Remain and Farage's comments, rocketing to 1.5 dollars, its strongest performance in 2016.
- 11.25pm - Gibraltar is the first area to declare, with a predictable landslide for Remain at 96% of the vote.

Friday, June 24, 2016:

- 12.04am - The first big result is declared, with a narrow win in Newcastle for Remain with 50.7% against Leave on 49.3%. Newcastle-upon-Tyne was second to announce with a slight win for the Remain campaign by 1,806 votes from a total of 129,072. It was an expected win in Newcastle, but not by the margin many suspected, and shortly afterwards the odds of Leave winning the vote was slashed by bookmakers.
- 12.20am - Sunderland votes to Leave by a significant margin, with 61% in the Tyne and Wear town in favour of Brexit compared with 39% backing Remain.
- 12.30am - Sterling tumbles against the US dollar as jitters over a possible swing to Leave wipe earlier gains off the pound, with a near 4.7% drop - greater than the Black Wednesday crash in 1992.
- 1.30am – People started to sense that Leave would win, and it showed in their Google searches.
- 1.55am - The City of London count is announced as vote to Remain in the EU.

[44]https://www.independent.co.uk/news/uk/home-news/eu-referendum-nigel-farage-remain-edge-it-brexit-ukip-a7098526.html

- 2am - Bookmakers change their odds in favour of Leave winning the referendum, with Ladbrokes putting odds of 1/2 on a Brexit result. Having had an 86% chance of Remain winning at the close of polls, the odds shrink to 6/4, or 38%.
- 2.01am - Swansea votes to Leave, with 61,936 backing a Brexit against 58,307 voting to remain.
- 2.17am - Nigel Farage, who earlier said he sensed Remain would take victory, tweeted that he is "so happy with the results in North East England".
- 2.30am – Remain went back ahead for the first time since the Sunderland announcement after big wins in Lambeth and Glasgow.
- 3.44am – But over the next hour the Leave campaign enjoyed gain across Wales, Northern Ireland, Yorkshire and the Midlands to dwarf the majority of Remain's support in Scotland and London.
- 3.27am - Sheffield comes out for Leave, backing an exit from the EU by little over 5,000 votes.
- 3.51am - Leave's lead stretches to 500,000 votes as results pass 200 out of 382.
- 3.57am - Sterling's slide against the dollar continues after victories consolidate a lead for Leave. Trading figures show the pound at 1.37 dollars, down from a high last night of over 1.5 dollars.
- 6.02am - The Leave campaign officially passes the estimated winning post 16,763,272 in the EU referendum.
- 7.01am - The Bank of England says it will take "all necessary steps" to ensure monetary and financial stability in the wake of the Brexit vote.
- 7.04am - The final count of the EU referendum shows Leave won 51.9% of the total vote to Remain's 48.1%.
- 8.08am - The FTSE 100 falls more than 7% within minutes of the markets opening following Britain's decision to leave the EU.
- 8.50am - Bank of England governor Mark Carney says "some market and economic volatility can be expected" in the wake of the Brexit vote, but the Bank is well prepared. It also has £250bn to support the UK economy.

Appendix C: Theory

Additional Theory

Output costs are $C_o = C\left(W_o, P_o^M\left(P_i\left(P_{si}\right)\right), P_o^D\left(P_i\left(1\right)\right), R_o^T, R_o^V, 1\right)$ where R_o^T and R_o^V denote the costs of training and overtime (in units of the numeraire). They change by $\hat{C}_o = S_{WC}\hat{W}_o + S_{P^MC}\sum_i S_{P_iP^M}\sum_s S_{P_{si}P_i}\hat{P}_{si}$. Intermediate import prices change by $\hat{P}_{si} = \kappa^M\left(\hat{C}_{si} - \hat{E}_s\right) = -\kappa^M\delta^M\hat{E}_s$. Output prices change by $\hat{P}_{od} = \kappa\delta\hat{C}_o - \kappa\left(1-\delta\right)\hat{E}_d$ and the resulting change in sales to each destination is $S_d\hat{Q}_{od} = -\sigma S_d\hat{P}_{od} + \sigma S_d\hat{A}_d$. For the UK, $\hat{A}_{uk}$ summarises the change in the domestic aggregate price index because endowments do not change. In export destinations of the UK, $\hat{A}_d = 0$ when the UK is small in its destination market $d \neq UK$.

Let $S_d \equiv \tau_{od}Q_{od}/\sum_d \tau_{od}Q_{od}$ denote the share of sales in destination d. Then wage changes are determined by differentiating labour market clearing conditions ($\bar{L}_o = C_W\sum_d \tau_{od}Q_{od}$) which gives:

$$\begin{aligned}
0 =& \frac{C_{WW}W}{C_W}\hat{W} + \left(\frac{P^MC_{WP^M}}{C_W}\right)\left(\sum_i\sum_s \frac{P_iP_{P_i}^M}{P^M}\frac{P_{i_{P_{si}}}P_{si}}{P_i}\hat{P}_{si}\right) + \sum_d S_d\hat{Q}_d \\
=& \sigma_{WW}S_{WC}\hat{W} + \sigma_{WP^M}S_{P^MC}\hat{P}^M + \sum_d S_d\hat{Q}_d \\
=& \left(\sigma_{WW} - \delta S_{uk}\kappa\sigma\right)S_{WC}\hat{W} + \left(\sigma_{WP^M} - \delta S_{uk}\kappa\sigma\right)S_{P^MC}\hat{P}^M - \left(1-S_{uk}\right)\sigma\hat{P}^X + \sigma\sum_d S_d\hat{A}_d
\end{aligned}$$

Import prices change by

$$\hat{P}^M \equiv \sum_i S_{P_iP^M}\sum_{s\neq uk} S_{P_{si}P_i}\hat{P}_{si} = -\delta^M\kappa^M\left(\sum_i S_{P_iP^M}\sum_{s\neq uk} S_{P_{si}P_i}\hat{E}_s\right)$$

Export prices change by

$$\hat{P}^X = \kappa\sum_{d\neq uk} S_{dx}\left(\delta S_{WC}\hat{W} + \delta S_{P^MC}\hat{P}^M - \left(1-\delta\right)\hat{E}_d\right)$$

Substituting for the change in wages, the change in export prices is

$$\begin{aligned}
\hat{P}^X =& -\kappa\delta S_{P^MC}\left(\frac{\sigma_{WP^M} - \sigma_{WW}}{\sigma_{WW} - \delta\kappa\sigma}\right)\hat{P}^M \\
&+ \kappa\left(1-\delta\right)\left(\frac{\sigma_{WW} - \delta S_{uk}\kappa\sigma}{\sigma_{WW} - \delta\kappa\sigma}\right)\left(-\sum_{d\neq uk} S_{dx}\hat{E}_d\right) + A
\end{aligned}$$

where the aggregate shifter is $A \equiv -\sigma\kappa\delta\sum_d S_d\hat{A}_d/\left(\sigma_{WW} - \delta\kappa\sigma\right)$.

When A_d is generalized to be an explicit function of the destination exchange rate (as in a local pricing example of $A_d = \bar{A}_d / E_d$ for $\bar{A}_d > 0$), the RHS of the wage equation can be written just in terms of quantities. The appropriate regressions would then have the export quantity index changes (instead of the sterling export price index changes) on the LHS of the reduced form trade equations and on the RHS of the structural wage equation. To account for this channel, Table A1 uses export quantities to show that assumptions on the aggregate demand shifter are not constraining the first stage.

From the training choice, $T = C_{R^T} \sum_d \tau_d Q_d$ and the change in training is therefore

$$\hat{T} = (\sigma_{R^T W} - \delta S_{uk} \kappa\sigma) S_{WC} \hat{W} + (\sigma_{R^T P^M} - \delta S_{uk} \kappa\sigma) S_{P^M C} \hat{P}^M - (1 - S_{uk}) \sigma \hat{P}^X + \sigma \sum_d S_d \hat{A}_d.$$

Substituting for the wage change, the change in training is $\hat{T} = \alpha_T + \theta_{MT} \hat{P}^M + \theta_{XT} \hat{P}^X$ where α_T is an economy-wide shifter containing $\hat{A}_{uk}$, $\theta_{MT} \equiv S_{P^M C} (\sigma_{R^T P^M} - \delta S_{uk} \kappa\sigma) + \theta_{MW} S_{WC} (\sigma_{R^T W} - \delta S_{uk} \kappa\sigma)$ and $\theta_{XT} \equiv \theta_{XW} S_{WC} (\sigma_{R^T W} - \sigma_{WW})$. Similarly, firms' optimal choice of overtime workers is $V = C_{R^V} \sum_d \tau_d Q_d$, which also takes the form $\hat{V} = \alpha_V + \theta_{MV} \hat{P}^M + \theta_{XV} \hat{P}^X$ where α_V again is an economy-wide demand shifter, $\theta_{MV} \equiv S_{P^M C} (\sigma_{R^V P^M} - \delta S_{uk} \kappa\sigma) + \theta_{MW} S_{WC} (\sigma_{R^V W} - \delta S_{uk} \kappa\sigma)$ and $\theta_{XV} \equiv \theta_{XW} S_{WC} (\sigma_{R^V W} - \sigma_{WW})$.

Appendix D: Data Description

Exchange Rates Data

Reuters Datastream collects daily exchange rates for the most relevant traded currencies, including sterling rates against most currencies in the world. In the few cases for which no exchange rate against sterling was available, suitable conversion is based on its reported dollar exchange rate. The daily measures of exchange rate are defined as the value at the official time of closure of the New York Stock Exchange 4pm EST (8pm GMT).

Mapping of currencies to country of use is based on the official UN Operational Currency correspondence.[45] The final dataset contains 245 countries and 145 currencies.

The minute-by-minute exchange rates for a selected bundle of currencies against the sterling pound are taken from HistData.[46]

Trade Data

Quarterly time-series of import and export trade values (current price measure) and volumes (chained volume measure) are made available by ONS for 2 digit UK SIC (Standard

[45] https://treasury.un.org/operationalrates/OperationalRates.php
[46] http://www.histdata.com/download-free-forex-data/

Industry Classification) industries in sectors A, B and C: Agriculture, Forestry and Fishing; Mining and Quarrying; and Manufacturing. Those are supplemented by trade values and volumes for 13 aggregate of services product-industry: Sea Transport, Air Transport, Other Transport, Postal & Courier, Travel, Construction, Insurance, Financial, Intellectual Property, Telecommunications, Computer & Information, Other Business Services, Personal, Cultural & Recreational and Government. Import and export price indices are calculated as the ratio of trade values to trade volumes and, in the case of intermediates, this is calculated after the necessary input-output import use allocations are made.

Import and export flows are collected from the annual import values for 2015 taken from UN COMTRADE for goods and from the International Trade in Services (ITIS) survey of the ONS for services. Following Revenga (1992), only countries with trade shares greater than 2 per cent are used in the analysis.

Correspondence between COMTRADE HS-2012 (Harmonized Code 2012) product codes and UK SIC 2007 industry codes was obtained using a two-step crosswalk procedure. Firstly, we use Peter Schott's HS-2012 to NAICS 2012.[47] Secondly we map NAICS 2012 to NACE 2 using the Eurostat official correspondence table.[48]

ITIS is provided by ONS matched directly to the UK firm register hence identifying the industry of activity of the firm exporting or importing the services.

Data on import use is from the import use tables (product by industry) of the ONS for 2014.[49] Following Autor, Dorn and Hanson (2013), intermediate demand values are used. These do not include demand from households, non-profit institutions, serving households, central government, local authorities, gross fixed capital formation, valuables, changes in inventories and exports of goods and services.

Labour Force Survey Data

Labour force data refer to all employed individuals aged 22 to 65, and are taken from the UK Quarterly Labour Force Survey (QLFS) 2012 Q3 to 2018 Q2.

The 4-week training indicator is coded as one if the individual has "taken part in any education or any training connected with his/her job or a job that the individual might be able to do in the future in the past 4 weeks". The value of this variable is conditional on a positive answer to the question: "taken part in any education or any training connected with his/her job or a job that the individual might be able to do in the future in the past 3 months?". The

[47] http://faculty.som.yale.edu/peterschott/sub_international.htm

[48] http://ec.europa.eu/eurostat/ramon/relations/index.cfm?TargetUrl=LST_REL&StrLanguageCode=EN&IntCurrentPage=10

[49] https://www.ons.gov.uk/economy/nationalaccounts/supplyandusetables/datasets/ukinputoutputanalyticaltablesdetailed

same indicator is constructed for the 3-month training and used as robustness.

Hourly wages are calculated for individuals answering positively to the questions on weekly wages and hours are reported. The hourly wages are censored at the lowest UK minimum wage, the below 18 years of age minimum wage, in the relevant quarter. The small number of individuals working in industries labeled as household production (i.e.: UK SIC divisions 97, 98 and 99) are excluded from the samples of analysis.

Inflows and outflows are identified using the longitudinal dimension of the QLFS data. The QLFS interviews the same individual for 5 consecutive quarters, which permits inflows and outflows to and from employment in the 85 industries to be calculated. An inflow is defined as a worker in the industry who reported to be either: employed in a different industry, unemployed or inactive in the previous quarter interview. Similarly, an outflow is identified as an industry worker who reports in the next quarter interview to be either: employed in a different industry, unemployed or inactive. To ensure capture of legitimate industry switchers, information about whether the worker left a paid job in the past 3 months is combined with the starting year and month in the current job to guarantee that the switchers are identified correctly. The inflow rate is defined, for a given industry, as the weighted number of inflows divided by the employment count in the previous quarter. The outflow rate is calculated as the ratio of the weighted number of outflows to the employment count in the current quarter. The sample is restricted to individuals reporting in two consecutive quarters to minimise measurement error and attenuate attrition.

Confederation of British Industry Data

The Confederation of British Industry (CBI) is a UK business organisation that represents 190,000 businesses in total and whose trade associations account for one third of private sector employment. It undertakes monthly and quarterly surveys of its members in four broad industrial groupings: Industrial Trends Survey (ITS); Service Sector Survey (SSS); Financial Services Survey (FSS); Distributive Trades Survey (DTS). The quarterly surveys have larger sample size and greater question coverage and are used in this paper between 2012 Q3 and 2018 Q2 to match the main analysis. The quarterly ITS takes place in January, April, July and October; the quarterly SSS and DTS in February, May, August and November; and the quarterly FSS in March, June, September and December. The following question that is consistently asked in three of the four surveys, the ITS, SSS and FSS, is used in this paper: "Are you more, or less optimistic than you were three months ago about the overall business situation in your sector?". Three responses are permitted in a tick box set up: More; Same; Less. Coverage compared to the analysis of the rest of the paper is reduced to 63 out of the total 85 2-digit industries, because the DTS does not have a comparable question on optimism

and because the CBI does not survey some industries (notably in agriculture, mining, waste recycling, construction and largely public sector industries). The 63 industries comprise 25 manufacturing industries in the ITS, 35 service sector industries in the SSS and 3 financial sector industries in the FSS. Between 2012 Q3 and 2018 Q2 there are a total of 16776 answers to the optimism question, with there being 10264 in ITS, 4167 in SSS and 2345 in FSS. LFS industry cell size weights are applied when the responses are aggregated.