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Potential consequences of post-Brexit trade barriers for earnings inequality in the UK

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Potential Consequences of post-Brexit Trade Barriers for Earnings Inequality in the UK

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Abstract

We examine the distributional consequences of post-Brexit trade barriers on wages in the UK. We quantify changes in trade costs across industries accounting for input-output links across domestic industries and global value chains. We allow for demand substitution by firms and consumers and worker reallocation across industries. We document the impact at the individual and household level. Blue-collar workers are the most exposed to negative consequences of higher trade costs, because they are more likely to be employed in industries that face increases in trade costs, and are less likely to have good alternative employment opportunities available in their local labour markets. Overall new trade costs have a regressive impact with lower-paid workers facing higher exposure than higher-paid workers once we account for the exposure of other household members.

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1 Introduction

On June 23rd 2016 the UK voted to leave the European Union after over 40 years of membership. The ultimate impact of this decision ('Brexit') remains unclear. However, it is likely to lead to increases in the costs of trade between the UK and the EU, which is by far the UK's largest trading partner. Increased trade costs will affect many economic outcomes, including aggregate GDP (Dhingra et al. (2016)), prices (Clarke et al. (2017)), aggregate employment in different countries (Vandenbussche et al. (2017)), foreign direct investment (Breinlich et al. (2019)) and employment in specific industries (Head and Mayer (2017)).

Our contribution in this paper is to quantify the likely *distributional* impacts of changes in (tariff and non-tariff) trade costs on the earnings of UK workers and households using detailed micro data. Our measure reflects: (i) the exposure of the industry a worker is employed in to changes in trade barriers, including through input-output linkages, (ii) the worker's outside options, as measured by the concentration of related jobs in the local labour market that are exposed to changes in trade costs, (iii) assumptions about the responsiveness of firms and workers to these changing circumstances, and (iv) the exposure of other family members, reflecting how well the worker is insured through family circumstances.

We discuss the potential role of each of these factors in determining the impact of Brexit on earnings inequality in the UK. Previous studies have looked at the likely impact of Brexit on different industries or across different regions according to their industry composition (Chen et al. (2018); Dhingra et al. (2017)). Our approach and use of micro data allow us to examine the exposure and outside options of individual workers, and to see how these vary by workers' occupation, locality, point in the earnings distribution and family circumstances.

We focus on changes in trade barriers associated with a hard 'WTO rules' Brexit, as this is the default outcome in the event the UK and EU fail to strike an agreement. We start by describing each industry's exposure to potential new trade costs with the EU using relatively simple measures that account for direct (i.e on their own exports and imports to and from the EU) and indirect (including trade barriers faced by upstream and downstream industries) exposure. Using these measures we show that the industries that are most exposed to new trade costs are clothing and textiles, chemicals, transport equipment and food and drink manufacturers. These industries are disproportionately likely to employ workers in blue-collar occupations (machine operatives and those in skilled trades).

These measures of the trade costs faced by different industries allow us to map out workers' *ex-ante* exposure to post-Brexit trade barriers in a transparent way based on current employment patterns. However, it does not account for various margins of adjustment that will determine the ultimate impact of Brexit on workers' welfare. These potentially include substitution by firms and consumers in response to relative price shifts, and the potential for workers employed in exposed industries to find alternative employment.

To account for these we propose a more general 'response-inclusive' measures of workers' exposure based on the predictions of specific-factor models of labour demand (Jones (1965)). Kovak (2013) and Dix-Carneiro and Kovak (2015) use such measures to study the impact of unilateral tariff liberalisation on different regions and workers in Brazil. We extend the models used in these papers to allow for input-output links across firms and for different changes trade barriers across a country's trading partners. These extensions turn out to be important: industries' total exposure to new trade barriers accounting for upstream and downstream links often differs significantly from industries' direct exposure.[1]

The response-inclusive measure we propose can be interpreted as providing a 'sufficient statistic' for relative wage impacts on different workers, under the assumptions that labour is mobile across industries, immobile across occupations and regions, capital is a specific factor, there is perfect competition and market clearing. An interpretation of these assumptions is that they imply our results are indicative of relative wage impacts over the short to medium term. To consider the longer run effects we would need to consider the impact on foreign investment, competition, innovation and productivity and changes in overall aggregate demand in the UK and its trading partners; which is beyond the scope of this paper. We also do not account for short run exchange rate dynamics in the event of a hard Brexit. Exchange rate depreciations may blunt impacts on workers who are directly employed in export activities, although the direction and magnitude of exchange rate changes will depend on a number of factors that are difficult to predict. Any depreciations would also raise general prices and the costs of imported inputs.

We find substantial variation in exposure across workers both by occupation and locality. Exposure is highest among older, less educated and male workers whereas women are more likely to be employed in non-traded industries that are less exposed to new trade costs. Exposure is also greatest for workers in the middle of

[1]Borusyak and Jaravel (2018) also incorporate input-output links in their assessment of the impacts of the 'China shock' on different skill groups in the US. Our approach additionally includes the important regional dimension to assess the impact of trade shocks, allowing heterogeneity in effects *within* as well as across different worker types.

the individual earnings distribution, where workers in blue-collar occupations are concentrated. Workers in some high earning occupations (such as managers, professionals and technical workers) are also often employed in highly exposed industries, but these workers typically have better outside options (alternative job opportunities in less exposed industries in their locality). As a result, these workers are less affected if we allow mobility across industry (but not occupation or locality).

Exposure across the distribution of household earnings is more regressive than over individual workers. This is because (typically female) workers at the bottom of the earnings distribution are often partnered with workers in more highly exposed occupations in the middle of the distribution. Thus while low earning workers may not themselves be exposed to the increase in trade barriers, they may be indirectly affected through impacts on their partners and thus on household income. This is particularly important for understanding the pattern of exposure by gender: accounting for partners' exposure tends to mitigate overall exposure for men, but to exacerbate it for women.

Exposure depends crucially on the concentration of a worker's occupation and industry, as this affects their outside options. Workers in occupations and localities where the demand for their skills is very concentrated will have fewer outside options, and so be more hard hit. This suggests that the degree of labour mobility across regions, industries and occupations will be key determinants of the distributional impacts of Brexit. Previous studies have found that the mobility of less educated workers across both regions and sectors in response to trade shocks tends to be low (Gregg et al. (2004); Autor et al. (2014)). Since we find that these workers are the most exposed, policies that target these frictions will therefore be highly relevant in the wake of Brexit induced trade shocks. Alternatively, the important spatial dimension of exposure could provide justification for 'place-based' policies that target assistance at adversely affected regions.

Our analysis relies on a number of key parameter assumptions, including the size of trade elasticities and the substitutability of different types of labour with each other and with capital. We have taken estimates of these from the literature where they exist. We also examine the sensitivity of our results to alternative assumptions, and show that they are broadly robust to reasonable alternatives. The pattern of impacts generated by our model is largely driven by the importance of the EU as both a destination of exports, and source of imported intermediates, for certain industries. While we also assume that labour supply remains fixed, we discuss potential implications of changes in EU migration in Appendix H. The correlation between EU migrant shares and exposure is positive owing to the fact

that EU migrants are more often employed in the most exposed occupations, but only weakly so, because migrants also tend to cluster in less exposed regions (such as London). This suggests there is limited scope for reductions in labour supply to considerably change our estimates of relative impacts across workers, unless patterns of migration were also to significantly change.

Our approach builds on a growing literature showing that sudden changes in trading arrangements ('trade shocks') can have complex and heterogeneous impacts across different workers. Recent studies have highlighted the importance of a worker's location in determining their exposure to a given shock. Workers living in areas with a greater concentration of affected industries tend to fare worse than similar workers elsewhere, and these effects can persist for many years (Dix-Carneiro (2014), Helpman et al. (2013), Topalova (2007), Hakobyan and McLaren (2016), Autor et al. (2013), Dix-Carneiro and Kovak (2017)). This suggests that labour and capital are slow to reallocate in response to demand shocks. Moreover, trade shocks can affect workers through multiple channels. The growth of global value chains has increasingly led to firms importing components or service inputs from abroad (Antrás et al. (2017), Bernard et al. (2018), Johnson (2014)), which has the implication that changes in trade barriers not only affect industries through changes in import competition (potentially at the same time as new or reduced export opportunities), but can also change opportunities for firms to increase their efficiency and reduce costs, with knock-on effects on the wages of their employees (Hummels et al. (2014)). Trade shocks can also be propagated to non-traded industries within countries through input-output links between domestic firms, amplifying their effects on the labour market (Acemoglu et al. (2015); Tintelnot et al. (2018); Vandenbussche et al. (2017)), and altering their distributional impact. By considering the potential role of intra-household insurance, our analysis also reflects the fact that spousal labour supply has been identified as an important insurance mechanism (Blundell et al. (2016)), that has so far been neglected in the trade literature. All these factors have potentially important implications for evaluating the impact of changes in trade barriers on both inter-personal and inter-regional inequality and are thus important to incorporate in any distributional analysis.

The structure of the rest of the paper is as follows. The next section describes the central post-Brexit trade scenario we consider. Section 3 discusses how we measure exposure and the key assumptions associated with our response-inclusive measures. Section 4 discusses exposure across individual workers. Section 5 discusses exposure across households and the scope for intra-household insurance (measured through correlations in exposure across partners). Section 6 reports the proportion of highly

exposed workers and households in different regions. A final section summarises and concludes.

Online Appendices give further details: Appendix A discusses data sources; Appendix B discusses our assumptions on tariffs in a hard Brexit scenario; Appendix C discusses model derivations and results; Appendix D reports how we allocated estimates of non-tariff barriers and elasticity estimates across sectors; Appendix E reports industry level changes in value-added in our model; Appendix F provides additional analysis; Appendix G discusses the sensitivity of our results to different assumptions on key parameters and non-tariff barriers; Appendix H discusses the potential for reductions in EU immigration post-Brexit to mitigate distributional impacts.

2 Post-Brexit trade scenario

Exactly what Brexit will mean for the UK's trading relationships will probably remain unclear for many years. We analyse the effects of changes in the UK's trading relationship with the EU and the rest of the world following a 'hard' Brexit in which the UK and EU fail to agree a comprehensive trade agreement. We assess this relative to a case in which the UK remained in the EU. We allow for changes in both tariff and non-tariff barriers to trade (NTBs). The latter category includes the costs of complying with customs checks, new technical and regulatory barriers to trade and so on. We take estimates of NTBs for different sectors from the UK government's Brexit analysis (House of Commons Exiting the European Union Committee (2018)). This provides estimates of the NTBs that would apply under different possible Brexit scenarios. These estimates were produced using a combination of results from gravity models and more qualitative estimates of potential increases in non-tariff trade costs (see HM Government (2018) for details).

We assume that the UK's exports to the EU will face the EU's existing 'most favoured nation' (MFN) tariffs and the government's estimates of new NTBs under a 'WTO-rules' scenario. In this scenario, we also assume that the UK sets its own MFN tariffs according to the 'no deal' tariff schedule announced in March 2019, and that these are newly applied to imports from the EU.[2] This implies a substantial - though not complete - liberalisation of the UK's MFN tariffs relative to the rest of the world.[3] 72% of the UK's MFN tariff lines see some liberalisation (Gasiorek

[2]We describe how we allocate these tariffs to industries in Appendix B.

[3]Appendix E shows the effect on different industries' value-added in an alternative case where we assume the UK unilaterally eliminates all import tariffs following a hard Brexit (making the same assumptions about NTBs as we do here). This leads to larger value-added losses in some food

et al. (2019)), though tariffs are maintained at their existing levels for vehicles and textiles and above zero for many agricultural and food products.[4]

We also assume that new NTBs apply to imports from the EU but at lower rates to those that are expected to apply to UK exports to the EU. This is because, for example, while the EU is expected to require UK exports of agricultural and medical products to the EU to be approved by EU authorities, the UK will continue to allow EU approved goods to enter the UK (Klemperer (2019)). To account for this and many other asymmetries, we set UK NTBs on EU imports to be half of the rates that are assumed to apply to UK exports to the EU. We report how we allocated NTBs across sectors in Appendix D. Since there is a great deal uncertainty about the value of NTBs that will apply to different sectors, we also show how our results are affected when we alternatively assume uniform NTBs across sectors in Appendix G.

Tariff data on the EU's current MFN tariffs are taken from UNCTAD's Trade Analysis Information System (TRAINS) database accessed through the World Integrated Trade Solutions (WITS) website. Specific duties are converted to ad-valorem equivalent values using the WITS AVE calculator. Information on the UK government's 'no deal tariffs' is taken from documents published online.[5]

3 Exposure to changing trade barriers

We start by describing the ratio of new (tariff and non-tariff) trade costs with the EU to current UK value-added in each industry, accounting for both direct and indirect exposure through upstream and downstream links across industries.

This provides a measure of workers' ex-ante exposure to new trade barriers based on their current industry of employment. However, it does not account for workers' outside options and the likely substitution responses of consumers and firms as relative prices change. We therefore derive a measure from a model of labour demand in which workers are mobile across industries but immobile across local labour markets. This more general measure allows for changing demand for final and intermediate goods and services in the UK, EU and non-EU markets, and

industries. In this, alternative scenario, we also find that there are larger reductions in consumer prices and hence overall exposure. However the industries differentially affected by the additional tariff reductions tend to be small with the result that the *relative* exposure of different workers in the unilateral free trade scenario is similar to the trade scenario we assume in our main analysis.

[4]The UK government stated that these tariffs would not apply to goods crossing the land border from the Republic of Ireland to Northern Ireland. We assume that tariffs apply to all imports regardless of how they enter the UK.

[5]https://www.gov.uk/government/news/temporary-tariff-regime-for-no-deal-brexit-published

for the potential impact these have on demand for the labour of different occupation groups in local labour markets across the UK.

3.1 Increased trade costs with the EU by industry

We measure the exposure of an industry to increased costs due to new trade barriers between the UK and the EU as a proportion of each industry's current value-added. This is given by:

$$\mathbf{V}^{-1}\left[(\mathbf{I}-\mathbf{S})^{-1}\mathbf{\Sigma}_{EU}\hat{\tau}^{EU,X}+(\mathbf{I}-\mathbf{\Gamma}'^{,UK})^{-1}\mathbf{\Gamma}'^{EU}\hat{\tau}^{EU,M}\right] \tag{3.1}$$

where $\mathbf{\Sigma}_{EU}$ is a matrix with the share of each industry's output currently exported to the EU on the diagonal; $\mathbf{\Gamma}^{UK}$ and $\mathbf{\Gamma}^{EU}$ are matrices of input-output coefficients, with elements γ_{ji}^{EU} and γ_{ji}^{UK} denoting the shares of EU and UK inputs from industry j needed to produce £1 worth of output in industry i respectively. The impact of Brexit-induced changes in tariff and non-tariff barriers are summarised in the vectors $\hat{\tau}^{EU,X}$ and $\hat{\tau}^{EU,M}$, which are the proportional change in these trade barriers applying respectively to exports to, and imports from the EU. $\mathbf{S}$ is a matrix with $\frac{\gamma_{ij}^{UK}X_j}{X_i}$ in element ij (X_i denoting output in industry i). $\mathbf{V}$ is a matrix with each industry's share of value-added in total output on the diagonal; pre-multiplying the expression by this matrix means that we express trade costs as a proportion of each industry's value-added. $\mathbf{I}$ is the identity matrix.

The terms $\mathbf{\Sigma}_{EU}\hat{\tau}^{EU,X}$ and $\mathbf{\Gamma}'^{,EU}\hat{\tau}^{EU,M}$ in (3.1) reflect the industry's *direct* exposure to increased trade costs (i.e the additional costs that they would pay on their own exports to, and imports from the EU). We also capture *indirect* exposure by pre-multiplying these terms by adjusted Leontief inverses of input-output coefficients, $(\mathbf{I}-\mathbf{S})^{-1}$ and $(\mathbf{I}-\mathbf{\Gamma}'^{,UK})^{-1}$. This pre-multiplication means that (3.1) also captures changes in trade costs faced by industries to which i supplies intermediate inputs (as well as the changes in trade costs faced by the industries those industries supply to and so on). Similarly, it accounts for changes in trade costs on imports faced by industries upstream of those from which i purchases its inputs.

In what follows we refer to 3.1 as our 'ex-ante' measure of industry/worker exposure to new trade costs (that is, before any worker reallocation or substitution responses). Our ex-ante exposure measure treats trade barriers as fully incident on UK firms (i.e. they are assumed to pay both the increased cost of exporting to the EU and the increased costs of importing from the EU). It can be thought of as an upper bound to UK industries' exposure to new trade costs, since in practice some of the incidence is likely to be borne by EU firms as prices adjust.

We measure industry exports and inputs from two sources. The UK Input-Output (IO) tables from the ONS describe the sale and purchase relationships between 102 UK industries, reporting the proportion of output each industry exports to the EU and their use of imported inputs. They do not record the source of imported inputs. In order to understand the degree to which industries specifically make use of EU inputs, we supplement the national IO tables with data from the 2014 World Input-Output Database (WIOD, see Timmer et al. (2015); Timmer et al. (2016) for detailed descriptions). We use the WIOD tables to separate out imported inputs by industry according to their country of origin. Industries in the WIOD tables are broader (56 industries rather than 102), and we assume that the split of intermediate inputs into imports from the EU and non-EU countries is the same for all industries covered by a given WIOD heading.

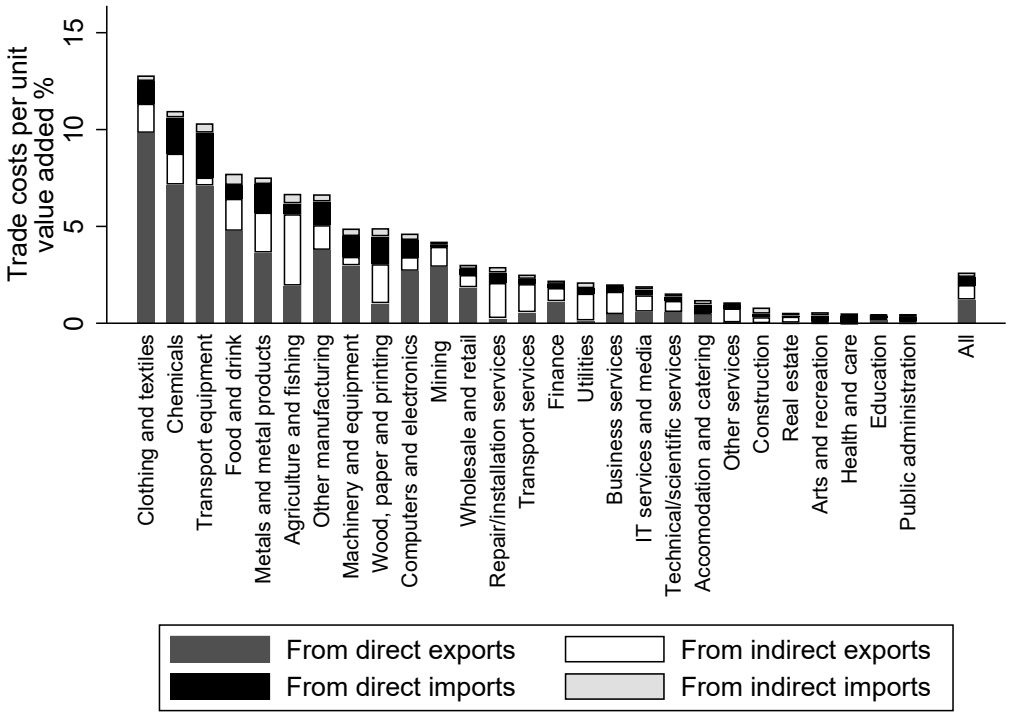
Figure 3.1 shows the change in UK-EU trade costs that apply to different UK industries under the hard Brexit scenario described in Section 2. We measure these at the level of the 102 industries identified in the input-output tables; for ease of interpretation Figure 3.1 groups these into 27 larger industry categories.[6]

We separate these changes into the parts due to i) the trade costs applying to each industry's direct exports to the EU (in dark grey) ii) the trade costs applying to each industries indirect exports to the EU (in white) iii) the trade costs applying to each industry's direct use of inputs imported from the EU (in black) and iv) the trade costs applying to each industry's indirect use of inputs imported from the EU (in light grey).[7]

[6]See Appendix E for the full list of industries and how they are grouped into these categories.

[7]Indirect export trade costs are defined $\mathbf{V}^{-1}\left[(\mathbf{I}-\mathbf{S})^{-1}\mathbf{\Sigma}_{EU}\hat{\tau}^{EU,X}-\mathbf{\Sigma}_{EU}\hat{\tau}^{EU,X}\right]$ (i.e total less direct exposure). Indirect import trade costs are defined as $\mathbf{V}^{-1}\left[(\mathbf{I}-\mathbf{\Gamma}'^{,UK})^{-1}\mathbf{\Gamma}'^{EU}\hat{\tau}^{EU,M}-\mathbf{\Gamma}'^{EU}\hat{\tau}^{EU,M}\right]$.

Figure 3.1: *Changes in trade costs per unit UK value-added by industry*

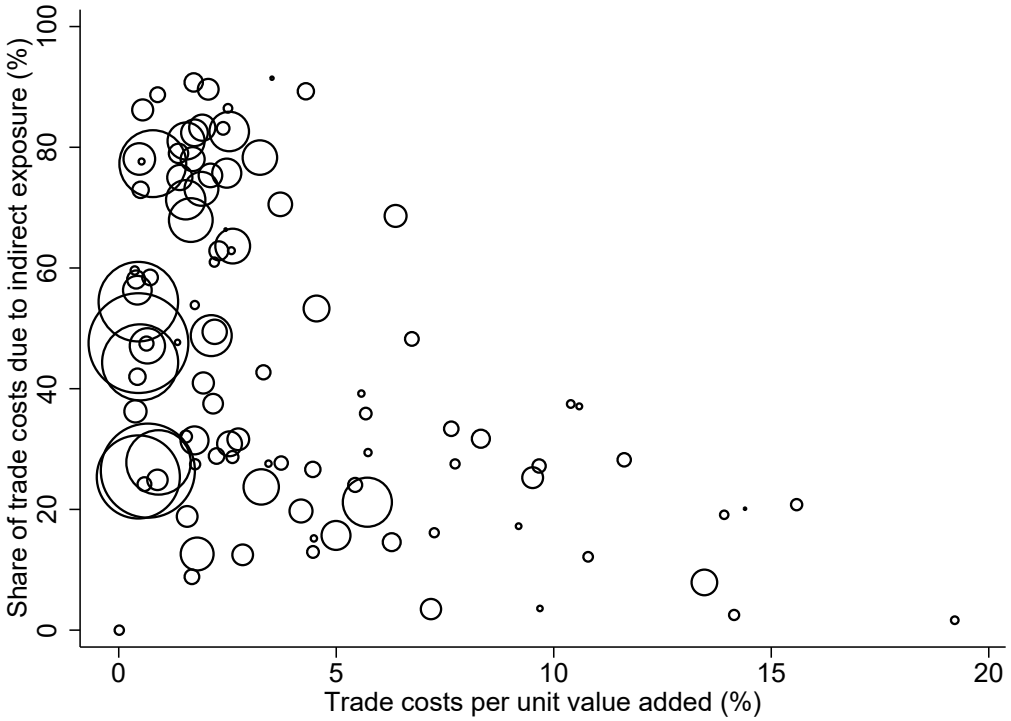


Note: Authors' calculations (see text for sources). Trade costs are defined as in equation 3.1. The 102 industries we use for our analysis have been grouped into 27 larger industry groupings for convenience (see Appendix E for details).

The figure shows considerable variation across industries in the magnitude of their exposure to trade cost increases. Increases in trade costs are highest for the clothing and textiles, chemicals and transport equipment industries. Exposure to (direct and indirect) costs of imported inputs are an important part of the increase, overall representing 25% of the change in trade costs. Indirect exports are also an important element, accounting for 30% of the total increase. Indirect costs are relatively more important for service industries. Service industries face low direct exposure to both changes in export and import costs, but many of these industries have high indirect exposure because they supply to more highly exposed exporters. Among service industries, indirect export exposure to trade costs is particularly important for repair and installation services, business and transport services.

The importance of input-output links becomes more apparent when accounting for the number of workers employed in each industry. Figure 3.2 shows this by plotting the magnitude of increased trade costs against the share of these increased trade costs that are due to indirect imports and exports (i.e. upstream and downstream input-output links). Each marker represents one of the 102 industries and the size of the markers is scaled by the industry's share of total employment.

Figure 3.2: *Trade costs per unit UK value-added and proportion of trade cost changes due to indirect exposure by industry*



Note: Authors' calculations (see text for sources). Each marker represents one of the 102 industries we use for our analysis. The size of the markers represents the share of each industry in total employment.

Figure 3.2 shows that industries whose exposure is primarily direct (due to trade barriers on their own imports and exports from the EU), tend to account for a relatively small share of total employment. By contrast, indirect exposure through input-output links tends to be relatively more important for larger industries. The relation between industry size and the importance of indirect trade costs means that 40% of workers' exposure to new trade costs is due to indirect imports and exports. This highlights the importance of incorporating both international and domestic input-output links when attempting to assess both industries' and workers' exposure to changes in trade barriers.

3.2 Workers' exposure: a model of labour demand

Exposure to post-Brexit trade costs with the EU across industries does not account for a number of factors that determine how individual workers will ultimately be affected by these increased costs. Workers employed in industries that experience reductions in value-added may be able to find re-employment elsewhere; firms may adjust prices in response to shifting demand patterns; consumers may substitute away from products that have become relatively more expensive (for example,

UK consumers may switch away from EU imports and towards UK products). In this section, we outline a 'response-inclusive' exposure measure which accounts for worker reallocation and demand substitution by firms and consumers (detailed derivations and discussion are provided in Appendix C).

We build on specific-factor models of labour demand such as those that have been used to analyse trade shocks in other settings (Jones (1975), Kovak (2013), and Dix-Carneiro and Kovak (2015)). Industries in these models operate with CES production technology that creates output by combining inputs of different skill groups of labour and capital. Firms decide how much labour to hire from each skill group on the basis of demand for their output. Our approach extends these models, most importantly by incorporating input-output links across industries and countries, which the previous subsection showed were an important determinant of new trade costs faced by industries.

Our model-based approach allows us to quantify the exposure of individual workers taking into account shifting patterns of demand as a result of changes in trade barriers post-Brexit and worker reallocation. However, the measure remains restrictive in many dimensions, capturing only the short-term impacts of new trade barriers and not longer term impacts of Brexit on for instance investment, productivity growth or reduced aggregate demand. This measure provides sufficient statistics for the real wage changes workers in different local labour markets and skill types would experience as a result of shifting demand patterns due to new trade barriers given the following assumptions:

- **Factor (labour and capital) mobility:** Industries in each local labour market make use of inputs of labour, a geographically and industry specific 'capital' input, and intermediate goods. Labour is defined by skill group. Workers are assumed to be completely mobile across industries but immobile across labour markets and skill groups.
  - These assumptions mean that the choice of skill groups is important. For our main results we define skill groups using 1-digit occupations (there are 9 of these). In Appendix G Table G.1 we show transition rates across these occupations. In the same appendix, we show that our main results are robust to assuming that workers are more mobile across occupations by allowing for mobility across occupations within three broader skill groups (classified on the basis of workers' transitions).
  - The assumption of geographic immobility of both labour and capital is intended to reflect the large and persistent location-specific impacts of

trade shocks on both wages and employment (Topalova (2007), Hakobyan and McLaren (2016), Autor et al. (2013), Dix-Carneiro and Kovak (2017)). These papers suggest that labour and capital are slow to reallocate across labour markets in response to shocks. In principle we could incorporate mobility across labour markets into our analysis if we had good estimates of the relevant elasticities.

- **Labour and product markets:** We make the following assumptions about labour and product markets.
  - Factor markets clear within each local labour market.
  - Each country (the UK, the EU and non-EU countries) produce distinct varieties of goods and services.
  - Firms in all countries sell their output in a global product market in which there is perfect competition. Output may be sold to UK consumers, consumers in the EU, consumers in non-EU countries or to other UK industries (for use as intermediate inputs).
  - Changes in UK, EU and non-EU demand affect the prices of UK varieties of goods and services sold in world markets. However, we assume that changes in the UK's purchases of EU and non-EU varieties following Brexit will be too small relative to the overall market for these goods to affect the world prices of EU and non-EU varieties.[8]

- **Firm production technology:** We assume there is a representative firm for each industry in each local labour market. These firms decide how much labour to hire locally given product prices, the cost of intermediate inputs (which are both determined at the national level), and wages (which vary across local labour markets and skill groups).
  - Firms produce output using a Leontief combination of intermediate inputs and *value-added* from factor inputs (different labour types and capital).[9]
  - Value-added is a Constant Elasticity of Substitution (CES) combination of labour from different skill groups and capital.

[8] This assumption means we avoid having to model the effects of supply and demand changes on the prices of EU and non-EU varieties.

[9] Costa et al. (2019) find evidence that increases in the costs of intermediate inputs (caused by the Sterling depreciation following the Brexit referendum) reduce workers wages, consistent with them being gross complements. This lends support to our assumption of Leontief technology.

  - To produce output, factor inputs are combined with intermediate inputs from different industries that are consumed in fixed quantities per unit of output. Inputs from a given supplier industry are CES composites of different national varieties (UK, EU and non-EU imports). Thus, as the price of EU goods and services increases, UK firms may switch towards domestic varieties.
  - Firm technology does not change in response to Brexit.

- **Consumer preferences:** Consumer preferences for final output in all countries are Cobb-Douglas across the output of different industries. This means that the share of consumer spending going to each industry is constant. Within each industry consumers substitute between UK, and EU and non-EU varieties according to CES preferences. Consumer preferences in our model are homothetic and thus do not depend on the distribution of incomes. This means that the effects of changes in the cost of living are common across workers and income groups.[10]

This measure of exposure depends on how changes in trade costs affect each industry and on the mix of industries and skill groups within each local labour market. Workers in an occupation and local labour market will have greater exposure if the industries in that area which experience larger (direct and indirect), increases in trade costs employ relatively more workers of that occupation group.

The methods we use to calibrate key parameters in our model are as follows:

1. Employment shares of workers by skill group, industry and local labour market come from the Annual Survey of Hours and Earnings (ASHE, Office for National Statistics (2019a)) and the Business Structure Database (BSD, Office for National Statistics (2019b)), see Appendix A. Local labour markets are taken as Travel to Work Areas (TTWAs), which are defined using commuting flow data from the 2011 Census.

2. Cost shares of workers by skill group and industry come from ASHE and ONS input-output tables, see Appendix A.[11]

[10] Non-homothetic preferences may mean that trade shocks have additional distributional consequences (Borusyak and Jaravel (2018)). We abstract from those here, although they could in principle be incorporated into our analysis if we had good estimates of how preferences varied with income.

[11] Our data are mostly taken from the period before the June 2016 referendum. Trade data is taken from the 2014 input-output tables. The Business Structure Database is drawn from a snapshot of the Inter-Departmental Business Register that is taken in April each year with the

3. Elasticity of substitution between factors of production for each industry is set to 1 for all industries in our baseline results (i.e. we assume Cobb-Douglas technology). As with the other elasticities in our model, there is uncertainty over the value of this parameter. We discuss the implications of allowing alternative values of this parameter in Appendix G.

4. Elasticities of substitution between UK and EU varieties of final goods and services produced by each industry are set according to the elasticities reported in Caliendo and Parro (2015) in our baseline results. These are similar to the elasticities reported in other studies. For service industries (not covered in Caliendo and Parro (2015)), we follow Costinot and Rodríguez-Clare (2014) and set these to a value of five. We discuss the implications of our results to alternative values of these elasticities in Appendix G.

5. Elasticities of substitution between UK, EU and non-EU varieties of intermediate inputs purchased from each industry are assumed to be the same as the elasticities of substitution across different national varieties of final goods and services in each industry.

6. The share of UK output which is exported, the import penetration of EU producers and the values of input-output coefficients are taken from the ONS input-output tables.

3.3 Key areas of uncertainty

It is worth highlighting some key areas of uncertainty in our analysis and potential limitations of our model.

There is considerable uncertainty about the costs associated with non-tariff barriers. These will ultimately depend on policy decisions taken by the UK and EU. Existing estimates of potential new NTBs are similar across studies, but these estimates are often produced using similar methods (gravity models of trade flows across countries with different trading arrangements).[12] The NTBs we use are also estimated at a relatively high level of industry aggregation (for 9 groups which we

reporting period covering the previous financial year. ASHE is also carried out in April. The 2016 versions of the BSD and ASHE data we use therefore precede the referendum result. This means that employment shares we use are not affected by post-referendum uncertainty that has shown to effect hiring decisions and firm entry into export markets in the literature (Javorcik et al. (2019); Crowley et al. (2018))

[12]For a comparison of estimates of non-tariff barriers from different studies see Figure 7 in International Monetary Fund (2018)

allocate across 102 industries). We report the allocation of NTBs to different sectors in Appendix D. We also report the sensitivity of our results relative to a case where we assume uniform NTBs across sectors in Appendix G.

The assumptions underlying our response-inclusive measure also impose a number of restrictions on firm, worker and consumer responses to changing trade barriers.

We assume that workers are immobile across local labour markets, and that the definition of a 'local labour market' is the same for workers in different skill groups. This is to keep the model tractable. However, there is evidence that skilled workers are more mobile. For example there are estimated to be 416 TTWAs for workers with low qualifications compared to 153 for workers with high qualifications (Office for National Statistics (2016)). This means that we may understate the relative exposure of less skilled workers.

In addition our assumptions on firms' production technology assume that the elasticity of substitution between intermediate inputs and workers in different skill types is constant (and equal to zero). Some studies have found that high-skilled workers are more complementary with production inputs than low-skilled workers (Hummels et al. (2014); Costa et al. (2019)).

In principle, changes in the prices of UK intermediate inputs purchased abroad could in turn affect the prices of these countries exports with additional knock on affects on the prices paid by UK firms and consumers. Consistent with our assumption that UK is too small to affect foreign prices in a substantial way, we do not account for this channel in what follows.

4 Exposure across individuals

The response-inclusive measure of workers' exposure to increased trade costs is based on predicted changes in demand by firms for workers in different occupation groups. To contextualise the results below we start by summarising the characteristics of workers employed in different occupations. We use the 2017 Quarterly Labour Force Survey (QLFS, Office for National Statistics, Social Survey Division (2019b)).[13]

Table 4.1 shows that managers, professionals and technical professionals have the highest average weekly earnings and are most likely to hold a degree. Machine operatives and workers in skilled trades are much less likely to hold a degree, but

[13]The QLFS is a nationally representative survey of UK households with information on earnings and demographics of household members (described further in Appendix A).

despite this are on average relatively well paid. Workers in these occupations are also disproportionately older, male and likely to be employed in manufacturing. Workers in administrative, other service, sales and elementary occupations are on average less well paid and more likely to be employed in service (as opposed to manufacturing), industries. Those employed in administrative and other service occupations are also disproportionately likely to be female.

Table 4.1: *Characteristics of workers in different occupations*

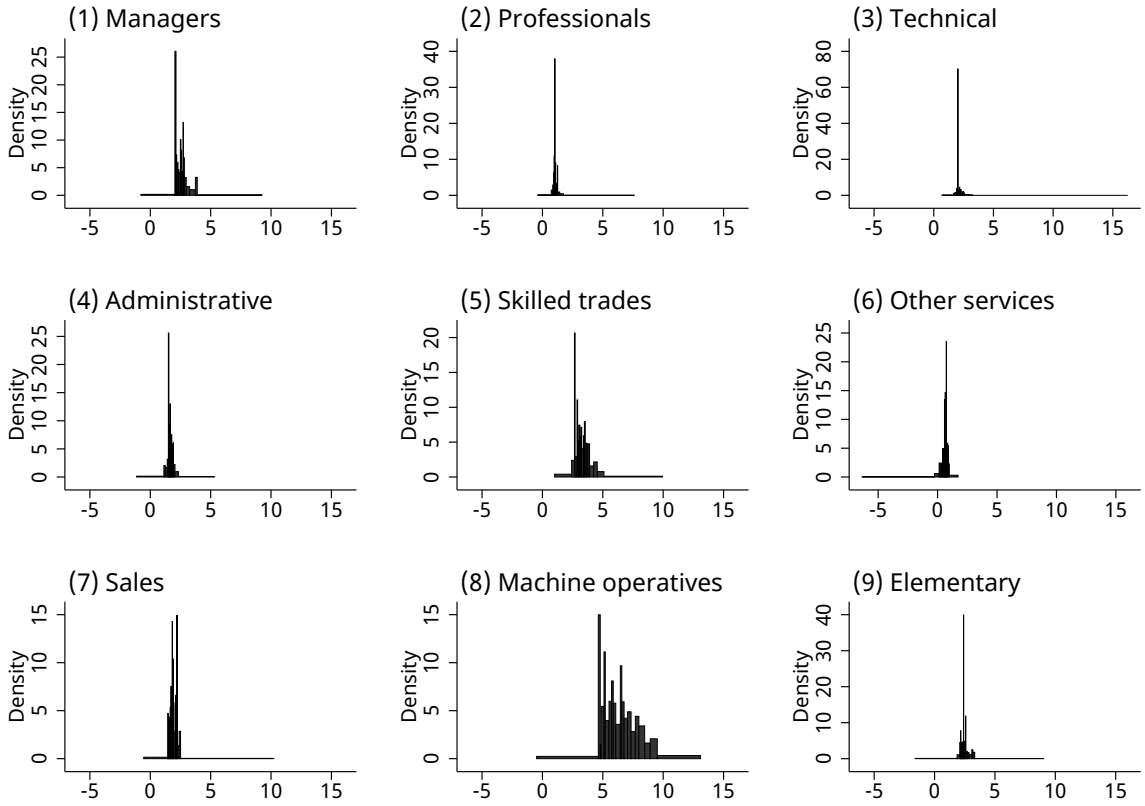
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Occupations	% total	Prop. degree	Prop. male	Prop. manuf.	Age	Weekly earnings (£)	HH earnings (£)
1. Managers	9.5	0.47	0.65	0.12	44.5	868	1,213
2. Professional	20.9	0.75	0.48	0.06	41.2	735	1,117
3. Technical	14.1	0.47	0.57	0.11	39.3	641	997
4. Administrative	11.6	0.26	0.25	0.07	41.9	384	584
5. Skilled trades	7.8	0.09	0.89	0.26	39.5	510	766
6. Other service	9.8	0.18	0.19	0.00	39.8	280	394
7. Sales	8.7	0.16	0.38	0.03	35.9	271	464
8. Machine ops	6.1	0.07	0.88	0.32	43.7	464	675
9. Elementary	11.4	0.09	0.53	0.08	37.8	261	434
All	100	0.35	0.51	0.05	40.4	527	836

Note: Authors' calculations from 2017 Quarterly Labour Force Survey. Household earnings are defined as the sum of the weekly earnings of the household head and their partner.

To examine the exposure of workers to changes in trade costs we assign the response-inclusive measures described in subsection 3.2 to workers based on their local labour market (defined as their TTWA of residence) and occupation.

Figure 4.1 shows the distribution of exposure for each of the 9 occupation groups. There is considerable variation in exposure across occupations. Exposure is highest among machine operatives and skilled trades occupations and lowest among other service, professional and administrative occupations. Some managers are also relatively highly exposed.

Figure 4.1: *Distribution of response-inclusive exposure to changes in trade costs by occupation*



Note: Authors' calculations from 2017 Quarterly Labour Force Survey. Exposure is the output of the model outlined in Section 3.2 for a 'WTO rules' Brexit. It varies by workers' region and across nine occupation groups.

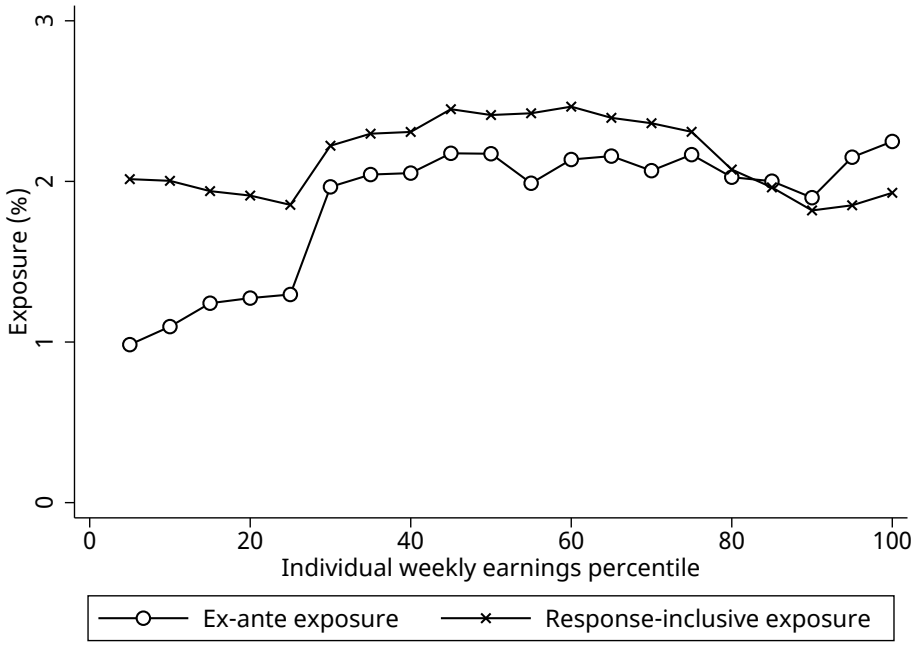
Figure 4.1 also shows there is a great deal of variation in exposure *within* some occupations. Variation in the response-inclusive exposure measure reflects differences in the industrial composition of employment across local labour markets. The wide dispersion of exposure among machine operatives, for instance, indicates that in some local labour markets highly exposed industries employ a large fraction of workers in this occupation. The large differences in exposure across local labour markets can be interpreted as an indication that geographic labour mobility, and policies which facilitate this, will be a key determinant of the distributional impacts of new trade barriers.

The distribution of ex-ante exposure to trade costs (not shown in Figure 4.1), which varies according to workers' current industry, is also greatest for machine operatives and those in skilled trades. This measure has a much more highly skewed distribution within each occupation; exposure is concentrated in a few industries that employ a relatively small share of workers. This is because the ex-ante exposure measure does not allow for the possibility that workers in exposed industries

find jobs elsewhere, with knock-on effects on the wages of other workers in their occupation and local labour market. These equilibrium effects, incorporated in our response-inclusive measures, reduce the dispersion of exposure.

Comparing Figure 4.1 and Table 4.1 suggests a positive correlation between average earnings and exposure. For example sales, administrative and other service occupations have relatively low levels of average earnings and are relatively highly exposed. Figure 4.2 shows the relationship between exposure and earnings explicitly by plotting the mean level of trade cost and response-inclusive exposure at different percentiles of the individual earnings distribution.

Figure 4.2: *Measures of individual ex-ante and response-inclusive exposure over the earnings distribution*



Note: Authors' calculations from 2016 Annual Survey of Hours and Earnings and 2016 Business Structure Database. Ex-ante exposure is defined as the sum of new tariff and non-tariff barriers that would apply to exports to the EU and imports of intermediate inputs from the EU under a 'WTO rules' Brexit (as a percentage of UK value-added) in each worker's main industry of employment. Response-inclusive exposure is the output of the model outlined in Section 3.2 for a 'WTO rules' Brexit. It varies by workers' region and across nine occupation groups. We smooth by plotting average exposure within five percentile bands.

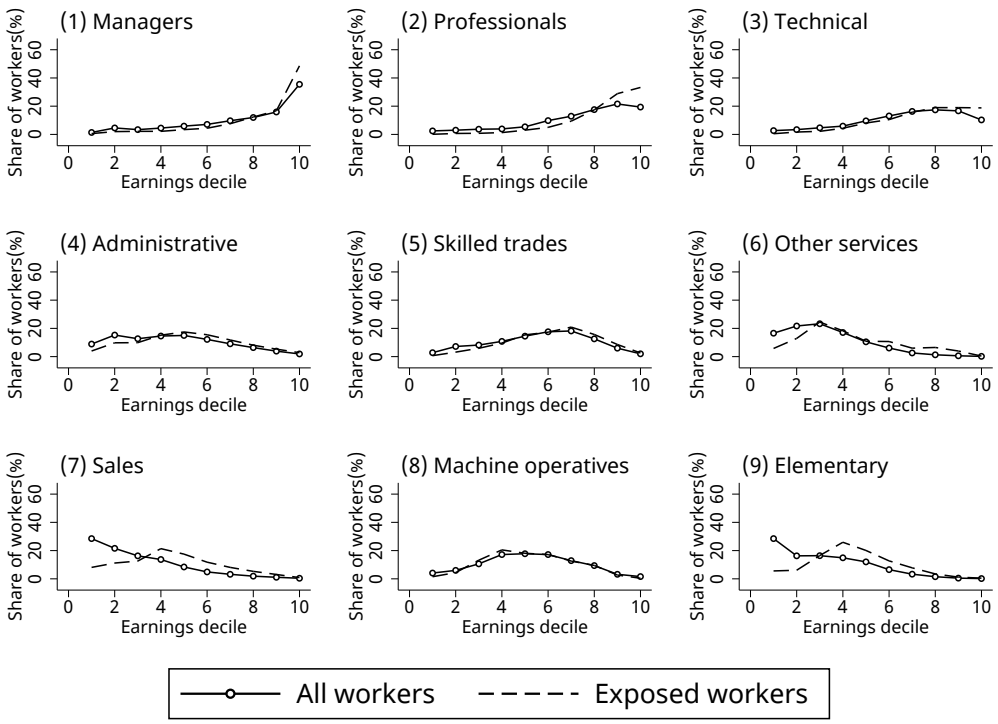
Figure 4.2 shows that if we just consider the exposure of workers based on the industry that they work in using the ex-ante measure, it appears as if higher-earning individuals are more exposed than individuals at the bottom of the earnings distribution. However, this assessment changes considerably when we allow for worker reallocation and demand substitution.

The reason for the differences in relative impacts between the two exposure measures is due to the effects of worker reallocation on equilibrium wages for each

occupation. Workers in highly exposed industries tend to earn more than other workers in the same occupation, and this is true both for low-skilled and high-skilled occupations. When increased trade costs cause employment in these industries to fall, workers in low-skilled occupations leaving these industries drive down the wages of lower-earning workers in the same occupation. This explains the relatively greater exposure of lower-earning workers under our response-inclusive measure. At the same time, the effects on highly exposed workers in skilled occupations at the top of the earnings distribution are cushioned by the availability of outside options in their local labour market. Hence exposure is relatively lower for high earners when workers are allowed to change industries.[14]

[14]The ex-ante exposure measures may also differ from the response-inclusive exposure measures because of consumer substitution in response to relative price changes. Figure F.1 in Appendix F compares the ex-ante and response-inclusive exposure measures when we 'switch-off' worker mobility across industries. The two exposure measures are very similar in this case, which implies worker mobility is the primary cause to of the differences between the two exposure measures shown in Figure 4.2.

Figure 4.3: *Share of workers and workers in industries "highly exposed" to new trade costs with the EU in different deciles of the individual earnings distribution of all workers (by occupation)*



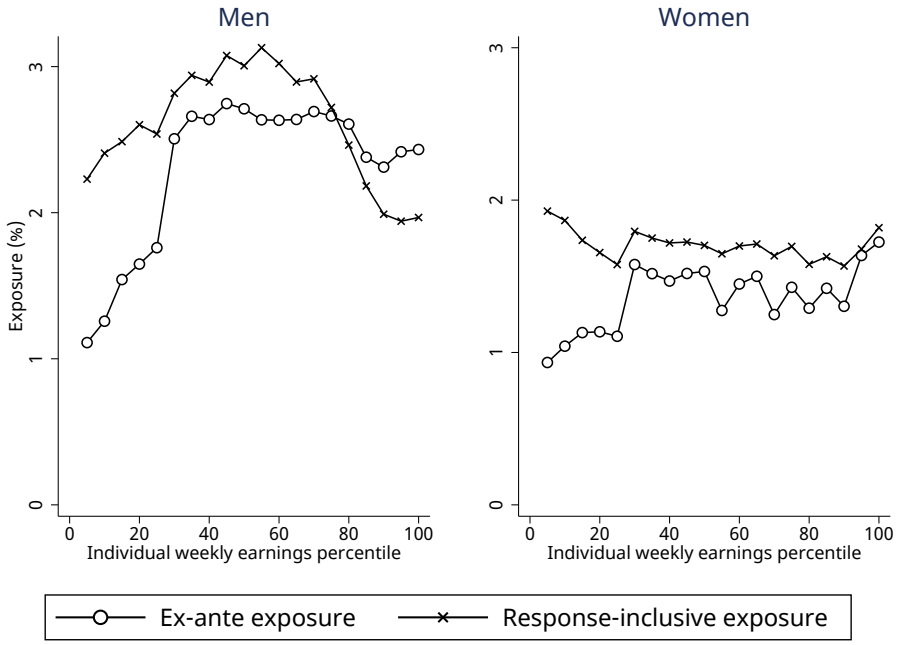
Note: Authors' calculations using 2016 Annual Survey of Hours and Earnings and 2016 Business Structure Database. Figure shows shares of workers and workers in highly exposed industries by decile of the individual earnings distribution. Highly exposed industries are defined as industries for which new (direct and indirect) trade costs account for 5% or more of industry value-added. Exposure is defined as the sum of new tariff and non-tariff barriers that would apply to exports to the EU and imports of intermediate inputs from the EU under a 'WTO rules' Brexit (as a percentage of UK value-added) in each worker's main industry of employment.

Figure 4.3 show evidence of these patterns by plotting the share of all workers and the share of 'highly-exposed' workers (defined as workers employed in industries with ex-ante exposure measure of 5% or more), in each earnings decile for different occupations. The top panel of the figure shows this information for managers, professionals and technical occupations, which together account for 98% of workers in the top earnings decile. Workers in these occupations employed in highly exposed industries are over-represented at the top of the earnings distribution. Workers in other service, sales and elementary occupation account for 70% of the bottom earnings quintile. Figure 4.3 shows that workers in these occupations employed in highly exposed industries are over-represented in the middle of the earnings distribution.

Figure 4.2 shows the relationship between exposure and earnings for all workers. Table 4.1 shows large differences in the gender composition of different occupations

suggesting it is also interesting to consider how this relationship varies across men and women. This is shown in Figure 4.4, which displays exposure across the overall earnings distribution separately for men and women. This highlights two significant points First, exposure is higher for men at almost all points of the earnings distribution. Second, the overall impact of increased trade costs is highest among lower-earning men, whereas there is little variation across the earnings distribution for women.[15]

Figure 4.4: *Measures of individual exposure over the weekly earnings distribution by gender*



Note: Authors' calculations from 2016 Annual Survey of Hours and Earnings and 2016 Business Structure Database. Ex-ante exposure is defined as the sum of new tariff and non-tariff barriers that would apply to exports to the EU and imports of intermediate inputs from the EU under a 'WTO rules' Brexit (as a percentage of UK value-added) in each worker's main industry of employment. Response-inclusive exposure is the output of the model outlined in Section 3.2 for a 'WTO rules' Brexit. It varies by workers' region and across nine occupation groups. We smooth by plotting average exposure within five percentile bands.

The gender-specific patterns shown in Figure 4.4 are different from the overall relationship between exposure and earnings shown in Figure 4.2 because there are large differences in gender composition across the earnings distribution. This is shown in Figure F.2, which plots the share of workers at different percentiles of the earnings distribution that are female. This shows an almost monotonic negative relationship between the female share and earnings. Whereas 70-75% of workers in

[15]Results are very similar when we use a 3-way as opposed to a 9-way occupation split.

the bottom 20% of the earnings distribution are female, this share falls to 20-25% among workers in the top earnings decile.[16]

The gender differences in the level of exposure and its relationship with earnings shown in Figure 4.4 suggest there may be considerable variation in exposure between members of a couple. This suggests a potentially important difference between household and individual-level exposure. We address this in the following section.

5 Exposure across households

So far we have considered the exposure of individual workers. However, welfare impacts will also depend on the exposure of other members of a worker's household. For some workers, this means that measures of individual exposure will understate the likely impact of increased trade costs on their welfare, if, for example they are married to a worker employed in a highly exposed occupation. For other workers, the degree of exposure may be overstated if other members of the household are less impacted and hence provide them with insurance (Blundell et al. (2016)).

The extent to which intra-household insurance is possible depends on whether those employed in exposed industries have partners with some labour force attachment and on the correlation in exposure across members of a couple.[17] In this section we examine the potential for partners to insure workers and the impact that such insurance has on the distributional impacts of higher trade costs by drawing on the QLFS, which allows us to identify members of the same household.

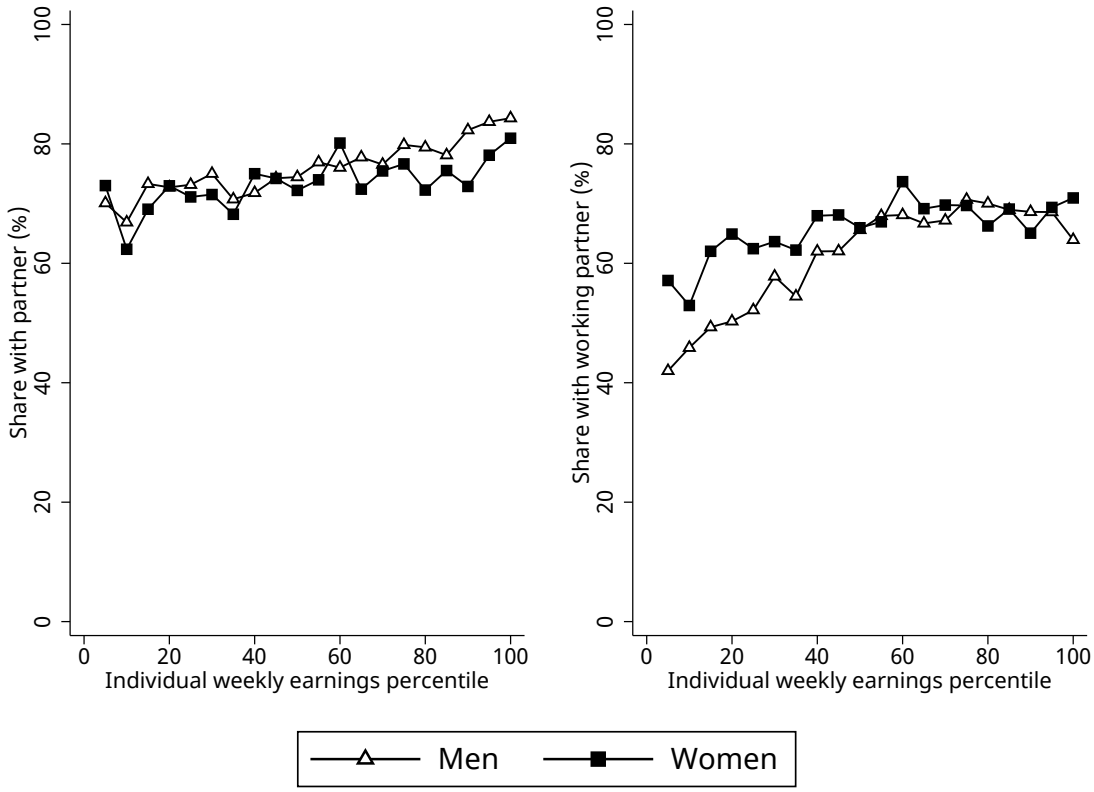
Two factors that influence the scope for intra-household insurance are whether or not workers have a partner and whether or not that partner is employed. Figure 5.1 shows how these household characteristics vary across men and women at different points of the overall earnings distribution. The left panel of the figure shows a slight positive relationship between having a partner and earnings for both men and women. The right panel shows the relationship between having a working partner and earnings is somewhat stronger for men than women. For example around 43% of men in the bottom earnings decile have a working partner in comparison to around 65% of men in the top earnings decile, while the equivalent percentages for women are 55% and 70%. This shows there is less scope for intra-household insurance

[16]Table F.1 in Appendix F shows how exposure varies according to other demographic characteristics. Exposed workers are more likely to be older and less educated than other workers.

[17]This is under the assumption that household structures remain unchanged. There is however evidence that household formation and dissolution may itself also be affected by trade shocks (Autor et al. (2018)).

among low-earners than high-earners, with low-earning men likely to benefit the least from any insurance provided by a working partner.

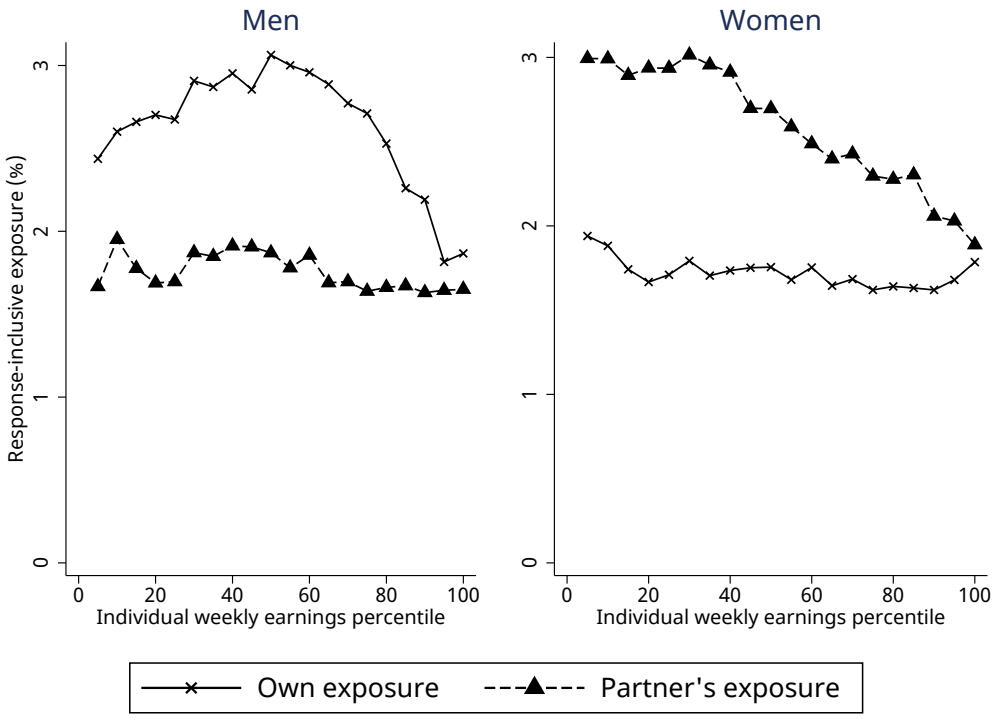
Figure 5.1: *Household characteristics of men and women over the individual earnings distribution*



Note: Authors' calculations using 2017 Quarterly Labour Force Survey. Partners include married spouses and unmarried cohabitees.

For workers that do have a working partner, whether intra-household insurance mitigates or exacerbates an individual's exposure to negative effects of post-Brexit trade barriers depends on the correlation of exposure across partners. Figure 5.2 shows how this correlation varies with earnings by plotting workers' own response-inclusive exposure and that of their partner at different percentiles of the earnings distribution. The figure shows that intra-household insurance has very different implications for men and women. At all levels of earnings, the exposure of men's partners is lower than their own, whereas the exposure of women's partners is higher than their own. This implies that household insurance acts to mitigate the individual exposure among men, while it exacerbates it among women.

Figure 5.2: *Own and partner's response-inclusive exposure by gender over the individual earnings distribution*



Note: Authors' calculations using 2016 Annual Survey of Hours and Earnings, 2017 Quarterly Labour Force Survey and 2016 Business Structure Database. Figure shows exposure predicted by our model across percentiles of the individual earnings distribution. We smooth by plotting average exposure within five percentile bands. Exposure is the output of the model outlined in Section 3.2 for a 'WTO rules' Brexit. It varies by workers' TTWA and across nine occupation groups. We merge exposure into the 2016 Annual Survey of Hours and Earnings to obtain estimated impacts over the earnings distribution of individual workers. We merge these into the 2017 Quarterly Labour Force Survey on the basis of workers' current occupation and their current Government Office Region rather than TTWA (a level of geographic detail which is not available in public versions of the QLFS) to obtain partners' exposure.

Figure 5.2 also shows the potential value of intra-household insurance varies across the earnings distribution for men and women. The left panel shows that the difference between own and partner's exposure is greatest among men with working partners in the middle of the earnings distribution, suggesting this group would gain most from insurance provided by their partners. These middle-earning men are also the most highly exposed group of workers, which reflects the fact that the exposure of men's partners varies very little across the earnings distribution. By contrast the right panel shows that women in the bottom 40% of the earnings distribution have partners that are highly exposed both relative to their own exposure and other workers. This shows that although partners act to increase the exposure of women at all levels of earnings, the effect is greatest among low-earning women.

Taken together, Figures 5.1 and 5.2 suggest there is scope for intra-household insurance to substantially change our assessment of the distributional impact of post-Brexit trade barriers. Figure 5.3 shows that this is indeed the case. The figure plots individual's response-inclusive exposure alongside a household-level measure of response-inclusive exposure that is the sum of individual and partners' exposure weighted by their respective share of household earnings (for workers without an employed partner, the household exposure measure is the same as the individual exposure measure). This shows that when exposure is measured at the household level there is a moderate regressive pattern across the earnings distribution, with workers in the top 20% of the earnings distribution relatively less exposed than workers on lower levels of earnings.[18]

Figure 5.3 shows the impact of intra-household insurance is most negative among workers in the bottom 20% of the earnings distribution. As discussed above, these workers are overwhelmingly female and the difference between the individual and household measures of exposure at this part of the earnings distribution is therefore primarily due to the patterns shown in the right panel of Figure 5.2.

[18]While Figure 5.3 considers distributional consequences across the individual earnings distribution, Figure F.3 shows that household exposure exhibits a similar regressive pattern across the household earnings distribution.

Figure 5.3: *Workers' and their households' response-inclusive exposure over the individual earnings distribution*

Note: Authors' calculations using 2016 Annual Survey of Hours and Earnings, 2017 Quarterly Labour Force Survey and 2016 Business Structure Database. Figure shows exposure predicted by our model across percentiles of the individual earnings distribution. We smooth by plotting average exposure within five percentile bands. Exposure is the output of the model outlined in Section 3.2 for a 'WTO rules' Brexit. It varies by workers' TTWA and across nine occupation groups. We merge exposure into the 2016 Annual Survey of Hours and Earnings to obtain estimated impacts over the earnings distribution of individual workers. We merge these into the 2017 Quaterly Labour Force Survey on the basis of workers' current occupation and their current Government Office Region rather than TTWA (a level of geographic detail which is not available in public versions of the QLFS) to obtain household exposure. Household exposure is calculated using predicted exposure for household heads and their partners (if they have one) weighted by their shares in total household earnings (reflecting differences in hours worked). To be included in the sample, households must have at least one member in work.

The results in this section show that accounting for the correlation of exposure among household members can significantly alter our assessment of distributional impacts of new trade barriers. Failing to account for the exposure of the household members would lead us to understate the exposure of low-paid workers.

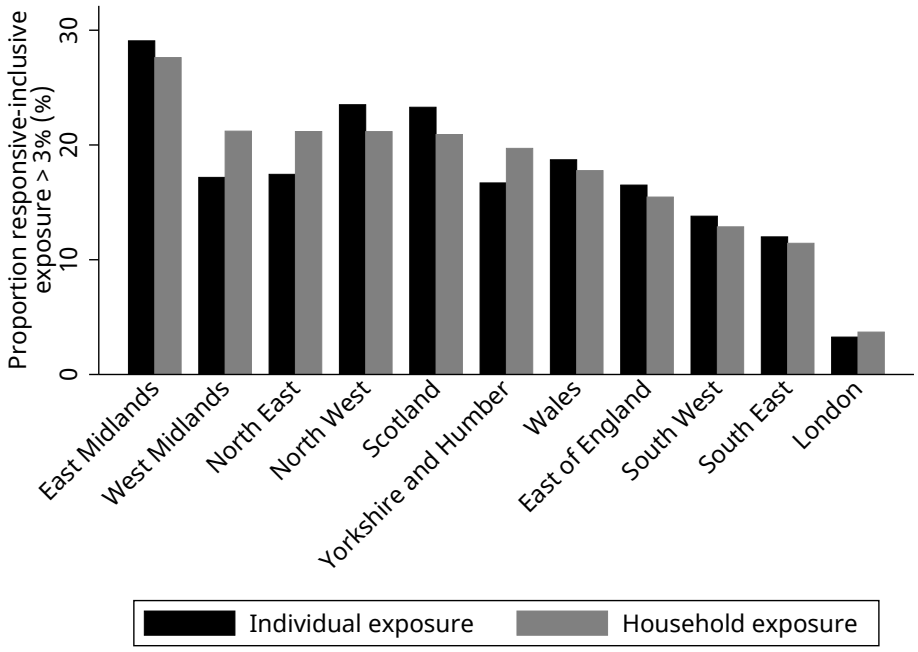
6 Exposure across regions

Figure 6.1 shows the proportion of individuals and households with high levels of exposure in different regions of Great Britain.[19] High exposure is defined as having

[19]We do not include Northern Ireland here as it is not included in the ASHE dataset.

response-inclusive exposure of 3% or more (corresponding to roughly the top fifth of households by exposure). Household exposure is highest in the East and West Midlands where 28% and 21% of households are highly exposed respectively. It is lowest in London and the South East where the proportion of workers in highly exposed households is 4% and 11% respectively. In most regions the proportions of highly exposed individuals is similar to the proportion of highly exposed households, and there are proportionally fewer highly exposed households than individuals. Notable exceptions to this are the West Midlands and the North East. In these regions, the proportion of exposed households is greater than the proportion of exposed individuals. This reflects the fact that individuals with low exposure in these regions are more likely to be partnered with individuals who have relatively high exposure (and whose individual exposure is high enough to bring their household above the 3% threshold).

Figure 6.1: *Workers' and their households' response-inclusive exposure in different regions of the Great Britain*



Note: Authors' calculations using 2016 Annual Survey of Hours and Earnings, 2017 Quarterly Labour Force Survey and 2016 Business Structure Database. Figure shows exposure predicted by our model across percentiles of the individual earnings distribution. Exposure is the output of the model outlined in Section 3.2 for a 'WTO rules' Brexit. It varies by workers' TTWA and across nine occupation groups. We merge exposure into the 2017 Quarterly Labour Force Survey on the basis of workers' current occupation and their current Government Office Region to obtain household and individual exposure within each region. Household exposure is calculated using predicted exposure for household heads and their partners (if they have one) weighted by their shares in total household earnings (reflecting differences in hours worked). To be included in the sample, households must have at least one member in work.

7 Conclusion

In this paper we have presented measures of the exposure of different UK workers to changes in trade barriers following a 'hard' Brexit. The variation we find in exposure across different TTWAs and occupations suggests that workers' location and mobility, as well as their industry, are likely to be important when considering how to mitigate any adverse consequences of any changes in the UK's future trade policy. We also found that individual's exposure and the exposure of their households can be quite different, particularly at the bottom of the individual earnings distribution. This highlights the importance of considering household rather than just individual circumstances when providing workers with compensation or assistance in coping with future trade shocks.

Our analysis also suggests that frictions to inter-industry and inter-regional mobility are likely to be particularly important for determining impacts on low educated workers in blue-collar occupations (specifically machine operatives and those employed in skilled trades). While workers currently employed in highly exposed industries in some occupations (such as managers) often have reasonably good outside options within their local labour markets, workers in blue-collar occupations often do not. This may be concerning as these workers tend to have fewer formal educational qualifications, and their skills may therefore be more industry specific. These workers also tend to be less mobile (Gregg et al. (2004)), and also appear to commute shorter distances. Previous studies have shown that blue-collar workers tend to be worst affected by episodes of trade liberalisation, with those displaced from tradable industries often only finding re-employment in low-wage service industries (Goos and Manning (2007), Autor et al. (2014), Goos et al. (2014), Dix-Carneiro and Kovak (2017)) and with less educated workers faring particularly badly (Hakobyan and McLaren (2016)). The reason these workers are also likely to be negatively affected by *increases* in trade barriers following Brexit is because they are employed in tradeable sectors which are most exposed to the negative affects of reduced access to the EU market as a source of intermediate inputs and of demand for exports.

Policy can potentially play an important role in overcoming frictions affecting displaced workers. Recent papers have indicated that targeted financial assistance and training provided to displaced workers in the US through the Trade Assistance Adjustment program can encourage both geographic and inter-sectoral mobility with large effects on earnings and employment (Hyman (2018)). Other papers have shown that providing information on labour market conditions to job seekers can encourage such workers to broaden their search to other occupations and receive

more invitations to interview as a result (Belot et al. (2019)). Place-based policies may also be useful for directing assistance to localities where exposure is particularly concentrated. Our findings on the distribution of likely exposure reveal where these and other policy interventions should be targeted.

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Online Appendices

A Data sources

Our analysis draws on data from several sources.

We use the 2016 Business Structure Database (BSD) to measure the industrial composition of each local labour market. The BSD is an administrative dataset covering the employment, turnover and industry of all 'local units' (plants and offices) for UK firms whose turnover exceeds the threshold for VAT payments (£85,000 in 2016/17). In 2004 the BSD was estimated to account for almost 99% of economic activity in the UK.

Local labour markets are defined using the 228 Travel to Work Areas (TTWAs); geographical units analogous to American Commuting Zones. The boundaries of TTWAs are delineated by the Office for National Statistics (ONS) such that (in normal cases) i) at least 75% of workers in the TTWA also reside in that TTWA, and ii) at least 75% of those residing in the TTWA also reside in that TTWA.[20] Over time, the number of TTWAs has tended to fall as commuting distances have risen.

We take data on individual workers from the 2016 Annual Survey of Hours and Earnings (ASHE). ASHE is a 1% sample of employees aged 16 or older in Great Britain (the UK, excluding Northern Ireland), who earn above the lower earnings limit of the UK national insurance system (£112 per week in 2016/17).

We take information from the 2017 Quarterly Labour Force Survey (QLFS) to look at the exposure of households in addition to individual workers, as well as to examine exposure according to variables that are not included in ASHE (such as education). The QLFS is a nationally representative survey of UK households, interviewing all members aged 16 and over.

Information on industry exports and inputs comes from two sources. The first is the ONS Input-Output (IO) tables. These describe the sale and purchase relationships between industries, including the proportion of output each industry exports to the EU and their use of imported inputs. We use these tables to examine the effect of trade barriers on 102 different industries. The national IO tables do not record the source of imported inputs. In order to understand the degree to which industries specifically make use of EU inputs, we supplement the information contained in the IO tables with data from the 2014 World Input-Output Database (WIOD, see Timmer et al. (2015); Timmer et al. (2016) for detailed descriptions). This database was specifically developed for the purpose of analysing the sources of and uses of industries' inputs and output. We use the WIOD tables to separate out imported inputs by industry according to their country of origin. The industry headings in the WIOD tables are somewhat broader than those in the national input-output tables (with 56 industries rather than 102), we assume that the split of intermediate inputs into imports from the EU and non-EU countries is the same for all industries covered by a given WIOD heading.

[20] Areas must also have a minimum size of 3500 economically active residents. Thresholds below 75% are sometimes accepted as part of a trade-off between ensuring areas have sufficient workforce size and defining self-contained areas.

B Tariffs and trade barriers

The UK governments 'no deal tariffs' are published online.[21] These tariffs have been published at the level of 8-digit commodity codes (and occasionally varying within 8 digit commodity codes). Some of these tariffs are specific and others are ad-valorem. Tariff changes may also vary across the countries with which the UK currently has preferential trading agreements (through its membership of the EU).

To calculate new tariff rates at an industry level we make use the analysis by Gasiorek et al. (2019). We separate goods into two digit product classification codes that see (near) total liberalisation, no liberalisation and partial liberalisation of MFN tariffs.

Out of 97 two digit sectors, 69 see all MFN tariffs eliminated, and a further 15 only retain positive tariffs on a handful of commodities. We set the UK's external tariffs for these goods to zero. A further five sectors see no liberalisation (including motor vehicles and textiles). For these sectors we assume the UK's tariffs will remain the same as the EU current external tariffs. These are taken from UNCTAD's Trade Analysis Information System (TRAINS) database accessed through the World Integrated Trade Solutions (WITS) website. For the remaining eight sectors which see partial liberalisation we set the UK's external tariffs to half the EU's current external tariff rates.

Specific duties are converted to ad-valorem equivalent values using the WITS AVE calculator. That is, it is calculated as a value of the average unit price of goods in 6 digit HS commodities traded among OECD countries (UNCTAD's 'method 2'). For tariff-rate adjustable quotas we use the value of tariffs that are applied once quotas have been exceeded.

C Model derivations

In this appendix we more formally describe the exposure measure discussed in Section 3.2.

C.1 Firm production technology

Let G^o refer to labour from occupation group o in region r. All labour types are assumed to be completely mobile across industries but immobile across regions. T_{ir} is an industry region specific factor of production which is fixed over time and also geographically immobile (which we refer to as 'capital'). Output for each industry i and region r is produced according to the following gross output function

$$Q_{ir} = \min \left\{ \frac{F_i(G^1_{ir}, G^2_{ir}..G^O_{ir}, T_{ir})}{1 - \sum_j g_{ji}}, \min \left\{ \frac{x_{1i}}{g_{1i}}..., \frac{x_{ji}}{g_{ji}}, ...\frac{x_{Ni}}{g_{Ni}} \right\} \right\} \tag{C.1}$$

where x_{ji} refers to inputs purchased from industry j by industry i, and g_{ji} are the coefficients in a Leontief production function. N is the number of industries and O the number of occupations. The production inputs x_{ji} are assumed to be a

[21] https://www.gov.uk/government/news/temporary-tariff-regime-for-no-deal-brexit-published

Constant Elasticity of Substitution (CES) composite of different national varieties (with elasticity of substitution across national varieties of output from industry i given by ξ_i).

The function F_i in equation C.1 is a value-added function which we assume also takes a CES form where ζ_i is the elasticity of substitution of factor inputs for industry i. Let $Y_i \equiv F_i(G^1_{ir}, G^2_{ir}, ...G^O_{ir}, T_{ir})$.

C.2 Labour market

We start from the assumption that markets clear in all local labour markets and for all labour types. For convenience, in what follows, we drop r subscripts. The market clearing condition for workers in occupation group o is

$$\sum_i a^o_i Y_i = G^o \tag{C.2}$$

where a^o_i is quantity of input from workers in occupation o needed to produce a unit of value-added in industry i. The market clearing condition for the specific factor is

$$a_{Ti} Y_i = T_i \tag{C.3}$$

Using $\hat{x}$ refers to the proportional change in x (i.e $\frac{dx}{x}$), and differentiating the market clearing conditions for each occupation group and C.3 gives the following

$$\sum_i \lambda^o_i (\hat{a}^o_i + \hat{Y}_i) = \hat{L} \tag{C.4}$$

$$\hat{Y}_i = -\hat{a}_{Ti} \tag{C.5}$$

where $\lambda^o_i = G^o_i / G^o$ is the proportion of workers in occupation group o who are employed in industry i in a given region.

Moreover the assumption of perfect competition implies that the cost of producing a unit of output is equal to the price P_i. Thus

$$(1 - \sum_j g_{ji}) \left(\sum_{o=1}^{O} a^o_i w^o + a_{Ti} s_i \right) + \sum_j g_{ji} q_j = P_i \ \forall i \tag{C.6}$$

where w^o is the local wage of workers in occupation o and s_i is the return to industry specific local factors (capital).

Thus

$$\sum_{o=1}^{O} a^o_i w^o + a_{Ti} s_i = p_i \ \forall i \tag{C.7}$$

where

$$p_i = \frac{P_i - \sum_j g_{ji} q_{ji}}{1 - \sum g_{ji}} \tag{C.8}$$

So that

$$\hat{p}_i = \frac{\hat{P}_i - \sum_j \gamma_{ji}\hat{q}_j}{1 - \sum_j \gamma_{ji}} \tag{C.9}$$

$\hat{P}_i$ is the change in industry i's output price and $\hat{q}_{ji}$ the change in the price of inputs purchased from industry j by industry i. γ_{ji} is the share of inputs from industry j needed to produce £1's worth of output in industry i. Equation (C.9) is equivalent to the proportional change in each industry's value-added as a result of post-Brexit trade barriers.

Cost minimisation and the envelope-theorem together imply that

$$\sum_{o=1}^{O} \theta_i^o \hat{a}_i^o + \theta_{Ti}\hat{a}_{Ti} = 0 \tag{C.10}$$

where θ_i^o is the share of occupation group o in an industry's value-added. More precisely for a given occupation group g

$$\theta_i^g = \frac{a_i^g w^g}{\sum_{o=1}^{O} a_i^o w^o + s_i a_{Ti}} \tag{C.11}$$

Differentiating (C.7) and combining the result with equation (C.10) gives

$$\hat{p}_i = \sum_{o=1}^{O} \theta_i^o \hat{w}_o + \theta_{Ti}\hat{s}_i \tag{C.12}$$

Now, since our production function is CES, we also know that for each occupation o

$$\hat{a}_i^o - \hat{a}_{Ti} = \zeta_i(\hat{s} - \hat{w}^o) \tag{C.13}$$

$$\implies \hat{Y}_i = \zeta_i(\hat{s} - \hat{w}^o) - \hat{a}_i^o \tag{C.14}$$

We use expressions (C.13) and (C.14) to rewrite the differentiated market clearing conditions (C.4) in terms of prices

$$\sum_i \lambda_i^o(\zeta_i(\hat{s}_i - \hat{w}^o)) = \hat{G}^o \tag{C.15}$$

For simplicity we set changes in the supply of labour from different occupation groups $\hat{G}^o$) to zero. These may be affected however if there are changes in the net in-flow of workers across different regions.

For what follows it will also be helpful to write these expression out in matrix form (after setting $\zeta_i = \zeta$). The equilibrium factor market clearing conditions and zero profit conditions can be written as

$$\left[\begin{array}{ccccc|cccc} \theta_{T1} & 0 & 0 & 0 & 0 & \theta_1^1 & \theta_1^2 & ... & \theta_1^O \\ 0 & \theta_{T2} & 0 & 0 & 0 & \theta_2^1 & \theta_2^2 & ... & \theta_2^O \\ ... & 0 & \theta_{T3} & 0 & 0 & ... & ... & & \\ 0 & ... & ... & ... & \theta_{TN} & \theta_N^1 & \theta_N^2 & ... & \theta_N^O \\ \hline \lambda_1^1 & \lambda_2^1 & ... & ... & \lambda_N^1 & -1 & 0 & ... & 0 \\ \lambda_1^2 & \lambda_2^2 & ... & ... & \lambda_N^2 & 0 & -1 & ... & 0 \\ ... & ... & ... & ... & ... & ... & ... & ... & \\ \lambda_1^O & \lambda_2^O & ... & ... & \lambda_N^O & 0 & 0 & ... & -1 \end{array}\right] \left[\begin{array}{c} \hat{s}_1 \\ \hat{s}_2 \\ ... \\ \hat{s}_N \\ \hline \hat{w}^1 \\ \hat{w}^2 \\ ... \\ \hat{w}^O \end{array}\right] = \left[\begin{array}{c} \hat{p}_1 \\ \hat{p}_2 \\ ... \\ \hat{p}_N \\ \hline 0 \\ 0 \\ ... \\ 0 \end{array}\right] \tag{C.16}$$

In more compact notation this is

$$\left[\begin{array}{c|c} \mathbf{\Theta} & \theta \\ \hline \lambda' & -\mathbf{I} \end{array}\right] \left[\begin{array}{c} \hat{\mathbf{s}} \\ \hline \hat{\mathbf{w}} \end{array}\right] = \left[\begin{array}{c} \hat{\mathbf{p}} \\ \hline \mathbf{0} \end{array}\right] \tag{C.17}$$

which means we can write

$$\hat{\mathbf{p}} = \mathbf{\Theta}\hat{s} + \theta\hat{\mathbf{w}} \tag{C.18}$$

and

$$\hat{\mathbf{w}} = \lambda'\hat{\mathbf{s}} \tag{C.19}$$

implying

$$\hat{\mathbf{w}} = \lambda'(\mathbf{\Theta} + \theta\lambda')^{-1}\hat{\mathbf{p}} \tag{C.20}$$

Finally, to obtain real wage changes we need to calculate changes in workers' cost of living. The change in consumers' cost of living in response to a marginal vector of price changes can be calculated using Shephard's lemma and households' expenditure shares for the output of different domestic and foreign industries. We take these from the UK input-output tables.

C.3 Supply elasticities

The envelope theorem implies that

$$\sum_{o=1}^{O} \theta_i^o \hat{a}_i^o + \theta_{Ti}\hat{a}_{Ti} = 0 \tag{C.21}$$

Adding and subtracting $\sum_{o=1}^{O} \theta_i^o \hat{a}_{Ti}$, and exploiting the fact that $\sum_{o=1}^{O} \theta_i^o + \theta_{Ti} = 1$ and using expression (C.5) gives

$$-\hat{a}_{Ti} = \sum_{o=1}^{O} \theta_i^o(\hat{a}_i^o - \hat{a}_{Ti}) = \hat{Y}_i \tag{C.22}$$

Then exploiting the fact that production technology is CES we get

$$\hat{Y}_i = \zeta_i \sum_{o=1}^{O} \theta_i^o (\hat{s}_i - \hat{w}^o) \tag{C.23}$$

Write this out in matrix form

$$\hat{\mathbf{Y}} = \mathbf{Z}\left[diag(\theta e^O)\hat{\mathbf{s}} - \theta\hat{\mathbf{w}}\right] \tag{C.24}$$

where

$$\mathbf{Z} = \begin{bmatrix} \zeta_1 & 0 & ... & \\ ... & \zeta_2 & ... & 0 \\ 0 & ... & 0 & \zeta_N \end{bmatrix} \tag{C.25}$$

and e^O is a $O \times 1$ vector of ones.
Then using (C.20)

$$\hat{\mathbf{Y}} = \mathbf{Z}\left[\left(diag(\theta e^O) - \theta\lambda'\right)(\mathbf{\Theta} + \theta\lambda')^{-1}\right]\hat{\mathbf{p}} \tag{C.26}$$

which means

$$\begin{aligned} \hat{\mathbf{Y}} = \mathbf{V}^{-1}\mathbf{Z}\left[\left(diag(\theta e^O) - \theta\lambda'\right)(\mathbf{\Theta} + \theta\lambda')^{-1}\right] \times \\ (\hat{\mathbf{P}} - \mathbf{\Gamma}'^{UK}\hat{\mathbf{P}} - \mathbf{\Gamma}'^{EU}\hat{\tau}^{EU,M} - \mathbf{\Gamma}'^{NEU}\hat{\tau}^{NEU,M}) \end{aligned} \tag{C.27}$$

where $\hat{\tau}^{NEU,M}$ and $\hat{\tau}^{EU,M}$ are the tariff changes on imports from non-EU countries and EU countries respectively, and where

$$\mathbf{V} = \begin{bmatrix} (1-\theta_{I1}) & 0 & ... \\ ... & (1-\theta_{I2}) & ... \\ 0 & ... & (1-\theta_{IN}) \end{bmatrix} \tag{C.28}$$

Now in order to go from the change in *value-added* to the change in output note that

$$Y_{ir} = Q_{ir} - Q_{ir}\sum_j g_{ji} \tag{C.29}$$

hence

$$\hat{Y}_{ir} = \hat{Q}_{ir} \tag{C.30}$$

Thus

$$\hat{\mathbf{Q}}_r = \mathbf{H}_r^{UK}\hat{\mathbf{P}} - \mathbf{H}_r^{EU}\hat{\tau}^{EU,M} - \mathbf{H}_r^{NEU}\hat{\tau}^{NEU,M} \tag{C.31}$$

$$\mathbf{H}_r^{UK} = \mathbf{V}^{-1}\mathbf{Z}\left[\left(diag(\theta e^O) - \theta\lambda'\right)(\mathbf{\Theta} + \theta\lambda')^{-1}\right](\mathbf{I} - \mathbf{\Gamma}'^{UK}) \tag{C.32}$$

and

$$\mathbf{H}_r^{EU} = \mathbf{V}^{-1}\mathbf{Z}\left[\left(diag(\theta e^O) - \theta\lambda'\right)(\mathbf{\Theta} + \theta\lambda')^{-1}\right]\mathbf{\Gamma}'^{EU} \tag{C.33}$$

and

$$\mathbf{H}_r^{NEU} = \mathbf{V}^{-1}\mathbf{Z}\left[\left(diag(\theta e^O) - \theta\lambda'\right)(\mathbf{\Theta} + \theta\lambda')^{-1}\right]\mathbf{\Gamma}'^{NEU} \tag{C.34}$$

National analogs to $\mathbf{H}_r^{UK}$, $\mathbf{H}_r^{EU}$, and $\mathbf{H}_r^{NEU}$ can be found using the fact that for $k \in \{UK, EU, NEU\}$

$$\mathbf{H}^k = \Omega_r \mathbf{H}_r^k \tag{C.35}$$

where Ω_r is a diagonal matrix giving each the share of output in each industry-region out of national output for that industry

$$\Omega_j = \begin{bmatrix} Q_{1j}/\sum_r Q_{1r} & 0 & ... \\ 0 & Q_{2j}/\sum_r Q_{2r} & ... \\ 0 & 0 & Q_{2j}/\sum_r Q_{3r} \\ .. & ... & ... \end{bmatrix} \tag{C.36}$$

We calculate these shares using firm-level revenue statistics taken from the Business Structure Database.

C.4 Product market

Total demand for the output of each UK industry i can be sub-divided into final UK demand, intermediate demand from other UK industries, EU demand and non-EU foreign demand.

$$X_i = X_i^{UK,Inter} + X_i^{UK,Final} + X_i^{EU} + X_i^{NEU} \tag{C.37}$$

Which means that

$$\hat{X}_i = \sigma_i^{UK,Final}\hat{X}_i^{UK,Final} + \sigma_i^{UK,Inter}\hat{X}_i^{UK,Inter} + \sigma_i^{EU}\hat{X}_i^{EU} + \sigma_i^{NEU}\hat{X}_i^{NEU} \tag{C.38}$$

where for instance

$$\sigma_i^{UK,Final} = \frac{X_i^{UK,Final}}{X_i^{UK,Inter} + X_i^{UK,Final} + X_i^{EU} + X_i^{NEU}} \tag{C.39}$$

$X_i^{UK,Inter}$ is the sum of demands for the output of UK industry i for use as inputs in other industries. The proportional change in this variable is given by

$$\hat{X}_i^{UK,Inter} = \sum_j \frac{\gamma_{ij}X_j}{X_i}\hat{x}_{ij}^{UK} \tag{C.40}$$

where $\hat{x}_{ij}^{UK}$ is the proportional change in demand by industry j for the output of industry i. We can also write this as

$$\hat{x}_{ij}^{UK} = \hat{b}_{x_{ij}^{UK}} + \hat{g}_{ij} + \hat{Q}_j \tag{C.41}$$

in which

$$b_{x_{ij}^{UK}} = \frac{x_{ij}^{UK}}{x_{ij}} \tag{C.42}$$

(i.e. the share of UK inputs in total demand by industry j for inputs from industry i). Note that $\hat{g}_{ij} = 0$. Since the production function for producing intermediate inputs using different national varieties is CES, we know that

$$\hat{b}_{x_{ij}^{UK}} = \xi_j(\hat{q}_{ij} - \hat{P}_i) \tag{C.43}$$

Moreover, exploiting the envelope-theorem (Shephard's lemma)

$$\hat{q}_{ij} = \theta_{x_{ij}}^{UK}\hat{P}_i + \theta_{x_{ij}}^{EU}\hat{\tau}_i^{EU,M} + \theta_{x_{ij}}^{NEU}\hat{\tau}_i^{NEU,M} \tag{C.44}$$

where $\theta_{x_{ij}}^{UK}$ is the cost share of UK goods in intermediates from industry i that are supplied to industry j.

This means that the total change in demand for intermediates from UK industry i in other industries j following a change in UK and foreign prices for industry i is given by

$$\hat{x}_i^{UK} = \sum_j \frac{\gamma_{ij}^{UK}X_j}{X_i}\left(\hat{Q}_j + \left(\xi_j(\theta_{x_{ij}}^{UK} - 1)\hat{P}_i + \theta_{x_{ij}}^{EU}\hat{\tau}^{EU,M} + \theta_{x_{ij}}^{NEU}\hat{\tau}^{NEU,M}\right)\right) \tag{C.45}$$

Let $\mathbf{B}^{UK}$ be a matrix with $\frac{\gamma_{ij}^{UK}X_j}{X_i}\xi_j(\theta_{x_{ij}}^{UK} - 1)$ in its diagonal entries ($i = 1..N$) and zero in all the off-diagonal entries, $\mathbf{B}^{EU}$ has diagonal entries $\sum_j \frac{\gamma_{ij}^{UK}X_j}{X_i}\xi_j\theta_{x_{ij}}^{EU}$ and $\mathbf{B}^{NEU}$ has diagonal entries $\sum_j \frac{\gamma_{ij}^{UK}X_j}{X_i}\xi_j\theta_{x_{ij}}^{NEU}$

Thus, the total change in demand for the output of all industries is given by the system of equations

$$\hat{\mathbf{X}} = \mathbf{\Sigma}_{UK,Final}\hat{\mathbf{X}}_{UK,Final} + (\mathbf{B}^{UK}\hat{\mathbf{P}} + \mathbf{B}^{EU}\hat{\tau}^{EU,M} + \mathbf{B}^{NEU}\hat{\tau}^{NEU,M}) + \mathbf{S}\hat{\mathbf{X}} + \mathbf{\Sigma}_{EU}\hat{\mathbf{X}}^{EU} + \mathbf{\Sigma}_{NEU}\hat{\mathbf{X}}^{NEU} \tag{C.46}$$

where terms in bold are vectors or matrices, and $\mathbf{S}$ is a matrix with $\frac{\gamma_{ij}^{UK}X_j}{X_i}$ in element ij.

Assuming that EU and non-EU foreign output prices are unaffected by Brexit (i.e that the UK is "small" relative to EU and non-EU markets), and letting $\hat{\tau}^{k,M}$ refer to changes in trade costs on the UK's imports from the country k, and $\hat{\tau}^{k,X}$ refer to changes in trade costs for UK exports to k, then we have that

$$\hat{\mathbf{X}}_{UK,Final} = \left(\mathbf{E}^{UK,EU}\hat{\tau}^{EU,M} + \mathbf{E}^{UK,NEU}\hat{\tau}^{NEU,M} + \mathbf{E}^{UK}\hat{\mathbf{P}}\right) \tag{C.47}$$

$$\hat{\mathbf{X}}_{EU} = \mathbf{E}^{EU}(\hat{\mathbf{P}} + \hat{\tau}^{EU,X}) \tag{C.48}$$

$$\hat{\mathbf{X}}_{NEU} = \mathbf{E}^{NEU}(\hat{\mathbf{P}} + \hat{\tau}^{NEU,X}) \tag{C.49}$$

where $\mathbf{E}^{UK,EU}$ is a matrix of cross-price elasticities for the output of UK industries given price changes in EU industries, $\mathbf{E}^{UK,NEU}$ the same but for non-EU industries, and $\mathbf{E}^{EU}$ and $\mathbf{E}^{NEU}$ matrices of elasticities of demand for UK output in EU and non-EU destinations.

Thus, substituting and rearranging, we have that

$$\begin{aligned}\hat{\mathbf{X}} = (\mathbf{I}-\mathbf{S})^{-1}\Bigg(&\boldsymbol{\Sigma}_{UK,Final}\big(\mathbf{E}^{UK,EU}\hat{\tau}^{EU,M} + \mathbf{E}^{UK,NEU}\hat{\tau}^{NEU,M} + \mathbf{E}^{UK}\hat{\mathbf{P}}\big) \\ &+\boldsymbol{\Sigma}_{EU}(\mathbf{E}^{EU}(\hat{\mathbf{P}} + \hat{\tau}^{EU,X})) + \boldsymbol{\Sigma}_{NEU}(\mathbf{E}^{NEU}\hat{\mathbf{P}} + \hat{\tau}^{NEU,X}) + \\ &(\mathbf{B}^{UK}\hat{\mathbf{P}} + \mathbf{B}^{EU}\hat{\tau}^{EU,M} + \mathbf{B}^{NEU}\hat{\tau}^{NEU,M})\Bigg)\end{aligned} \tag{C.50}$$

In equilibrium, we set this equal to expression (C.31). Doing this and solving for the equilibrium vector $\hat{\mathbf{P}}^*$ gives

$$\begin{aligned}\hat{\mathbf{P}}^* = &\left(\mathbf{H}^{UK} - (\mathbf{I}-\mathbf{S})^{-1}\left(\boldsymbol{\Sigma}_{UK,Final}\mathbf{E}^{UK} + \boldsymbol{\Sigma}_{EU}\mathbf{E}^{EU} + \boldsymbol{\Sigma}_{NEU}\mathbf{E}^{NEU} + \mathbf{B}^{UK}\right)\right)^{-1} \\ &\Bigg[(\mathbf{I}-\mathbf{S})^{-1}\Bigg((\boldsymbol{\Sigma}_{UK,Final}\mathbf{E}^{UK,EU} + \mathbf{B}^{EU})\hat{\tau}^{EU,M} + (\boldsymbol{\Sigma}_{UK,Final}\mathbf{E}^{UK,NEU} + \mathbf{B}^{NEU})\hat{\tau}^{EU,M} + \\ &\boldsymbol{\Sigma}_{EU}\mathbf{E}^{EU}\hat{\tau}^{EU,X} + \boldsymbol{\Sigma}_{NEU}\mathbf{E}^{NEU}\hat{\tau}^{NEU,X}\Bigg) + \mathbf{H}^{EU}\hat{\tau}^{EU,M} + \mathbf{H}^{NEU}\hat{\tau}^{NEU,M}\Bigg]\end{aligned} \tag{C.51}$$

To gain intuition for the factors driving a given set of price changes, we consider a simpler formula in which we suppose that all demand is final and we only change the trade costs associated with one industry i. In this case, we can write

$$\hat{P}_i^* = \hat{\tau}_i\left(\frac{\sigma_i^{UK,Final}\varepsilon_i^{UK,EU} - \sigma_i^{EU}\varepsilon_i^{EU}}{\eta_i^{UK} + \sigma_i^{UK,Final}\varepsilon_i^{UK} + \sigma_i^{EU}\varepsilon_i^{EU} + \sigma_i^{NEU}\varepsilon_i^{NEU}}\right) \tag{C.52}$$

where η_i^{UK} is the supply elasticity of UK industry i with respect to its own output price. This means that for each industry, the price change for domestic output in response to the tariff change is larger in absolute terms if:

1. UK consumers are willing to substitute UK products for EU ones ($\uparrow \varepsilon_i^{UK,EU}$)
2. EU consumers' demand for UK goods is inelastic ($\downarrow \varepsilon_i^{EU}$)
3. UK consumers have a small own price elasticity ($\downarrow \varepsilon_i^{UK}$)
4. Supply of UK industries is relatively inelastic ($\downarrow \eta_i^{UK}$)

5. Domestic consumption is large relative to exports to the EU ($\downarrow \sigma_i^{EU}$ or $\uparrow \sigma_i^{UK,Final}$).

C.4.1 Consumer preferences

To complete the model, we need to specify consumer preferences. Let UK consumers' utility be given by

$$U_{UK} = \sum_i \alpha_i \ln c_i \tag{C.53}$$

where c_i is a composite of EU, Non-EU and UK varieties of each good.

$$c_i = [\delta_{UK} c_{UK,i}^{\frac{\rho_i - 1}{\rho_i}} + \delta_{EU} c_{EU,i}^{\frac{\rho_i - 1}{\rho_i}} + \delta_{NEU} c_{NEU,i}^{\frac{\rho_i - 1}{\rho_i}}]^{\frac{\rho_i}{\rho_i - 1}} \tag{C.54}$$

The separable nature of these preferences mean that we are assuming no cross-price effects across industries. Given total expenditure, expenditures within each industry are also constant. However, there are cross-price effects *within* industries between UK, EU and non-EU varieties. Preferences are also homothetic which means that demand does not depend on the distribution of incomes.

These preferences imply the following demand elasticities for the output of UK industry i

$$\varepsilon_i^{UK} = \frac{\partial \ln c_i^{UK}}{\partial \ln P_{UK,i}} = \rho_i(s_{UK,i} - 1) - s_{UK,i} \tag{C.55}$$

$$\varepsilon_i^{UK,EU} = \frac{\partial \ln c_i^{UK}}{\partial \ln P_{EU,i}} = -s_{EU,i}(1 - \rho_i) \tag{C.56}$$

where $s_{k,i}$ is the share of spending on industry i devoted to the variety from country k.

Demand for the UK variety of the good thus increases more if ρ_i is greater (EU and UK goods are close substitutes). Moreover, if $\rho_i > 1$, it will be greater if the share of EU goods in the UK market is greater.

If we hold expenditure fixed (ignoring changes in factor incomes arising through price changes) we can use this to fill in the diagonal elements of $\mathbf{E}^{UK,EU}$. The off-diagonal elements are zero.

We will also assume similar preferences for EU and non-EU consumers, allowing us to obtain EU demand elasticities for UK goods.

The elasticity of demand for UK products in EU and non-EU foreign markets is then

$$\varepsilon_i^{EU} = \rho_i(s_{EU,UK,i} - 1) - s_{EU,UK,i} \tag{C.57}$$

and

$$\varepsilon_i^{NEU} = \rho_i(s_{NEU,UK,i} - 1) - s_{NEU,UK,i} \tag{C.58}$$

where $s_{EU,UK,i}$ and $s_{NEU,UK,i}$ are the shares of UK exports in EU and non-EU purchases of i respectively. We take these shares from the WIOD tables.

D Non-tariff barriers and elasticities by sector

Table D.1 shows how we allocate NTBs and elasticity estimates across different industries.

Table D.1: *Non-tariff barrier and elasticity estimates by industry (%)*

		Change in non-tariff barriers		Elasticity
		Exports (UK to EU)	Imports (EU to UK)	(ρ_i)
Agriculture & fishing	Products of agriculture, hunting and related services	17.6	8.8	8.11
	Products of forestry, logging and related services	17.6	8.8	8.11
	Fishing and aquaculture products and services	17.6	8.8	8.11
Mining	Coal and lignite	6.1	3.1	15.72
	Petroleum, gas and metal ore extraction	6.1	3.1	15.72
	Other mining and quarrying products	6.1	3.1	15.72
	Mining support services	6.1	3.1	15.72
Food & drink	Preserved meat and meat products	16.4	8.2	2.55
	Other processed and preserved food products	16.4	8.2	2.55
	Vegetable and animal oils and fats	16.4	8.2	2.55
	Dairy products	16.4	8.2	2.55
	Grain mill products, starches and starch products	16.4	8.2	2.55
	Bakery and farinaceous products	16.4	8.2	2.55
	Other food products	16.4	8.2	2.55
	Prepared animal feeds	16.4	8.2	2.55
	Alcoholic beverages and tobacco products	16.4	8.2	2.55
	Soft drinks	16.4	8.2	2.55
Clothing & textiles	Textiles	12.0	6.0	5.56
	Wearing apparel	12.0	6.0	5.56

	Leather and related products	12.0	6.0	5.56
Wood, paper & printing	Non-furniture products made of wood etc.	12.0	6.0	10.83
	Paper and paper products	12.0	6.0	9.07
	Printing and recording services	12.0	6.0	9.07
Chemicals, pharmaceuticals & refining	Coke and refined petroleum products	6.1	3.1	51.08
	Chemicals	12.3	6.2	4.75
	Paints and varnishes	12.3	6.2	4.75
	Soap and cleaning substances	12.3	6.2	4.75
	Other chemical products	12.3	6.2	4.75
	Basic pharmaceutical products	12.3	6.2	4.75
Other manufacturing	Rubber and plastic products	12.3	6.2	1.66
	Glass and stone abrasives	12.0	6.0	2.76
	Cement, lime and plaster	12.0	6.0	2.76
	Furniture	12.0	6.0	5
	Other manufactured goods	12.0	6.0	5
Metals & metal products	Basic iron and steel	12.0	6.0	7.99
	Other basic metals and casting	12.0	6.0	7.99
	Metal products excl. machinery	12.0	6.0	7.99
Machinery & equipment	Weapons and ammunition	6.1	3.1	1.52
	Machinery and equipment n.e.c.	6.1	3.1	1.52
Computers & electronics	Computer, electronic and optical products	6.1	3.1	10.6
	Electrical equipment	6.1	3.1	10.6

Transport equipment	Motor vehicles, trailers and semi-trailers	13.0	6.5	1.01
	Ships and boats	6.1	3.1	1.01
	Air and spacecraft and related machinery	6.1	3.1	1.01
	Other transport equipment	6.1	3.1	1.01
Repair & installation services	Ships repair and maintenance	6.1	3.1	5
	Aircraft and spacecraft repair and maintenance	6.1	3.1	5
	Other repair and installation	12.0	6.0	5
	Computer and personal goods repair	9.5	4.7	5
Utilities	Electricity transmission and distribution	9.5	4.7	5
	Gas distribution	9.5	4.7	5
	Water treatment and supply	9.5	4.7	5
	Sewerage services	9.5	4.7	5
	Waste collection and treatment	9.5	4.7	5
	Other waste management services	9.5	4.7	5
Construction	Construction	0.0	0.0	5
Wholesale & retail	Motor vehicle wholesale and retail trade and repair	20.1	10.1	5
	Wholesale trade services	20.1	10.1	5
	Retail trade services	20.1	10.1	5
Transport services	Rail transport services	9.5	4.7	5
	Land transport services	9.5	4.7	5
	Water transport services	9.5	4.7	5
	Air transport services	9.5	4.7	5
	Warehousing and transport support services	9.5	4.7	5
	Postal and courier services	9.5	4.7	5

Accommodation & catering	Accommodation services	9.5	4.7	5
	Food and beverage serving services	9.5	4.7	5
IT services & media	Publishing services	9.5	4.7	5
	Audiovisual media production and distribution	9.5	4.7	5
	Telecommunications services	9.5	4.7	5
	Computer programming, consultancy and related services	5.8	2.9	5
	Information services	5.8	2.9	5
Finance	Financial services, except insurance and pension funding	9.1	4.5	5
	Insurance and pension funding	9.1	4.5	5
	Auxiliary finance and pension services	9.1	4.5	5
Real estate	Real estate services and imputed rent	5.8	2.9	5
	Real estate services on a fee or contract basis	5.8	2.9	5
Business services	Legal services	5.8	2.9	5
	Accounting and auditing services	5.8	2.9	5
	Head office and management consulting services	5.8	2.9	5
	Advertising and market research services	5.8	2.9	5
	Employment services	5.8	2.9	5
	Office admin and support services	5.8	2.9	5
Technical & scientific services	Architecture and engineering services	5.8	2.9	5
	Scientific research and development services	5.8	2.9	5

	Other professional, scientific and technical services	5.8	2.9	5
	Veterinary services	9.5	4.7	5
Other services	Rental and leasing services	5.8	2.9	5
	Travel agency and related services	9.5	4.7	5
	Security and investigation services	9.5	4.7	5
	Services to buildings and landscape	9.5	4.7	5
	Services furnished by membership organisations	9.5	4.7	5
	Other personal services	9.5	4.7	5
	Services of households as employers of domestic personnel	9.5	4.7	5
Public administration	Public administration and defence services	16.6	8.3	5
Education	Education services	16.6	8.3	5
Health & care	Human health services	16.6	8.3	5
	Residential care and social work services	16.6	8.3	5
Arts & recreation	Creative, arts and entertainment services	9.5	4.7	5
	Libraries, archives, museums and other cultural services	9.5	4.7	5
	Gambling and betting services	9.5	4.7	5
	Sports services and amusement and recreation services	9.5	4.7	5

E Industry changes in value-added

Table E.1 shows the change in value-added by industry under our baseline Brexit scenario described in section 2. In the second column, we show value-added changes

under and alternative Brexit scenario in which the UK also unilaterally eliminates all import tariffs.[22]

Table E.1: *Changes in value-added by detailed industry under different trade scenarios (%)*

		Baseline	UFT
Agriculture & fishing	Products of agriculture, hunting and related services	-0.9	-3
	Products of forestry, logging and related services	-15	-14
	Fishing and aquaculture products and services	-26.7	-26.9
Mining	Coal and lignite	3.1	3.5
	Petroleum, gas and metal ore extraction	-5.7	-5.7
	Other mining and quarrying products	-2.7	-2.6
	Mining support services	-1.7	-1.6
Food & drink	Preserved meat and meat products	-10	-12.5
	Other processed and preserved food products	-12.9	-13.5
	Vegetable and animal oils and fats	-45.1	-43.7
	Dairy products	-29.6	-60.7
	Grain mill products, starches and starch products	-47.1	-49.9
	Bakery and farinaceous products	-5.3	-5
	Other food products	-12.1	-12.9
	Prepared animal feeds	-33.9	-33.3
	Alcoholic beverages and tobacco products	-4.1	-3.8
	Soft drinks	-1.7	-0.5
Clothing & textiles	Textiles	-13.6	-14.1
	Wearing apparel	-20	-19.9
	Leather and related products	-13.5	-13.2
Wood, paper & printing	Non-furniture products made of wood etc.	2.6	2.7
	Paper and paper products	-2.8	-2.8
	Printing and recording services	0.3	0.4
Chemicals, pharmaceuticals & refining	Coke and refined petroleum products	-11.3	-11.6
	Chemicals	-25.6	-25.5
	Paints and varnishes	-5.7	-5.4
	Soap and cleaning substances	-13.1	-12.7
	Other chemical products	-35.1	-34.8
	Basic pharmaceutical products	-8	-8

[22]Results for "Services of households as employers of domestic personnel" are not reported due to there being only a small number of enterprises in this industry in the BSD data.

Other manufacturing	Rubber and plastic products	-10	-10
	Glass and stone abrasives	-7.1	-7.3
	Cement, lime and plaster	-6.4	-6.7
	Furniture	-19.1	-18.6
	Other manufactured goods	-19.1	-18.4
Metals & metal products	Basic iron and steel	-3.8	-3.8
	Other basic metals and casting	2.2	2.3
	Metal products excl. machinery	-4.2	-4.1
Machinery & equipment	Weapons and ammunition	-4.7	-4.4
	Machinery and equipment n.e.c.	-5.3	-5.2
Computers & electronics	Computer, electronic and optical products	-16.8	-16.8
	Electrical equipment	-0.9	-0.9
Transport equipment	Motor vehicles, trailers and semi-trailers	-4.9	-4.8
	Ships and boats	0.1	-0.4
	Air and spacecraft and related machinery	-0.8	-0.7
	Other transport equipment	-7.7	-7.5
Repair & installation services	Ships repair and maintenance	3.4	3.8
	Aircraft and spacecraft repair and maintenance	-0.2	-0.1
	Other repair and installation	-4.2	-4
	Computer and personal goods repair	-6.1	-6
Utilities	Electricity transmission and distribution	-4.1	-4.1
	Gas distribution	-0.6	-0.7
	Water treatment and supply	-0.4	-0.4
	Sewerage services	-3.7	-3.7
	Waste collection and treatment	4.7	4.8
	Other waste management services	-3.7	-3.8
Construction	Construction	-3.2	-3.2
Wholesale & retail	Motor vehicle wholesale and retail trade and repair	-3.8	-3.9
	Wholesale trade services	-2.9	-3
	Retail trade services	-4.7	-4.8
Transport services	Rail transport services	-4.7	-4.9
	Land transport services	-4.2	-4.2
	Water transport services	-4	-3.9
	Air transport services	-4.5	-4.7

	Warehousing and transport support services	-3.2	-3.4
	Postal and courier services	-3	-3.1
Accommodation & catering	Accommodation services	-3.1	-3.2
	Food and beverage serving services	-2.4	-2.3
IT services & media	Publishing services	-4.2	-4.2
	Audiovisual media production and distribution	-2.8	-2.8
	Telecommunications services	-2.3	-2.2
	Computer programming, consultancy and related services	-2.2	-2.1
	Information services	-3	-3
Finance	Financial services, except insurance and pension funding	-4.3	-4.2
	Insurance and pension funding	-2.7	-2.7
	Auxiliary finance and pension services	0.6	0.7
Real estate	Real estate services and imputed rent	-1.5	-1.5
	Real estate services on a fee or contract basis	-0.7	-0.6
Business services	Legal services	-1.3	-1.2
	Accounting and auditing services	-2.4	-2.4
	Head office and management consulting services	-2.2	-2.2
	Advertising and market research services	-1.5	-1.5
	Employment services	-0.8	-0.6
	Office admin and support services	-2.8	-2.7
Technical & scientific services	Architecture and engineering services	0.2	0.2
	Scientific research and development services	-1	-0.9
	Other professional, scientific and technical services	-3	-3.1
	Veterinary services	-2.5	-2.5
Other services	Rental and leasing services	-2.3	-2.3
	Travel agency and related services	-3.3	-3.4
	Security and investigation services	-2.3	-2.2
	Services to buildings and landscape	-2.4	-2.4
	Services furnished by membership organisations	-1.8	-1.7
	Other personal services	-1.8	-1.8

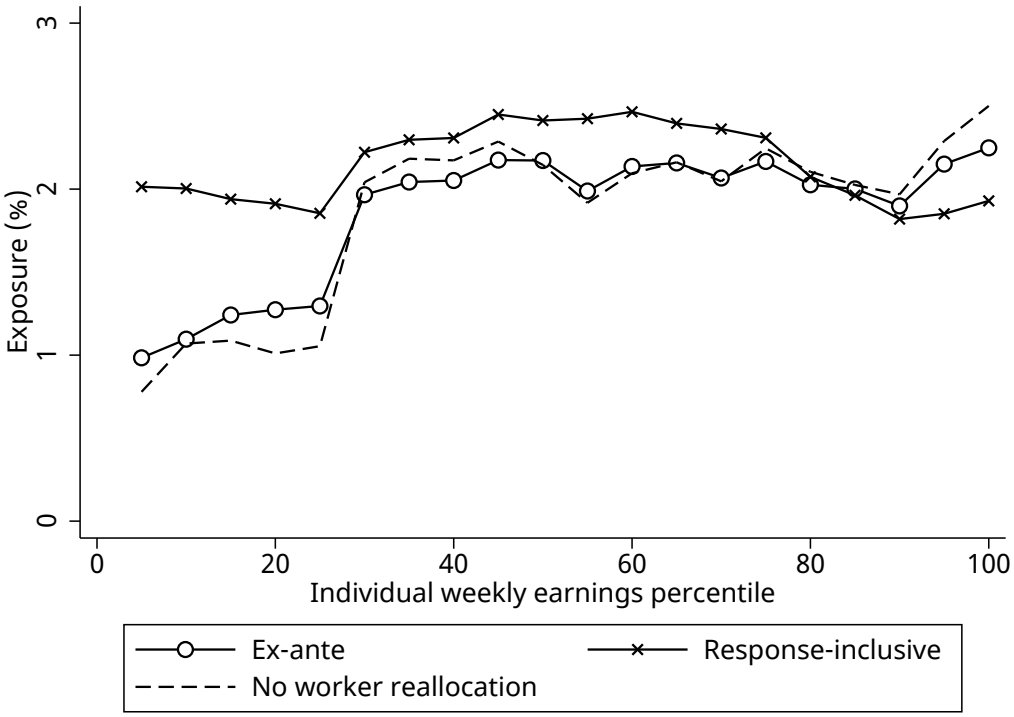
	Services of households as employers of domestic personnel	-2.3	-2.3
Public administration	Public administration and defence services	1	1.1
Education	Education services	-1.8	-1.8
Health & care	Human health services	-2.2	-2.3
	Residential care and social work services	-1	-1
Arts & recreation	Creative, arts and entertainment services	-1.7	-1.7
	Libraries, archives, museums and other cultural services	-1.4	-1.4
	Gambling and betting services	-1.1	-1.1
	Sports services and amusement and recreation services	0	0

F Additional figures and tables

This section contains additional results and figures referred to in the main text.

Figure F.1 shows the relationship between worker's exposure and their individual earnings for a case where we allow for consumer substitution response to price changes, but do not allow for worker mobility across industries. We plot this alongside exposure according to our ex-ante exposure measure (which turns out to be very similar) and the response-inclusive exposure measure plotted in Figure 4.2.

Figure F.1: *Workers' exposure across the individual earnings distribution under different assumptions about worker mobility*



Note: Authors' calculations using 2016 Annual Survey of Hours and Earnings and 2016 Business Structure Database. Ex-ante exposure is defined as the sum of new tariff and non-tariff barriers that would apply to exports to the EU and imports of intermediate inputs from the EU under a 'WTO rules' Brexit (as a percentage of UK value-added) in each worker's main industry of employment. Response-inclusive exposure is the output of the model outlined in Section 3.2 for a 'WTO rules' Brexit. It varies by workers' region and across nine occupation groups. We smooth by plotting average exposure within five percentile bands. The 'no worker reallocation' case is the same as the response-inclusive measure but for a case where workers are assumed to be immobile across industries. This varies by workers' current industry of employment.

Table F.1 shows how workers' demographic characteristics vary according to their quintile of response-inclusive exposure. Workers in the most exposed quintile are disproportionately likely to be older, less educated and male than other workers

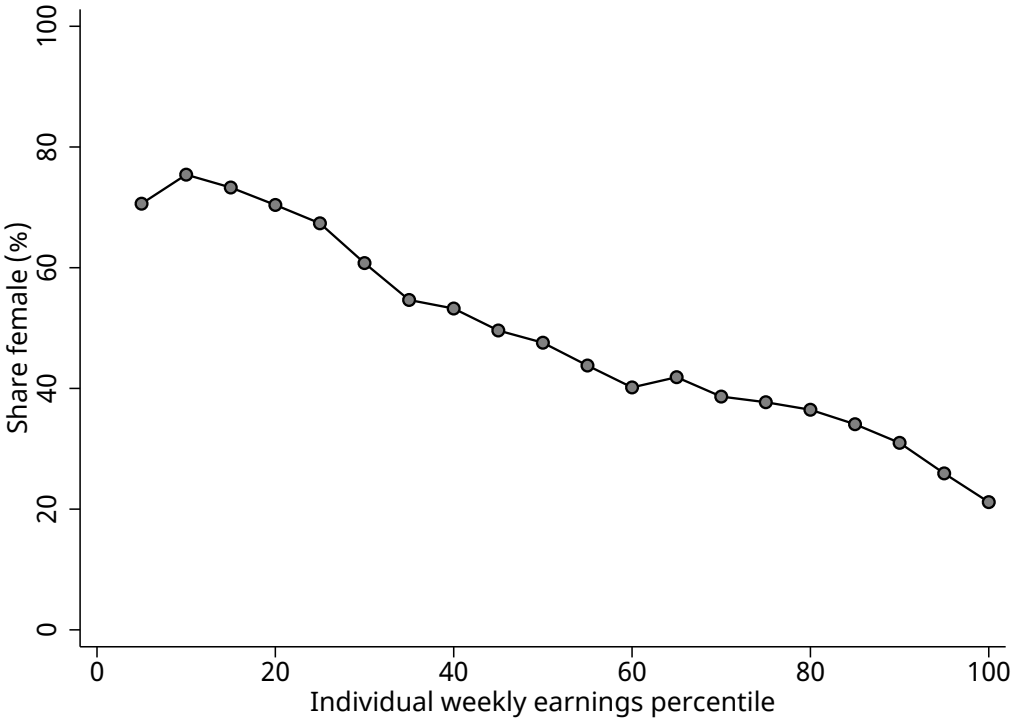
Table F.1: *Average (mean) worker characteristics by quintile of response-inclusive exposure*

	(1)	(2)	(3)	(4)	(5)	(6)
	Mean exposure	Age	Male	Low educ	Male × low educ	Female × low educ
Lowest	0.80	40.4	0.35	0.21	0.06	0.15
2	1.44	40.8	0.37	0.27	0.08	0.19
3	2.09	39.9	0.50	0.31	0.14	0.17
4	2.53	38.9	0.55	0.51	0.28	0.23
Highest	4.53	42.2	0.82	0.54	0.47	0.08
All	2.18	40.4	0.51	0.36	0.19	0.17

Note: Authors' calculations using 2016 Annual Survey of Hours and Earnings, 2017 Quarterly Labour Force Survey and 2016 Business Structure Database. Exposure is the output of the model outlined in Section 3.2 for a 'WTO rules' Brexit. It varies by workers' TTWA and across nine occupation groups. We merge these into the 2017 QLFS on the basis of workers' current occupation and their current Government Office Region rather than TTWA (a level of geographic detail which is not available in public versions of the QLFS). Column (1) shows average exposure predicted by our model among workers within each quintile of workers' exposure. Column (2) shows average age. Columns (3), (4), (5) and (6) show the proportions of workers in each quintile who are male, low educated, low educated male and low educated female. Individuals are classed as having low education if their highest qualification is GCSEs or lower.

Figure F.2 shows the share of women represented over the distribution of individual earnings. Roughly 70% of workers in the bottom 5% of earners are women, compared to 20% in the top 5%.

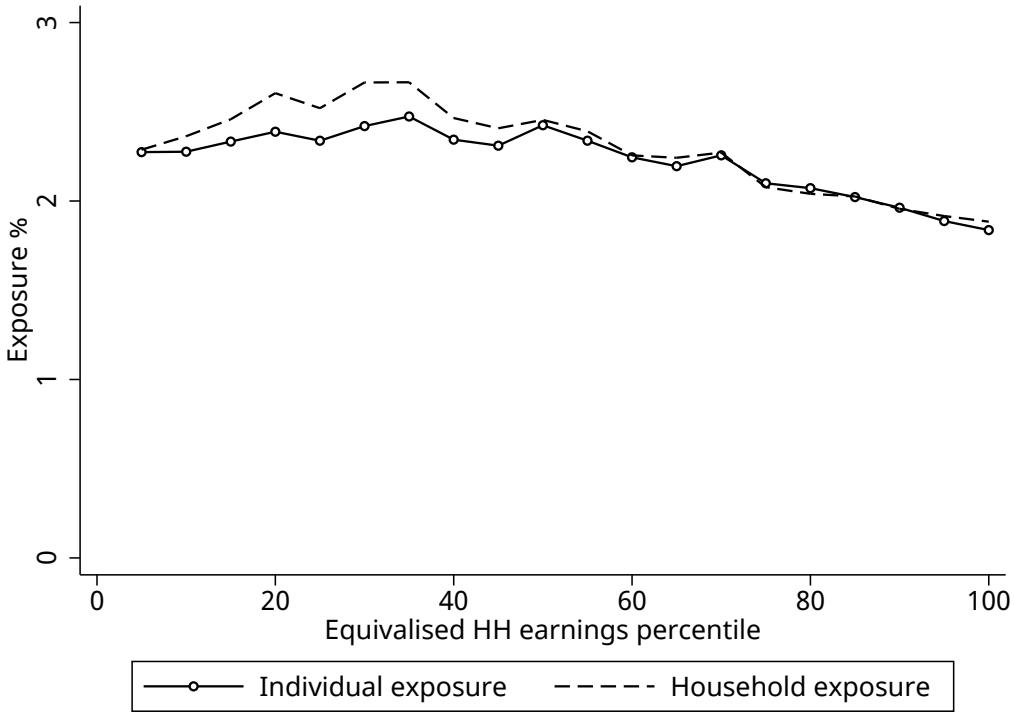
Figure F.2: *Gender composition of the individual earnings distribution*



Note: Authors' calculations using 2017 Quarterly Labour Force Survey.

Figure F.3 shows how our response-inclusive exposure measure varies across the distribution of household earnings. It shows both average individual exposure by household earnings and household exposure (defined as an earnings weighted average of individual exposure). Both tend to be greater for lower-earning households. The fact that average individual exposure is less than household exposure at the bottom of the earnings distribution tells us that the primary earners in low earning households tend to be more exposed than their partners.

Figure F.3: *Individual workers' and households' exposure across the household earnings distribution*



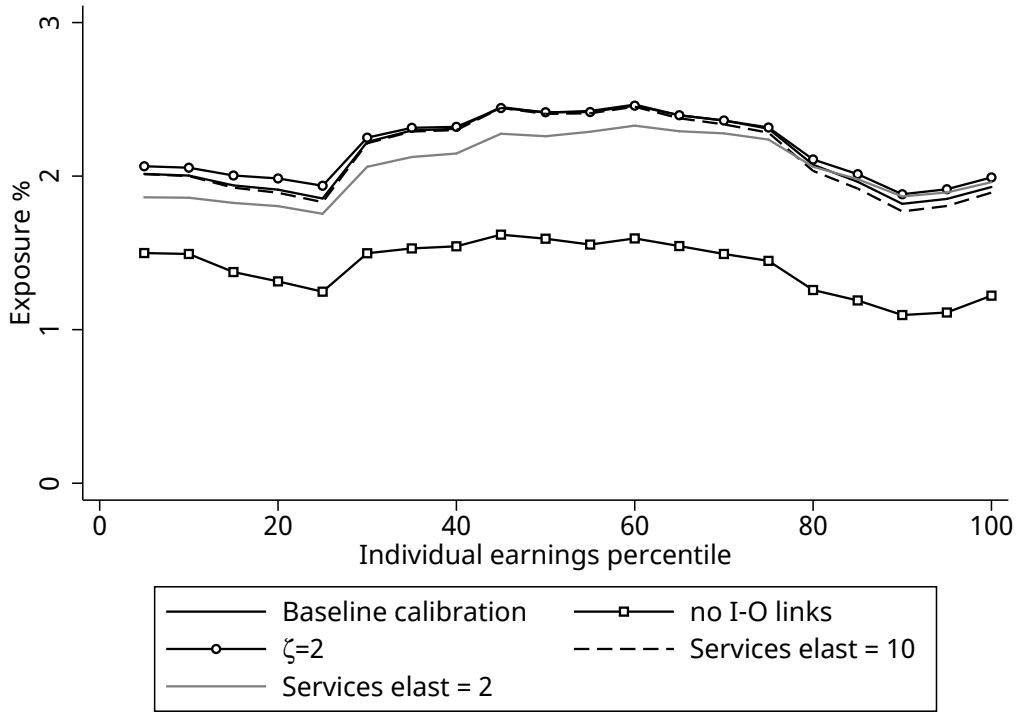
Note: Authors' calculations using 2016 Annual Survey of Hours and Earnings, 2017 Quarterly Labour Force Survey and 2016 Business Structure Database. Figure shows exposure predicted by our model across percentiles of the equivalised household earnings distribution. We smooth by plotting average exposure within five percentile bands. Exposure is the output of the model outlined in Section 3.2 for a 'WTO rules' Brexit. It varies by workers' TTWA and across nine occupation groups. We merge measures of exposure into the 2017 Quarterly Labour Force Survey on the basis of workers' current occupation and their current Government Office Region rather than TTWA (a level of geographic detail which is not available in public versions of the QLFS) to obtain individual and household exposure by household earnings. Household exposure is calculated using predicted exposure for household heads and their partners (if they have one) weighted by their shares in total household earnings (reflecting differences in hours worked). To be included in the sample, households must have at least one member in work. Household earnings are equivalised using the modified OECD scale.

G Sensitivity analysis

This Appendix examines how our results are affected by changes in different parameters.

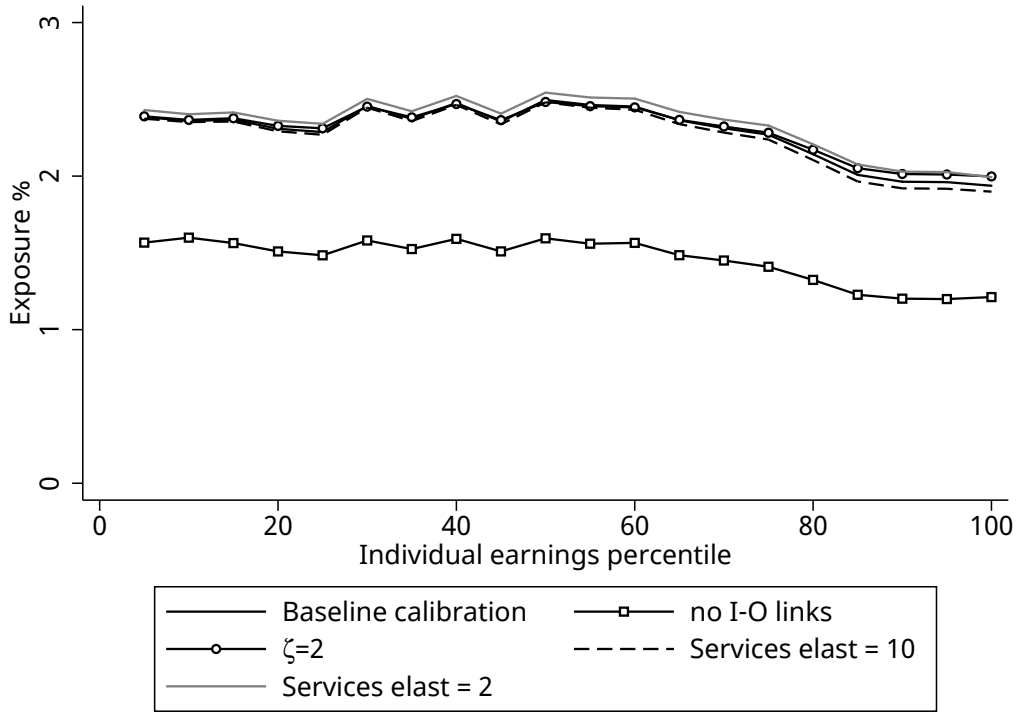
Figures G.1 and G.2 show how exposure over the earnings distribution changes when we make different modelling assumptions. Figure G.1 shows workers' exposure and Figure G.2 shows the exposure of workers' households across the distribution of individual earnings.

Figure G.1: *Measures of individual exposure over the earnings distribution under different modelling assumptions*



Note: Authors' calculations using 2016 Annual Survey of Hours and Earnings and 2016 Business Structure Database. Figure shows exposure predicted by our model across percentiles of the individual earnings distribution given different modelling assumptions. We smooth by plotting average exposure within five percentile bands. Exposure is the output of the model outlined in Section 3.2 for a 'WTO rules' Brexit. It varies by workers' TTWA and across nine occupation groups.

Figure G.2: *Measures of household exposure over the individual earnings distribution under different modelling assumptions*

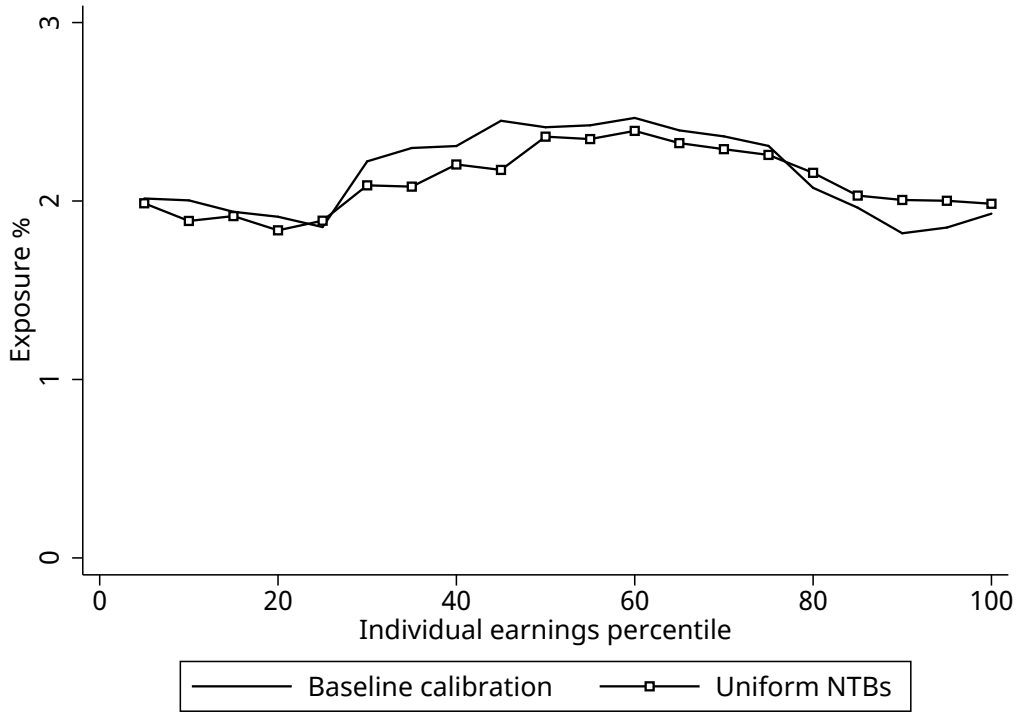


Note: Authors' calculations using 2016 Annual Survey of Hours and Earnings, 2017 Quarterly Labour Force Survey and 2016 Business Structure Database. Figure shows exposure predicted by our model across percentiles of the individual earnings distribution given different modelling assumptions. We smooth by plotting average exposure within five percentile bands. Exposure is the output of the model outlined in Section 3.2 for a 'WTO rules' Brexit. It varies by workers' TTWA and across nine occupation groups. We merge measures of exposure into the 2017 Quarterly Labour Force Survey on the basis of workers' current occupation and their current Government Office Region rather than TTWA (a level of geographic detail which is not available in public versions of the QLFS) to obtain individual and household exposure by household earnings. Household exposure is calculated using predicted exposure for household heads and their partners (if they have one) weighted by their shares in total household earnings (reflecting differences in hours worked). To be included in the sample, households must have at least one member in work. Household earnings are equivalised using the modified OECD scale.

Figures G.3 and G.4 show how exposure over the earnings distribution changes when we apply uniform changes in NTBs across sectors (10% on all exports to the EU and 5% on all imports from the EU to the UK). This is to check how sensitive our results are to assumptions on the distribution of NTBs across sectors.

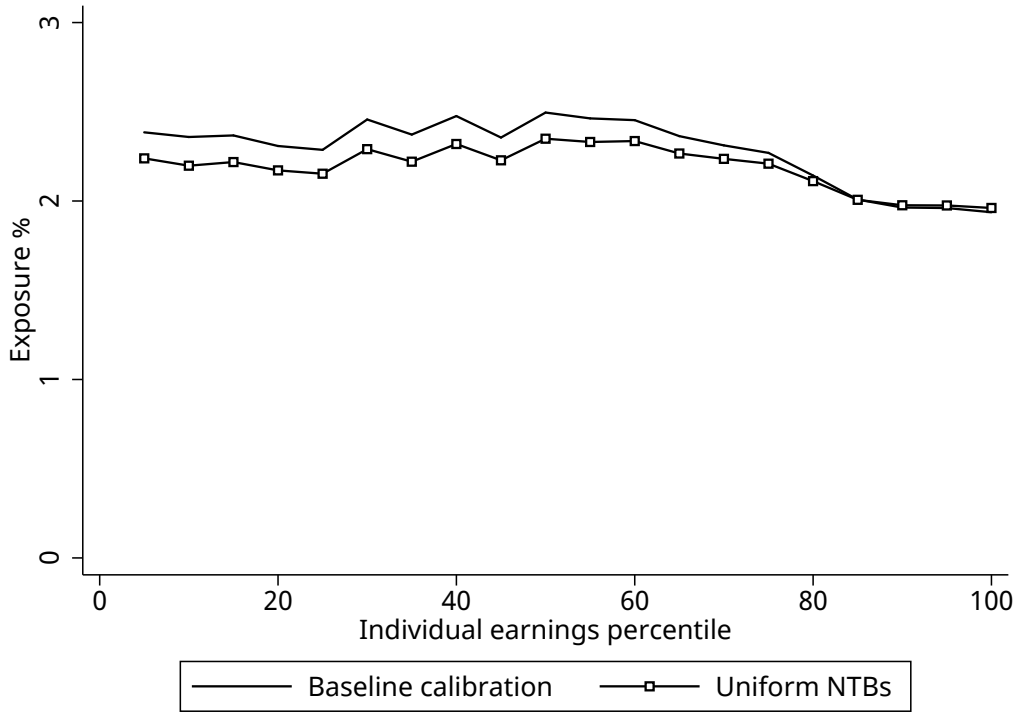
Figure G.3 shows workers' exposure and Figure G.4 shows the exposure of workers' households across the distribution of individual earnings. In both cases the distribution of exposure is similar to our baseline model. This suggests our results are mainly driven by the importance of the EU market for different sectors, rather than specific assumptions about the non-tariff barriers different sectors are likely to face.

Figure G.3: *Measures of individual exposure over the earnings distribution - uniform non-tariff barriers across sectors*



Note: Authors' calculations using 2016 Annual Survey of Hours and Earnings and 2016 Business Structure Database. Figure shows exposure predicted by our model across percentiles of the individual earnings distribution in our baseline model and for a case where we set new non-tariff barriers to be uniform across sectors (with a tariff equivalent of 5% on all UK imports from the the EU and 10% on all UK exports to the EU). We smooth by plotting average exposure within five percentile bands. Exposure is the output of the model outlined in Section 3.2 for a 'WTO rules' Brexit. It varies by workers' TTWA and across nine occupation groups.

Figure G.4: *Measures of household exposure over the individual earnings distribution - uniform non-tariff barriers across sectors*



Note: Authors' calculations using 2016 Annual Survey of Hours and Earnings, 2017 Quarterly Labour Force Survey and 2016 Business Structure Database. Figure shows exposure predicted by our model across percentiles of the individual earnings distribution in our basline model and for a case where we set new non-tariff barriers to be uniform across sectors (with a tariff equivalent of 5% on all UK imports from the the EU and 10% on all UK exports to the EU). We smooth by plotting average exposure within five percentile bands. Exposure is the output of the model outlined in Section 3.2 for a 'WTO rules' Brexit. It varies by workers' TTWA and across nine occupation groups. We merge measures of exposure into the 2017 Quarterly Labour Force Survey on the basis of workers' current occupation and their current Government Office Region rather than TTWA (a level of geographic detail which is not available in public versions of the QLFS) to obtain individual and household exposure by household earnings. Household exposure is calculated using predicted exposure for household heads and their partners (if they have one) weighted by their shares in total household earnings (reflecting differences in hours worked). To be included in the sample, households must have at least one member in work. Household earnings are equivalised using the modified OECD scale.

G.1 Broader skill groups

In the main body of the paper we examine the possibilities for workers employed in different occupations to find alternative employment within each local labour market. In this appendix we describe we discuss occupation transitions observed in the data, and the sensitivity of our results to using alternative (broader) occupational headings.

To better understand the extent to which workers move between occupations, we use the 5-quarter longitudinal version of the QLFS (Office for National Statistics, Social Survey Division (2019a)) which follows the same individuals for up to one year. In Table G.1 we show transition rates between each of the occupational groups from the first quarter in which they were interviewed to the last. In Table G.2 we

do the same but condition on whether or not individuals have changed jobs (not necessarily occupations) in the past year. These tables show that even workers who change jobs are most likely to remain in their old occupations. However, there is evidence of mobility between certain occupation headings. For example workers in management are quite likely to move into technical roles (and vice versa).

Table G.1: *Transition rates between occupations (annual, 2014-2017)*

To		From 1. Managers	2. Professional	3. Technical	4. Admin	5. Skilled trades	6. Other service	7. Sales	8. Machine operatives	9. Elementary	N
1.	Managers	**81.04**	5.05	5.61	3.03	1.62	0.75	1.31	0.69	0.90	3,206
2.	Professional	3.07	**87.45**	4.53	1.73	1.22	1.05	0.36	0.30	0.29	6,946
3.	Technical	4.78	7.01	**78.76**	3.82	1.10	1.08	1.81	0.78	0.86	4,082
4.	Admin	2.74	3.34	5.01	**83.85**	0.60	0.92	1.79	0.77	0.98	3,356
5.	Skilled trades	1.94	2.29	1.80	0.56	**88.43**	0.63	0.53	2.05	1.76	2,835
6.	Other service	1.07	3.62	1.75	1.95	0.32	**87.11**	1.11	0.52	2.55	2,514
7.	Sales	3.07	1.81	4.39	4.45	1.48	1.32	**78.49**	0.88	4.12	1,822
8.	Machine operatives	1.31	0.85	1.76	0.79	4.09	0.51	0.96	**84.73**	4.99	1,762
9.	Elementary	1.17	0.77	1.58	1.98	2.67	2.47	2.95	3.07	**83.34**	2,473

Note: Authors' calculations from 5-quarter Longitudinal Quarterly Labour Force Survey in years 2014-2017. Cells give the probability a worker in a given occupation in their first interview is working in a given occupation in their fifth interview.

Table G.2: *Transition rates between occupations for those who changed jobs (annual, 2014-2017)*

To		From 1. Managers	2. Professional	3. Technical	4. Admin	5. Skilled trades	6. Other service	7. Sales	8. Machine operatives	9. Elementary	N
1.	Managers	**43.08**	12.31	15.38	8.46	5.38	3.85	3.85	1.54	6.15	130
2.	Professional	6.90	**71.62**	10.61	2.65	2.12	2.12	1.59	0.53	1.86	377
3.	Technical	8.12	15.23	**54.31**	8.63	2.03	3.05	4.06	2.54	2.03	197
4.	Admin	7.14	7.14	12.09	**53.85**	2.20	6.59	4.95	1.65	4.40	182
5.	Skilled trades	2.21	5.15	5.88	2.21	**58.82**	4.41	2.94	9.56	8.82	136
6.	Other service	1.92	7.69	4.49	12.18	0.64	**50.00**	7.69	2.56	12.82	156
7.	Sales	4.80	6.40	12.00	16.80	7.20	8.80	**28.80**	1.60	13.60	125
8.	Machine operatives	4.82	2.41	8.43	0.00	14.46	2.41	2.41	**43.37**	21.69	83
9.	Elementary	2.33	3.49	5.81	6.40	5.81	11.63	18.02	6.40	**40.12**	172

Note: Authors' calculations from 5-quarter Longitudinal Quarterly Labour Force Survey in years 2014-2017. 'Changing jobs' is defined as reporting leaving paid employment at any time between the first and fifth interviews of the survey. Cells give the probability a worker who was in a given occupation in their first interview, and who changed jobs between survey waves, is working in a given occupation in their fifth interview.

To examine how our results might change if we allowed for a greater degree of cross-occupation mobility, we split workers into a three distinct groups in which job moves appear relatively more likely, and in which educational and earnings requirements appear similar. We define these groups as "white-collar" (occupation groups 1-3), "blue-collar" (occupation groups 5 and 8) and "low-skilled" workers (occupation groups 4, 6 and 7).

In Table G.3 we show transition rates across these groups for all workers, those who change jobs and those who involuntarily change jobs (defined as those who report leaving a job between the 1st and 5th quarter of the QLFS due to being dismissed, made redundant, taking voluntary redundancy, because they had a temporary job that came to an end or because they left their work for health reasons). The transition rates we estimate conditional on workers changing jobs suggest that workers are quite unlikely to move out of these broad occupation groups, even when they are forced to leave their previous roles. Between two thirds and three quarters of individuals report being re-employed in occupations under the same heading as before.

Table G.3: *Transition probabilities across skill groups, 2014-2017*

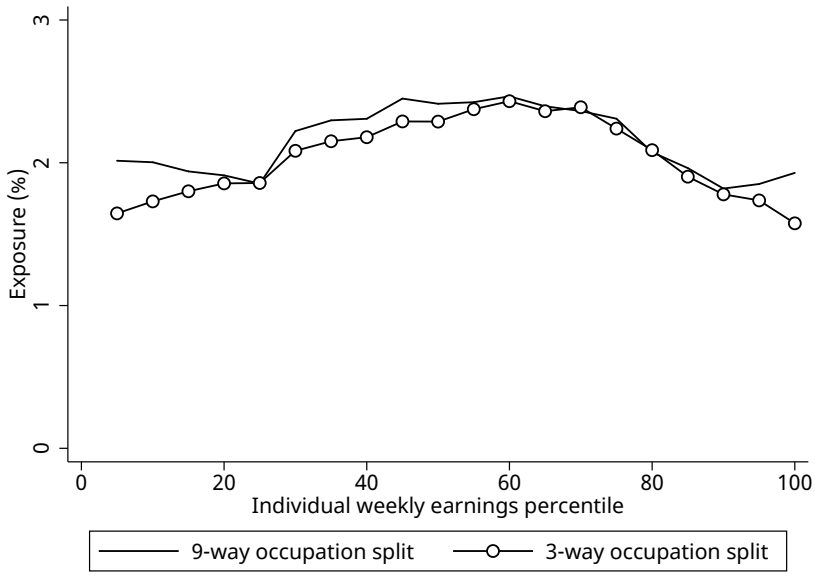
To From	White-collar	Blue-collar	Low-skilled	N
All workers				
White-collar	89.75	2.48	7.77	10,165
Blue-collar	4.94	89.84	5.22	4,597
Low-skilled	5.19	1.81	93.00	14,234
Changes jobs				
White-collar	74.33	6.93	18.74	635
Blue-collar	21.46	64.38	14.16	219
Low-skilled	13.49	3.98	82.53	704
Changes jobs involuntarily				
White-collar	75.00	7.26	17.74	124
Blue-collar	24.59	67.21	8.20	61
Low-skilled	18.06	5.56	76.39	144

Note: Author's calculations using the 5-quarter Longitudinal Quarterly Labour Force Survey in years 2014-2017. Cells give the probability a worker in a given skill group in their first interview is working in a given skill group in their fifth interview. "White-collar" workers are those working in occupations with first digit ISCO codes 1-3), "blue-collar" are those working in occupations with first digit ISCO codes 5 and 8, and "low-skilled" workers are those working in occupations with first digit ISCO codes of 4, 6, 7 and 9). Job changes are classed as involuntary if workers report leaving a job between the 1st and 5th quarter of the QLFS due to being dismissed, made redundant, taking voluntary redundancy, because they had a temporary job that came to an end or because they left their work for health reasons.

Figures G.5 and G.6 show exposure of workers and their households' over the earnings distribution when we use a three-way occupation split. While the pattern of exposure over the earnings distribution is similar to our baseline scenario, workers at

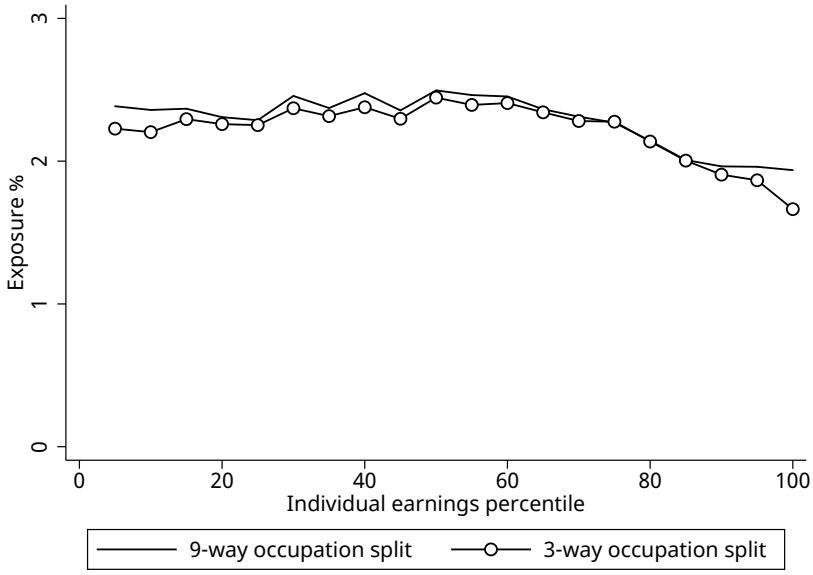
the higher end of the earnings distribution do relatively better under this scenario. The patterns are similar to those in under our baseline 9-way occupation split, indicating that allowing workers to shift into other similar occupations does not greatly affect our results.

Figure G.5: *Measures of individual exposure over the earnings distribution - 3-way vs 9-way occupation split*



Note: Authors' calculations using 2016 Annual Survey of Hours and Earnings, 2017 Quarterly Labour Force Survey and 2016 Business Structure Database. Figure shows exposure predicted by our model across percentiles of the individual earnings distribution when we use a three-way (as opposed to nine-way) occupations split alongside results from our baseline model. We smooth by plotting average exposure within five percentile bands. Exposure is the output of the model outlined in Section 3.2 for a 'WTO rules' Brexit. It varies by workers' TTWA and across three occupation groups. We merge exposure into the 2016 Annual Survey of Hours and Earnings to obtain estimated impacts over the earnings distribution of individual workers.

Figure G.6: *Measures of household exposure over the individual earnings distribution - 3-way vs 9-way occupation split*



Note: Authors' calculations using 2016 Annual Survey of Hours and Earnings, 2017 Quarterly Labour Force Survey and 2016 Business Structure Database. Figure shows exposure predicted by our model across percentiles of the individual earnings distribution when we use a three-way (as opposed to nine-way) occupations split alongside results from our baseline model. We smooth by plotting average exposure within five percentile bands. Exposure is the output of the model outlined in Section 3.2 for a 'WTO rules' Brexit. It varies by workers' TTWA and across three occupation groups. We merge measures of exposure into the 2017 Quarterly Labour Force Survey on the basis of workers' current occupation and their current Government Office Region rather than TTWA (a level of geographic detail which is not available in public versions of the QLFS) to obtain individual and household exposure by household earnings. Household exposure is calculated using predicted exposure for household heads and their partners (if they have one) weighted by their shares in total household earnings (reflecting differences in hours worked). To be included in the sample, households must have at least one member in work. Household earnings are equivalised using the modified OECD scale.

H Effects of other policy changes: immigration

The analysis in the main text focused specifically on the impact of new trade barriers on different skill groups. Another area where post-Brexit policy changes are expected is the UK's migration policy. In particular, the UK may seek to make it harder for workers from the EU to come to the UK with an emphasis on reducing the immigration of those working in 'low-skilled' occupations. How might this affect workers' relative exposure?

To assess whether reduced migration might mitigate the impacts described above, Table H.1 shows the share of workers in each skill group who are EU migrants. EU migrants account for 7.3% of the total workforce, but 15.0% of workers in elementary occupations and 14.7% of machine operatives.

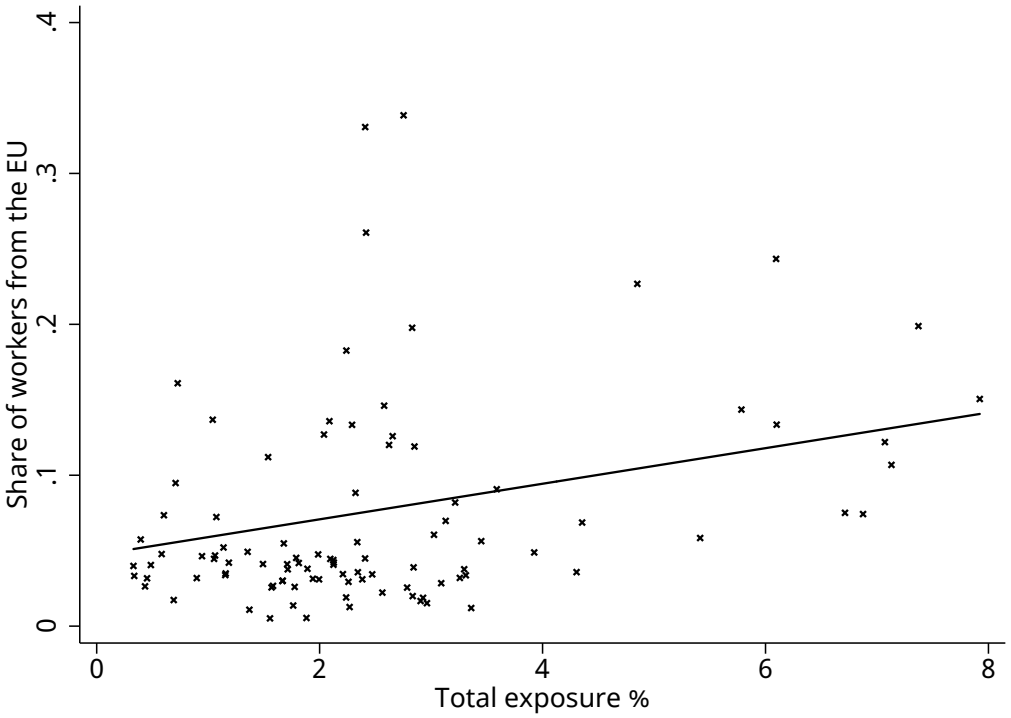
Table H.1: *Share of workers who are EU migrants by occupation*

	Share from EU %
1. Managers	5.0%
2. Professional	6.1%
3. Technical	4.7%
4. Administrative	4.2%
5. Skilled trades	9.0%
6. Other service	6.0%
7. Sales	5.8%
8. Machine ops	14.7%
9. Elementary	15.0%
All	7.3%

Note: Authors' calculations from 2017 Quarterly Labour Force Survey. EU migrants are defined as those with non-UK EU nationality.

Figure H.1 plots the correlations between migrant shares in different UK regions and average exposure for different occupation groups. Overall, occupation group-region cells with larger predicted wage declines tend to have greater share of workers from the EU, although the population-weighted correlation (0.27) is not strong. One reason for the weakness of this correlation is that the largest shares of migrant workers tend to be in London, where the exposure to changes in trade barriers among all occupation groups is also relatively low.

Figure H.1: *Share of workers who are EU migrants versus overall exposure to post-Brexit changes in trade costs by occupation group and Government Office Region*



Note: Authors' calculations using 2016 Annual Survey of Hours and Earnings, 2017 Quarterly Labour Force Survey and 2016 Business Structure Database. Exposure is the output of the model outlined in Section 3.2 for a 'WTO rules' Brexit. Individual points are average exposure within UK Government Office Regions for workers in one of the nine occupation groups.

These results show there may be some scope for reduced migration to mitigate some of the wage impacts of increased trade barriers. However, it should be noted that studies of the impact of immigration on the relative wages of different workers tend to find small effects. Nickell and Saleheen (2017) use variation in the share of immigrants across regions in Britain to assess the impact of immigration on wages. They find that the largest wage impacts were on workers in semiskilled or unskilled service sector occupations (essentially corresponding to the occupation groups numbered 4, 6 and 7 in Table H.1). Among this group each 10 percentage point increase in the share of migrants was associated with a 2 per cent reduction in pay (roughly 1.5 per cent once the impact of migration on the composition of workers in each group was accounted for). A 10 percentage point increase is roughly equal to the entirety of the increase in the immigrant share of the workforce over the past decade (Portes (2018)). Dustmann et al. (2013) find that a one percentage point increase in the migrant/non-migrant ratio leads to a decrease in wages of 0.6 per cent at the 5th percentile of the UK's wage distribution and of 0.5 per cent at the 10th percentile. They find positive impacts of migration across the remainder of the wage distribution. This suggests that changes in migrant flows would need to be large to fully offset the differences in exposure across occupations described for example in Figure 4.1.