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INVITED REVIEW

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Global value chains, trade shocks and jobs: An application to Brexit

Hylke Vandenbussche[1] | **William Connell**[2] | **Wouter Simons**[2]

[1]Department of Economics, University of Leuven (KU Leuven), Leuven, Belgium

[2]European Commission, Brussels, Belgium

Correspondence
Hylke Vandenbussche, Department of Economics, University of Leuven (KU Leuven), Naamsestraat 69, B-3000 Leuven, Belgium.
Email: hylke.vandenbussche@kuleuven.be

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Abstract

We develop a network trade model with country-sector level input–output linkages with the objective of evaluating the impact of trade shocks. This framework is particularly useful to decompose the direct and the indirect trade effects of both a bilateral and a third country trade shock, evaluated at the country-sector level. Using the sectoral World Input–Output Database (WIOD) combined with sectoral employment data, we evaluate the impact in terms of value added and employment of different scenarios of Brexit for 56 industries in the 27 Member States of the European Union, as well as the United Kingdom. In this respect, we consider both the results under the current EU–UK Trade agreement, as well as a counterfactual scenario in which WTO tariffs would apply. In contrast to other studies, we find EU-27 value added and job losses to be substantially higher than hitherto believed as a result of the closely integrated EU network structure. Our approach finds that upstream sectors are particularly vulnerable to indirect trade shocks effects due to their network centrality.

KEYWORDS

Brexit, Global Value Chains, Input–output data, network model, value-added trade

Hylke Vandenbussche, William Connell and Wouter Simons contributed equally to this analysis.

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1 | INTRODUCTION

Production processes are increasingly fragmented within and across national boundaries. To assess the impact of trade shocks in a world of global value chains, several models and approaches have been developed. For example, Caliendo and Parro (2014) build a Ricardian model with sectoral linkages and trade in intermediate goods to quantify the welfare effects from tariff changes. Anderson et al. (2015) offer a structural gravity approach with and without intermediates in production to quantify output and welfare effects. These models show that accounting for intermediate goods in production and sectoral linkages is of the utmost importance since these channels amplify the trade and welfare effects of trade costs and tariffs relative to one sector gravity models (Anderson & Van Wincoop, 2003). This paper proposes an alternative approach that builds on these insights but digs deeper into the input–output (I-O) structure, which results in a more detailed quantification of the economic effects of trade shocks. In the course of this paper, we argue that our approach is particularly useful to explicitly decompose the direct and indirect (via third countries) value added and employment effects of both a bilateral and a third country trade shock, evaluated at the country-sector level. This will allow us, for instance, to quantify how Brexit will affect the Belgian steel sector not just through a reduction in bilateral exports of steel from Belgium to the UK, but also through a reduction of Belgian steel exports used in German cars, which are subsequently shipped to the UK.

A lot of work in recent years has gone into identifying the welfare gains and losses from trade policy, albeit without a strong focus on inter-sectoral linkages and intermediates (see Costinot and Rodríguez-Clare (2014) for an overview).[1] An increasing number of papers in trade also turn to I-O data in the context of trade policy but with a different focus, for example Blanchard et al. (2016) who show that countries, which are more connected in global value chains have lower tariff protection between them, Dhingra et al. (2017) who evaluate Brexit on UK household income levels and Caliendo and Parro (2014) who assess the welfare effects of NAFTA. Blonigen (2016) examined the downstream effects of industrial policy in the steel sector. Finally, several studies in international trade have now shown that gross trade flows do not necessarily reflect the domestic production underlying the trade flow but value added is more appropriate (Bernard et al., 2018; Koopman et al., 2014).[2]

This paper provides more than just policy conclusions about Brexit. The academic contribution of this paper is to show that the network effects of a trade shock cannot be uncovered with a more traditional gravity one sector model.[3] Nor can they be uncovered with existing multi-country, multi-sector models given that the input–output structure assumed in these alternative models is at sector level, which contrasts to the country-sector level used in this paper.[4] In other words, while most network models use the Ricardian assumption, where every input is assumed to be sourced from only one particular country (e.g. German cars source steel only from the cheapest source), we rely on the Armington assumption. In such a setting, an input can

[1]An analysis of welfare effects would be outside the scope of this paper, which focuses on quantifying the direct and indirect value added impact at the level of the country-sector.

[2]Bernard et al. (2018) empirically show that many products shipped by manufacturing firms are not produced in-house, but are 'carry-along trade', that is gross export sales are much larger than the domestic production shipped.

[3]In the Brexit debate only a few papers have emphasised the importance of input–output linkages (Chen et al., 2018; Giammetti et al., 2020).

[4]See Caliendo and Parro (2014), Dhingra et al. (2015), Eaton and Kortum (2002), Felbermayr et al. (2018) or Yotov et al. (2016).

simultaneously be sourced from several countries as for instance, in the case of German automotive producers, they can use Belgian, Polish and Slovakian steel. An important characteristic of the Armington setup is that, at sectoral level, it is in line with publicly available world Input–Output (I-O) databases.[5] Consequently, while a Ricardian approach results in a gravity model with I-O linkages between sectors, the Armington assumption leads to a richer network model with I-O linkages between country-sectors, which results in a framework that is better equipped to study trade shocks taking into account all the network linkages.

Where other models are general equilibrium in nature, our framework is partial equilibrium and short-term in the sense that we do not consider reallocation effects across sectors. In this paper, we purposely focus on the short-run static effects of different counterfactual Brexit trade shocks, and we allow for job losses and unemployment at the country-sector level. Clearly, not all workers who lose their job as a result of the shock will remain unemployed as at least some will find their way to other jobs in the same or a different sector. However, such a process may take time, which is why there is room for a paper that explores the negative job effects at country-sector level, even before the reallocation of workers across sectors (or firms) takes place. This paper analyses the short-term trade effects of Brexit and does not consider foreign direct investment (FDI) responses to trade policy, which may take longer to materialise. Moreover, we disregard any dynamic effects of Brexit related to investment and innovation, capital mobility and migration. In the empirical application, we focus on the trade destruction effects of the trade shock,[6] which corresponds to studying the nodes in the existing network that will be affected. Consequently, in our empirical application, we refrain from making empirical estimates about the creation of new nodes in the global network, which would entail a much more speculative exercise. While a permanent change in the network structure is likely to occur, it would typically take time to materialise.[7] In the structural gravity literature, where trade diversion effects are relatively easy to quantify, there are a number of studies (cfr. Magee, 2008) that suggest that trade diversion effects can mitigate some of the trade destruction effects of a trade shock. However, they are typically small compared to the first-order trade effects, which are the main focus of this paper.[8]

The country-sector level approach followed in this paper does not account for firm heterogeneity. However, given the limited geographical scope of current firm-level data sets, these would not allow to trace all upstream and downstream linkages in production. For this reason, we turn to I-O data, where we can trace all the upstream and downstream linkages in production for each country-sector. These linkages are captured in our network model through the Leontieff coefficients.[9] In addition, global I-O databases have an underlying proportionality assumption embed-

[5]Contrary to the sectoral aggregation of I-O tables, the Ricardian and Armington assumption are empirically equivalent at variety level.

[6]In the network model developed in Section 2, we do obtain a closed form solution for the trade diversion effects of a trade shock in a network context.

[7]Other papers have aimed at quantifying trade diversion and substitution effects (see Giammetti et al., 2020), which may result in lower estimates of the Brexit impact.

[8]Magee (2008) finds that bilateral trade flows are estimated to increase by 82% after countries engage in a regional agreement and this effect is significant across different econometric specifications. On the contrary, the variable capturing trade diversion reduces imports from outside by 2.9% but is not significant across different econometric specifications, suggesting that trade diversion is rather small.

[9]To our knowledge, a comprehensive database with firm-level production linkages across the globe is not available. For this reason, many firm-level studies with information on firm-level trading are often limited in their geographic scope and typically only include firms from one country without information on who these firms are buying from or selling to (see Amiti and Konings, 2007; Topalova and Khandelwal, 2011 or Vandenbussche and Viegelahn, 2018).

ded in the way the data are constructed.[10] However, this potential shortcoming cannot be overcome with firm-level data either. Indeed, firm-level input–output linkages also require making a proportionality assumption when deciding which inputs are used in which outputs (see Vandenbussche & Viegelahn, 2018).

Our country-sector level approach offers a number of important advantages compared to more aggregate country-level analysis such as Noguera (2012). These advantages are not unique to this study but shared by all studies that use sector-level input–output analysis. First, we allow for tariff heterogeneity across sectors. Second, trade elasticities are allowed to differ across sectors, that is consumers (and firms) respond differently to price changes in different sectors. Third, we include services in our analysis, which is important given that services are increasingly traded as well as embedded in the exports of goods. Trade in services is not subject to a WTO tariff, but services are indirectly subject to tariffs when used as an input in goods trade and services are also subject to non-tariff barriers. Finally, as the production linkages between two countries typically differ greatly across sectors, our country-sector approach yields a more precise assessment of the indirect effects of a trade shock.

The main features of our network model are as follows. A nested Cobb-Douglas-CES structure is assumed on the consumption and production side. Gravity equations for intermediate and final bilateral exports are obtained and combined with an Input–Output structure, which yields an expression that allows for the quantification of the impact of tariff changes on value added at the country-sector level. Our framework predicts that an increase in import barriers results in a reduction of production and employment all along the supply chain. The potential losses in value added production depend on the sectoral trade elasticity, the value added shares in production, changes in the tariff and non-tariff barriers and the Leontief input–output coefficients. In the empirical application, potential employment losses are then obtained by combining the value added loses with the sectoral employment elasticities with respect to value added.

While our framework can be applied to any trade shock, in this paper we use it to predict the impact of different counterfactual scenarios of Brexit. The Free Trade Agreement (FTA) between the EU and the UK of December 2020 has officially avoided the installation of permanent import tariffs on either side. However, the introduction of WTO tariffs on the trade across the channel is still a distinct possibility.[11] For this reason, in this paper, we consider the free trade agreement scenario (soft Brexit), where hard tariffs are absent but non-tariff barriers apply (new customs procedures, border checks, new certificates of origin, VAT administration, sanitary and phytosanitary measures, new labelling, delays etc.). In addition, we also consider a benchmark scenario in which hard tariffs additionally apply (hard Brexit) between the UK and the EU-27 and consider all other trade relations to remain unchanged. This benchmark is useful since the current trade regime is probably somewhere in between the soft and the hard Brexit scenario. Given the high uncertainty surrounding the current rules and the likelihood that tariffs can be imposed in the future, the soft Brexit scenario developed in this paper is probably too optimistic and the outcomes are more likely in the range between the soft and the hard Brexit scenario both developed in this paper.

[10]In the WIOD tables, the use of the BEC classification to identify intermediate trade flows removes the proportionality assumption across use categories (intermediate consumption, final consumption and capital formation). However, there is still a proportionality assumption to allocate bilateral intermediate trade flows across using industries.

[11]Under the Brexit Agreement, tariffs can still be imposed whenever rules-of-origin are not respected, or whenever products standard diverge sufficiently.

This paper relies on the World Input–Output Database (WIOD) to analyse global production networks. WIOD has also been used by Foster-McGregor and Stehrer (2013), Timmer et al. (2014), Timmer et al. (2015) and others to investigate the inter-sector and international linkages in supply chains, albeit to address different questions. The database contains more disaggregated sectoral information than the data used by Johnson and Noguera (2012) that only include four composite sectors including one service sector. Given our sectoral focus, WIOD is quite appropriate given its coverage of 56 sectors including 30 service sectors. While our interest lies in the job losses of trade shocks, our approach differs from Autor et al. (2013), who assess US employment effects of Chinese import penetration at the regional level as they do not consider the input–output linkages between industries. The novelty of our approach is that we consider all the upstream and downstream employment effects of a trade shock. In that respect, our approach is closer to Feenstra and Sasahara (2018) who study the labour demand effects of US exports and imports from China. Their paper is entirely empirical whereas we rely on a network model to identify the critical parameters to quantify the value added impact of Brexit.

In comparison to other studies, we find the losses for the EU-27 countries as a result of Brexit to be much higher than previously thought and to be mainly driven by the increase in non-tariff barriers. The main reason is that our approach incorporates all national and international country-sector-level input–output linkages in both goods and services. Given that EU-27 production networks are closely integrated, changes in tariff and non-tariff barriers do not just affect direct bilateral trade flows between any EU-27 country and the UK, but also indirect trade flows via third countries. Indeed, we find that on average, the indirect effects of a hard Brexit amount to ca. 70% of the total Brexit impact for the EU-27 country-sectors. This finding suggests that production networks in the EU are closely integrated and that an approach that fails to account for these indirect effects would significantly underestimate the effects of Brexit in terms of sector-level production and jobs.

The remainder of this paper is organised as follows. In Section 2, we describe the theoretical model and obtain an expression for a country-sector's value added production and its determinants on the basis of which we obtain clear predictions on the effects of trade shocks. In Section 3, we explain the methodology and describe the data used in this analysis. Section 4 presents the results of different Brexit scenarios. Section 5 compares our results to existing results in the literature and Section 6 concludes.

2 | A GLOBAL NETWORK MODEL OF TRADE

This section describes the theoretical framework that forms the basis of the analysis of trade shocks in this paper. In this section, we restrict to spelling out the most important features of the model and summarising its key results. A detailed description of the model's assumptions and derivations can be found in the Appendix. Throughout this section, countries are denoted by i, j and k and sectors by r, s and z.[12]

The model is based on the Armington assumption, which means that goods produced by different sources are imperfect substitutes. As a result, within a sector, goods from different countries can coexist in the same destination market, even though their prices may differ as they are

[12]We need at least three symbols in the model to denote countries and sectors because input–output models typically consider three nodes in a supply chain: (1) the supplier of intermediate inputs, (2) the final producer and (3) the consumer.

determined by the country-sector's marginal production cost and costs of trade with the destination country.[13] Consumers (and firms) in the destination country have a love-for-variety and prefer to consume positive amounts of each available variety.

A nested Cobb-Douglas-CES structure is assumed on the demand and supply side. Consumers and producers rely on a Cobb-Douglas combination of quantities sourced from different sectors. The sector-specific goods are CES aggregates across all countries the goods can be sourced from. Firms maximise profits and households maximise utility taking factor and goods prices as given. Under iceberg-type trade barriers, we thus derive optimal intermediate and final demand, which can be plugged into the market clearing condition. In a similar vein as Anderson and Van Wincoop (2003), but at the sector level, we can solve for prices to obtain gravity equations for intermediate and final bilateral exports.

Using matrix algebra and the structure of I-O tables, we can write a country-sector's value added production as a function of global Leontief coefficients and gravity equations for final demand. Define each element Λ_{is}^{kz} of the Leontief inverse matrix $\boldsymbol{\Lambda}$ as the Leontief coefficient that measures the total of dollars worth of country-sector kz goods required to meet 1 dollar worth of is' final demand. This value combines kz goods used as inputs in is directly, as well as kz goods used as inputs in other industries which then also produce inputs for is. Defining v^{kz} as the value added to output ratio, we can write the total value added production by country-sector kz as:

$$va^{kz} = v^{kz} \sum_{i=1}^{N} \sum_{s=1}^{S} \Lambda_{is}^{kz} \sum_{j=1}^{N} f_j^{is}$$

$$va^{kz} = v^{kz} \sum_{i=1}^{N} \sum_{s=1}^{S} \Lambda_{is}^{kz} \sum_{j=1}^{N} \left(\frac{y^{is} \alpha_j^s \sum_{r=1}^{S} \left(1 - \beta^{jr}\right) y^{jr}}{y^w} \left(\frac{\tau_j^{is}}{\Pi^{is} P_j^s} \right)^{1-\sigma_s} \right) \tag{1}$$

where we substitute the gravity relation for final demand f_j^{kz}, which relates bilateral final goods trade between firms in country-sector kz and the consumers in country j to (i) the economic masses of source (y^{kz}) and destination ($\sum_{s=1}^{S} \left(1 - \beta^{js}\right) y^{js}$)[14] relative to the economic mass of the world (y^w), (ii) the importance of sector z final goods in the destination's consumption (α_j^z), (iii) the bilateral trade costs, which can take the form of tariffs or non-tariff barriers (NTBs), between countries k and j in sector z (τ_j^{kz}), and (iv) outward and inward multilateral resistance terms (Π^{kz} and P_j^z).

This value added production (and the jobs depending on it) might be severely impacted in the case of a trade shock such as Brexit. Equation (1) shows that an import tariff (or NTB equivalent) imposed on a specific good does not only affect the producer of the good, but also the suppliers of goods and services whose output is used as an input in the production of the good. This implies that when the UK imposes a tariff on German cars, the Belgian steel sector, which supplies inputs to the German car industry will also be affected, even in the absence of a UK import tariff on Belgian steel. This channel is missing in a traditional gravity approach but can be captured by our sector-level model.

[13]As in Noguera (2012), production and trade costs are the only determinants of prices in our model. This does not imply that firms cannot charge mark-ups. In WIOD, however, we have no information on the underlying firm-level distribution within each sector. The absence of mark-ups in the model is assumed at sectoral level.

[14]This expression reflects the fact that consumers in country j get their income from supplying labor to all sectors s.

Assessing the impact of a trade shock in this framework amounts to considering what happens when the variable trade costs (τ) change.[15] Our interest lies in the change dva^{kz} in country-sector kz' value added production, which we find to equal:

$$\mathrm{d}va^{kz} = -v^{kz}\sum_{i=1}^{N}\sum_{s=1}^{S}\left(\sigma_s - 1\right)\Lambda_{is}^{kz}\sum_{j=1}^{N}\hat{\tau}_j^{is}e_j^{is} \tag{2}$$

where we defined $\hat{\tau}_j^{is} \equiv \frac{\mathrm{d}\tau_j^{is}}{\tau_j^{is}} - \frac{\mathrm{d}\Pi^{is}}{\Pi^{is}} - \frac{\mathrm{d}P_j^s}{P_j^s}$ as the proportionate change in tariffs τ_j^{is} relative to the proportionate changes in the multilateral resistance (MR) terms. From Equation (2), we can derive the following general result. Rising trade costs reduce bilateral trade flows e_j^{is} (of both final and intermediate goods) between any country-sector is and j. As kz has an interest Λ_{is}^{kz} in each of these bilateral flows, va^{kz} will decrease as well. The drop depends on the magnitude of the change in relative trade costs $\hat{\tau}_j^{is}$ between is and j and the corresponding trade elasticity σ_s.

When examining trade policy, it is important to take into account that the multilateral resistance (MR) terms will change along with the tariffs. Therefore, Equation (2) not only examines the impact of $\frac{\mathrm{d}\tau}{\tau_j^{is}}$ but also that of $\frac{\mathrm{d}\Pi^{is}}{\Pi^{is}}$ and $\frac{\mathrm{d}P_j^s}{P_j^s}$ through $\hat{\tau}_j^{is}$. As it is relative tariffs that matter rather than absolute tariffs to determine a country's global competitiveness, individual tariff changes should be compared with changes in the average tariff, which is captured by the multilateral resistance terms. Suppose, for instance, that the UK tariff on Belgian goods goes up by 3%. Further suppose for a moment that the UK raises its tariffs on all its other trading partners with 2%, then the 'real' or 'relative' increases in the BE-UK tariff is only 1% (3%–2%). In that case, what matters for a country-sector's production change dva^{kz} is the tariff change it faces relative to the tariff change its competitors face.

However, under different hypothetical Brexit scenarios, the only countries that are likely to face increased tariffs from the UK are the EU-27, whereas the tariffs the UK imposes on its other trading partners such as the United States will not change. This means that US goods will become relatively less expensive for the UK, even though the UK tariffs on US imports do not change. The reason is that Brexit actually decreases (i.e. $\hat{\tau}_{\mathrm{UK}}^{\mathrm{US},s} < 0$) the 'relative' US-UK trade costs compared to EU-UK trade costs. As a result, some trade will be diverted from the EU-27-UK to the US-UK. The MR changes $\frac{\mathrm{d}\Pi^{is}}{\Pi^{is}}$ and $\frac{\mathrm{d}P_j^s}{P_j^s}$ are essential for trade diversion to happen. We can see this by disentangling the change $\hat{\tau}_j^{is}$ into its different components, namely the tariff change and the MR changes:

$$\mathrm{d}va^{kz} = -\underbrace{v^{kz}\sum_{i=1}^{N}\sum_{s=1}^{S}\left(\sigma_s - 1\right)\Lambda_{is}^{kz}\sum_{j=1}^{N}\frac{d\tau_j^{is}}{\tau_j^{is}}e_j^{is}}_{\text{trade destruction effect}} + \underbrace{v^{kz}\sum_{i=1}^{N}\sum_{s=1}^{S}\left(\sigma_s - 1\right)\Lambda_{is}^{kz}\sum_{j=1}^{N}\left[\frac{d\Pi^{is}}{\Pi^{is}} + \frac{dP_j^s}{P_j^s}\right]e_j^{is}}_{\text{trade diversion effect}} \tag{3}$$

[15]We disregard exchange rate effects on EU-UK trade. Recent work has shown that exchange rate effects may have little effect on trading firms as most importers are also exporters, that is a depreciation of say the pound would be bad for UK firms' imports but great for their exports (Amiti et al., 2014).

Equation (3) shows that the change in kz' value added production after a change in trade costs τ is a combination of a 'trade destruction effect'' (−) as a result of higher tariffs and a 'trade diversion effect' (+) caused by the change in the multilateral resistance terms.

The 'trade destruction effect' measures the drop in va^{kz} that is caused by the reduced trade between any country-sector is and country j. This drop depends on how the output of country-sector kz is used by country i's sector s, as it is the latter sector's exports that will face increased protectionist measures from country j.

The 'trade diversion effect', consists of two channels. First, country-sector is will divert some of its exports away from j to alternative destinations that do not impose tariffs on its goods, since these destinations have now become relatively more attractive (i.e. less expensive) for is to export to. This is caused by the increase in is' outward MR term Π^{is}. Second, the fact that j increases the tariffs on its imports will raise the average price in market j, which makes the market less competitive, captured by the increase in j's inward MR term P_j^s. As a result, any country i will find it easier to export to country j. Both the first and second channel of trade diversion increase the exports of is and hence its production, which results in an increase in its demand for inputs from country-sector kz, which in turn increases the latter's value added production va^{kz}. Therefore, the 'trade diversion effect' can mitigate some of the negative 'trade destruction effect' on va^{kz}. The results can be summarised in the following proposition:

Proposition *The change in kz' value added production after a trade shock depends on two effects. First, the negative 'trade destruction effect' indicates that the loss in va^{kz} depends on kz' connection with each exporting country-sector is. The drop in va^{kz} will be greater, (i) the higher is the trade elasticity in sectors (higher $(\sigma_s - 1)$); (ii) the greater is the increase in protection imposed by j on sectors goods originating in country i (higher $\frac{d\tau_j^{is}}{\tau_j^{is}}$); (iii) the greater is the production interlinkage of kz with is (higher Λ_{is}^{kz}) and (iv) the stronger is the direct bilateral trade relation in both final and intermediate goods between i and j in sector is. Second, these negative effects will be mitigated through the 'trade diversion' channel, as some of kz' production will be used in exports that are diverted to different destinations after the trade shock.*

Equation (3) sums up the effects of a trade shock on va^{kz}. It characterises all the different channels through which a trade shock affects a sector's output. It also shows why the effect of a trade shock such as Brexit can substantially vary by sector, depending on production interlinkages with other sectors as captured by the Leontief coefficients (Λ), the linkages to exporting sectors (e), the product differentiation in the sector (σ) and the extent of the sector-level tariff (or NTB equivalent) change ($\frac{d\tau}{\tau}$).

3 | EMPIRICAL APPLICATION TO BREXIT

This section takes the model to the data and simulates the effects of different scenarios of Brexit using input–output data for the latest available year (2014) from WIOD, which covers 43 countries and 56 sectors. While empirically we simulate a scenario of increased trade costs on both sides of the channel, for expository simplicity we just discuss the effects of a unilateral UK protection on EU goods, since the analysis is entirely symmetric. We investigate the impact on kz' production when the EU faces a higher cost of exporting to the UK using Equation (3).

In our Brexit application, we concentrate on the short-run effects and restrict Equation (3) to the first term that measures the 'trade destruction' effect. In order to divert trade, new business contacts have to be established, new contracts negotiated and so on, which takes some time to materialise. Consequently, we refrain from making empirical estimates about the creation of new nodes in the global network, as this would entail a much more speculative exercise. For this reason we focus on the trade destruction effect, which is the first-order trade effect and captures the main effects resulting from Brexit trade shock.[16] The drop in value added production as a result of increased UK trade protection on EU goods (higher $\tau_{UK}^{EU,s}$) under Brexit will thus be approximated by:

$$\mathrm{d}va^{kz} \approx -v^{kz} \sum_{i \in \mathrm{EU}}^{N} \sum_{s=1}^{S} (\sigma_s - 1) \frac{\mathrm{d}\tau_{\mathrm{UK}}^{\mathrm{EU},s}}{\tau_{\mathrm{UK}}^{\mathrm{EU},s}} \Lambda_{is}^{kz} e_{\mathrm{UK}}^{is}$$

Next, we distinguish two different channels of value added loss by decomposing the trade destruction effect of UK protection into 'direct' and 'indirect' losses. These refer, respectively, to the losses in value added of country-sector kz stemming from direct bilateral trade (via domestic sectors) with the UK and the value added losses arising through its production linkages with other affected sectors in other EU-27 countries. For any country-sector kz, the loss in va^{kz} can be decomposed into a 'direct' (via domestic sectors) and 'indirect' (via foreign sectors) loss as follows:

$$dva^{kz} \approx -\underbrace{v^{kz} \sum_{s=1}^{S} (\sigma_s - 1) \frac{d\tau_{\mathrm{UK}}^{\mathrm{EU},s}}{\tau_{\mathrm{UK}}^{\mathrm{EU},s}} \Lambda_{ks}^{kz} e_{\mathrm{UK}}^{ks}}_{\text{direct loss}} - \underbrace{v^{kz} \sum_{i \in \mathrm{EU} \setminus \{k\}}^{N} \sum_{s=1}^{S} (\sigma_s - 1) \frac{d\tau_{\mathrm{UK}}^{\mathrm{EU},s}}{\tau_{\mathrm{UK}}^{\mathrm{EU},s}} \Lambda_{is}^{kz} e_{\mathrm{UK}}^{is}}_{\text{indirect loss}} \tag{4}$$

Equation (4) thus captures the effect on va^{kz} of increased UK trade protection on EU-27 goods and services. Similarly, the effects of increased EU-27 protection on UK goods and services can be obtained from Equation (4) by simply reversing the country of origin and destination.[17] In Section 4, we present results for the UK and the EU-27 combined even though these were first obtained separately.[18]

3.1 | Value added production losses

In this section, we lay out our empirical strategy to estimate changes in value added resulting from a trade shock, where Equation (4) holds the key variables for the estimation. From the WIOD database, we obtain the value added share of country-sector kz' production, v^{kz}, which captures the value added, obtained as gross output minus gross intermediate inputs, per unit of

[16] In the structural gravity literature, where trade diversion effects are relatively easy to quantify, there are a number of studies that suggest that trade diversion effects are typically low compared to the first-order trade effects, which is the main focus on in this paper. For example, Magee (2008) finds that bilateral trade flows are estimated to increase by 82% after countries engage in a regional agreement and this effect is significant across different econometric specifications. On the contrary, the variable capturing trade diversion reduces imports from outside by 2.9% but is not significant across different econometric specifications, suggesting that trade diversion is rather small. Similarly, Soloaga and Wintersb (2001) find trade diversion in only 2 out of the 9 FTAs analysed.

[17] Note that our theoretical framework predicts a loss in UK production even if we only consider trade protection imposed by the UK itself. The main mechanism is that it increases the price of (EU-27) inputs for UK firms and it decreases the demand for UK inputs that are embedded in EU-27 goods and services destined to the UK consumer.

[18] The two separate sets of results are available upon request.

gross output. From the WIOD database, we also compute the Leontief coefficients, Λ_{is}^{kz}, and the direct trade (final and intermediate) flows e_j^{is} from country *is* to country *j*.

In addition, the estimation of Equation (4) requires the use of sectoral trade elasticities, $\sigma_s - 1$. This set of variables measures the proportionate decrease in sectoral demand after a 1% increase in sectoral trade costs. Indeed, higher UK tariffs and Non-Tariff Barriers (NTBs) are likely to increase the price of EU-27 products in the UK (and vice versa), which will lower UK consumers' demand of EU-27 goods as they substitute away to products of cheaper origin. The economic literature has shown that trade elasticities vary both across countries and sectors. This is Imbs and Méjean (2017), who use product-level gross export flows between 1995–2004 to estimate trade elasticities based on a multi-sector model developed by Arkolakis et al. (2012) and Costinot and Rodríguez-Clare (2014).[19] In order to allow for the heterogeneity across sectors that is present in the theoretical framework, we use the average sectoral trade elasticity across EU countries reported by Imbs and Méjean (2017). In this way, we obtain elasticities for 16 different manufacturing sectors. For the remaining sectors, we assign a trade elasticity of −4, which is a lower-bound estimate of the trade elasticities reported in earlier literature.[20,21] While our results depend on the choice of the trade elasticity, what has to be kept in mind is that our results vary linearly with the trade elasticity, that is doubling the trade elasticity in every sector, doubles the value added gains from Brexit. Hence, results depend monotonically on the trade elasticity parameter.

Finally, Equation (4) also hinges on the increase in trade barriers, that is $\frac{d\tau_{\mathrm{UK}}^{\mathrm{EU},s}}{\tau_{\mathrm{UK}}^{\mathrm{EU},s}}$. We consider two Brexit scenarios, an optimistic ('soft Brexit') and a pessimistic ('hard Brexit') scenario. In reality, the Brexit deal between the EU and UK avoided the installation of permanent import tariffs on either side, which justifies the analysis of a 'soft' Brexit scenario where hard tariffs are absent but relatively low NTBs apply. However, given the high uncertainty surrounding the current and future regulatory standards and the likelihood that tariffs can be imposed in the future, we argue that the current EU-UK Brexit Agreement ranges between the 'soft' and 'hard' Brexit scenario presented in this paper.

In our empirical application, in the 'soft Brexit' scenario, the UK continues to belong to the EU Single Market or Customs Union and tariffs remain zero, while NTBs increase by 2.77%, consistently with Dhingra et al. (2017). The quantification of NTBs in Dhingra et al. (2017) as well as in this paper is based on Berden et al. (2009), which computes the tariff equivalent of non-tariff barriers to trade between the EU and the United States and vice versa for a subset of sectors. These barriers include 'border measures' (such as customs procedures) and 'behind-the-border measures' that result from domestic regulations and standards. Part of these regulatory differences between trade partners are driven by language, geography and culture and refer to frictions that cannot be eliminated. The weighted average tariff equivalent for the NTBs on US-EU trade amounts to 20.4%, of which only 54% (roughly 11%) is

[19]Other trade elasticities estimates in the literature confirm this heterogeneity. Baier and Bergstrand (2001) use trade data to estimate a demand elasticity of −6.4, while Broda et al. (2017) use ten-digit HS data to obtain price elasticities of around −12. A paper by Coşar et al. (2016) uses a trade elasticity of −5.7. Ossa (2015) estimates sector level trade elasticities, which range between −1.5 and −25.

[20]The use of the lower-end estimate is justified given that we analyse trade in value added rather than gross flows and that our data are at sector level and not at product-level.

[21]Related to trade elasticities, we assume complete pass-through of tariffs into domestic prices (congruent with the model).

reducible. Following Dhingra et al. (2017), we consider a NTB tariff equivalent of 2.77% on EU-UK trade, corresponding to one quarter of the reducible NTB level of 11% observed on EU-US trade.[22,23]

In the hypothetical 'hard' Brexit scenario, the UK would have left the Single Market and all trade between the EU-27 countries and the UK would have been governed by the World Trade Organization (WTO) rules. This would have implied an increase in all trade tariffs from the current level of 0% to the sectoral 'applied tariffs' imposed under the Most Favored Nations (MFN) clause, which would have differed by sector.[24] In our counterfactual analysis of 'hard' Brexit, we use the unweighted MFN tariffs between the United States and the EU across the different sectors. Consequently, in the 'hard' Brexit scenario, we assume EU-UK and UK-EU trade to be subject to an increase in the trade tariffs on goods from 0% to the MFN tariff in each sector. In terms of NTBs, based on Dhingra et al. (2017), we assume that under a 'hard' Brexit scenario, NTBs would have risen further to a tariff equivalent of 8.31%, corresponding to three quarters of the estimated NTBs that apply to EU-US trade.

3.2 | Employment losses

To arrive at employment effects, we require an employment elasticity. An employment elasticity measures the proportionate drop in employment after a 1% decrease in value added production. Konings and Murphy (2006) using European firm-level data, estimate employment elasticities with respect to value added for manufacturing and non-manufacturing sectors. They find employment elasticities to range between 0.57 and 0.72 in manufacturing sectors and find the average employment elasticity in non-manufacturing sectors to be 0.33.[25,26] Given our focus on European data, we use the lower bound of these sectoral estimates. Similar to the trade elasticities, the Brexit results on employment depend linearly on the choice of the employment elasticity. Thus, once we have obtained the relative drop in employment from the decrease in production, we compute the absolute number of jobs lost by multiplying by the country-sector's total employment base.[27]

[22]The imposed Non-Tariff Barriers apply to trade in goods as well as services.

[23]Alternatively, Felbermayr et al. (2018) use sectoral costs calculated using gravity estimations in order to obtain directional NTBs changes between the EU and the UK.

[24]In reality, application of trade tariffs may occur if Rules-of-Origin are violated or in situations where product standards would differ.

[25]In theory, Hamermesh (1986) argued that a production function characterised by constant returns to scale is identified by an elasticity of 1, which differs from empirical evidence.

[26]An employment elasticity of 1 would imply that wages do not adjust and stay constant. An employment elasticity below 1 suggests that wages adjust somewhat but are not fully flexible since that would imply an observed employment elasticity of 0.

[27]Throughout the analysis, we assume that any job lost in the UK is not going to move to the EU-27 and vice versa.

TABLE 1 'Soft' and 'Hard' Brexit scenario. Losses from reciprocal trade protection

	'Soft' Brexit				'Hard' Brexit			
	Value added		Employment		Value added		Employment	
	(million $)	(% of VA)	(1000 pers)	(% of EMP)	(million $)	(% of VA)	(1000 pers)	(% of EMP)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
AUT	−995	−0.25%	−4.12	−0.10%	−4016	−0.99%	−17.02	−0.40%
BEL	−2899	−0.58%	−10.06	−0.22%	−11782	−2.35%	−42.39	−0.93%
BGR	−127	−0.24%	−4.02	−0.12%	−512	−0.97%	−17.89	−0.52%
CYP	−67	−0.31%	−0.35	−0.10%	−222	−1.02%	−1.22	−0.34%
CZE	−952	−0.48%	−11.14	−0.22%	−3985	−2.01%	−47.31	−0.93%
DEU	−15364	−0.42%	−69.06	−0.16%	−63699	−1.76%	−291.93	−0.68%
DNK	−1362	−0.43%	−4.11	−0.15%	−5283	−1.67%	−16.90	−0.61%
ESP	−2749	−0.21%	−15.84	−0.09%	−11902	−0.91%	−70.41	−0.39%
EST	−68	−0.28%	−0.69	−0.11%	−257	−1.04%	−2.71	−0.45%
FIN	−633	−0.25%	−2.39	−0.10%	−2348	−0.95%	−9.08	−0.36%
FRA	−8376	−0.32%	−34.50	−0.13%	−33190	−1.25%	−141.32	−0.52%
GRC	−233	−0.11%	−1.42	−0.04%	−831	−0.38%	−5.57	−0.14%
HRV	−94	−0.18%	−1.27	−0.08%	−355	−0.69%	−4.97	−0.32%
HUN	−554	−0.44%	−7.28	−0.17%	−2256	−1.78%	−30.75	−0.73%
IRL	−3077	−1.30%	−11.32	−0.58%	−13575	−5.74%	−50.33	−2.59%
ITA	−5713	−0.29%	−31.23	−0.13%	−24599	−1.23%	−139.14	−0.57%
LTU	−157	−0.34%	−1.64	−0.12%	−653	−1.42%	−7.43	−0.56%
LUX	−260	−0.43%	−0.45	−0.13%	−919	−1.51%	−1.63	−0.46%
LVA	−91	−0.31%	−0.13	−0.03%	−343	−1.19%	−0.44	−0.11%
MLT	−153	−1.56%	−0.55	−0.38%	−476	−4.86%	−1.75	−1.21%

(Continues)

TABLE 1 (Continued)

	'Soft' Brexit				'Hard' Brexit			
	Value added		Employment		Value added		Employment	
	(million $)	(% of VA)	(1000 pers)	(% of EMP)	(million $)	(% of VA)	(1000 pers)	(% of EMP)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
NLD	−5604	−0.68%	−18.60	−0.21%	−21523	−2.59%	−73.20	−0.84%
POL	−2110	−0.41%	−28.42	−0.18%	−8618	−1.68%	−122.95	−0.78%
PRT	−570	−0.26%	−6.32	−0.14%	−2494	−1.16%	−29.72	−0.66%
ROU	−418	−0.22%	−9.39	−0.11%	−1775	−0.95%	−43.43	−0.50%
SVK	−520	−0.53%	−4.00	−0.18%	−1939	−1.99%	−15.79	−0.71%
SVN	−115	−0.25%	−1.03	−0.11%	−461	−1.02%	−4.22	−0.45%
SWE	−1742	−0.33%	−5.10	−0.11%	−6596	−1.24%	−19.97	−0.45%
2*EU−27	2*−55004	2*−0.38%	2*−284.44	2*−0.15%	2*−224609	2*−1.54%	2*−1209.47	2*−0.62%
UK	−34012	−1.21%	−139.86	−0.45%	−125497	−4.47%	−526.83	−1.71%

Note: (i) The total losses are obtained under reciprocal trade protection. In other words, the results presented in the table are obtained by summing the effects from both UK protection against EU-27 and EU-27 protection against the UK. (ii) Employment data in Eurostat is missing for some sectors in the following countries: Estonia, Latvia, Lithuania, Luxembourg, Malta and Sweden. Therefore, the presented employment results for these countries will likely underestimate the true impact.

4 | RESULTS

4.1 | Results by country

In this section we present the results in the two scenarios of Brexit. Table 1 shows the overall effects of a 'soft' Brexit scenario, where we sum over all the losses from tariffs applied by both trading partners. Columns (1) and (2) show the losses in terms of value added[28] and Columns (3) and (4) display the losses in terms of employment. In a similar manner, Table 1 also shows the overall estimated effects of the hypothetical 'hard' Brexit scenario. While the sector-level effects are aggregated at the country level, our analysis is carried out entirely at sectoral level.

We observe that the UK is hit *relatively* harder than the EU-27. Brexit would reduce economic activity in the UK three times more than in the EU-27. The UK is estimated to experience a drop in value added production as a percentage of GDP of 1.2% under a 'soft' Brexit and up to 4.5% under a 'hard' Brexit scenario. This corresponds to UK job losses of around 140 000 jobs in the 'soft' Brexit and 530,000 jobs in the 'hard' Brexit scenario. For the EU-27, the *absolute* job losses are larger, with the number of EU-27 jobs at risk varying between 280,000 jobs and 1, 2 million jobs respectively. This corresponds to value added losses as a percentage of GDP of 0.4% for the 'soft' and 1.5% for the 'hard' Brexit. The results clearly show that Brexit appears to be an EU-wide shock, which is not just limited to countries that are close located to the UK, but also affects more distant countries. The main reason is that production networks tied to the UK run across many EU-27 countries. Take for example the case of Czech Republic, which is estimated to be hit relatively hard by Brexit mainly through indirect trade (e.g. supplying inputs to the German car industry, which in turn find their way to the UK). In Figure 1, we visualise the total employment losses (in absolute terms) for every EU-27 Member State and the UK as a result of a 'hard' Brexit. The intensity of blue represents the relative impact, as a share of total employment, where darker countries are bound to suffer more from Brexit in relative terms.

Given the uncertainty surrounding the application of NTBs when predicting the economic consequences of trade shocks, it is important to be able to distinguish between those effects originated from MFN tariffs compared to NTBs. Using the 'hard' Brexit scenario, the potential effect of NTBs on value added can easily be documented in Table 2, which splits the estimated value added effects under the 'hard' Brexit scenario by type of trade barrier. Overall, the value added loss due to the increase in NTBs is estimated to be two to four times higher than the loss induced by the rise in tariffs. The discrepancy is particularly large in services-driven economies such as Cyprus, Malta, Luxembourg and the UK, as tariffs do not apply to trade in services.

4.2 | Direct versus indirect effects by country

This section decomposes the total impact from a 'hard' Brexit[29] into the direct and indirect impact of the trade shock. When we do this at the country-sector level, it turns out that on average 70% of the Brexit impact is due to indirect trade, which will be discussed in more detail in the

[28]Total Value Added (TVA) for each country is obtained using the WIOD database.

[29]For expositional simplicity, we only discuss results of the 'hard' Brexit scenario in the remainder of the paper.

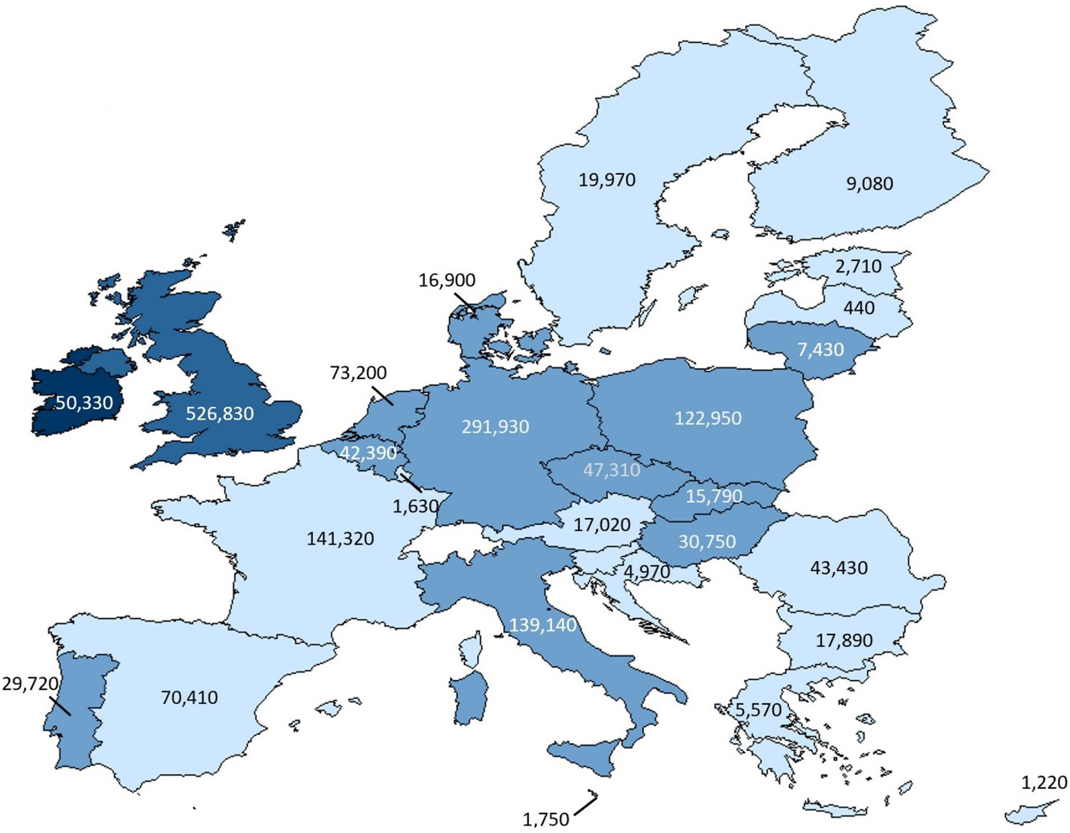

FIGURE 1 'Hard' Brexit Employment Losses (absolute numbers).
Note: The absolute number in each country refers to the employment losses predicted under a reciprocal 'hard' Brexit scenario. The intensity of the blue color reflects the relative impact as a share of total employment, with darker shades indicating the most affected countries in relative terms [Colour figure can be viewed at wileyonlinelibrary.com]

next section. For expositional purposes; however, we also pursue this decomposition at the more aggregate country level and display the results in Table 3.

At the country level, we follow the decomposition in Equation 4, where the indirect impact of Brexit is defined as the loss in value added that a country as a whole incurs as a result of its intermediate production being used in third country exports to the UK. The direct effect then captures the loss in value added from Brexit related to its own exports (of all its domestic sectors). Results of this aggregation of direct versus indirect effects at country level are shown in Table 3, which reveals substantial heterogeneity among Member States in the magnitude of the defined indirect effect. Countries like Germany and France have an indirect effect of 15%, while a country like Slovenia has a much larger indirect trade effect of Brexit at the county-level of 45%. By and large, it appears that countries that are geographically close to the UK have a relatively large direct effect from Brexit, owing to their direct trade with the UK. When we average over all Member States, the indirect effect at a country level is close to 20%. In other words, on overage across EU countries, one-fifth of the loss in value added stemming from Brexit is due to their trade with third countries.

Our study is unique in documenting this differentiation and quantifying the indirect impact, which could provide an indication of the error margin in traditional gravity models when

TABLE 2 'Hard' Brexit scenario. Impact of MFN tariffs vis-à-vis NTBs

	'Hard' Brexit		
	Losses (% VA) from MFN tariffs	**Losses (% VA) from NTBs**	**Total losses (% of VA)**
	(1)	**(2)**	**(3)**
AUT	−0.25%	−0.74%	−0.99%
BEL	−0.61%	−1.74%	−2.35%
BGR	−0.25%	−0.72%	−0.97%
CYP	−0.10%	−0.92%	−1.02%
CZE	−0.57%	−1.44%	−2.01%
DEU	−0.49%	−1.27%	−1.76%
DNK	−0.38%	−1.29%	−1.67%
ESP	−0.28%	−0.63%	−0.91%
EST	−0.21%	−0.83%	−1.04%
FIN	−0.18%	−0.76%	−0.95%
FRA	−0.30%	−0.95%	−1.25%
GRC	−0.06%	−0.32%	−0.38%
HRV	−0.14%	−0.55%	−0.69%
HUN	−0.47%	−1.31%	−1.78%
IRL	−1.84%	−3.90%	−5.74%
ITA	−0.37%	−0.86%	−1.23%
LTU	−0.40%	−1.02%	−1.42%
LUX	−0.23%	−1.28%	−1.51%
LVA	−0.25%	−0.94%	−1.19%
MLT	−0.17%	−4.69%	−4.86%
NLD	−0.57%	−2.02%	−2.59%
POL	−0.45%	−1.24%	−1.68%
PRT	−0.36%	−0.79%	−1.16%
ROU	−0.28%	−0.67%	−0.95%
SVK	−0.39%	−1.60%	−1.99%
SVN	−0.26%	−0.76%	−1.02%
SWE	−0.26%	−0.98%	−1.24%
EU−27	−0.41%	−1.13%	−1.54%
UK	−0.84%	−3.64%	−4.47%

Note: The losses reported are obtained using a reciprocal 'hard' Brexit scenario, which implies summing the effects from both UK protection against EU-27 and EU-27 protection against the UK.

estimating the impact of Brexit. The reason is that these models would only take into account the direct impact and not the indirect impact of Brexit, which we show to be substantial across the board. At this point, it is important to point out that the UK and the EU-27 also stand to be affected by their own tariffs, as shown in Column (3) in Table 3. Consider the case of UK steel that is used in German cars that are exported back to the UK. Trade protection imposed by the UK on

TABLE 3 'Hard' Brexit scenario. Decomposition of value added losses

	'Hard' Brexit					
	(1)		(2)		(3)	
	Direct VA loss		Indirect VA loss		VA loss from own trade protection	
	million $	(% of Total loss)	million $	(% of Total loss)	million $	(% of Total loss)
AUT	−2159	(54%)	−1571	(39%)	−286	(7%)
BEL	−8662	(74%)	−2284	(19%)	−836	(7%)
BGR	−299	(58%)	−175	(34%)	−38	(8%)
CYP	−103	(46%)	−104	(47%)	−15	(7%)
CZE	−2542	(64%)	−1203	(30%)	−240	(6%)
DEU	−49640	(78%)	−9851	(15%)	−4207	(7%)
DNK	−4138	(78%)	−780	(15%)	−365	(7%)
ESP	−9236	(78%)	−1982	(17%)	−683	(6%)
EST	−148	(58%)	−88	(34%)	−21	(8%)
FIN	−1491	(64%)	−649	(28%)	−208	(9%)
FRA	−25704	(77%)	−5093	(15%)	−2392	(7%)
GRC	−598	(72%)	−162	(19%)	−72	(9%)
HRV	−208	(59%)	−122	(34%)	−25	(7%)
HUN	−1429	(63%)	−676	(30%)	−151	(7%)
IRL	−12300	(91%)	−605	(4%)	−670	(5%)
ITA	−19436	(79%)	−3862	(16%)	−1301	(5%)
LTU	−459	(70%)	−151	(23%)	−42	(7%)
LUX	−422	(46%)	−420	(46%)	−77	(8%)
LVA	−229	(67%)	−85	(25%)	−29	(8%)
MLT	−434	(91%)	−25	(5%)	−16	(4%)
NLD	−14578	(68%)	−5047	(23%)	−1897	(9%)
POL	−5883	(68%)	−2178	(25%)	−557	(7%)
PRT	−1919	(77%)	−440	(18%)	−135	(5%)
ROU	−1079	(61%)	−593	(33%)	−104	(6%)
SVK	−1341	(69%)	−498	(26%)	−100	(5%)
SVN	−221	(48%)	−206	(45%)	−34	(7%)
SWE	−4487	(68%)	−1569	(24%)	−540	(8%)
UK	−119161	(95%)			−6337	(5%)

Note: (i) This table decomposes the total VA losses under a reciprocal 'hard' Brexit scenario, which is obtained by summing the effects from both UK protection against EU-27 and EU-27 protection against the UK. Column (1) shows the direct effect and captures the VA loss due to the increased costs a country faces when exporting from its own sectors. Column (2) shows the indirect effect, which captures the VA loss for a country as a result of the increased costs that other countries face when exporting from their own sectors. Column (3) shows the country's loss due to the increased trade costs it imposes on other countries. In the case of UK steel that is used in German cars that are exported to the UK, Column (3) would capture the loss in UK steel production as a result of reduced exports of German cars to the UK following UK trade protection.

(ii) Employment data in Eurostat is missing for some sectors in the following countries: Estonia, Latvia, Lithuania, Luxembourg, Malta and Sweden. Therefore, the presented employment results for these countries will likely underestimate the true impact.

German cars would reduce German car manufacturers' exports to the UK, their production and ultimately their demand for UK steel.

4.3 | Results by country-sector

There are large differences in the impact of Brexit across country-sectors. Table 4 lists those sectors that stand to lose most from a 'hard' Brexit in terms of value added and employment, in each country. For example, in terms of value added, the German 'Motor Vehicles' sector would have lost the most from a hypothetical 'hard' Brexit, while in terms of employment, it would be 'Machinery & Equipment'.[30] In the UK, the sector that loses most is the services sector 'Administrative & Support activities'. These sector-level losses are the combination of both direct effects and indirect effects.

We cannot display the split between the direct and indirect Brexit impact for every country-sector in Europe, but the average indirect effect across all country-sectors is close to 70%. This suggests that many country-sectors are affected by Brexit through their network linkages and through trade to the UK via third countries and sectors rather than through their direct trade with the UK. However, the magnitude of the indirect effect appears to be affected by the network centrality of the sector and its degree of upstreamness (or downstreamness) in the supply chain. To illustrate this point, in Figure 2, we list a number of sectors for both the UK and Germany, where we display the direct against the indirect effect at the level of the country-sector, expressed as a percentage of the total impact of the sector's value added. The main purpose is to illustrate that the magnitude of the indirect effect of the trade shock appears to go hand in hand with the network centrality of the sector. The sectors on the left-hand side of Figure 2 are typical downstream sectors that produce final goods, which are closer to the consumer, for example motor vehicles, furniture, textiles and food products. For these downstream sectors, the direct impact (represented by the dark bar) clearly constitutes the lion's share of the impact of Brexit.

The sectors at the right end of Figure 2 are more upstream sectors, whose output is used as an input in the production process of other industries. These include manufacturing of metal products, wood, mining and services such as insurance. We clearly see that for those upstream sectors, the impact of a 'hard' Brexit is largely indirect, where for instance, almost 56% *of the value added production losses in 'Metals Products' for Germany are due to an decrease in exports of other domestic or foreign sectors after a hypothetical 'hard' Brexit*. *For Germany*, the upstream sector '*Metals Products*' displays much larger indirect production effects from Brexit than the downstream car sector. The reason is that metal is used as an input in many other sectors. Consequently, in the case of hypothetical trade shock such as Brexit, it is not just the tariff change in metals that affects the metals production but also tariff changes in all sectors that use metals and then ship output to the UK. Finally, the difference between Germany and the UK appears to be quite small in most sectors, which confirms the idea that there is more heterogeneity across sectors than across countries in terms of the importance of the indirect network effects in the total impact of a hypothetical 'hard' Brexit scenario. We do observe significant differences in some sectors, however. The Mining industry provides a good example, with indirect effects that are much larger in Germany than in the UK in this sector. Direct exports of German mining output to the UK are limited since

[30] The reason is that the value added contribution per worker differs substantially across sectors, which means that the same reduction in value added might lead to different employment effects in different sectors.

TABLE 4 'Hard' Brexit. Most affected sectors across countries

	'Hard' Brexit			
	Value added terms		**Employment terms**	
AUT	Machinery & Equipment	C28	Metal products	C25
BEL	Food Product	C10-C12	Food product	C10-C12
BGR	Textiles	C13-C15	Live animals	A01
CYP	Financial services	K64	Administrative and support act.	N
CZE	Electronics and Computers	C26	Metal products	C25
DEU	Motor vehicles	C29	Machinery & Equipment	C28
DNK	Mining and quarrying	B	Food Product	C10-C12
ESP	Food Product	C10-C12	Live Animals	A01
EST	Wood and Cork	C16	Wood and Cork	C16
FIN	Paper Products	C17	Administrative and support act.	N
FRA	Administrative and support act.	N	Administrative and support act.	N
GRC	Water transport	H50	Live Animals	A01
HRV	Other services	R_S	Metal products	C25
HUN	Electronics and Computers	C26	Electronics and Computers	C26
IRL	Food Product	C10-C12	Live Animals	A01
ITA	Textiles	C13-C15	Textiles	C13-C15
LTU	Petroleum Products	C19	Textiles	C13-C15
LUX	Financial Services	K64	Administrative and support act.	N
LVA	Wood and Cork	C16	Administrative and support act.	N
MLT	Other services	R_S	Other services	R_S
NLD	Wholesale trade	G46	Administrative and support act.	N
POL	Wholesale trade	G46	Live Animals	A01
PRT	Textiles	C13-C15	Textiles	C13-C15
ROU	Textiles	C13-C15	Textiles	C13-C15
SVK	Real Estate	L68	Metal products	C25
SVN	Metal products	C25	Metal products	C25
SWE	Petroleum Products	C19	Machinery & Equipment	C28
UK	Administrative and support act.	N	Administrative and support act.	N

Note: (i) The most affected sector can differ depending on whether we look in terms of value added or employment. The reason is that the value added contribution per worker can differ dramatically across sectors, which means that the same drop in value added might lead to different employment effects in different sectors. (ii) Employment data in Eurostat is missing for some sectors in the following countries: Estonia, Latvia, Lithuania, Luxembourg, Malta and Sweden.

most of the sector's output is used as an input in other German and EU-27 sectors, before it is shipped to the UK. The significance of this indirect channel for German mining is reflected by the large blue bar. The mining industry in the UK, in contrast, has a much higher share of direct

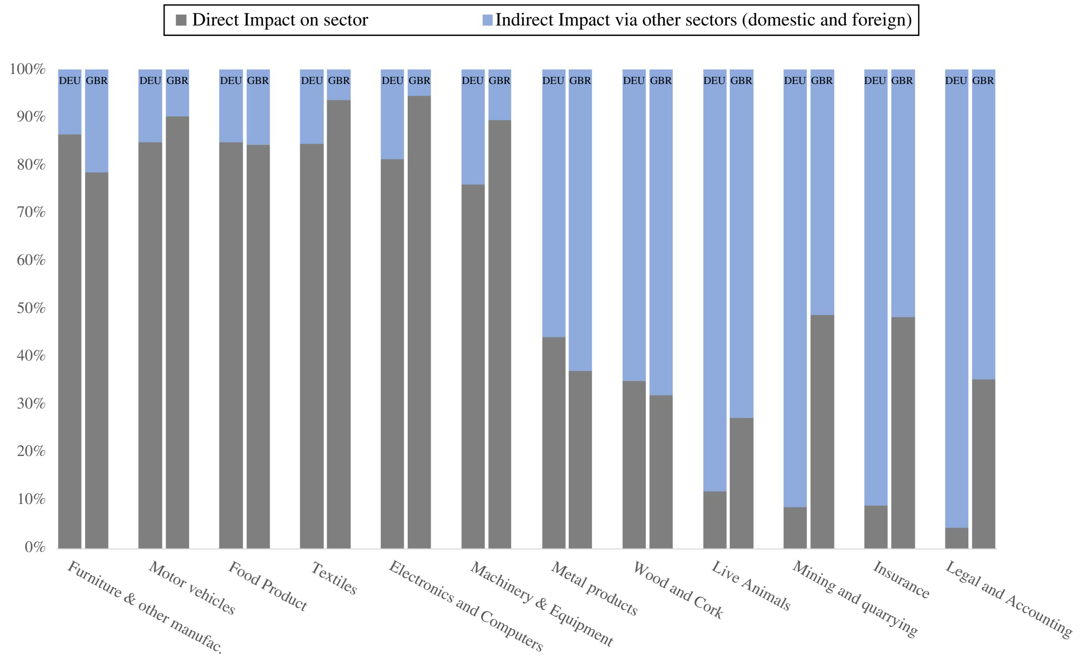

FIGURE 2 'Hard' Brexit. Decomposition of losses at country-sector level.
Note: The indirect impact of a country-sector is computed as the share of the value added production loss that is due to a decrease in exports of other domestic or foreign sectors after a 'hard' Brexit Scenario. The direct impact is the share of the value added production loss that is due to the sector's own decreased of exports after a 'hard' Brexit Scenario. The results in the Figure are mainly driven by the sector's position in the supply chain, and not so much by the tariff or NTB structure (for instance if trade barriers would be significantly higher in downstream vis-à-vis upstream sectors) [Colour figure can be viewed at wileyonlinelibrary.com]

exports to Europe, and therefore, a larger grey bar for indirect impact. Indeed, there are fewer industries (i.e. only the UK's domestic sectors) that can process the mining inputs before they are exported to the UK.[31]

Moreover, Figure 2 suggests that a network approach like ours is especially relevant to accurately quantify the impact of a trade shock in upstream sectors, which hinges in large part on the indirect channel. In those upstream sectors, a gravity approach would only consider direct trade flows at sector level to the final destination and disregard a substantial share of the impact of a trade shock. Our network approach aims to overcome this limitation by also quantifying the production and employment effects in a sector that result from its linkages to other exporting country-sectors.

5 | DISCUSSION

This section compares our results with other papers. Emerson et al. (2017) summarise the results of a set of papers that study the impact of Brexit under an optimistic and pessimistic scenario that

[31]Note that only bilateral trade between UK and EU-27 is subject to increased trade barriers due to Brexit. The indirect impact in the mining example in the text does not capture UK mining output exported to a non-EU country, which then exports to the EU-27.

are in line with our 'soft' and 'hard' Brexit scenarios.[32] For the UK, our results are in line with those of other studies,[33] while for the EU-27 our results diverge somewhat. The negative impact that we find for the EU-27 is larger, with losses being approximately three times as high as put forward by other papers. Previous studies find larger *absolute* losses for the UK than for the EU-27 as a whole, whereas we find the *absolute* loss in value added production for the EU-27 to be 1.7 times larger than the UK losses. As the EU-27 economy is roughly 6–7 times larger than the UK's, an absolute loss in VA production that is 1.7 times higher ('hard' Brexit) for the EU-27 seems plausible. The same holds true for employment. However, the ratio of the EU-27's impact to UK's impact is slightly higher when evaluating potential employment losses. This indicates that in the EU-27, relatively more employment is concentrated in sectors that will be hit harder by Brexit.

IJtsma et al. (2018) finds that the UK has become much less integrated into global production networks than other EU countries over the period 2000–2014. This offers a potential explanation as to why the results that we report are larger than in other studies on Brexit. In a network setting, it is very important to take on board the indirect linkages in trade to have a correct assessment of all the effects of a trade shock. This then adds to the effects of direct trade captured earlier in the literature. Moreover, since many services are intermediates that are embedded in manufactured goods, the inclusion of services reinforces the negative impact on local jobs resulting from indirect trade effects via 'third countries'. Our analysis relies on the WIOD database that fully covers the services sectors. Finally, the larger impact of the Brexit trade shock in this paper demonstrates the importance of the sector-level dimension for an analysis of trade shocks and suggests a potential bias in studies that are based on a more aggregated country-level analysis.

In this paper, we only focus on the static effects of a trade shock and do not include dynamic effects such as access to foreign markets, firm investment and innovation, capital mobility or accumulation and migration. Clearly, if Brexit would trigger more European FDI into the UK in order to avoid trade barriers, some of the negative trade effects for the UK would be mitigated. If multinationals leave the UK due to the decrease in the attractiveness of the UK as an FDI destination as a result of the restricted access to the EU Single Market, foreign investment previously flowing into the UK may be diverted to the EU-27 Member States, which would aggravate the losses for the UK. This makes it difficult to predict whether the more dynamic longer-run aspects of Brexit would aggravate or mitigate the negative trade effects that we report in this paper. Also, our model assumes perfect pass-through of tariff and non-tariff barriers into prices, which is an assumption that might not hold in reality. With imperfect pass-through, prices and demand effects will tend to be smaller. What we do know is that the trade effects are first order in magnitude and these are likely to account for the main part of the Brexit impact, while the dynamic effects, although potentially important, are only of a second order nature.[34] In terms of timing, we assume all effects to occur immediately after Brexit happens, which will have a substantial impact on the size of the UK and EU-27 economies. The induced reduction in value added would be permanent, with the economies shrinking compared to the counterfactual scenario where the UK does not leave the Single Market. However, in reality it can take some time for this effect to materialise, especially considering that Non-Tariff Barriers (NTBs) can have a lagged effect.[35]

[32]See Aichele and Felbermayr (2015), Ottaviano et al. (2014), the OECD study by Booth et al. (2015), Kierzenkowski et al. (2016), Rojas-Romagosa (2016) and HMTreasury (2016).

[33]See, for instance, Aichele and Felbermayr (2015), Booth et al. (2015), Ottaviano et al. (2014) and Rojas-Romagosa (2016).

[34]See for example Dhingra et al. (2017), HMTreasury (2016), Kierzenkowski et al. (2016).

[35]Jung (2012) estimates that for NTBs an adjustment period of 10 to 12 years could be in order.

6 | CONCLUSION

This paper develops a new network trade model with country-sector level input–output linkages in production. This model is well-suited to evaluate trade shocks and quantify the short-term impact when tariffs and/or non-tariff barriers are imposed. We derive a closed-form solution for the trade destruction and trade diversion effects of a trade shock on all goods and services sectors in the network.

We apply our network theory to various counterfactual Brexit trade shocks using data from WIOD on input–output production structures and trade and employment elasticities from the literature in order to generate predictions on the change in value added and employment for every country-sector on both sides of the Channel. We consider several Brexit scenarios, which range from the current Brexit Agreement where tariffs are avoided but non-tariff barriers are present, to a scenario that explicitly considers the imposition of tariffs since tariffs can still occur under the present EU-UK Agreement whenever rules-of-origin are violated or diverging product standards emerge. We focus on the short-run trade destruction effects, even before trade diversion takes place and we aggregate results at country level for representation purposes.[36] A key insight from the model is that every EU-27 Member State is not only affected through its direct trade with the UK, but also via an indirect channel, depending on its indirect exports to the UK via 'third' countries.

An EU-27 country's value added is not just affected by trade barriers on its own exports to the UK (gravity approach), but by all trade barriers on goods and services that are further down the value chain in Europe and are subsequently exported to the UK (network approach). With our approach, we document the losses in value added for all EU-27 countries as well as the UK, that result from a pass-through of tariffs into higher prices for final and intermediate goods and services, resulting in lower demand and a loss in sector-level production and employment. Our findings clearly indicate that the indirect effects of the trade shock, a channel typically omitted in the traditional gravity approach to trade shocks, turn out to be substantial.

We further observe a strong heterogeneity in the impact of Brexit across different industries. A sector's network centrality, its upstream and downstream supply chain interlinkages, as well as the trade barriers the sector and its trade partners will face all play a role in determining the magnitude of the losses. In particular, upstream sectors, such as the German metal industry, will be mainly exposed to Brexit through exports to the UK of industries further down the supply chain. Downstream sectors like the German automotive industry, in contrast, are likely affected directly by increased barriers to trade with the UK.

Our findings give support to the idea that the network centrality of sectors determine the impact of an aggregate shock through a 'cascade effect' in the input–output network (Acemoglu et al., 2012). In that sense, the network approach that we follow to quantify the impact of a trade shock on employment is very different from Autor et al. (2013), who study the local employment effects in the United States of trade liberalisation with China but do not take into account downstream effects. In this paper, we provide a more encompassing approach of the overall employment effects brought about by a shift in trade policy.

We rely on observed data to document the global fragmentation of production processes, which is a limitation in the sense that these sources only capture pre-Brexit supply structures. In future research, however, the network model can be used for ex-post evaluations of trade shocks.

[36] In the longer run, some of the negative effects of the shock that we report here can be mitigated through trade diversion effects and substitution effects Giammetti et al. (2020).

An analysis of the input–output structure and how they change over time would allow researchers to study to what extent trade shocks might induce technological innovation or productivity shifts in production.

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DATA AVAILABILITY STATEMENT

Not applicable.

ORCID

Hylke Vandenbussche https://orcid.org/0000-0002-4073-0097

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APPENDIX

Theoretical framework

We use superscripts to denote the country-sector of origin and subscripts to denote the country-sector of destination, for example the quantity of intermediate steel from Belgium shipped to the German car industry is denoted by $X_{DE,car}^{BE,steel}$. In general, countries are denoted by i, j and k and sectors by r, s and z. Demand for labor by country k's sector z for example is captured by L_{kz}. Throughout this section, upper-case symbols refer to real quantities, whereas lower-case symbols denote their nominal counterparts.

The model is based on the Armington assumption, which means that goods produced by different sources are imperfect substitutes. As a result, within a sector, goods from different countries can coexist in the same destination market, even though their prices may differ as they are determined by the country-sector's marginal production cost and costs of trade with the destination country.[37] Consumers (and firms) in the destination country have a love-for-variety and prefer to consume positive amounts of each available variety.

Consumer demand

The representative consumer in country k derives utility from consuming quantities of an aggregate final good F_k:

$$U_k = F_k = \prod_{s=1}^{S} \left[F_k^s\right]^{\alpha_k^s} \tag{5}$$

which is a Cobb-Douglas combination of quantities F_k^s consumed of final goods from all sectors $s \in S$, with α_k^s the corresponding share in total expenditures. This sector-specific final good is a CES aggregate across all countries the good can be purchased from,

$$F_k^s = \left[\sum_{i=1}^{N} \left(F_k^{is}\right)^{\frac{\sigma_s - 1}{\sigma_s}} \right]^{\frac{\sigma_s}{\sigma_s - 1}} \tag{6}$$

where $\sigma_s > 1$ is the elasticity of substitution (for final goods) within sector s between the countries of origin $i \in N$.[38]

[37]As in Noguera (2012), production and trade costs are the only determinants of prices in our model. This does not imply that firms cannot charge mark-ups. In WIOD, however, we have no information on the underlying firm-level distribution within each sector. The absence of mark-ups in the model is assumed at sectoral level.

[38]For simplicity, we assume this sector-specific elasticity of substitution to be the same across all countries k.

Producers

In country k's sector z, output Y^{kz} is produced according to a Cobb-Douglas technology combining labor L_{kz} and intermediate inputs X_{kz}[39]:

$$Y^{kz} = (L_{kz})^{1-\beta^{kz}}(X_{kz})^{\beta^{kz}} \tag{7}$$

where β^{kz} represents the share of intermediate expenditures in total sales of country k's sector z. The intermediate goods composite X_{kz} is a Cobb-Douglas combination of intermediate goods from all sectors $s \in S$, X^s_{kz}:

$$X_{kz} = \prod_{s=1}^{S}\left[X^s_{kz}\right]^{\gamma^s_{kz}} \tag{8}$$

where X^s_{kz} denotes the real aggregate demand of intermediates from sector s by country k's sector z, and γ^s_{kz} is the corresponding share in total expenditures on inputs. The sector-specific intermediate good X^s_{kz} is a CES aggregate across all countries the input can be purchased from:

$$X^s_{kz} = \left[\sum_{i=1}^{N}\left(X^{is}_{kz}\right)^{\frac{\rho_s-1}{\rho_s}}\right] \tag{9}$$

where $\rho_s > 1$ is the elasticity of substitution (for intermediate goods) between the countries of origin within sector s.[40] Note that this nested Cobb-Douglas-CES structure is similar to that of the consumer demand aggregates.

Utility and profit maximisation

Let w_{kz} denote the price of labor in country k's sector z (L_{kz}) and p^{kz} the price of output from kz (Y^{kz}). Given iceberg-type trade barriers, in order to satisfy country j's demand of one unit of kz, kz needs to produce τ^{kz}_j units, with $\tau^{kz}_j > 1$. The price of one unit of kz's output in destination j then equals $p^{kz}_j = \tau^{kz}_j p^{kz}$ accounting for differences in trade costs across destinations j. Note that we typically assume there are no barriers to trade within a country, that is $\tau^{kz}_k = 1$.

Firms maximise profits by choosing L_{kz} and X^{is}_{kz} and households maximise utility choosing F^{is}_k subject to their budget, which equals $I_k = \sum_{z=1}^{S} w_{kz} L_{kz}$, that is their income from supplying labour L_{kz} to each sector z in country k. Firms and households take factor price w_{kz} and goods prices $\tau^{kz}_j p^{kz}$ as given. This results in the optimal nominal counterparts of real demand (which are denoted by a lower-case symbol and that are obtained by multiplying real demand by the corresponding price). Nominal output of kz is represented by $y^{kz} \equiv p^{kz}Y^{kz}$. The CES price index in country k of final goods from sector s equals $P^s_k = \left[\sum_{i=1}^{N}(p^{is}_k)^{1-\sigma_s}\right]^{\frac{1}{1-\sigma_s}}$. The price of the aggregate intermediate input X_{kz} is given by the Cobb-Douglas price index $PI_{kz} = \prod_{s=1}^{S}(P^s_k)^{\gamma^s_{kz}}$ where P^S_k is the CES price index in country k for intermediate goods from sector s, which we assume, for tractability, to be the same as the corresponding price index for final goods (this implies that $\sigma_s = \rho_s$ and that the price of a certain good

[39]Following several standard trade models, we only account for labour as a factor of production. This assumption can be relaxed, for instance by accounting for high-and low skilled labour.

[40]For simplicity, we assume this sector-specific elasticity of substitution to be the same across all countries k.

from sector s is the same whether it is sold as an intermediate or a final good).[41] The (FOB) price of output from kz equals $p^{kz} = \left(\frac{w_{kz}}{1-\beta^{kz}}\right)^{1-\beta_{kz}} \left(\frac{PI_{kz}}{\beta^{kz}}\right)^{\beta^{kz}}$.[42] The optimal nominal demands then equal:

$$l_{kz} \equiv w_{kz} L_{kz} = (1-\beta^{kz}) y^{kz}$$

$$x_{kz} \equiv PI_{kz} X_{kz} = \beta^{kz} y^{kz}$$

$$x^{s}_{kz} \equiv P^{s}_{k} X^{s}_{kz} = \gamma^{s}_{kz} \beta^{kz} y^{kz}$$

$$x^{is}_{kz} \equiv p^{is}_{k} X^{is}_{kz} = \tau^{is}_{k} p^{is} X^{is}_{kz} = \left(\frac{\tau^{is}_{k} p^{is}}{P^{s}_{k}}\right)^{1-\sigma_s} \gamma^{s}_{kz} \beta^{kz} y^{kz} \tag{10}$$

$$f^{is}_{k} \equiv p^{is}_{k} F^{is}_{k} = \tau^{is}_{k} p^{is} F^{is}_{k} = \left(\frac{\tau^{is}_{k} p^{is}}{P^{s}_{k}}\right)^{1-\sigma_s} \alpha^{s}_{k} \sum_{z=1}^{S} \left(1-\beta^{kz}\right) y^{kz} \tag{11}$$

Market clearing

Let $e^{kz}_{j} \equiv f^{kz}_{j} + \sum_{s=1}^{S} x^{kz}_{js}$ denote the nominal gross exports from country-sector kz to (the consumer and producers in) country j. Market clearing requires

$$y^{kz} = \sum_{j=1}^{N} e^{kz}_{j} \tag{12}$$

Following the same logic as in Anderson and Van Wincoop (2003), we derive gravity equations for final and intermediate goods exports, but now at the sector level. Denote world nominal output by y^{w} and country-sector kz's share in world output by $\theta^{kz} \equiv y^{kz}/y^{w}$. Substituting Equations (10) and (11) into Equation (12) allows to solve for prices p^{is}. Substituting these into the price index P^{s}_{k} and plugging the resulting expression for P^{s}_{k} into (10) and (11) results in the following gravity equations for intermediate and final bilateral exports and equilibrium price indices:

$$x^{kz}_{js} = \frac{y^{kz} \gamma^{z}_{js} \beta^{js} y^{js}}{y^{w}} \left(\frac{\tau^{kz}_{j}}{\Pi^{kz} P^{z}_{j}}\right)^{1-\sigma_z} \tag{13}$$

$$f^{kz}_{j} = \frac{y^{kz} \alpha^{z}_{j} \sum_{s=1}^{S} \left(1-\beta^{js}\right) y^{js}}{y^{w}} \left(\frac{\tau^{kz}_{j}}{\Pi^{kz} P^{z}_{j}}\right)^{1-\sigma_z} \tag{14}$$

[41]The assumption that firms and consumers share the same price elasticities allows us to substantially simplify the analysis, as in Noguera (2012).

[42]The assumption of perfect pass-through inherent to this theoretical framework is a limiting assumption since pass-through depends on firm size with larger firms having lower pass-through rates (Amiti et al., 2014). However, in the WIOD data we have no information on the underlying firm size distribution within a sector.

$$P_j^z = \left[\sum_{k=1}^{N} \theta^{kz} \left(\frac{\tau_j^{kz}}{\Pi^{kz}}\right)^{1-\sigma_z}\right]^{\frac{1}{1-\sigma_z}}$$

$$\Pi^{kz} = \left[\sum_{j=1}^{N} \phi_j^z \left(\frac{\tau_j^{kz}}{P_j^z}\right)^{1-\sigma_z}\right]^{\frac{1}{1-\sigma_z}}$$

where $\phi_j^z = \sum_{s=1}^{S} \theta^{js}(\gamma_{js}^z \beta^{js} + \alpha_j^z(1-\beta^{js}))$ is a measure of the importance of goods from sector z for producers and consumers in country j. It takes into account (i) the dependence of producers in all sectors s in country j on intermediates from sector z through $\theta^{js}\gamma_{js}^z\beta^{js}$ and (ii) the importance of goods from sector z in the final demand by households in country j (through α_j^z) and the total income these households earn in all sectors s in j (through $\theta^{js}(1-\beta^{js})$).

Equation (13) relates bilateral intermediate trade between firms in country-sector kz and country-sector js to (i) the economic masses of source and destination relative to the world, (ii) the importance of inputs in the destination's production (β^{js}) and the importance of sector z goods within these inputs (γ_{js}^z), (iii) the bilateral trade costs between countries k and j in sector z (τ_j^{kz}), and (iv) outward and inward multilateral resistance terms (Π^{kz} and P_j^z). Similarly, Equation (14) relates bilateral final goods trade between firms in country-sector kz and the consumers in country j to (i) the economic masses of source (y^{kz}) and destination ($\sum_{s=1}^{S}(1-\beta^{js})y^{js}$)[43] relative to the economic mass of the world (y^w), (ii) the importance of sector z final goods in the destination's consumption (α_j^z), (iii) the bilateral trade costs between countries k and j in sector z (τ_j^{kz}), and (iv) outward and inward multilateral resistance terms (Π^{kz} and P_j^z).

Input–output production linkages

Dividing both sides of Equation (13) by y^{js} we obtain the technical coefficient a_{js}^{kz} or 'dollar's worth of inputs from kz per dollar's worth of output of js':

$$\frac{x_{js}^{kz}}{y^{js}} \equiv a_{js}^{kz} = \frac{y^{kz}\gamma_{js}^z\beta^{js}}{y^w}\left(\frac{\tau_j^{kz}}{\Pi^{kz}P_j^z}\right)^{1-\sigma_z} \tag{15}$$

Plugging the technical coefficients into the market clearing in condition in Equation (12), we have

$$y^{kz} = \sum_{j=1}^{N}(\sum_{s=1}^{S} x_{js}^{kz} + f_j^{kz}) = \sum_{j=1}^{N}\sum_{s=1}^{S} a_{js}^{kz}y^{js} + \sum_{j=1}^{N} f_j^{kz}$$

which can be summarised for all countries and sectors as

$$\mathbf{Y} = \mathbf{AY} + \sum_{j=1}^{N} \mathbf{f_j} \tag{16}$$

[43]This expression reflects the fact that consumers in country j get their income from supplying labor to all sectors s.

where $\mathbf{f_j}$ is the $(S * N)$ x 1 vector of country j's final demands and $\mathbf{A}$ the (S^*N) x (S^*N) global bilateral input–output matrix at the sectoral level. The system in Equation (16) can be written as

$$(\mathbb{I} - \mathbf{A})\mathbf{Y} = \sum_{j=1}^{N} \mathbf{f_j} \tag{17}$$

with $\mathbb{I}$ the (S^*N) x (S^*N) identity matrix. If $(\mathbb{I} - \mathbf{A})$ can be inverted, we can find the solution for nominal output as

$$\mathbf{Y} = (\mathbb{I} - \mathbf{A})^{-1} \sum_{j=1}^{N} \mathbf{f_j} = \mathbf{\Lambda} \sum_{j=1}^{N} \mathbf{f_j} \tag{18}$$

where $\mathbf{\Lambda}$ is known as the Leontief inverse matrix. Each element Λ_{is}^{kz} of $\mathbf{\Lambda}$ is the Leontief coefficient that measures the total of dollars worth of country-sector kz goods required to meet 1 dollar worth of is' final demand. This value combines kz goods used as inputs in is directly as well as kz goods used as inputs in other industries which then also produce inputs for is. Using this, we can obtain country k's nominal output in sector z as

$$\begin{aligned} y^{kz} &= \sum_{i=1}^{N} \sum_{s=1}^{S} \Lambda_{is}^{kz} \sum_{j=1}^{N} f_j^{is} \\ &= \sum_{i=1}^{N} \sum_{s=1}^{S} \Lambda_{is}^{kz} \sum_{j=1}^{N} \left(\frac{y^{is} \alpha_j^s \sum_{r=1}^{S} \left(1 - \beta^{jr}\right) y^{jr}}{y^w} \left(\frac{\tau_j^{is}}{\Pi^{is} P_j^s} \right) 1 - \sigma_s \right) \end{aligned} \tag{19}$$

where we substituted the gravity relation from Equation (14) for the final value f_j^{is} flowing from country-sector is to the consumer in country j. Finally, we can transform this into value added production. For this purpose, we assume that the value added share of a country-sector's production is the part that is generated by its labour. Looking back at the production function in (7), the value created by country-sector kz after accounting for the intermediates used is captured by the share of labor $1 - \beta^{kz}$. Hence, following Noguera (2012) we find the value added embodied in kz's nominal production y^{kz} as $(1 - \beta^{kz})y^{kz}$ where $1 - \beta^{kz} \equiv v^{kz}$ is the value added to output ratio. The total value added production by kz can thus be written as

$$va^{kz} = v^{kz} \sum_{i=1}^{N} \sum_{s=1}^{S} \Lambda_{is}^{kz} \sum_{j=1}^{N} f_j^{is} \tag{20}$$

This value added production (and the jobs depending on it) might be severely impacted in the case of a trade shock, which is the subject of the next section.

Evaluating trade shocks

In this section, we examine the impact of a trade shock such as Brexit on a country-sector's value added production. Equation (20) shows that an import tariff imposed on a specific good does not only affect the producer of the good, but also the suppliers of goods and services whose output is used as an input in the production of the good. This implies that when the UK imposes a tariff on German cars, the Belgian steel sector, which supplies inputs to the German car industry will also be affected, even in the absence of a UK import tariff on Belgian steel. This channel is missing in a traditional gravity approach but can be captured by our sector-level model.

Assessing the impact of a trade shock amounts to considering what happens when the variable trade costs (τ) change.[44] For this purpose we now evaluate the new gravity Equation in 19 and the total value added in (20) when τ changes. Our interest lies in the change dva^{kz} in country-sector kz's value added production, which we find to equal

$$\mathrm{d}va^{kz} = \underbrace{v^{kz}\sum_{i=1}^{N}\sum_{s=1}^{S}\Lambda_{is}^{kz}\sum_{j=1}^{N}df_j^{is}}_{\text{final trade effect}} + \underbrace{v^{kz}\sum_{i=1}^{N}\sum_{s=1}^{S}\mathrm{d}\Lambda_{is}^{kz}\sum_{j=1}^{N}f_j^{is}}_{\text{intermediate trade effect}} \tag{21}$$

Next, we apply the following rule to Equation (21): Differentiating $\Lambda^{-1}\Lambda = \mathbb{I}$ yields $\Lambda^{-1}\mathrm{d}\Lambda + d\Lambda^{-1}\Lambda = 0$ from which it follows that $\mathrm{d}\Lambda = -\Lambda\mathrm{d}\Lambda^{-1}\Lambda$. Given that $\Lambda = [\mathbb{I} - A]^{-1}$, we have that $\mathrm{d}\Lambda^{-1} = -\mathrm{d}A$ and hence $\mathrm{d}\Lambda = \Lambda\mathrm{d}A\Lambda$, from which it is straightforward to obtain the individual elements $\mathrm{d}\Lambda_{is}^{kz}$. Hence, we obtain

$$\begin{aligned}
\mathrm{d}va^{kz} &= v^{kz}\sum_{i=1}^{N}\sum_{s=1}^{S}\left(1-\sigma_s\right)\Lambda_{is}^{kz}\sum_{j=1}^{N}\hat{\tau}_j^{is}f_j^{is} + v^{kz}\sum_{h=1}^{N}\sum_{r=1}^{S}\sum_{h'=1}^{N}\sum_{r'=1}^{S}\left(1-\sigma_r\right)\Lambda_{hr}^{kz}a_{h'r'}^{hr}\hat{\tau}_{h'}^{hr}\sum_{i=1}^{N}\sum_{s=1}^{S}\Lambda_{is}^{h'r'}\sum_{j=1}^{N}f_j^{is}\\
&= v^{kz}\sum_{i=1}^{N}\sum_{s=1}^{S}\left(1-\sigma_s\right)\Lambda_{is}^{kz}\sum_{j=1}^{N}\hat{\tau}_j^{is}f_j^{is} + v^{kz}\sum_{h=1}^{N}\sum_{r=1}^{S}\sum_{h'=1}^{N}\sum_{r'=1}^{S}\left(1-\sigma_r\right)\Lambda_{hr}^{kz}a_{h'r'}^{hr}y^{h'r'}\hat{\tau}_{h'}^{hr}\\
&= v^{kz}\sum_{i=1}^{N}\sum_{s=1}^{S}\left(1-\sigma_s\right)\Lambda_{is}^{kz}\sum_{j=1}^{N}\hat{\tau}_j^{is}f_j^{is} + v^{kz}\sum_{i=1}^{N}\sum_{s=1}^{S}\sum_{j=1}^{N}\sum_{r=1}^{S}\left(1-\sigma_s\right)\Lambda_{is}^{kz}x_{jr}^{is}\hat{\tau}_j^{is}\\
&= -v^{kz}\sum_{i=1}^{N}\sum_{s=1}^{S}\left(\sigma_s-1\right)\Lambda_{is}^{kz}\sum_{j=1}^{N}\hat{\tau}_j^{is}\left\{f_j^{is}+\sum_{r=1}^{S}x_{jr}^{is}\right\} = -v^{kz}\sum_{i=1}^{N}\sum_{s=1}^{S}\left(\sigma_s-1\right)L_{is}^{kz}\sum_{j=1}^{N}\hat{\tau}_j^{is}e_j^{is}
\end{aligned} \tag{22}$$

from which we can derive the following general result. Rising trade costs reduce bilateral trade flows e_j^{is} between any country-sector is and j. As kz has an interest Λ_{is}^{kz} in each of these bilateral flows, va^{kz} will decrease as well. The drop depends on the magnitude of the change in relative trade costs $\hat{\tau}_j^{is}$ between is and j and the corresponding trade elasticity σ_s.

In Equation (22), we defined $\hat{\tau}_j^{is} \equiv \frac{\mathrm{d}\tau_j^{is}}{\tau_j^{is}} - \frac{\mathrm{d}\Pi^{is}}{\Pi^{is}} - \frac{\mathrm{d}P_j^s}{P_j^s}$ as the proportionate change in tariffs τ_j^{is} relative to the proportionate changes in the multilateral resistance (MR) terms. When examining trade policy, it is important to take into account that the multilateral resistance (MR) terms will change along with the tariffs. Therefore, Equation (22) not only examines the impact of $\frac{d\tau}{\tau_j^{is}}$ but also that of $\frac{d\Pi^{is}}{\Pi^{is}}$ and $\frac{dP_j^s}{P_j^s}$. As it is relative tariffs that matter rather than absolute tariffs to determine

[44]We disregard exchange rate effects on EU-UK trade. Recent work has shown that exchange rate effects may have little effect on trading firms as most importers are also exporters, that is a depreciation of say the pound would be bad for UK firms' imports but great for their exports (Amiti et al., 2014).

a country's global competitiveness, individual tariff changes should be compared with changes in the average tariff, which is captured by the multilateral resistance terms. Suppose, for instance, that the UK tariff on Belgian goods goes up by 3%. Further suppose for a moment that the UK raises its tariffs on all its other trading partners with 2%, then the 'real' or 'relative' increases in the BE-UK tariff is only 1% (3%–2%). In that case, what matters for a country-sector's production change dva^{kz} is the tariff change it faces relative to the tariff change its competitors face.

However, under Brexit, the only countries that are likely to face increased tariffs from the UK are the EU-27, whereas the tariffs the UK imposes on its other trading partners such as the United States will not change. This means that US goods will become relatively less expensive for the UK, even though the UK tariffs on US imports do not change. The reason is that Brexit actually decreases (i.e. $\hat{\tau}_{UK}^{US,s} < 0$) the 'relative' US-UK trade costs compared to EU-UK trade costs. As a result, some trade will be diverted from the EU-27-UK to the US-UK. The MR changes $\frac{d\Pi^{is}}{\Pi^{is}}$ and $\frac{dP_j^s}{P_j^s}$ are essential for trade diversion to happen. We can see this by disentangling the change $\hat{\tau}_j^{is}$ into its different components, namely the tariff change and the MR changes:

$$dva^{kz} = \underbrace{-\ v^{kz} \sum_{i=1}^{N} \sum_{s=1}^{S} \left(\sigma_s - 1\right) \Lambda_{is}^{kz} \sum_{j=1}^{N} \frac{d\tau_j^{is}}{\tau_j^{is}} e_j^{is}}_{\text{trade destruction effect}} + \underbrace{v^{kz} \sum_{i=1}^{N} \sum_{s=1}^{S} \left(\sigma_s - 1\right) \Lambda_{is}^{kz} \sum_{j=1}^{N} \left[\frac{d\Pi^{is}}{\Pi^{is}} + \frac{dP_j^s}{P_j^s} \right] e_j^{is}}_{\text{trade diversion effect}} \tag{23}$$

Equation (23) shows that the change in kz's value added production after a change in trade costs τ is a combination of a 'trade destruction effect' (−) as a result of higher tariffs and a 'trade diversion effect' (+) caused by the change in the multilateral resistance terms.

The 'trade destruction effect' measures the drop in va^{kz} that is caused by the reduced trade between any country-sector is and country j. This drop depends on how the output of country-sector kz is used by country i's sector s, as it is the latter sector's exports that will face increased protectionist measures from country j.

The 'trade diversion effect', consists of two channels. First, country-sector is will divert some of its exports away from j to alternative destinations that do not impose tariffs on its goods, since these destinations have now become relatively more attractive (i.e. less expensive) for is to export to. This is caused by the increase in is' outward MR term Π^{is}. Second, the fact that j increases the tariffs on its imports will raise the average price in market j, which makes the market less competitive, captured by the increase in j's inward MR term P_j^s. As a result, any country i will find it easier to export to country j. Both the first and second channel of trade diversion increase the exports of is and hence its production, which results in an increase in its demand for inputs from country-sector kz, which in turn increases the latter's value added production va^{kz}. Therefore, the 'trade diversion effect' can mitigate some of the negative 'trade destruction effect' on va^{kz}.