Brexit, Trade in Intermediates, and Global Value Chains: Beyond the UK and the EU*

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Abstract

The discussion on Brexit has focused mostly on the future trade relationship between the EU and the UK. However, Brexit will also have significant impacts on the rest of the world, most often ignored in the public debate, particularly in countries that have the UK as their major trading partner. Many of these countries also rely on the larger EU markets for imports. In this paper, I estimate the impact of several post-Brexit trade policies on welfare gains from trade and global value chain patterns - for the UK, the EU27, and the rest of the world. First, I build a multi-country multi-sector static general equilibrium model of trade policy shocks, which is a variant of the Armington model, to quantify the impact of these different post-Brexit scenarios. Second, for counterfactual exercises, I calibrate the model to match the 2015 Eora input-output data and the state of the world before Brexit. The potential post-Brexit scenarios include Hard Brexit, Soft Brexit, UK-EU FTA (TCA), UK-USA FTA, and UK-EU-USA FTA. I find hard Brexit as the worst-case, with losses ranging from 0.04 to 1.88 percent and an average loss of 0.27 percent in total consumption-equivalent welfare of households. Also, I find that the UK-EU FTA (TCA) led to losses for all countries except for the USA, but losses were minimal compared to a Hard Brexit. The effect on GVC patterns is significant for countries other than the UK and the EU. Japan, China, Singapore, South Korea, Hong Kong, Kenya, etc., are some countries affected the most.

Keywords: Brexit, Trade in intermediates, Global value chains, Tariffs, Non-tariff trade barriers, Applied general equilibrium, Input-Output linkages, Welfare.

JEL Classification: D57, F10, F11, F13, F14, F15, F17.

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The biggest opportunities from Brexit will come from more trade with the REST of the WORLD

— Liz Truss, 2021

1 Introduction

On June 23rd, 2016, the United Kingdom (UK) voted to exit the European Union (EU). There have been a series of events since the fateful day of that referendum. The UK formally departed the EU as a member state on January 31st, 2020, more than three and a half years after Britain held its first referendum on Brexit. After endless discussions and extensions of the withdrawal date about when, how, and whether the UK should exit the EU, negotiation on post-Brexit policies eventually culminated. Still, perhaps new negotiations may continue in the future. Among the post-Brexit policies that continue to be negotiated, is the future trade agreement between the UK and the EU, one of the major policy areas affected most following Brexit. This stems from the fact that the UK has had no independent policy on international trade relations for more than 40 years and has consistently relied on the EU trade policies as a member. The UK has now reclaimed its autonomy, and its negotiations on trade policy with the EU and some third countries, are still ongoing, and they will possibly take some time. This dissolution may then create a trade policy effect with the UK, the remaining 27 European Union member countries (henceforth, EU27), and the rest of the world, much of which has been ignored from the public discussion (Mendez-Parra et al., 2016).

Hence the need to consider the effect of Brexit, not restricted to the UK and the EU only, which is the focus of this paper, emphasizing some key countries in the rest of the world. This is because the UK remains a significant trading partner of most of these third countries, and some of them rely heavily on the larger EU markets for imports. Therefore, if the UK and the EU are negatively impacted following Brexit, these adverse effects could trickle down to these third countries. The different possible Brexit scenarios to be adopted in the short- or long-term will create an economic impact in the form of higher trade costs, a more restricted EU migration, reduced foreign direct investment, high structural unemployment, and a growth slowdown. This paper abstracts from the political implications and considers only the economic ramifications of Brexit resulting from higher trade costs.

In this paper, I estimate the impact of post-Brexit trade policies on welfare effects, global value chain, and trade flows – in the UK, EU, and the rest of the world, particularly in countries with the UK as their major trading partner. Specifically, my paper provides quantitative answers to the following three questions. First, what are the welfare effects and the magnitude of gains from trade under different potential post-Brexit trade policy scenarios? Second, how do these possible post-Brexit scenarios affect global value chain patterns? Third, how does this affect trade flows?

Over the past decades, technological, institutional, and political advancements have resulted in a sharp fragmentation of the production process across national borders and the reorganization of global economic activity. This is because firms of the 21st century deem it necessary and profitable for production to be organized worldwide. For this reason, global production is currently structured into global value chains (henceforth, GVCs), where firms source inputs or components from multiple producers based in different countries and then use them either as intermediate inputs or for final consumption globally. A typical product with expansive GVCs linkages is a bicycle, with multiple countries involved in its production stages. As an illustration, China and Taiwan are top producers of bicycles, yet they have parts, such as brake, which are produced in Japan, Singapore, or Malaysia; pedal and crank produced in Japan, Singapore, or locally in China; frame produced domestically or sourced from Vietnam or Italy; Saddle imported from Italy, or Spain or locally, and wheel created internally or abroad from Italy or France. So, all countries involved obtain some value and benefit from the final product export. Still, this value-added is concealed in conventional trade models and statistics, which ascribe the entire value of a good and service to the country that exports the final product.

Therefore, the need to study models with global production linkages instead of the traditional gravity model. The cost of trade barriers will be multiplied in GVCs due to the multiple movements of products across national borders. This implies that a disruption in one part of the value chain will produce a domino effect; if one country is affected due to a trade policy effect, all others will be affected. Emphasizing further, falling trade barriers and advances in information and transportation technologies have allowed firms to disentangle production into various activities performed at different locations to benefit from additional factor costs (Feenstra and Hanson, 1997; Grossman and Rossi-Hansberg, 2008). This suggests it is better to consider a multistage production trade when discreetly evaluating trade policy effects or idiosyncratic shocks instead of only the bilateral trade component (Acemoglu et al., 2012; Johnson, 2014). Yi (2003) and Yi (2010) also justify how growth in GVCs magnifies the welfare gains to trade barriers compared to bilateral trade.

According to a report by the IMF, Brexit is more likely to have a heterogeneous impact on the different sectors of the economy (IMF, 2018). Moreover, there is an interrelationship between industries and countries (Caliendo and Parro, 2015); for instance, if the price in one sector of a country increases, this could affect other related industries either in the same country or other countries. For this reason, this study estimates the economic impact of Brexit at the country-sector level.

Motivated by the above considerations in this section, I build a multi-country multi-sector static general equilibrium model of trade policy shock, a variant of the Armington model, to quantify the impact of different post-Brexit scenarios. The model features 33 countries, the UK, EU27, 30 selected countries that trade most with the UK and the rest of the world; 12 sectors, 11 tradable sectors, and a single service sector; input-output production linkages; and trade policy. To answer the research questions quantitatively, I made the following key contribution to the literature.

In my quantitative analysis, first, I calibrate the model's parameters so that its general equilibrium matched the 2015 Eora MRIO input-output table when the world had not yet conceived of the possibility of Brexit, termed as no-Brexit equilibrium. Second, to quantify the overall impact of Brexit, I compare this no-Brexit general equilibrium state with the equilibrium of different potential post-Brexit scenarios that are likely to occur sometime in the future due to changes in tariff and non-tariff trade barriers. To evaluate the impact of Brexit, I specify a set of possible trade policies that could replace UK-EU membership in my model. I follow Steinberg (2019), Dhingra et al. (2017), Dhingra et al. (016b), and other related papers to establish five possible scenarios. These potential post-Brexit scenarios include Soft Brexit, Hard Brexit, UK-EU FTA,[1] UK-USA FTA, and UK-EU-USA FTA.

Soft Brexit is when the UK retains its single market access to the EU through bilateral negotiation or with continued membership in the European Economic Area (EEA). Still, non-tariff trade barriers (henceforth, NTBs) will increase between the UK and the EU. On the other hand, if a hard Brexit occurs, the UK will lose its single market access to the EU and its preferential trade with the rest of the world, as it has always traded with third countries under the EU rules as a member. If this scenario happens, trade between the UK and the EU and between the UK and other third countries will be governed by the World Trade Organization (WTO) rules. NTBs will increase substantially under this scenario relative to soft Brexit.

Unlike Steinberg (2019), Dhingra et al. (2017), and other papers, this paper examines three other possible post-Brexit scenarios apart from the soft- and hard Brexit. That is, the UK-USA FTA, in which the UK and the United States of America (henceforth, USA) form a free trade agreement (hence, FTA); and UK-EU-USA FTA, in which the UK, EU, and the USA form a trilateral agreement. Finally, the UK-EU FTA is the current scenario wherein the UK and EU form a free trade agreement. I estimate the applied effective tariff for the no-Brexit state and MFN tariff for counterfactual exercise using data from COMTRADE, World Trade Organization (WTO) - Integrated Database (IDB), and United Nations Conference on Trade and Development (henceforth, UNCTAD) TRAINS data. NTBs, which are a component of iceberg trade costs are hard to observe from literature (Kehoe et al., 2017; Dean et al., 2009; Goldberg and Pavcnik, 2016). Hence, I calibrate my iceberg trade cost from the model by matching the model and data moments. Specifically, I calibrate the model to match intermediate input and final demand quantities in the input-output matrix. I calibrate distinct iceberg trade costs for intermediate input and final goods to match these moments. This allows matching the model to the 2015 Eora input-output matrix. Afterward, I assumed that NTBs constitute about 20 percent of the iceberg trade cost. Then I simulated this NTB respective to the assumptions for each of the five post-Brexit policies.

With the model calibrated, I solve the equilibrium of the five post-Brexit scenarios to quantify the effect of Brexit by comparing these scenarios to the no-Brexit state. Hard Brexit is

[1] Current Brexit in effect, the EU-UK Trade and Cooperation Agreement (TCA)

the worst-case scenario, and soft Brexit is the best-case scenario compared to the former and the other methods. I measure welfare in total consumption equivalence, which explains the proportion of annual consumption households will be willing to give up in each post-Brexit scenario to remain in the no-Brexit equilibrium state. Welfare losses range from 0.04 to 1.88% in total consumption of households, with an average welfare loss of 0.27% for all countries except India in hard Brexit. Aside from the UK, Japan, Bangladesh, Kenya, and China are the most affected countries. UK-EU FTA led to losses for all countries except for the USA, but the losses were minimal compared to a Hard Brexit. UK-USA FTA leads to a welfare loss of a near negative zero for the USA and a loss of 0.04% for the UK, while in a UK-EU-USA FTA, the UK and the USA will face small welfare losses of 0.03% and 0.05%. The EU27 gains welfare for all scenarios except under hard Brexit and UK-EU scenarios where it experiences losses, though these losses are more than half less than UK losses.

The current model of this paper features a roundabout production (where imported intermediate input is used for final consumption and as an input for production) which only quantifies trade in intermediate inputs and explains the welfare effects. So, the results of GVC are calculated directly from the calibrated input-output matrix and not quantitatively determined from the model.[2]

This paper aims to quantify the effect of these post-Brexit scenarios on GVC patterns. I employed the two measures of GVC participation, backward and forward participation, by Antràs and Chor (2013) and Wang et al. (2017). Backward participation is the participation at the downstream level, which is the ratio of foreign value-added to gross export. Forward participation is the ratio of domestic value-added to gross export and the upstream participation level. To analyze changes in GVC positioning of different countries in GVCs, I use the richer measures by Antràs and Chor (2018), which considers production staging distance from final use and primary factors of production. The two positioning measures are upstream and downstream positioning. Lower values of the downstream positioning index imply that final demand use occurs less on stages downstream from primary factors of production. For upstream positioning, lower values suggest that final demand, on average, occurs less in production

[2]Future extension of this model will feature a multi-stage production that allows the impact on the global value chain to be estimated quantitatively from the model.

stages upstream from the final demand of the sector.

The findings indicate a decrease in backward and forward participation for all countries under hard and soft Brexit, but forward participation reduces more for most countries. These post-Brexit scenarios hit countries that are well involved in forward participation the hardest. China and South Korea stand out as countries with a significant increase in production staging according to upstream and downstream positioning under hard and soft Brexit.

Related Literature: This paper builds upon several strands of literature on Brexit, trade policy shock, and global value chains. First, it contributes to the literature on the economic impact of Brexit. Most recent studies have used dynamic (Steinberg, 2019; McGrattan and Waddle, 2020), static, and reduced-form estimation models (Dhingra et al., 2017, 016b; Ebell et al., 2016; Baker et al., 2016) to estimate the impact of Brexit, from higher trade costs and other factors on UK welfare and trade with the EU. My paper is the first to use a multi-country multi-sector static general equilibrium model to evaluate the impact of Brexit on the UK, EU, and other third countries that trade with them. Also, it is the first paper to examine Brexit effects on a wider range of countries not limited to the UK and EU only; and estimate the effect of Brexit on GVCs. Second, it contributes to the broad literature that quantifies the impact of trade policy reforms using many countries, many sectors, and input-output linkages (Caliendo and Parro, 2015; Costinot and Rodríguez-Clare, 2014; Giri et al., 2021). These studies reveal the importance of within-sector and international variation in finding the aggregate effects of trade policy shock. My paper builds on this literature by using a variant of the Armington model with many countries and sectors to analyze the effects of Brexit quantitatively. Third, this paper contributes to recent expansive empirical literature on GVC measures (Yi, 2003, 2010; Johnson and Noguera, 2012; Fally, 2012; Antràs et al., 2012; Antràs and Chor, 2013; Fally and Hillberry, 2018; Johnson and Moxnes, 2013; Alfaro et al., 2019; Miller and Temurshoev, 2017; Wang et al., 2017; Antràs and De Gortari, 2020).

Paper Layout: The paper is organized as follows. Section 2 documents data and stylized facts and provides evidence on UK trade with other countries apart from the EU. Section 3 presents the model of a trade policy shock. Section 4 provides detail on the quantitative analysis of the model. Section 5 discusses the measures of GVC participation and positioning.

Section 6 presents the quantitative findings on the welfare impact of Brexit. Section 7 provides quantitative results on GVC participation and positioning changes. Finally, section 8 concludes.

2 Data and Stylized Facts

Brexit has happened, but does it affect welfare and UK and EU's participation and positioning in GVCs due to possibly changing post-Brexit trade policies? Does this produce spillover effects on other countries that trade with the UK and the EU? To answer these questions, this section summarizes data and provides more detailed evidence on the UK and EU trade with other countries. Further, it reveals how open the UK is to trade with the rest of the world aside from the EU, and the proportion of export flows between these three regions that are linked to GVC activities.

2.1 Trade Flows, Production, GVCs, and Decomposition

Welfare and GVC changes that may arise from post-Brexit depend not only on trade policy changes but also on the trade openness between the UK, EU, and countries that trade with them most. Sectoral production may also be critical in determining how positioning in GVCs may switch. For instance, there could be competition between emerging countries like China, which has a dominant position at the downstream and upstream levels, and some developing countries at the upstream level only. To illustrate trade flow pattern, bilateral trade decomposition, and sectoral production between the UK, EU, and some selected third countries that trade with the most, I use the 2015 Eora Multi-Region Input-Output (henceforth, Eora) Database.

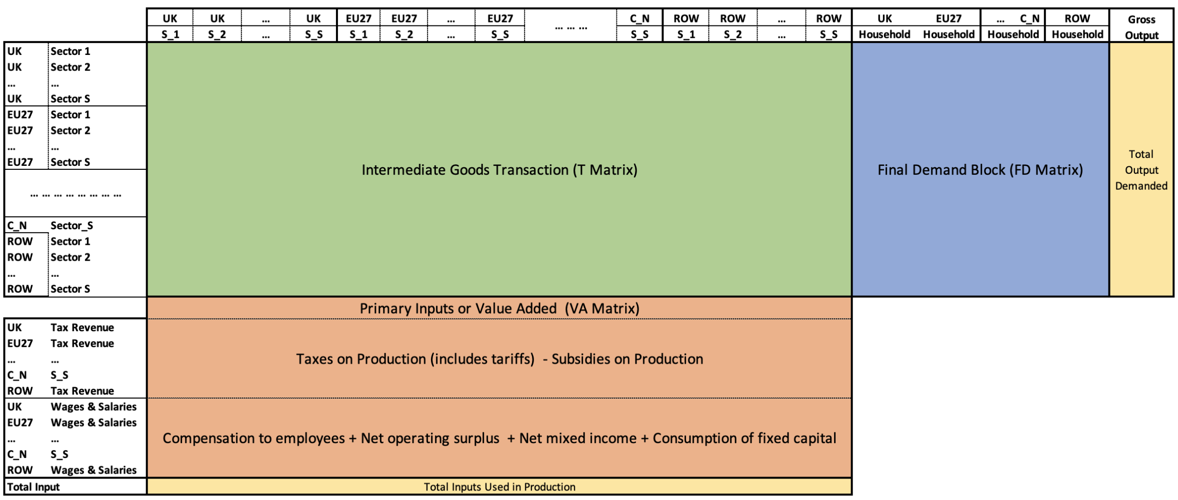
2.1.1 Input-Output Data

I use the Eora26 (Lenzen et al., 2012; Kanemoto et al., 2011) version, which is harmonized into a 26-sector classification. This data allows studying the effect of Brexit not limited to only the UK and the EU. The information has a broader sample of 190 countries and the rest of the world. However, this data source is considered less reliable than the World Input-Output Database (henceforth, WIOD), a source deemed to provide high-quality and reliable data for 43 countries and the rest of the world. I avoid using this data because most countries in the database are high- and medium-income countries in Europe, Asia, and North America. That is not adequate for this study because the paper aims to find the impact of Brexit on more countries where all continents and income levels are appropriately represented. Also, unlike Eora data, this database has been widely used in recent international trade studies, including other analyses of Brexit like Steinberg (2019), Dhingra et al. (2017), and Dhingra et al. (016b).

I use the 2015 version of the Eora data since that year is a year before the Brexit referendum and a few years before Brexit came into existence. I aggregate all services sectors into a single service sector and aggregate 30 large countries that have the UK as their major trading partner. Overall, I have 33 regions, the UK, EU27, 30 large countries, and the remaining smaller regions, plus the rest of the world. I have 26 sectors, 11 tradable sectors, and 15 services sectors aggregated into a single service sector. The regional and sectoral aggregation of the data is presented in Tables 11 to 16

In further detail, I describe the structure and the content of the Eora table. Figure 1 display a more realistic structure of the input-output table. The three main components (matrices) of the table are (1) Intermediate input (T matrix); (2) Final demand (FD matrix); and (3) Value-added (VA matrix). There are six components of final demand aggregated: (1) household final consumption; (2) non-profit institutions serving households; (3) Government final consumption; (4) gross fixed capital formation; (5) changes in inventories, and (6) acquisitions less disposals of valuables. The value-added matrix is also composed of six items as shown in the table: (1) compensation of employees; (2) taxes on production; (3) subsidies on production; (4) net operating surplus; (5) net mixed-income, and (6) consumption of fixed capital.

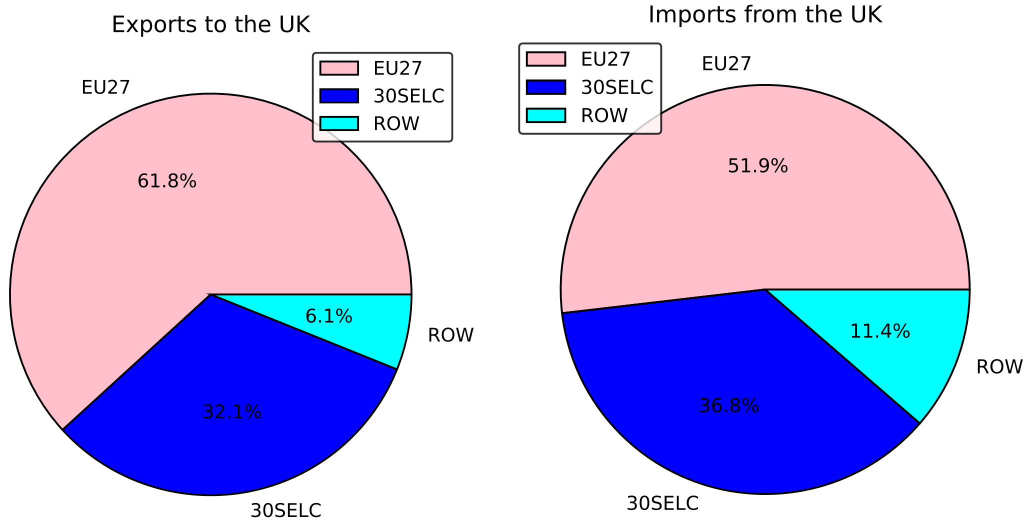
Figure 1: Eora MRIO Input-Output Table Structure



2.1.2 Aggregate Trade Flows

Aggregate trade flows refer to the total flow of imports and exports between the UK and the EU27, 30 selected countries, and the rest of the world – which explains the components and direction of trade between the UK and these three regions. Figure 2 shows that EU27 is not the only major trading partner of the UK, but then the UK trades heavily with the 30 selected countries and moderately with the rest of the world. Overall, trade between the UK and the EU27 is more than half of the UK's total trade. The EU27 exports to the UK and imports from the UK are approximately 62% and 52%; whereas the 30 selected countries export and import with the UK are 32% and 37%. Further, UK trade with the rest of the world looks less but is still significant considering that it is above 5% and can make a difference to total trade (export: 6% and import: 11%). This evidence suggests the need to examine the effect of Brexit, not limited to the UK and the EU, but to consider its global impact.

Figure 2: Aggregate Trade Flows between the UK and All Other Countries



Source: The author's calculations are based on 2015 Eora data.

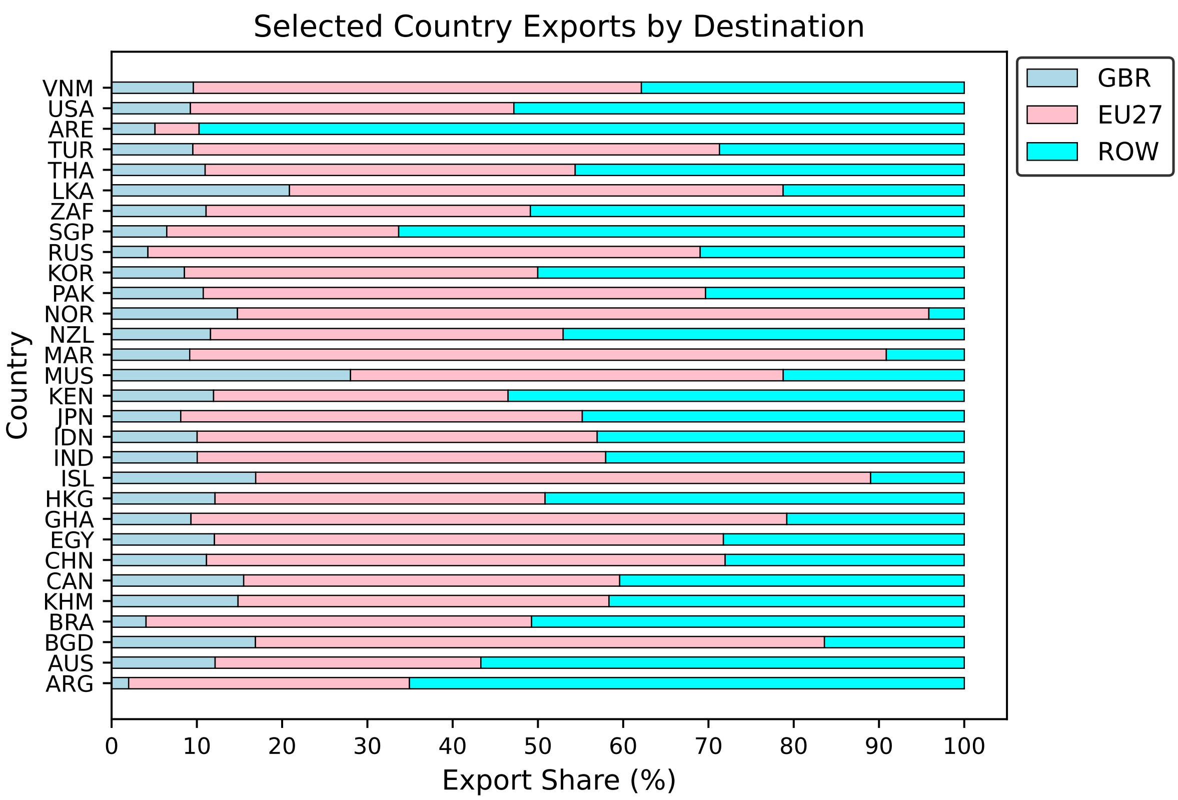
2.1.3 Trade with Selected Countries

Figure 3 presents a visualization of each of the 30 selected country's exports to the UK, EU27, and the rest of the world. Comprehensively, all the selected countries export larger proportions of their goods and services to the EU27 (4 to 89%) and the rest of the world (5 to 82%) than to the UK (2 to 28%). The UK alone receives more than 5% of each of these selected countries' export except for Brazil (4%) and Argentina (2%). Countries like Mauritius (28%) and Sri Lanka

(21%) have more than 20% of export to the UK; followed by Israel (16.9%), Bangladesh (16.87%), Canada (15.5%), Cambodia (14.8%), Norway (14.8%), Australia (12.14%), Hong Kong (12.13%), Egypt (12.1%), Kenya (11.96%), New Zealand (11.6%), China (11.13%), South Africa (11.1%), and others that have more than 10% of export. For exports to EU27, Norway (81%) and Morocco (82%) have the most significant, and UAE (5.2%) has the least. Similarly, for export to the rest of the world, Norway (4.2%) exports the largest, and UAE (89.73%) exports the smallest.

These empirical facts indicate that the effect of Brexit on trade may be heterogeneous for these selected countries. However, the possible drastic consequences of Brexit may be more specifically crucial for some countries, as the UK may not represent an essential destination for all the selected countries.

Figure 3: Thirty Selected Country Exports to the UK, EU, and the Rest of the World



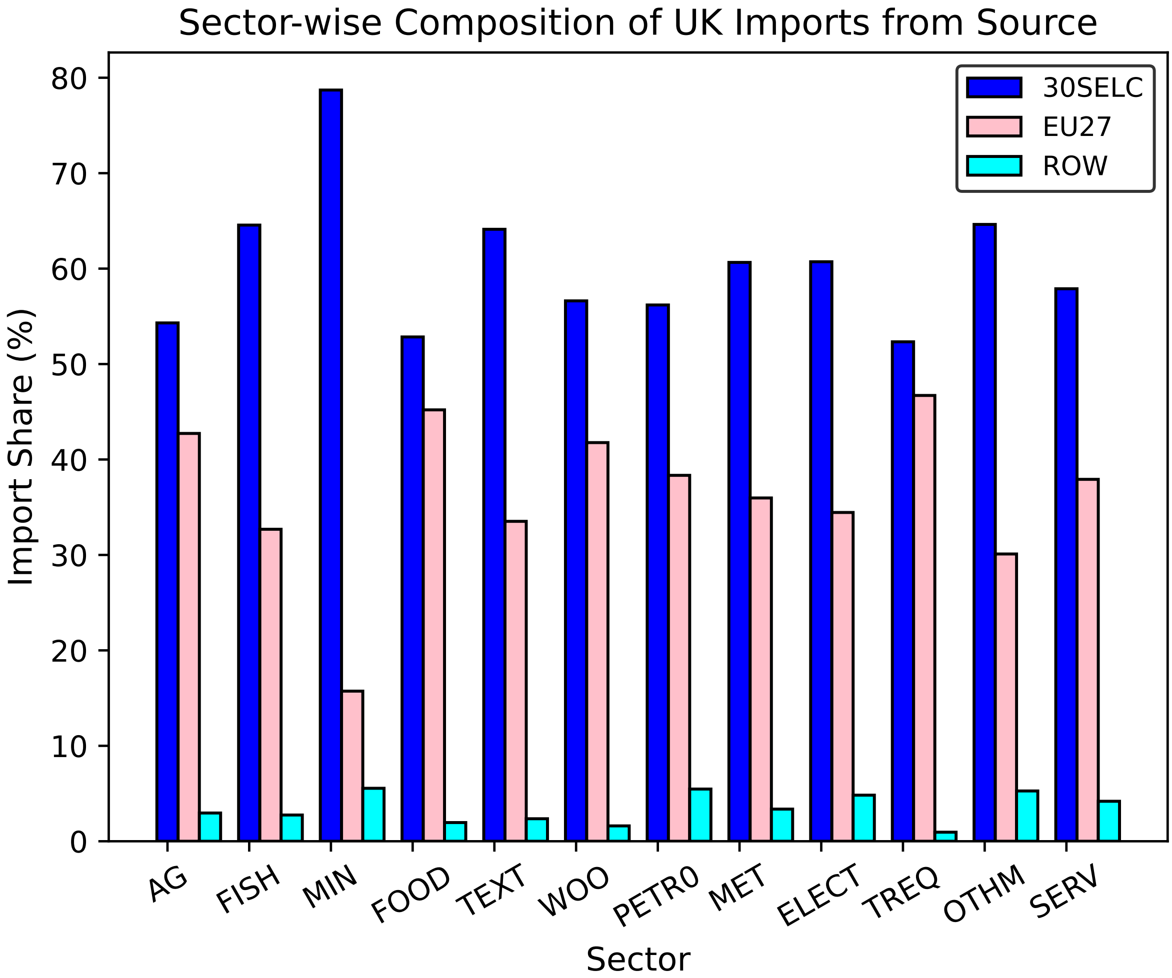
Source: The author's calculations are based on 2015 Eora data.

2.1.4 Sectoral Composition of UK Trade Flows

The structure of the UK economy heavily relies on the service sector (almost 81% of total output in 2021), which dominates all other sectors in its economy. Following this, the UK economy is highly directed toward producing and manufacturing high-tech intermediate inputs to regional value chains. From Figure 4, the UK does not import large amounts from the rest of the world across all the stated 12 sectors (almost 0.95 to 5.6%) for this study. Instead, the UK is a significant importer of the 30 selected countries (nearly 52 to 79%), followed by the EU27 (roughly 16 to 47%) across all sectors. Now, for the 30 selected countries, the sectors the UK imports most from are Mining and quarrying (78.7%), other manufacturing (64.6%), fishing (64.6%), textiles and wearing apparel (64%), metal products (60.6%), and electrical and machinery (60.7%).

For instance, though the UK has extensive reserves of iron and copper ores, these ores are still largely imported from North America, China, Brazil, and Australia. Further, the UK imports almost twice as much fish as it exports from some of these 30 selected countries (China, Norway, Iceland, Vietnam); for example, codfish, a significant fish in the UK, is primarily sourced from China and Iceland. Countries like China, Bangladesh, Turkey, India, and Cambodia export more textiles and apparel to the UK; for example, Bangladesh exports 90% of its textiles and garments to the UK. This suggests that most of these selected countries that export significant amounts to the UK in these sectors are most likely to be directly affected by Brexit due to resulting possible changes in trade costs.

Figure 4: Composition of UK Imports from EU and the Rest of the World by Sector

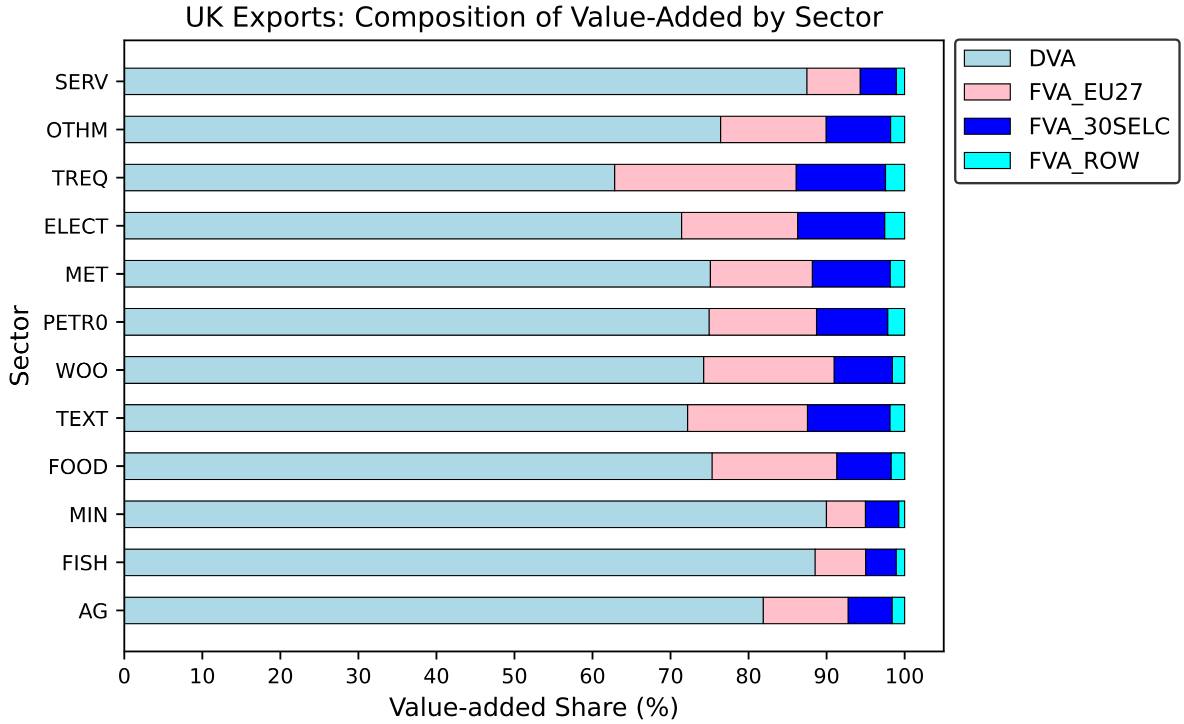


Source: The author's calculations are based on 2015 Eora data.

In Figure 5, I decompose the gross exports of each sector to identify the origin of their value-added. This visualization reveals the degree to which UK exports depend on imported inputs of goods and services. More than 60% of UK exports contain domestic value-added (DVA: nearly 63 to 90%), and the remaining share is foreign value-added (FVA) from EU27 (5 to 23%), selected countries (4 to 11.5%), and the rest of the world (0.8 to 3%), which determines the level of dependence. UK's export dependence on foreign inputs is considerable, with more sourced from EU27 than the selected countries. Consequently, if Brexit hampers imports from EU27 and the 30 selected countries, imports equivalent to around 9 to 34% of the value of exports might be costly due to possible new trade barriers. For EU27, the sectors with the highest share of FVA in UK exports are transport equipment, wood and paper, food and beverages, textiles and wearing apparel, and electrical and machinery (23.4, 16.7, 16, 15.5, and 14.9%, respectively). The sectors that embody the largest share of the selected countries' value-added include electrical and machinery, transport equipment, textiles and garments, metal products, and petroleum products (11, 11.5, 10.6, 10, and 9%, respectively).

Forward linkages examine where UK DVA is absorbed and capture its value contained in UK inputs transported to other countries for further manufacturing and exports through the value chain. In contrast, backward linkages look at the foreign content from other countries embedded in UK exports. These two linkages determine how the UK is integrated into global value chains with EU27, selected countries, and the rest of the world.

Figure 5: Sectorwise Value-added Composition of UK Exports



Source: The author's calculations are based on 2015 Eora data.

2.1.5 Global Value Chains: Insights from Decomposition of UK-EU Bilateral Exports

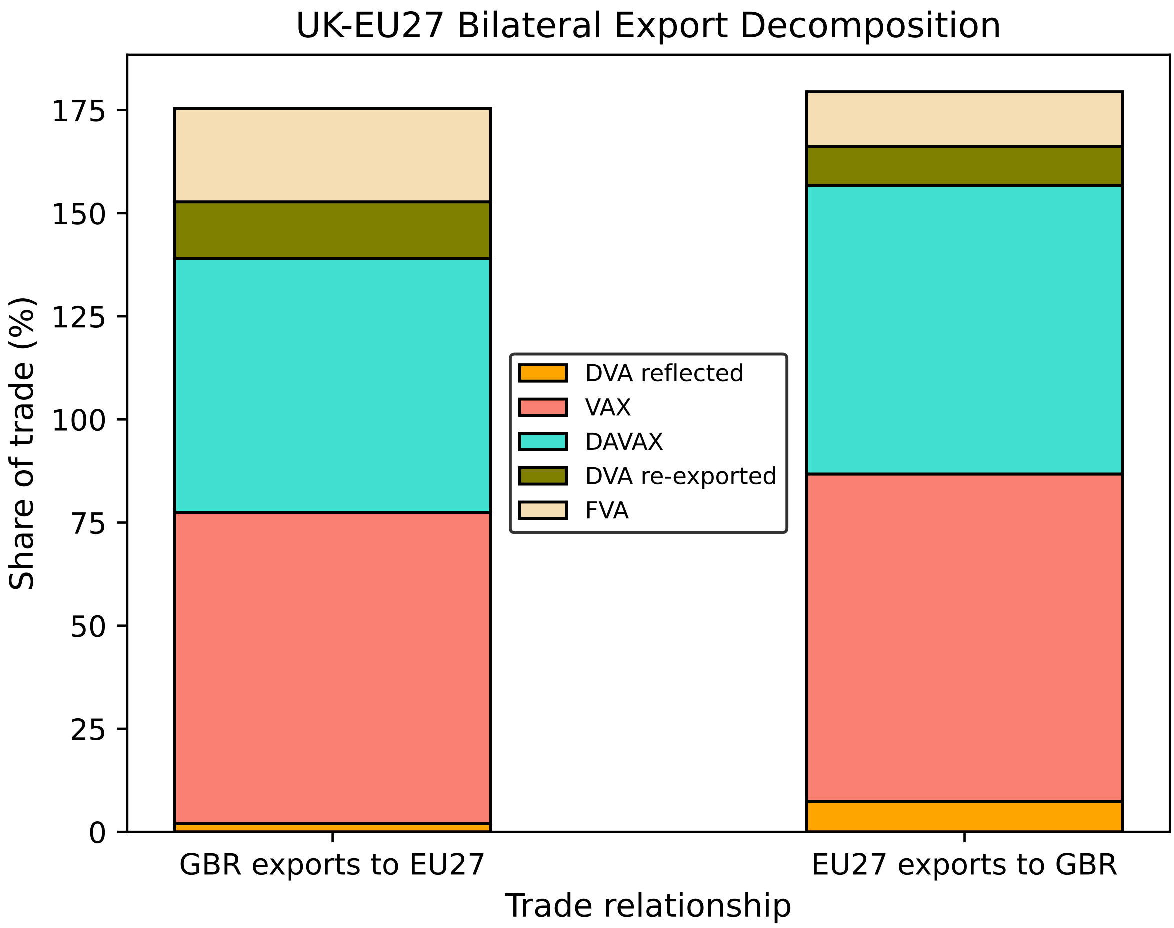
This subsection dissects the decomposition of bilateral exports between the UK and the EU27 to uncover the proportion and components of export flow between these two regions linked to GVC activities and third countries' engagement in this flow. As explained earlier in section 1, GVCs refer to goods and services crossing multiple (at least two) production stages in different countries before the final product reaches the destination market.[3] Bilateral export is divided

[3]Therefore, if intermediate inputs cross just one border, they are not part of the GVC trade.

into two major components, domestic (DVA) and foreign content (FVA). The domestic content is divided into two, 1) DVA reflected – which is finally absorbed by the exporting country itself or resold to the exporting country, and 2) VAX – which is value-added to gross exports. VAX is further split into two, i) Directly absorbed value-added in exports (DAVAX) - the part of intermediate input that is directly absorbed by the importing country (DVA that crosses just one border), ii) DVA re-exported – the remaining part which is redirected to third countries (DVA indirectly absorbed by importing country). The above components contributing to GVC trade are DVA re-exported, DVA reflected, and FVA.

Figure 6 display the elements of bilateral export flows. Both trade relationships between the UK and the EU27 have DVA reflected (UK-EU27: 2%, EU27-UK: 7%) as the smallest of the components. Export flows crossing just one border, also known as Ricardian trade, is roughly 62% for UK-EU27 and 70% for EU27-UK; whereas DVA re-exported is nearly 14% for UK-EU27 and 10% for EU27-UK. Lastly, the foreign content (FVA) component contained in UK-EU27 trade is approximately 23% and 13% for EU27-UK. The sizable proportions of FVA and DVA re-exported in the UK, and EU27 export describes other countries' engagement in GVC. This suggests that if these two regions are affected, it will also affect other countries in the value chain.

Figure 6: Decomposition of UK-EU Bilateral Exports



Source: The author's calculations are based on 2015 Eora data.

3 A Model of Trade Policy Shock Evaluation

This section uses a quantitative general equilibrium model to analyze the impact of possible post-Brexit trade policies on some key economies apart from the UK and the EU economy. The model of this paper builds on the Armington trade model of Anderson and Van Wincoop (2003), which examines an economy of one-good endowment, and Noguera (2012), which extends the former to include production using trade in intermediate goods. To build on their model, I incorporate sectoral heterogeneity and input-output linkages, which is comparable to Caliendo and Parro (2015), (henceforth, CP) and Giri et al. (2021) multi-country multi-sector model with international input-output linkages; but they use the Eaton and Kortum (2002), (henceforth, EK) Ricardian trade model. The model of this paper is based on the Armington assumption, which states that goods are imperfect substitutes by their country of origin and constant elasticity of substitution (CES, henceforth) preferences. Households and firms love variety and value the consumption of goods from all sectors of the world.

3.1 Environment

Consider a world of *N* countries and *S* sectors in each country. Countries are denoted by *i* and *j* and sectors by *r* and *s*. There are two types of sectors, either tradable or services (tradable and non-tradable). Each country has agents, including a representative household and a group of homogenous firms. Households work and consume final goods, whereas firms produce a single good differentiated by the country of origin, which can be used both as a final good and an intermediate good. Thus, goods produced are considered as intermediate or final depending on their usage after production. Overall, there are *N**S* sectors and *N**S* number of goods in the market. There is one factor of production, labor, which is inelastically supplied to the market. All goods and factor markets are perfectly competitive, and labor is immobile across countries but mobile across sectors. Superscripts in the model denote sectors, and subscripts denote countries. When there is a pair of superscripts, the first indicates the sector of destination and the second, sector of origin. Similarly, the first denotes the destination country with a pair of countries, and the second represents the source country.

3.2 Households

Each country *j* is populated by a representative household whose preferences are represented by a Constant Elasticity of Substitution (CES, henceforth) utility function. The household derives utility from a final consumption good C_j, which is a Cobb-Douglas combination of the sectoral composite final goods ($s \in S$) used for consumption C_j^s:

$$U_j = C_j = \prod_{s=1}^{S} [C_j^s]^{\alpha_j^s}, \quad \text{where} \sum_{s=1}^{S} \alpha_j^s = 1. \tag{1}$$

The α_j^s term is the share of total expenditure spent on final goods. C_j^s is a CES aggregate across all countries the good can be purchased from:

$$C_j^s = [\sum_{i=1}^{N} (c_{ji}^s)^{\frac{\sigma^s - 1}{\sigma^s}}]^{\frac{\sigma^s}{\sigma^s - 1}} \tag{2}$$

where $\sigma^s > 1$ is the elasticity of substitution for final goods between the countries of origin within sector s.[4] Household income denoted by Y_j is derived from two sources: labor supplied at a wage of w_j and transfers received from tariff revenue T_j on a lump-sum basis: $Y_j = w_j \bar{L_j} + T_j$. Labor endowment is $\bar{L}_j$ for country j.

3.3 Production Technology

In each tradable good sector $s \in S$ of country $i \in N$, output (q_i^s) is produced according to a roundabout[5] Cobb-Douglas technology by combining labor and tradable and non-tradable intermediate inputs:

$$q_i^s = A_i^s l_i^{s\beta_i^s} M_i^{1-\beta_i^s} \tag{3}$$

where l_i^s is the labor in country i sector s used in production and $1 > \beta_i^s > 0$ is the value added share of output in country i sector s. Both shares of value added and intermediate input vary across countries and sectors. A_i^s is the country-sector specific production technology parameter. The intermediate composite good M_i is a nested Cobb-Douglas-CES combination of intermediate goods from all sectors $r \in S$ across all countries the input can be purchased from:

$$\begin{gathered} M_i = \prod_{r=1}^{S} [\sum_{j=1}^{N} m_{ij}^{sr \frac{\rho^r - 1}{\rho^r}}]^{\frac{\rho^r}{\rho^r - 1}}]^{\gamma_i^{sr}}, \\ \text{where} \sum_{r=1}^{S} \gamma_i^{sr} = 1 - \beta_i^s. \end{gathered} \tag{4}$$

where $\rho^r > 1$ is the elasticity of substitution for intermediate goods between the countries of origin within sectors r, and $\sigma^s = \rho^r$ for tractability. The parameter γ_i^{sr} is the sector share of intermediate inputs used in production and it captures input-output linkages between country-sector pairs.

3.4 Market Pricing

Given that intermediate goods are produced at constant returns to scale and markets are perfectly competitive, the cost of producing a unit of good in country i sector s is given by, $p_i^s = \frac{cost_i^s}{A_i^s}$. Where $cost_i^s$ is the cost of a bundle of labor and intermediate inputs in country i

[4] For simplicity, I assume the sector-specific elasticity of substitution is the same across all countries j.
[5] Roundabout input production, where input is either used for final consumption and as intermediate input

sector s, specified as:

$$cost_i^s = \eta_i^s w_i^{\beta_i^s} [\prod_{r=1}^{S} (P_i^{s\gamma_i^{sr}})]^{1-\beta_i^s}, \tag{5}$$

where w_i is the wage rate in country i, η_i^s is a country-sector specific constant,[6] and P_i^s is the CES price index in country i of composite intermediate good from sector s.

$$P_i^s = [\sum_{j=1}^{N} (p_{ij}^s)^{1-\sigma^s}]^{\frac{1}{1-\sigma^s}} \tag{6}$$

where p_{ij}^s is the price of output in country i from country j sector s. The Cobb-Douglas equation (1) consumption price index is given by:

$$P_j = \prod_{s=1}^{S} [\frac{P_j^s}{\alpha_j^s}]^{\alpha_j^s} \tag{7}$$

where P_j^s is the CES price index in country j of final good from sector s.

$$P_j^s = [\sum_{i=1}^{N} p_{ji}^s)^{1-\sigma^s}]^{\frac{1}{1-\sigma^s}} \tag{8}$$

3.5 International Trade Costs

I assume that tradable goods are costly and are subject to iceberg trade costs and tariff (ad-valorem import tariffs) trade barriers. Iceberg cost is defined in physical units with the standard assumption that, in order for country j to receive one unit of a sector s good, country i must ship $d_{ji}^s = 1 + \tilde{d}_{ji}^s$ units, in which $(d_{ji}^s - 1)$ *melts away* in transit (Samuelson, 1954). With iceberg cost, the cost of good at the destination to be consumed is given by: $p_{ji}^s = d_{ji}^s p_i^s$. Imported goods by country j have to pay an ad-valorem tariff $\tau_{ji}^s = 1 + \tilde{\tau}_{ji}^s$, so with import tariff, the cost of good at the destination to be consumed is given by: $p_{ji}^s = \tau_{ji}^s p_i^s$. Both d_{ji}^s and τ_{ji}^s are normalized to 1 for each country-sector domestic good. I combined the tariff and iceberg trade costs as $\kappa_{ji}^s = d_{ji}^s \tau_{ji}^s$. Therefore, with a combined trade cost, the cost of good at the destination to be consumed is defined as: $p_{ji}^s = \kappa_{ji}^s p_i^s$. The sectoral price index (8) can be

[6] $\eta_i^s = (\beta_i^s)^{-\beta_i^s} (1 - \beta_i^s)^{-(1-\beta_i^s)} [\prod_{r=1}^{S} (\gamma_i^{sr})^{-\gamma_i^{sr}}]^{(1-\beta_i^s)}$.

rewriten as:

$$P_j^s = [\sum_{i=1}^{N} d_{ji}^s \tau_{ji}^s p_i^s)^{1-\sigma^s}]^{\frac{1}{1-\sigma^s}} \tag{9}$$

3.6 Solving the Model

Households' maximize utility by choosing c_{ji}^s subject to the budget constraint Y_j, and producers maximizes profit by choosing labor demand l_i^s and composite intermediate input M_i sourced across all sectors of countries. Solving the two agents problems yields the following optimal demands:

$$\text{CES demand for final good:} \quad c_{ji}^s = \alpha_j^s \left(\frac{p_{ji}^s}{P_j^s}\right)^{-\sigma^s} \frac{\beta_i^s Q_i^s}{P_j^s} \tag{10}$$

$$\text{Total import value for final good:} \quad F_{ji}^s = \alpha_j^s \left(\frac{p_{ji}^s}{P_j^s}\right)^{1-\sigma^s} \beta_i^s Q_i^s \tag{11}$$

$$\text{CES demand for intermediate input:} \quad m_{ij}^{rs} = \gamma_i^{rs} \left(\frac{p_{ij}^s}{P_i^s}\right)^{-\sigma^s} \frac{(1-\beta_i^s)Q_i^s}{P_i^s} \tag{12}$$

$$\text{Total import value for input:} \quad X_{ij}^{rs} = \gamma_i^{rs} \left(\frac{p_{ij}^s}{P_i^s}\right)^{1-\sigma^s} (1-\beta_i^s)Q_i^s \tag{13}$$

$$\text{Optimal labor demand:} \quad l_i^s = \frac{q_i^s}{A_i^s} \left(\frac{\beta_i^s P_i^s}{(1-\beta_i^s)w_i}\right)^{1-\beta_i^s} \tag{14}$$

$$\text{Optimal price:} \quad p_i^s = \frac{w_i^{\beta_i^s} \prod_{s=1}^{S} P_i^{s\,1-\beta_i^s}}{A_i^s \beta_i^{s\beta_i^s} (1-\beta_i^s)^{1-\beta_i^s}} \tag{15}$$

where $Q_i^s = p_i^s q_i^s$ is the total gross value of output produced which is used for final consumption and as an intermediate input. So, $\beta_i^s Q_i^s$ and $(1-\beta_i^s)Q_i^s$ are shares of the output used for final consumption and as intermediate input, respectively. Trade balance and Total tariff revenue are specified as:

$$\text{Trade balance :} \quad \sum_{s=1}^{S}\sum_{j=1}^{N}[p_{ij}^s(c_{ij}^s + \sum_{r=1}^{S} m_{ij}^{rs})] = \sum_{r=1}^{S}\sum_{i=1}^{N}[p_{ji}^r(c_{ji}^r + \sum_{s=1}^{S} m_{ji}^{sr})] \tag{16}$$

$$\text{Tariff revenue :} \quad T_i = \sum_{s=1}^{S}\sum_{j=1}^{N}[p_j^s \tau_{ij}^s c_{ij}^s + p_j^s \tau_{ij}^s \sum_{r=1}^{S} m_{ij}^{rs}] \tag{17}$$

3.7 General Equilibrium

In characterizing the general equilibrium, I first define price indices, quantities, market clearing condition, and then define the equilibrium conditions.

Market Clearing: Goods market clears, where total gross output Q_j^s produced in country j sector s equals total import value of final goods from country j sector s by country i and intermediate input from country j sector s use in country i sector r. Labor market clears, with total labor supplied $\bar{L}_j$ equals the sum of labor demand l_j^s by country i sector s.

$$Q_j^s = F_{ij}^s + \sum_{s=1}^{S} X_{ij}^{rs}, \quad \text{where } r, s = 1, ..., S \tag{18}$$

$$\bar{L}_j = \sum_{s=1}^{S} l_j^s, \quad \text{where } j = 1, ..., N \tag{19}$$

Equilibrium: Given parameters $\{\alpha_i^s, \gamma_i^{rs}, \beta_i^s, \sigma^s, A_i^s, \tau_{ji}^s, d_{ji}^s\}$ and exogenous variable L_i, an equilibrium is a collection of prices $\{w_i, p_i^s, p_{ji}^s, P_i^s, P_i\}$, aggregate quantities $\{C_j^s, M_i, Y_j, T_j\}$, consumption $\{c_{ij}^s\}$, production $\{q_i^s\}$, and input allocations $\{l_i^s, m_{ij}^{rs}\}$ such that firms maximize profits, and consumers maximize utility subject to their budget constraints, and goods and labor market clears. The equilibrium of the model is established by these system of equations: (9), (11), (13), (14), (15), (16), and (17). I normalized wages to one for all countries at the no-Brexit equilibrium state to allow easy solving of the model.[7] After; I calculated the actual wages of all countries using equation 5. I then use these wages to solve and calibrate the model at the different counterfactual post-Brexit scenarios. The appendix discuss further on how prices and quantities are determined and how equilibrium is constructed.[8]

3.8 Model Flexibility

Following Antràs and Chor (2018), I relaxed the assumption that iceberg trade cost d_{ji}^s is country-sector by seller country.

[7] According to Walras's law

[8] It is coming soon in the appendix.

3.8.1 New Assumption and General Equilibrium

I consider the case where trade cost is distinct for input and final goods. Input trade costs are denoted by d_{ji}^{sr}, where tradables or non-tradables in sector r from country i are shipped to sector s in country j. Likewise, d_{ji}^{r} denotes trade cost incurred when tradables or non-tradables in sector r country i are shipped to final consumers in country j.

The differences in trade cost create heterogeneity in the attributes of the various inputs and final demand goods shipped from different production stages (or sub-sectors) in a sector. Yet, they are accumulated together into a sector in the EORA data. The heterogeneity also drives this in artificial trade barriers imposed on various subset industries in a sector. Therefore, different sectors purchasing goods and services from a particular industry will face additional trade costs depending on the country-sector pairs of input and country-sector by the country for final goods. This contributes to this paper's quantitative exercise for better matching the data to the model and allowing accurate measures directly from the EORA input-output data. With this new formulation of trade cost, the price indices will be different for input and final good, specify as:

$$\text{Price index for input:} \quad P_j^{sr} = [\sum_{i=1}^{N} (d_{ji}^{sr} \tau_{ji}^{r} {p_i}^{r})^{1-\sigma^r}]^{\frac{1}{1-\sigma^r}} \tag{20}$$

$$\text{Price index for final good:} \quad P_j^{r} = [\sum_{i=1}^{N} (d_{ji}^{r} \tau_{ji}^{r} {p_i}^{r})^{1-\sigma^r}]^{\frac{1}{1-\sigma^r}} \tag{21}$$

New Equilibrium: Given parameters $\{\alpha_i^s, \gamma_i^{rs}, \beta_i^s, \sigma^s, A_i^s, \tau_{ji}^s, d_{ji}^{sr}, d_{ji}^{r}\}$ and exogenous variable L_i, an equilibrium is a collection of prices $\{w_i, p_i^s, p_{ji}^s, P_j^{sr}, P_j^r, P_j\}$, aggregate quantities $\{C_j^s, M_i, Y_j, T_j\}$, consumption $\{c_{ij}^s\}$, production $\{q_i^s\}$, and input allocations $\{l_i^s, m_{ij}^{rs}\}$ such that firms maximize profits, and consumers maximize utility subject to their budget constraints, and goods and labor market clears. The equilibrium of the model is established by these system of equations: (11), (13), (14), (15), (15), (16), (17), (18), and (19).

3.9 Brexit Trade Policy in Model

The main triggers of trade policy effect that will occur after Brexit is due to changes in trade costs, which includes changes in tariffs and non-tariff trade barriers. Non-tariff trade barriers which is a component of iceberg trade cost is not easily observed, so I assumed is a fraction of the iceberg trade costs denoted as ξ. Following the relaxation of the iceberg trade costs in the model, non-tariff trade barriers will also be distinct for intermediate input and final good, denoted by $\xi^{sr}_{ji} = (1 + \tilde{\xi}^{sr}_{ji})$ and $\xi^{r}_{ji} = (1 + \tilde{\xi}^{r}_{ji})$ respectively. With these possible trade costs changes after Brexit, pricing strategy in the state of Brexit is defined distinctly for input and final good as:

$$\text{Price index for input:} \quad P^{sr}_{j} = [\sum_{i=1}^{N}\{(\tau^{r}_{ji})(\xi^{sr}_{ji})(d^{sr}_{ji} - \xi^{sr}_{ji})p_i{}^{r})\}^{1-\sigma^r}]^{\frac{1}{1-\sigma^r}} \tag{22}$$

$$\text{Price index final good:} \quad P^{r}_{j} = [\sum_{i=1}^{N}\{(\tau^{r}_{ji})(\xi^{r}_{ji})(d^{r}_{ji} - \xi^{r}_{ji})p_i{}^{r})\}^{1-\sigma^r}]^{\frac{1}{1-\sigma^r}} \tag{23}$$

4 Quantitative Analysis

The quantitative analysis is in three stages. First, I construct a benchmark that captures the state of the world before Brexit (no-Brexit state) during my calibration strategy, where I set the model's parameters so that the general equilibrium model matches the 2015 Eora Input-Output data. This no-Brexit equilibrium state represents the counterfactual effect that would have existed if Brexit had never happened.

Second, I construct five potential post-Brexit trade policy schemes using external data and calibrated iceberg trade cost parameters from the model. These schemes include Hard Brexit, in which the UK leaves the EU, loses its' single market access, and falls back to WTO rules; Soft Brexit, in which the UK maintains its access to the EU single market through bilateral negotiation or by staying in the European Economic Area (EEA) but exits the custom union;[9]; and the UK-EU FTA, which is the current Brexit in effect where the UK exited both the EU single market and customs union, but agrees on a free trade agreement(FTA).[10] The other two are the UK-USA FTA, where the UK and United States of America (henceforth, USA) form

[9]This is similar to the Norwegian approach in which Norway has full access to the EU single market but has limited barriers to trade with the EU.

[10]It is referred to as EU-UK Trade and Cooperation Agreement (TCA).

an FTA, and the UK-EU-USA FTA, in which the UK, EU, and the USA create an FTA.[11] These various post-Brexit schemes are due to two main exogenous effects: (i) changes in non-tariff trade barriers and (ii) changes in import tariffs. The focal point of this paper is on the selected countries that trade most with the UK, so the cost of trade between the UK and the EU, selected countries, and the rest of the world only changes ceteris paribus. I calibrated the iceberg trade costs using a simulated method of moments (SMM) estimator.

Third, I solve for the equilibrium that arises from these potential post-Brexit schemes. Then I estimate the impact of Brexit by comparing the equilibrium of these different post-Brexit scenarios with the no-Brexit equilibrium state. This section further describes the data sources used in the estimations and the calibration of the other parameters.

4.1 Eora MRIO Data for Quantitative Analysis

Trade is unbalanced in the aggregated regional data; the UK and 20 other countries have trade deficits. The remaining countries, such as EU27, China, Japan, Canada, New Zealand, Indonesia, Norway, Thailand, South Korea, Russia, etc., have trade surpluses. Trade imbalances are presented as interest payments on net foreign assets in a general equilibrium state, where current accounts are balanced. Therefore, a country with a trade deficit has net positive foreign investments and the contrary, which implies that treating the raw data at an equilibrium state is the counterfactual of net foreign assets positions. To avoid this, I use the RAS method Bacharach (1965) to construct a balanced matrix of the Eora input-output table. This balanced matrix represents the no-Brexit equilibrium state in the quantitative analysis. The differences between the raw data and the balanced matrix are slightly oversized, which could be due to the poor quality of the Eora MRIO data relative to the World Input Output Database (WIOD).

4.2 Calibration Strategy

I now describe how I calibrate the model for this paper. I calibrate two versions of the model, the benchmark model with 33 countries and 12 sectors,[12] and the aggregate model[13] with

[11]This is the same as Transatlantic Trade and Investment Partnership (TTIP), a trilateral negotiation arrangement halted in 2019.

[12]11 tradable sectors and 15 service sectors aggregated to a single service sector.

[13]Calibration estimates and results for the aggregate model are still in progress and will be in the next updated draft.

33 countries and two sectors, a single tradable sector[14] and the aggregated single service sector. My calibration strategy is in four stages. First, I assign standard parameters like trade elasticity from an external source. Second, I calibrate value-added and expenditure shares directly from the Eora data. Third, I calibrate the technology parameter from the input-output matrix using the estimated value-added and expenditure shares from the Eora data. Finally, given the assigned parameters and the data estimated parameters, I calibrate the remaining parameters from the model so that the model's general equilibrium matches the 2015 Eora input-output matrix.

4.2.1 Assigned Parameters

I use a combination of Giri et al. (2021) and CP estimates of sector-wise trade elasticity, also known as the model's Armington elasticities, σ^s. These are the only parameters I assigned using external parameter. For agricultural, fishing, mining, and the petroleum sector, I use CP estimates, all other sectors, I use Giri et al. (2021) estimates. This trade elasticity shows the responsiveness of trade flows to changes in trade costs. They used a 2-digit ISIC classification, so I mapped that directly to the sector set corresponding HS codes in the Eora database. I use the same elasticity for intermediate input and final good since I assume the model's elasticity of substitution is the same for both input and final good. I follow Costinot and Rodríguez-Clare (2014) and set all service sector elasticities to five, which is the average of Caliendo and Parro (2015) estimates. Table 1 lists these assigned elasticities ranging from 3.27 in the electrical and machinery sector to 15.72 in the mining and quarrying sector.

4.2.2 Calibrate Parameters

I show how I calibrate the other parameters of the model. The parameters associated with the share of intermediate input, γ_j^{sr} and final good, α_j^s, are estimated from the data. The intermediate input share, γ_j^{sr} the proportion of sector s in the total expenditure of sector r on input in the country j; and the final demand share, α_j^s in total expenditure of sector s in country j, are estimated using Eora Input-Output data. The targeted moments are defined with respect to the Eora matrix in section 2, which contains information on country-sector pair input flows X_{ji}^{sr}, country-pair final demand trade flows by sector F_{ji}^s, country-sector specific

[14] All tradable sectors from the benchmark model are aggregated to one tradable sector

Table 1: Armington Elasticities

Sector	Sector Code	Elasticity
Agriculture	AG	8.11
Fishing	FSH	8.11
Mining and Quarrying	MINQ	15.72
Food & Beverages	FDB	3.57
Textiles and Wearing Apparel	TWAP	4.43
Wood and Paper	WOPA	5.81
Petroleum, Chemical and Non-Metallic Mineral Products	PECH	11.21
Metal Products	METP	7.01
Electrical and Machinery	EMCH	3.27
Transport Equipment	TPEQ	4.47
Other Manufacturing	OTHM	5
Services	SERV	5

Source: Giri et al. (2021) and Caliendo and Parro (2015).

gross output Q_j^s and value-added VA_j^s. The observed values of these variables are denoted with tildes, and the shares in the model are recovered using:

$$\gamma_j^{sr} = \frac{\sum_{i=1}^{N} \tilde{X}_{ji}^{sr}}{\tilde{Q}_j^s} \tag{24}$$

$$\alpha_j^s = \frac{\sum_{i=1}^{N} \tilde{F}_{ji}^s}{\sum_{s=1}^{S} \sum_{i=1}^{N} \tilde{F}_{ji}^s} \tag{25}$$

The value-added share parameter, β_i^s in sector s is calculated from the data as the ratio of the value-added, VA_j^s to the gross output, Q_j^s. This can also be recovered as $1 - \sum_{s=1}^{S} \gamma_j^{sr}$. The parameter remaining to be measured from the data is the technology parameter A_i^s of sector s country i. Given the calibrated parameters (β_i^s, γ_j^{sr}) and the variables in the Eora matrix, I follow the approach of Kehoe and Kehoe (1994) to recover A_i^s from the production function in equation (3), using the total gross value of this production function re-specified as:

$$Q_i^s = A_i^s (wi^s l_i^s)^{\beta_i^s} (P_i M_i)^{1-\beta_i^s} \tag{26}$$

This is because the Eora MRIO data are measured in US dollar value terms for all entries in the table. Table 2 presents the description of the key parameters in the model.

Table 2: Parameters Calibrated from Data and Exogenous Variables

Parameter	Definition	Data Moments
β_j^s	Value-added shares	$\frac{VA}{GO}$
α_j^s	Sector-share final demand	Final use/Total final use
γ_j^s	Sector-share Int demand	Input use/total input
A_j^s	TF Productivity	Production function
L_i	Labor endowment	employment

4.2.3 No-Brexit State Tariff

I estimated tariffs for all countries represented in the Eora data using two primary data sources: UNCTAD TRAINS applied effective tariff[15] schedules for 6-digit HS industries[16], for all the countries represented in the data; and 2015 COMTRADE data on trade flows between the UK, EU27, selected countries, and the rest of the world for these same industries. I have 26 sectors, 11 tradable sectors, and 15 services sectors aggregated into a single service sector. First, I computed the average effective tariffs for trade between countries using UNCTAD and COMTRADE data. After, I weighted each average tariff by its imports from other countries to obtain the weighted average applied tariffs. These estimated weighted average tariffs are the tariffs in the no-Brexit equilibrium state based on tariffs that countries were trading on before Brexit happened.

The applied effective tariff data from UNCTAD TRAINS are bilateral tariffs at the sectoral level for 2015. But when 2015 tariff data is unavailable, I input this value with the closest available value, searching for the previous three years below or the most recent tariff after 2015. With this approach, I had tariff data available for all countries used for this study.

4.2.4 Iceberg Trade Cost Calibration

Finally, to match the model perfectly to the Eora data, I calibrate the two distinct iceberg trade costs for input, d_{ji}^{sr} and final demand, d_{ji}^{r} using SMM estimator to minimize the distance the data moments and simulated model moments. I match two key targeted data moments in the 2015 Eora matrix: (i) values in the intermediate input matrix and (2) values in the final demand matrix. To match these data moments, I use the assigned parameters and data calibrated

[15] Applied effective tariff is a combination of bilateral accord tariffs and MFN tariffs; if countries have an agreement with each other, then they trade based on that; otherwise, countries with no deal with each other, yet members of the WTO, trade based on MFN tariffs.

[16] UNCTAD: United Nations Conference on Trade and Development

parameters, and equations (11) for input and (13) for final good as the model moments, to match the data by calibrating the parameters d_{ji}^{sr} and d_{ji}^{r} distinctively. Two non-targeted moments, gross output and value-added, also match the model to the data. I add the two targeted moments to get the gross output and then subtract the input sum from the gross output to get the value-added. Table 3 reports the calibrated parameters.

Table 3: Calibrated Iceberg Trade Costs from Model

Sector	Input	Final Demand
AG	3.30	2.48
FSH	2.39	1.92
MINQ	2.18	1.70
FDB	13.04	7.26
TWAP	5.50	2.97
WOPA	5.16	2.84
PECH	2.98	2.10
METP	3.95	2.24
EMCH	18.57	7.79
TPEQ	6.73	4.49
OTHM	4.54	2.58
SERV	11.08	7.66
Moments	Intermediate Input	Final demand

4.3 Potential Post-Brexit Scenarios

Now that the model is calibrated and the no-Brexit equilibrium state is constructed, I explain the details of the five possible post-Brexit scenarios. Table 4 provides a sector-level tariff for applied, and MFN aggregated across countries. The different potential post-Brexit scenarios and their respective simulation approach are presented in Table 5.

4.3.1 Tariff Trade Barriers

Soft Brexit: Import tariffs changes to zero in this scenario, and the UK retains single market access to the EU. So, there is a zero tariff between the UK and the EU. Tariff for trade between the UK and other countries are based on the applied effective tariff or newly signed agreement tariff. But tariff for trade between all other countries remain the same at the no-Brexit equilibrium.

Hard Brexit: There is a change in tariff, which is estimated based on two data sources: EU's most-favored-nation (MFN) tariff schedule for 6-digit HS goods industries, which is sourced from World Trade Organization (WTO) - Integrated Database (IDB), and 2015 COMTRADE data on trade flows for UK, EU27, selected countries, and the rest of the world, for these same industries. The approach to computing is as follows. First, I calculated average MFN tariffs between the UK and the EU, between the UK and selected countries, and the rest of the world goods trade using WTO-IDB and COMTRADE data. I then computed weighted average MFNs for each country. The UK tariff on EU goods is weighed by imports from the UK, while imports from the UK weigh the EU tariff on the UK. Or say imports from Japan weigh Japan tariff on UK goods and UK's import weighs UK import from Japan. The same approach is used for all countries to obtain weighted average MFN. Finally, I multiply these averages by the goods (agriculture, fishing, mining, and all other sectors except services) total imports and exports since there are no tariffs in the services sector trade. I assume tariff between the EU27 and other countries and between different countries remains at the no-Brexit equilibrium tariff, which is the applied effective tariff. The MFN tariff data from WTO-IDB are bilateral tariffs at the sectoral level for 2015. But when 2015 tariff data is unavailable, I input this value with the closest available value, searching for the previous three years below or the most recent tariff after 2015. With this approach, I had MFN tariff data available for all countries used for this study.

UK-EU FTA: This is the scenario where the UK agrees on an FTA with the EU (tariff change to zero), although the UK exit both the single market and customs union. There will be a zero tariff between the UK and EU trade, and the tariff for all other countries' trade remains the same at the no-Brexit equilibrium. Exiting the EU single market and the customs union will impact non-tariff trade barriers, which are explained in the subsection below.

UK-USA FTA: In this scenario, the UK and USA will negotiate a bilateral agreement, and it is assumed that such a deal will reduce tariffs on goods and agriculture between the UK and USA. To simulate this scenario, I reduce the no-Brexit state tariff by 25 percent for trade between the UK and the USA and assume that all other tariff remains the same at the no-Brexit equilibrium.

UK-EU-USA FTA: In this scenario, the UK, EU, and the USA negotiate a trilateral trade agreement. This eliminates tariffs on goods between the three countries. But the tariff between all other countries remains at the no-Brexit equilibrium tariff.

Table 4: Applied Effective and MFN Tariff Estimates

Sector	Applied Tariff	MFN Tariff
AG	1.0484	1.0468
FSH	1.0466	1.0455
MINQ	1.0430	1.0442
FDB	1.0482	1.0499
TWAP	1.0412	1.0426
WOPA	1.0468	1.0480
PECH	1.0444	1.0453
METP	1.0445	1.0453
EMCH	1.0444	1.0451
TPEQ	1.0430	1.0447
OTHM	1.0521	1.0534
SERV	1.0458	1.0466

4.3.2 Non-Tariff Trade Barriers (NTB)

Relative to the tariff, non-tariff trade barriers are hard to observe directly from data. According to a report by Kehoe et al. (2017), non-tariff barriers are a component of iceberg trade costs (Dean et al., 2009; Goldberg and Pavcnik, 2016). I, therefore, estimated non-tariff trade barriers based on the calibrated iceberg trade cost in section 4.2.4. So, I assume 20 percent of the iceberg trade cost are NTBs, and the remaining are its other components. I then simulated these NTBs respective to each of the five Brexit scenarios, which are reported in Table 5

Soft Brexit: NTBs for trade between the UK and the EU27 will increase, so I assume NTBs will increase by 25 percent for trade between the UK and EU27. Yet, it remains the same for trade between all other countries. But trade between the UK and third countries depends on the type of agreement the UK has agreed on, whether a replication of the EU agreement with those countries or a newly signed agreement altogether.

Hard Brexit: In this scenario, NTBs for trade between the UK and the EU27 will increase substantially more than in the case of soft Brexit. Similarly, trade between the UK and other countries will increase. Therefore, I assume a 50 percent increase in NTBs for trade between the UK, the EU, and other countries.

UK-EU FTA: This is the current Brexit in existence. In this case, NTBs for trade between the UK and the EU27 will increase far more than in the case of soft Brexit but less than in the case of hard Brexit due to the withdrawal from the EU customs union. This may impose some rules of origin requirements, and the UK regulations and standards will diverge from those of the EU. I assume NTBs will increase by 40 percent for trade between the UK and EU27. Yet, it remains the same for trade between the UK and all other countries depending on the deal the UK agrees on with these third countries.

UK-USA FTA: The UK-USA NTB is assumed to fall, but in reverse, this may also raise the UK-EU27 NTBs. Therefore, I assume a 25 percent decrease in NTBs between UK and USA trade and a 25 percent increase in NTBs for trade between the UK and EU27. Trade costs between the UK and other countries remain the same depending on the deal the UK agrees on with these third countries.

UK-EU-USA FTA: In this scenario, NTBs for trade between these three countries reduce considerably. I assume a 50 percent reduction in NTBs for trade between these countries, ceteris paribus.

Table 5: Potential Post-Brexit Scenarios and Simulation Approach

	Trade Costs	
Post-Brexit Scenarios	**Tariff (τ)**	**NTBs (ξ)**
(a) Hard Brexit		
UK-EU27	MFN	50% Increase
UK-30SELC	MFN	50% Increase
UK-ROW	MFN	50% Increase
(b) Soft Brexit		
UK-EU27	0%	25% Increase
UK-30SELC	APP	Unchange
UK-ROW	APP	Unchange
(c) UK-EU FTA		
UK-EU27	0%	40% Increase
UK-30SELC	APP	Unchange
UK-ROW	APP	Unchange
(d) UK-USA FTA		
UK-EU27	APP	25% Increase
UK-USA	25% Decrease in APP	25% Decrease
UK-ROW	APP	Unchange
UK-30SELC	APP	Unchange
(e) UK-EU-USA FTA		
UK-EU27	0%	50% Decrease
UK-USA	0%	50% Decrease
USA-EU27	0%	50% Decrease
UK-30SELC	APP	Unchange
UK-ROW	APP	Unchange

Note: MFN is the WTO-governed tariff, and APP is the applied effective tariff that countries trade on if they have a preferential trade agreement. I assume the UK replicates the EU agreement or negotiates a better deal with third countries under a soft Brexit.

5 Unpacking Measures of GVC

The current model features a roundabout production (where imported intermediate input is used for final consumption and production input) that only quantifies trade in intermediate inputs and explains the welfare effects.[17] This study's theoretical multi-country multi-sector model provides a structural interpretation of all the cell entries in the Eora MRIO table. Fundamentally, this allows for quantitative estimation of the impact of post-Brexit scenarios due to changes in trade costs on different GVC measures. To do this, I map the model to the Eora MRIO matrix. So, the results of GVCs in this paper are estimated directly from the calibrated input-output matrix and not quantitatively determined from a multi-stage production model.

In this section, I discuss the measures of GVC participation and positioning used for this paper. The analysis is done in a unit of country-industry pair,[18] which allows measuring the extent to which a country-industry (e.g., cocoa bean in Ghana) is relatively upstream or downstream on the value chain. To calculate these measures, I use the Eora input-output table as discussed in section 2.1; to depict the model of this paper, as in section 3. The Eora data in Figure 7 considers a world economy with N countries and S sectors.[19] The intermediate input block is $N \times S$ by $N \times S$ square matrix, which contains information on intermediate purchases from sector r country j to sector s country i and is denoted by X_{ij}^{sr}. To the right of the input block, the final demand block is $N \times S$ by N with information of final good expenditure from sector r country j to country i, denoted by F_{ij}^{r}. Row-wise shows the output from sector r in a country j and column-wise shows the value-added and intermediate input used in production by sector s in the country i.

The value-added of country i is $1 \times N$ row vector. The sum of columns $N \times S + N$ in each table row gives the gross output Q_j^r, equal to the sum of rows in each column. The following two subsections estimate the measures of GVC participation and positioning from the Eora data. The latter is illustrated by the two bottom rows of the table, gross output in industry s in country i is also equal to the sum of (i) all intermediate purchases from sectors

[17] For the model to quantitatively estimate the impact of Brexit on GVCs patterns, it must feature a multi-stage production. But this study will instead use the approach of Wang et al. (2017) to empirically estimate trade and production patterns (GVCs) directly from the Eora MRIO data.

[18] Industries and sectors are used interchangeably

[19] Countries and sectors in the table are indexed the same way as in the model.

r in countries j; and (ii) value-added supplied for production in sector s by country i. More formally:

$$Q_i^s = \sum_{r=1}^{S} \sum_{j=1}^{N} X_{ij}^{sr} + VA_i^s \tag{27}$$

Figure 7: Visual Representation of Model in Eora Table

		Intermediate Input															Final demand use				
		UK	UK	...	UK	EU27	EU27	...	EU27	... ...		N	ROW	ROW	...	ROW	UK	EU27	... N	ROW	Gross Output
		S_s1	S_s2	...	S_S	S_s1	S_s2	...	S_S			S_S	S_s1	S_s2	...	S_S	Household	Household	Household	Household	
UK UK ... UK	Sector r1 Sector r2 ... Sector S	X_uusr1	X_uusr2			X_eusr1	X_eusr2			X_dusr1	X_dusr2		X_wusr1	X_wusr2			F_uur1	F_eur2	F_dur2	F_wur2	Q_ur1 Q_ur2 .... Q_urS
EU27 EU27 ... EU27	Sector r1 Sector r2 ... Sector S	....	....	....		....	....	....	....	....	...		....	....			....	....	....	....	Q_er1 Q_er2 .... Q_er2
... ... N	Sector S	....	....	....		....	....	....	....	....	...		....	....			....	....	....	....	
ROW ROW ROW	Sector r1 Sector r2 ... Sector S	X_uuSS	X_uuSS	....		X_euS	X_euSS	....		X_duSS	X_duSS		X_wuSS	X_wuSS			F_uuS	F_euS	F_duS	F_wuS	Q_jS
Valued -added		VA_us1	VA_us2	....	VA_uS	VA_es1	VA_es2	....	VA_eS		....	VA_iS		....		VA_NS					
Total input		Q_us1	Q_us2	....		Q_es1	Q_es2	....			....			....		Q_iS					Input = output

5.1 GVC Participation Measures

I follow the approach of Antràs and Chor (2013) and Wang et al. (2017) to estimate GVC participation index. There are two components of the overall GVC participation index: backward and forward participation measures. Backward participation is the ratio of foreign value-added (henceforth, FVA) to gross export, and forward participation is the ratio of domestic value-added (henceforth, DVA) to gross export.

Backward GVC participation index: This is also referred to as downstream participation, as it measures the proportion of a country's final good and services that is accounted for in the imported value-added. It is expressed as:

$$\text{Backward Participation Index} = \frac{\text{FVA}}{\text{Gross Exports}} \tag{28}$$

The numerator is the foreign value-added embodied in imported intermediate input used to produce final goods in a country. It also includes domestic factor content that has returned to the home country and is incorporated in those imported inputs to fulfill final domestic demand. In summary, FVA measures the proportion of a country's final good production containing domestic and foreign factors.

Forward GVC participation index: The second measure, also known as upstream participation, measures the share of a country's domestic value-added embodied in intermediate inputs exported globally and consumed by domestic and foreign firms. This measure excludes domestic value-added included in final goods shipped directly to consumers. Mathematically specified as:

$$\text{Forward Participation Index} = \frac{\text{DVA}}{\text{Gross Exports}} \tag{29}$$

The larger the ratio of a particular country's backward and forward participation, the greater the degree of engagement in GVCs. A higher degree of backward participation than forward participation implies that the country sector is more actively involved in downstream activities in GVCs.

5.2 GVC Positioning Measures

The GVC position index measures the overall position of a country on an aggregate level in GVCs. There are two measures, upstream and downstream positioning. Specifically, how upstream or downstream the value chains in a given sector s from a given country j. Upstreamness of a country sector is relative to final demand use, and downstreamness of a country sector is close to primary factors of production. The central perspective is that an industry that sells disproportionately to final consumers would appear to be downstream in GVCs. In contrast, a sector that sells a small amount to final consumers is likely to be upstream in GVCs.

Table 8 presents a straightforward measure of the upstream, term as FUGO, the share of final demand use in gross output; and downstreamness, VAGO is the value-added shares of the gross production. A lower value of FUGO means higher upstreams from final demand, and a higher value of VAGO implies higher upstreams or lower downstreamness. As easy as these two measures are to compute, they are limited in many ways. FUGO fails to capture the heterogeneity in upstreams of country-sector pairs beyond how the output is directly sold to final consumers or other sectors. VAGO does not account for a country-sector pair variation in the upstreams of inputs used in production.

There are other different measures of upstream and downstreamness. Still, for this paper, I utilize the richer measures by Antràs and Chor (2018), which considers production staging distance from final use and primary factors of production.

Upstreamness from Final Demand Use: First, I define the direct input requirement coefficients, which is the expenditure of sector s output from country i required to produce an amount that is worth sector r's output in country J, using the Eora table and is specified as:

$$a_{ij}^{sr} = \frac{X_{ij}^{sr}}{Q_j^s} \tag{30}$$

I then computed a weighted average position of a country-industry pair output in GVCs by multiplying through the different stages in a gross production by their respective production-staging distance from final use plus one. I divided all by Q_j^s.

$$U_i^r = 1 * \frac{F_i^r}{Q_i^r} + 2 * \frac{\sum_{s=1}^{S}\sum_{j=1}^{N} a_{ij}^{sr} F_j^s}{Q_i^r} + 3 * \frac{\sum_{s=1}^{S}\sum_{j=1}^{N}\sum_{t=1}^{S}\sum_{k=1}^{N} a_{ij}^{sr} a_{jk}^{st} F_k^t}{Q_i^r} + ... \tag{31}$$

Where $U_i^r \geq 1$ and lower values imply that final demand, on average, occurs less on production stages upstream from final demand of sector r in the country i. Eora data provides direct variables for computing input requirements and gross output. Therefore, upstreams from final use can be computed by a matrix inversion. The numerator represents $[I - A]^{-2}F$ and the denominator is $[I - A]^{-1}F$, where A is the $N \times S$ by $N \times S$ matrix of the direct input requirements, and F_j^s's is the final demand matrix.

Downstreamness from Primary Factors of Production: Similarly, I define the direct input requirement coefficients, which is the expenditure of sector s output from country i required to produce an amount that is worth sector r's output in country J, using the Eora table, and is expressed:

$$b_{ij}^{sr} = \frac{X_{ij}^{sr}}{Q_i^s} \tag{32}$$

I follow the same approach as the upstreams estimation to compute the weighted average position of a country-industry pair output in GVCs by multiplying through the different stages of the gross production by their respective production-staging distance from primary factors of production plus one and dividing each by Q_j^s.

$$D_j^s = 1 * \frac{VA_j^s}{Q_j^s} + 2 * \frac{\sum_{s=1}^{S}\sum_{j=1}^{N} b_{ij}^{sr} VA_i^r}{Q_j^s} + 3 * \frac{\sum_{r=1}^{S}\sum_{i=1}^{N}\sum_{t=1}^{S}\sum_{k=1}^{N} b_{ki}^{tr} b_{ij}^{sr} VA_k^t}{Q_j^s} + ... \tag{33}$$

As in the first measure, $D_j^s \geq 1$, and lower values mean that final demand use occurs less on stages downstream from primary factors of sector r in the country i. Direct variables from the Eora table are used to compute direct input requirements and gross output and are calculated by a matrix inversion. The numerator represents $[I-B]^{-2}V$ and the denominator is $[I-B]^{-1}V$, where B is the $N \times S$ by $N \times S$ matrix of the direct input requirements, and VA_j^s's is the row vector of value-added.

6 Results: Welfare Impact of Brexit

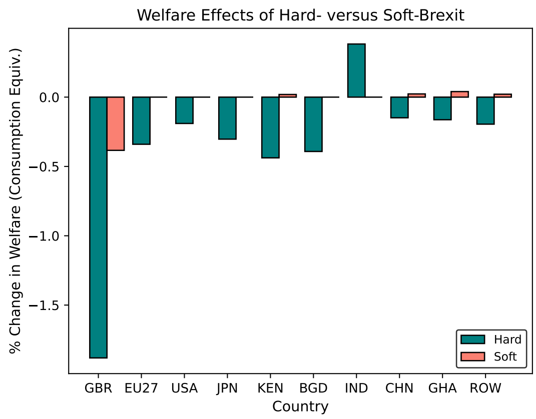
I measure welfare effects in terms of total consumption equivalence through a backward-looking method using the utility function in equation (1). This measure compares the welfare in the no-Brexit equilibrium state to the welfare in the different potential post-Brexit scenarios. It is expressed as a percent of their ratios, e.g., the percentage of hard Brexit to no-Brexit state multiplied by 100 percent:

$$\hat{W} = (\frac{C'}{C} - 1) * 100 \tag{34}$$

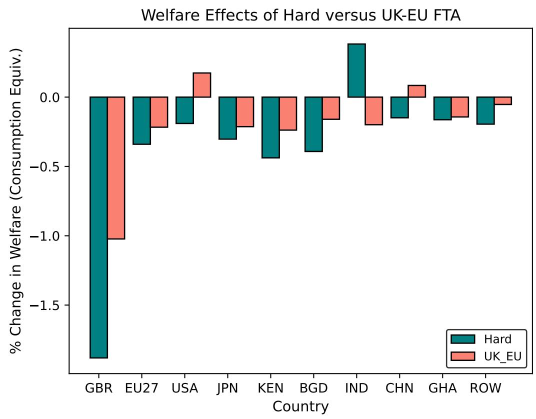
where C' is welfare at no-Brexit (before) equilibrium and C is the welfare for post-Brexit scenarios (after). Welfare gains from trade is the difference between before and after welfare. The baseline case that all other post-Brexit scenarios were compared to is the hard-Brexit equilibrium state. Table 7 in the appendix reports the welfare implications of the changes resulting from hard-Brexit, soft-Brexit, UK-EU FTA, UK-USA FTA, and UK-EU-USA. Hard Brexit leads to welfare losses for all countries except India (0.38%). These losses range from 0.04 to 1.88%, with an average welfare loss of 0.27%. Soft-Brexit was more on the gain side of welfare, with only three countries (UK (0.38%), Iceland, and Mauritius (0.001%)) having losses in this state of Brexit. However, the gains' magnitude was somewhat smaller than the losses in the hard-Brexit state. The average increase across countries for soft Brexit is 0.01%. The current Brexit (TCA: UK-EU FTA) led to losses for all countries except for the USA, but the losses were minimal compared to a Hard Brexit.

Figure 8 depict the different scenarios' welfare changes for ten countries, with a hard Brexit compared to all other designs. The UK-USA and UK-EU-USA states produce similar results with more welfare losses than gains in welfare. The magnitude of losses and gains are minor and almost the same for both UK-USA and UK-EU-USA FTAs. The UK and USA forming a bilateral agreement led to a near negative zero for the USA and a loss of 0.04% for the UK. However, if these three big economies start a trilateral deal (UK-EU-USA), the UK and the USA will face small welfare losses of 0.03% and 0.05%. The EU27 gains in welfare in the state of soft, UK-USA, and UK-EU-USA scenarios but experiences losses in hard and UK-EU scenarios, though these losses are more than half less than UK losses. China will face a more significant gain in soft-Brexit and UK-EU schemes relative to the losses in welfare in hard-Brexit. But UK-USA and UK-EU-USA FTA's will lead to a loss in welfare for China, but not as large as the losses in hard Brexit. Japan will face a loss in all scenarios except in soft Brexit, where it is near zero. In the case of Kenya, it will face a significant loss under a hard Brexit and UK-EU FTA but gains in welfare under a soft Brexit and UK-EU-USA FTA.

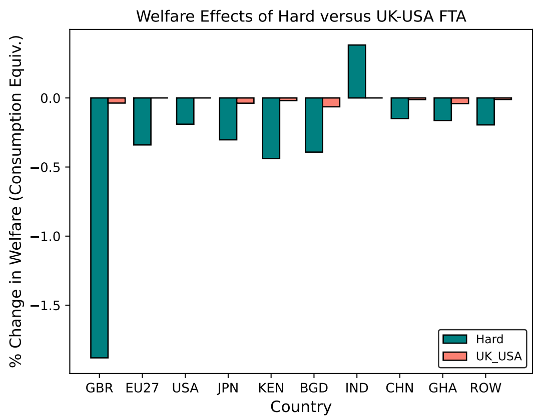
Figure 8: Welfare Changes from Brexit Scenarios



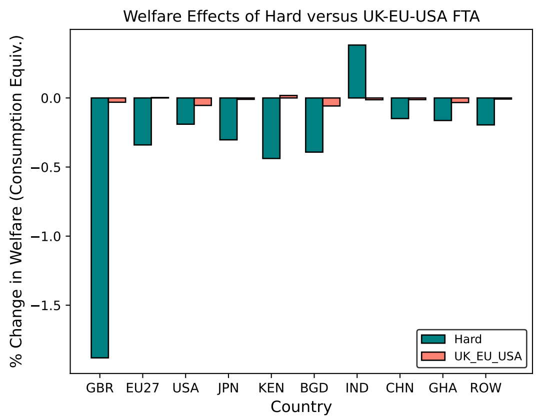
(a) Hard vs Soft



(b) Hard vs UK-EU FTA



(c) Hard vs UK-USA FTA



(d) Hard vs UK-EU-USA FTA

A hard Brexit is the worst-case scenario followed by UK-EU FTA for almost all countries compared to the other post-Brexit schemes. On the other hand, Soft-Brexit is the best case for all countries since the losses for Iceland and Mauritius were minimal, except for the UK, which is slightly higher but less than in a hard Brexit. The welfare losses for this paper are higher for hard and almost the same for a soft, when compared to estimates by Steinberg (2019), that find a welfare loss of 0.4% for soft-Brexit and 1.2% for hard-Brexit. Likewise, the losses for this paper were more minor compared to Dhingra et al. (2017) and Dhingra et al. (016b) with more significant estimates for both soft and hard Brexit. However, these estimates are more considerable than CP estimates of 0.1% for US gains from NAFTA. Other papers compared to in literature are Di Giovanni et al. (2014) with welfare gain of 0.4% from trade with China.

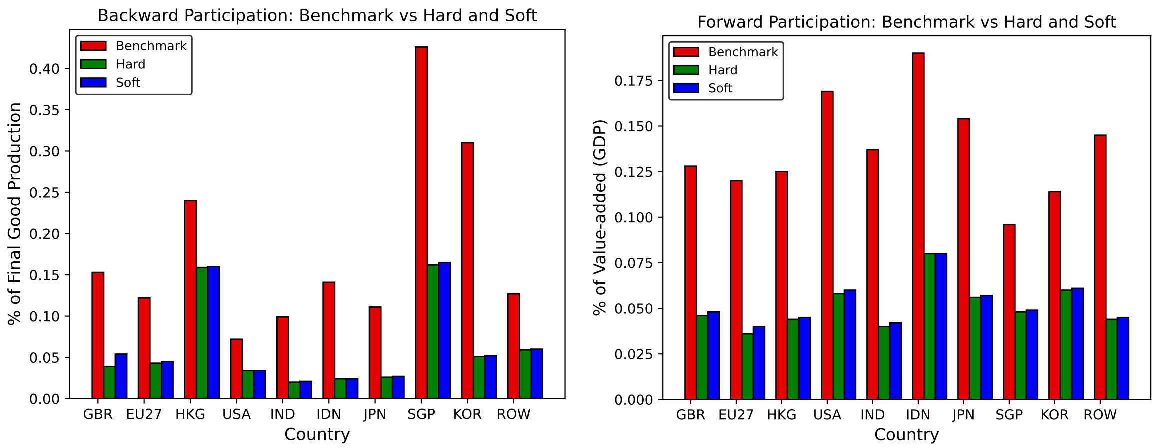
7 Results: GVC Impact of Brexit

I focus only on Hard- and Soft-Brexit scenarios to estimate the effects on GVC participation and positioning of countries in the Eora database. This is because the impact arising from the UK-EU, UK-USA, and UK-EU-USA FTA were minute, and other countries are somewhat unaffected. These estimations provide a structural interpretation of the Eora matrix and the different GVC measures calculated from the cell entries.

7.1 GVC Participation Implications

I begin in Figure 9 by plotting the changes in backward and forward GVC participation indexes for 10 of the selected countries and the remaining rest of the world in the Eora data sample. As earlier discussed, the backward GVC participation index measures the extent to which a country's final demand production uses imported inputs. The forward GVC participation index measures the proportion of domestic value-added exported embodied in intermediate input.

Figure 9: GVC Participation Changes from Brexit Scenarios



(a) FVA **(b)** DVA

Figure 9 indicates a fall in backward and forward participation for all countries in both scenarios, but forward participation falls more for most countries. At the benchmark equilibrium, all countries are more integrated into GVCs at both the forward and backward involvement, except the USA, which is less integrated at the backward and more at the forward participation. These countries move farther downstream and upstream under a hard and soft Brexit scheme. Indonesia and South Korea have a higher fall in backward participation for both hard- and soft Brexit. Hong Kong and Singapore, more downstream in GVCs at the benchmark, will reduce by a small amount under both hard and soft Brexit. This implies that both countries may remain more actively engaged in GVCs no matter the type of Brexit adopted. However, Singapore is less upstream than downstream.

At the benchmark equilibrium, most countries are more actively engaged in forward participation (upstream) than backward participation (downstream). The world's largest economy, the USA, is the least integrated into backward participation, followed by India and Japan. But the USA is more integrated into forward participation but more actively engaged at the upstream. Hard- and soft Brexit lead to higher percent changes in forward participation than backward participation. Almost all countries actively engaged in forward participation are hit the hardest by these post-Brexit scenarios. The changes in GVC participation indexes resulting from hard- and soft- Brexit are reported in the appendix in Table 9.

7.2 GVC Positioning Implications

A country's participation is distinct from its positioning in GVCs. This is because two countries can have the same position index values in a sector while having different degrees of participation in GVCs. Therefore, estimating the position index in conjunction with the participation index is imperative to get a holistic view of how it is integrated into global production.

Table 6: GVC Positioning Measure: Upstreamness and Downstreamness

Country	Calibrated Upstream	Hard Upstream	Soft Upstream	Calibrated Downstream	Hard Downstream	Soft Downstream
GBR	1.957	1.782	1.810	1.907	1.766	1.769
EU27	2.040	1.978	1.978	2.079	1.992	1.995
USA	1.826	1.762	1.762	1.819	1.788	1.789
JPN	1.959	1.854	1.854	1.966	1.812	1.812
KEN	1.694	1.609	1.611	1.649	1.548	1.549
BGD	1.734	1.695	1.695	1.752	1.668	1.668
IND	1.962	1.851	1.851	1.976	1.837	1.838
CHN	2.696	2.491	2.491	2.740	2.516	2.516
KOR	2.989	2.721	2.722	2.959	2.495	2.497

Table 6 presents the results of a few selected countries for discussion of positioning in GVCs implications of the different post-Brexit scenarios. The remaining countries positioning index changes are reported in the appendix in Table **??**. Both hard- and soft-Brexit produce similar results. In general, the pattern of changes in positioning is the same for all the countries, with an increase in production staging distance, following post-Brexit schemes. China and South Korea stand out as countries with a significant increase in production staging according to upstream and downstream positioning under hard and soft Brexit.

8 Conclusion

This paper builds a quantitative model of trade policy shocks with input-output linkages to examine the effect of Brexit not only on the UK and the EU. The impact of Brexit is quantified on welfare and on global value chain participation and positioning measures. The model features five potential outcomes for Brexit: Soft Brexit, in which tariffs on UK-EU trade remain at zero, but non-tariff trade barriers increase between the UK and the EU; Hard Brexit, in which both tariff and non-tariff trade barriers between the UK and the EU substantially increase; UK-USA FTA, where tariff and non-tariff barriers are reduced for trade between the UK and EU; UK-EU FTA, where there are no tariffs between the UK and the EU, but NTBs increase; and finally UK-EU-USA FTA, which has no tariffs between these three countries and non-tariff trade barriers fall. Simulations based on the model predict that Brexit will significantly impact the welfare of not only the UK and the EU but also the welfare of other countries, with more losses under the Hard-Brexit and UK-EU FTA scenarios, and relatively minor losses under the Soft-Brexit scenario. The findings indicate that a Hard Brexit is the worst-case scenario for the world as a whole, with welfare losses ranging from 0.04 to 1.88, and an average welfare loss of 0.27. On the other hand, Soft Brexit is the least harmful case. Finally, this paper examine the impact of Brexit on the participation and positioning of countries and sectors in GVCs. The results show that GVC participation and positioning changes under Soft and Hard Brexit, with a considerable changes in countries other than the UK and EU27. The countries most impacted are Singapore, China, Japan, South Korea, Kenya, and Hong Kong.

Overall, the results show that NTBs are the trade costs that will affect welfare, trade patterns, and production patterns most in a world with Brexit, relative to tariffs. This is because of the high heterogeneity in iceberg trade costs than the applied effective and WTO MFN tariffs. Also, the magnitude of the impact will depend on the trade agreement the UK negotiates after Brexit.

8.1 Extension of Paper

The following tasks for this paper are in three phases. First, I will replicate the quantification analysis for the aggregate model of 33 countries and two sectors, the tradables, and services sector. Second, I will use a gravity approach to estimate iceberg trade costs and then use those trade costs to calibrate Armington trade elasticities using the SMM estimator approach as by Giri et al. (2021). Finally, I will compare the welfare and GVC patterns results from calibrated iceberg trade costs from the model to the trade costs estimated from the gravity model.

References

Acemoglu, D., Carvalho, V. M., Ozdaglar, A., and Tahbaz-Salehi, A. (2012). The network origins of aggregate fluctuations. *Econometrica*, 80(5):1977–2016.

Alfaro, L., Chor, D., Antras, P., and Conconi, P. (2019). Internalizing global value chains: A firm-level analysis. *Journal of Political Economy*, 127(2):508–559.

Anderson, J. E. and Van Wincoop, E. (2003). Gravity with gravitas: A solution to the border puzzle. *American economic review*, 93(1):170–192.

Antràs, P. and Chor, D. (2013). Organizing the global value chain. *Econometrica*, 81(6):2127–2204.

Antràs, P. and Chor, D. (2018). *On the measurement of upstreamness and downstreamness in global value chains*. Routledge.

Antràs, P., Chor, D., Fally, T., and Hillberry, R. (2012). Measuring the upstreamness of production and trade flows. *American Economic Review*, 102(3):412–16.

Antràs, P. and De Gortari, A. (2020). On the geography of global value chains. *Econometrica*, 88(4):1553–1598.

Bacharach, M. (1965). Estimating nonnegative matrices from marginal data. *International Economic Review*, 6(3):294–310.

Baker, J., Carreras, O., Kirby, S., Meaning, J., and Piggott, R. (2016). Modelling events: the short-term economic impact of leaving the eu. *Economic Modelling*, 58:339–350.

Caliendo, L. and Parro, F. (2015). Estimates of the trade and welfare effects of nafta. *The Review of Economic Studies*, 82(1):1–44.

Costinot, A. and Rodríguez-Clare, A. (2014). Trade theory with numbers: Quantifying the consequences of globalization. In *Handbook of international economics*, volume 4, pages 197–261. Elsevier.

Dean, J. M., Signoret, J. E., Feinberg, R. M., Ludema, R. D., and Ferrantino, M. J. (2009). Estimating the price effects of non-tariff barriers. *The BE Journal of Economic Analysis & Policy*, 9(1).

Dhingra, S., Huang, H., Ottaviano, G., Paulo Pessoa, J., Sampson, T., and Van Reenen, J. (2017). The costs and benefits of leaving the eu: trade effects. *Economic Policy*, 32(92):651–705.

Dhingra, S., Ottaviano, G. I., Sampson, T., and Reenen, J. v. (2016b). The consequences of brexit for uk trade and living standards.

Di Giovanni, J., Levchenko, A. A., and Zhang, J. (2014). The global welfare impact of china: Trade integration and technological change. *American Economic Journal: Macroeconomics*, 6(3):153–83.

Eaton, J. and Kortum, S. (2002). Technology, geography, and trade. *Econometrica*, 70(5):1741–1779.

Ebell, M., Hurst, I., and Warren, J. (2016). Modelling the long-run economic impact of leaving the european union. *Economic Modelling*, 59:196–209.

Fally, T. (2012). Production staging: measurement and facts. *Boulder, Colorado, University of Colorado Boulder, May*, pages 155–168.

Fally, T. and Hillberry, R. (2018). A coasian model of international production chains. *Journal of International Economics*, 114:299–315.

Feenstra, R. C. and Hanson, G. H. (1997). Productivity measurement and the impact of trade and technology on wages: Estimates for the us, 1972-1990. *NBER Working paper*, (w6052).

Giri, R., Yi, K.-M., and Yilmazkuday, H. (2021). Gains from trade: Does sectoral heterogeneity matter? *Journal of International Economics*, 129:103429.

Goldberg, P. K. and Pavcnik, N. (2016). The effects of trade policy. In *Handbook of commercial policy*, volume 1, pages 161–206. Elsevier.

Grossman, G. M. and Rossi-Hansberg, E. (2008). Trading tasks: A simple theory of offshoring. *American Economic Review*, 98(5):1978–97.

IMF (2018). Selected issues - brexit: Sectoral impact and policies. Technical report, International Monetary Fund.

Johnson, R. C. (2014). Five facts about value-added exports and implications for macroeconomics and trade research. *Journal of Economic Perspectives*, 28(2):119–42.

Johnson, R. C. and Moxnes, A. (2013). Technology, trade costs, and the pattern of trade with multi-stage production. *Unpublished paper, Dartmouth College.*

Johnson, R. C. and Noguera, G. (2012). Accounting for intermediates: Production sharing and trade in value added. *Journal of international Economics*, 86(2):224–236.

Kanemoto, K., Lenzen, M., Geschke, A., and Moran, D. (2011). Building eora: a global multi-region input output model at high country and sector. In *19th International Input-Output Conference.*

Kehoe, P. J. and Kehoe, T. J. (1994). A primer on static applied general equilibrium models. *Federal Reserve Bank of Minneapolis Quarterly Review*, 18(1):2–16.

Kehoe, T. J., Pujolas, P. S., and Rossbach, J. (2017). Quantitative trade models: Developments and challenges. *Annual Review of Economics*, 9:295–325.

Lenzen, M., Kanemoto, K., Moran, D., and Geschke, A. (2012). Mapping the structure of the world economy. *Environmental science & technology*, 46(15):8374–8381.

McGrattan, E. R. and Waddle, A. (2020). The impact of brexit on foreign investment and production. *American Economic Journal: Macroeconomics*, 12(1):76–103.

Mendez-Parra, M., te Velde, D. W., and Winters, L. A. (2016). The impact of the uk's post-brexit trade policy on development. *London: ODI, UK Trade Policy Observatory (UKTPO).*

Miller, R. E. and Temurshoev, U. (2017). Output upstreamness and input downstreamness of industries/countries in world production. *International Regional Science Review*, 40(5):443–475.

Noguera, G. (2012). Trade costs and gravity for gross and value added trade. *Job Market Paper, Columbia University*, 4.

Samuelson, P. A. (1954). The pure theory of public expenditure. *The review of economics and statistics*, 36(4):387–389.

Steinberg, J. B. (2019). Brexit and the macroeconomic impact of trade policy uncertainty. *Journal of International Economics*, 117:175–195.

Wang, Z., Wei, S.-J., Yu, X., and Zhu, K. (2017). Measures of participation in global value chains and global business cycles. Technical report, National Bureau of Economic Research.

Yi, K.-M. (2003). Can vertical specialization explain the growth of world trade? *Journal of political Economy*, 111(1):52–102.

Yi, K.-M. (2010). Can multistage production explain the home bias in trade? *American Economic Review*, 100(1):364–93.

Appendix A: Tables

Table 7: Welfare Effects from Post-Brexit Scenairos (% Total Consumption Equiv.)

Country	Hard	Soft	UK-EU (TCA)	UK-US	UK-EU-US
GBR	-1.881	-0.384	-1.023	-0.037	-0.031
EU27	-0.340	0.000	-0.217	-0.000	0.003
ARG	-0.290	0.038	-0.203	-0.039	-0.034
AUS	-0.294	0.001	-0.166	-0.016	-0.011
BGD	-0.392	0.000	-0.160	-0.064	-0.058
BRA	-0.275	0.000	-0.099	-0.047	-0.045
KHM	-0.480	0.058	-0.259	0.000	0.011
CAN	-0.272	0.053	-0.260	-0.053	-0.043
CHN	-0.149	0.023	0.084	-0.012	-0.012
EGY	-0.193	0.032	-0.140	-0.032	-0.026
GHA	-0.163	0.040	-0.143	-0.041	-0.033
HKG	-0.141	0.000	-0.093	-0.002	0.007
ISL	-0.284	-0.001	-0.173	0.001	0.001
IND	0.383	0.000	-0.199	0.000	-0.013
IDN	-0.061	0.024	-0.032	-0.013	-0.035
JPN	-0.303	0.000	-0.213	-0.038	-0.010
KEN	-0.438	0.019	-0.238	-0.019	0.018
MUS	-0.084	-0.001	-0.054	0.007	0.002
MAR	-0.397	0.033	-0.197	-0.041	-0.034
NZL	-0.179	0.056	-0.179	-0.057	-0.044
NOR	-0.108	0.021	-0.108	-0.012	-0.019
PAK	-0.254	0.041	-0.185	-0.041	-0.030
KOR	-0.214	0.011	-0.122	-0.021	-0.013
RUS	-0.109	0.052	-0.109	-0.053	-0.050
SGP	-0.192	0.025	-0.134	-0.026	-0.019
ZAF	-0.319	0.001	-0.212	-0.027	-0.024
LKA	-0.043	0.038	-0.033	-0.039	-0.031
THA	-0.104	0.021	-0.101	-0.021	-0.014
TUR	-0.435	0.023	-0.234	-0.036	-0.029
ARE	-0.195	0.023	-0.153	-0.023	-0.017
USA	-0.190	0.000	0.174	-0.000	-0.054
VNM	-0.185	0.021	-0.150	-0.008	-0.001
ROW	-0.195	0.021	-0.053	-0.011	-0.008

Table 8: Eora Data: Final Demand and Value-added Shares in Gross Output

Country	Final Demand to Gross Output (FUGO)	Value-added to Gross Output (VAGO)
GBR	0.516	0.533
EU27	0.491	0.479
ARG	0.618	0.628
AUS	0.476	0.490
BGD	0.582	0.579
BRA	0.499	0.499
KHM	0.510	0.515
CAN	0.511	0.521
CHN	0.361	0.353
EGY	0.646	0.651
GHA	0.621	0.631
HKG	0.486	0.584
ISL	0.489	0.488
IND	0.513	0.510
IDN	0.495	0.501
JPN	0.520	0.515
KEN	0.603	0.620
MUS	0.609	0.619
MAR	0.565	0.571
NZL	0.452	0.441
NOR	0.531	0.572
PAK	0.528	0.523
KOR	0.305	0.298
RUS	0.479	0.499
SGP	0.455	0.420
ZAF	0.483	0.505
LKA	0.652	0.650
THA	0.432	0.412
TUR	0.696	0.697
ARE	0.523	0.533
USA	0.554	0.555
VNM	0.475	0.530
ROW	0.541	0.555

Table 9: Change in GVC Participation Indexes from Post-Brexit Scenarios

	Backward GVC Participation			Forward GVC Participation		
Country	**Benchmark**	**Hard**	**Soft**	**Benchmark**	**Hard**	**Soft**
GBR	0.153	0.039	0.054	0.128	0.046	0.048
EU27	0.122	0.043	0.045	0.120	0.036	0.040
ARG	0.096	0.023	0.023	0.116	0.040	0.040
AUS	0.109	0.018	0.019	0.158	0.056	0.057
BGD	0.049	0.006	0.006	0.129	0.039	0.041
BRA	0.075	0.013	0.013	0.136	0.044	0.045
KHM	0.103	0.008	0.008	0.148	0.045	0.047
CAN	0.170	0.048	0.049	0.091	0.026	0.027
CHN	0.122	0.044	0.045	0.139	0.048	0.049
EGY	0.053	0.011	0.011	0.164	0.045	0.049
GHA	0.066	0.007	0.008	0.150	0.053	0.055
HKG	0.240	0.159	0.160	0.125	0.044	0.045
ISL	0.169	0.009	0.010	0.122	0.052	0.057
IND	0.099	0.020	0.021	0.137	0.040	0.042
IDN	0.141	0.024	0.024	0.190	0.080	0.080
JPN	0.111	0.026	0.027	0.154	0.056	0.057
KEN	0.087	0.015	0.017	0.152	0.057	0.060
MUS	0.143	0.022	0.022	0.124	0.039	0.045
MAR	0.104	0.017	0.017	0.165	0.075	0.077
NZL	0.174	0.030	0.031	0.113	0.045	0.045
NOR	0.173	0.047	0.047	0.148	0.051	0.054
PAK	0.060	0.006	0.006	0.128	0.048	0.049
KOR	0.310	0.051	0.052	0.114	0.060	0.061
RUS	0.110	0.029	0.030	0.161	0.065	0.066
SGP	0.426	0.162	0.165	0.096	0.048	0.049
ZAF	0.157	0.026	0.028	0.151	0.058	0.062
LKA	0.084	0.010	0.010	0.124	0.042	0.045
THA	0.227	0.047	0.048	0.114	0.045	0.046
TUR	0.112	0.034	0.035	0.134	0.046	0.047
ARE	0.127	0.027	0.029	0.155	0.043	0.044
USA	0.072	0.034	0.034	0.169	0.058	0.060
VNM	0.151	0.020	0.020	0.152	0.056	0.058
ROW	0.127	0.059	0.060	0.145	0.044	0.045

Table 10: Change in GVC Positioning Indexes from Post-Brexit Scenarios

	Upstream			Downstream		
Country	**Benchmark**	**Hard**	**Soft**	**Benchmark**	**Hard**	**Soft**
GBR	1.957	1.782	1.810	1.907	1.766	1.769
EU27	2.040	1.978	1.978	2.079	1.992	1.995
ARG	1.658	1.563	1.563	1.636	1.527	1.528
AUS	2.114	1.954	1.954	2.047	1.918	1.919
BGD	1.734	1.695	1.695	1.752	1.668	1.668
BRA	2.006	1.919	1.919	2.003	1.895	1.896
KHM	1.983	1.894	1.894	1.966	1.825	1.824
CAN	1.951	1.819	1.820	1.923	1.746	1.747
CHN	2.696	2.491	2.491	2.740	2.516	2.516
EGY	1.575	1.506	1.506	1.565	1.503	1.503
GHA	1.647	1.576	1.577	1.617	1.524	1.525
HKG	2.160	1.859	1.858	1.880	1.795	1.797
ISL	2.043	1.986	1.989	2.044	1.756	1.757
IND	1.962	1.851	1.851	1.976	1.837	1.838
IDN	2.053	1.865	1.865	2.019	1.812	1.812
JPN	1.959	1.854	1.854	1.966	1.812	1.812
KEN	1.694	1.609	1.611	1.649	1.548	1.549
MUS	1.698	1.562	1.567	1.682	1.483	1.478
MAR	1.802	1.725	1.725	1.785	1.643	1.644
NZL	2.201	2.138	2.138	2.233	2.031	2.032
NOR	1.919	1.685	1.688	1.804	1.634	1.632
PAK	1.911	1.880	1.879	1.928	1.828	1.827
KOR	2.989	2.721	2.722	2.959	2.495	2.497
RUS	2.087	1.940	1.940	2.005	1.889	1.889
SGP	2.173	1.951	1.951	2.239	1.842	1.847
ZAF	2.070	1.895	1.897	1.992	1.804	1.806
LKA	1.576	1.507	1.508	1.583	1.448	1.448
THA	2.282	2.166	2.166	2.364	2.107	2.107
TUR	1.501	1.388	1.388	1.505	1.368	1.369
ARE	1.944	1.809	1.809	1.901	1.793	1.796
USA	1.826	1.762	1.762	1.819	1.788	1.789
VNM	2.139	1.741	1.742	1.943	1.618	1.618
ROW	1.888	1.733	1.733	1.835	1.773	1.775

Table 11: 33-Region Aggregation of Countries

Country Name	Country Code	33-Region Aggregation
United Kingdom	GBR	United Kingdom
Austria	AUT	EU27
Belgium	BEL	
Bulgaria	BGR	
Croatia	HRV	
Cyprus	CYP	
Czech Republic	CZE	
Denmark	DNK	
Estonia	EST	
Finland	FIN	
France	FRA	
Germany	DEU	
Greece	GRC	
Hungary	HUN	
Ireland	IRL	
Italy	ITA	
Lativa	LVA	
Lithuania	LTU	
Luxembourg	LUX	
Malta	MLT	
Netherlands	NLD	
Poland	POL	
Portugal	PRT	
Romania	ROU	
Slovakia	SVK	
Slovenia	SVN	
Spain	ESP	
Sweden	SWE	

Table 12: 33-Region Aggregation of Countries

Country Name	Country Code	33-Region Aggregation
Argentina	**ARG**	Argentina
Australia	**AUS**	Australia
Bangladesh	**BGD**	Bangladesh
Brazil	**BRA**	Brazil
Cambodia	**KHM**	Cambodia
Canada	**CAN**	Canada
China	**CHN**	China
Egypt	**EGY**	Egypt
Ghana	**GHA**	Ghana
Hong Kong	**HKG**	Hong Kong
Iceland	**ISL**	Iceland
Indonesia	**IND**	Indonesia
India	**IDN**	India
Japan	**JPN**	Japan
Kenya	**KEN**	Kenya
Mauritius	**MUS**	Mauritius
Morocco	**MAR**	Morocco
New Zealand	**NZL**	New Zealand
Norway	**NOR**	Norway
Pakistan	**PAK**	Pakistan
South Korea	**KOR**	South Korea
Russia	**RUS**	Russia
Singapore	**SGP**	Singapore
South Africa	**ZAF**	South Africa
Sri Lanka	**LKA**	Sri Lanka
Thailand	**THA**	Thailand
Turkey	**TUR**	Turkey
UAE	**ARE**	UAE
United States of America	**USA**	United States of America
Vietnam	**VNM**	Vietnam

Table 13: 33-Region Aggregation of Countries

Country Name	Country Code	33-Region Aggregation
Afghanistan	AFG	Rest of the World
Albania	ALB	
Algeria	DZA	
Andorra	AND	
Angola	AGO	
Antigua	ATG	
Armenia	ARM	
Aruba	ABW	
Azerbaijan	AZE	
Bahamas	BHS	
Bahrain	BHR	
Barbados	BRB	
Belarus	BLR	
Belize	BLZ	
Benin	BEN	
Bermuda	BMU	
Bhutan	BTN	
Bolivia	BOL	
Bosnia and Herzegovina	BIH	
Botswana	BWA	
British Virgin Islands	VGB	
Brunei	BRN	
Burkina Faso	BFA	
Burundi	BDI	
Cameroon	CMR	
Cape Verde	CPV	
Cayman Islands	CYM	
Central African Republic	CAF	
Chad	TCD	
Chile	CHL	
Colombia	COL	
Congo	COG	
Costa Rica	CRI	
Cuba	CUB	
Cote dIvoire	CIV	
North Korea	PRK	
DR Congo	COD	
Djibouti	DJI	
Dominican Republic	DOM	
Ecuador	ECU	
El Salvador	SLV	
Eritrea	ERI	
Ethiopia	ETH	

Table 14: 33-Region Aggregation of Countries

Country Name	Country Code	33-Region Aggregation
Fiji	FJI	Rest of the World
French Polynesia	PYF	
Gabon	GAB	
Gambia	GMB	
Georgia	GEO	
Greenland	GRL	
Guatemala	GTM	
Guinea	GIN	
Guyana	GUY	
Haiti	HTI	
Honduras	HND	
Iran	IRN	
Iraq	IRQ	
Israel	ISR	
Jamaica	JAM	
Jordan	JOR	
Kazakhstan	KAZ	
Kuwait	KWT	
Kyrgyzstan	KGZ	
Laos	LAO	
Lebanon	LBN	
Lesotho	LSO	
Liberia	LBR	
Libya	LBY	
Liechtenstein	LIE	
Macao SAR	MAC	
Madagascar	MDG	
Malawi	MWI	
Malaysia	MYS	
Maldives	MDV	
Mali	MLI	
Mauritania	MRT	
Mexico	MEX	
Monaco	MCO	
Mongolia	MNG	
Montenegro	MNE	
Mozambique	MOZ	
Myanmar	MMR	
Namibia	NAM	
Nepal	NPL	
Netherlands Antilles	ANT	
New Caledonia	NCL	
Nicaragua	NIC	
Niger	NER	
Nigeria	NGA	

Table 15: 33-Region Aggregation of Countries

Country Name	Country Code	33-Region Aggregation
Gaza Strip	PSE	Rest of the World
Oman	OMN	
Panama	PAN	
Papua New Guinea	PNG	
Paraguay	PRY	
Peru	PER	
Philippines	PHL	
Qatar	QAT	
Moldova	MDA	
Rwanda	RWA	
Samoa	WSM	
San Marino	SMR	
Sao Tome and Principe	STP	
Saudi Arabia	SAU	
Senegal	SEN	
Serbia	SRB	
Seychelles	SYC	
Sierra Leone	SLE	
Somalia	SOM	
South Sudan	SDS	
Sudan	SUD	
Suriname	SUR	
Swaziland	SWZ	
Switzerland	CHE	
Syria	SYR	
Taiwan	TWN	
Tajikistan	TJK	
TFYR Macedonia	MKD	
Togo	TGO	
Trinidad and Tobago	TTO	
Tunisia	TUN	
Turkmenistan	TKM	
Former USSR	USR	
Uganda	UGA	
Ukraine	UKR	
Tanzania	TZA	
Uruguay	URY	
Uzbekistan	UZB	
Vanuatu	VUT	
Venezuela	VEN	
Yemen	YEM	
Zambia	ZMB	
Zimbabwe	ZWE	
Rest of the World	ROW	

Table 16: Sector Aggregations

Sector No.	Sector Description	Eora Sector Codes	Author's Codes	HS Codes
1	Agriculture	AG	AG	1-2, 4-14
2	Fishing	FISH	FSH	3
3	Mining and Quarrying	MIN	MINQ	25-26
4	Food & Beverages	FOOD	FDB	15-24
5	Textiles and Wearing Apparel	TEXT	TWAP	41-43, 50-67
6	Wood and Paper	WOO	WOPA	44-49
7	Petroleum, Chemical and Non-Metallic Mineral Products	PETR0	PECH	27-40, 68-70
8	Metal Products	MET	METP	71-83
9	Electrical and Machinery	ELECT	EMCH	84-85, 90-91, 93
10	Transport Equipment	TREQ	TPEQ	86-89
11	Other Manufacturing	OTHM	OTHM	92, 94-97
12	Recycling	RECY		
13	Electricity, Gas and Water	UT		
14	Construction	CONST		
15	Maintenance and Repair	MAINT		
16	Wholesale Trade	WHOT		
17	Retail Trade	RETAIT		
18	Hotels and Restraurants	HOTEL		
19	Transport	TRANSP	SERV	99
20	Post and Telecommunications	TELEC		
21	Finacial Intermediation and Business Activities	FINAN		
22	Public Administration	PUB		
23	Education, Health and Other Services	EDU		
24	Private Households	PRIVH		
25	Others	OTH		
26	Re-export & Re-import	REI		