Brexit and Global Value Chains: Beyond the UK and the EU*

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Abstract

The discussion on Brexit has focused more 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 with the UK as their major trading partner. Besides, some of these countries rely heavily on the larger EU markets for imports. Primarily, in this paper, I estimate the impact of several post-Brexit trade policies on global value chain participation and positioning and the welfare gains from trade - in the UK, EU27, and the rest of the world. First, I build a multi-country multi-sector static general equilibrium model of trade policy shock, 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 Eora input-output data and the state of the world before Brexit. The various potential post-Brexit scenarios include Hard Brexit, Soft Brexit, UK-USA FTA, and UK-EU-USA FTA. I find hard Brexit to be the worst-case, with losses ranging from 0.005 to 0.4385 percent and an average loss of 0.2166 percent in total consumption-equivalent welfare of households. Also, I find that the UK-USA bilateral agreement has a gain for the USA and a loss of 0.0367 percent for the UK. Effect on GVC participation and positioning is significant for other countries than the UK and the EU. Some countries affected most are Japan, India, Hong Kong, and Kenya. The USA is the only large economy found to be less integrated into GVCs.

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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 was series of events since that fateful day of this 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 for Brexit. After endless discussions and extensions of the withdrawal date about when, how, and if the UK should exit the EU, negotiation on post-Brexit policies eventually culminated. Among these post-Brexit policies 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 has its trade policy with the EU and some third countries, and new trade negotiations are still ongoing with these third countries, possibly that will take some time. This dissolution may then create a trade policy effect with the UK, the remaining EU 27 countries (henceforth, EU27), and the rest of the world, which has been ignored from the public discussion (Mendez-Parra et al. (2016)).

Hence the need to consider the effect of Brexit, not limited 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 these countries rely heavily on the larger EU markets for imports. Therefore, if the UK and the EU are negatively impacted following Brexit, these adverse effects will 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 abstract away 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 global value chain participation and positioning, welfare effects, 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 participation and positioning 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 very necessary and profitable for production to be organized on a worldwide scale. 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 or 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 a disruption in one part of the value chain will produce a domino effect; if one country is affected due to 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, 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 non-tradable sector; input-output production linkages; and trade policy. I then made the following contribution to literature using this model.

In my quantitative analysis, first, I calibrate the model's parameters so that its general equilibrium matched an input-output matrix for 2015 when the world had not yet conceived the possibility of Brexit, termed as no-Brexit. 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. (2016b), and other related papers to establish four possible scenarios. These potential post-Brexit scenarios include Soft Brexit, Hard Brexit, UK-USA FTA, and UK-EU-USA FTA.

The state of soft Brexit is when the UK retains its single market access to the EU, with no tariff either through bilateral negotiation or with continued membership in the European Economic Area. Still, non-tariff trade barriers (henceforth, NTBs) will increase between the UK and the EU. On the other hand, if hard Brexit occurs, the UK will lose its single market access to the EU and lose its' preferential trade with the rest of the world, as it has always traded with other 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 under this scenario.

Unlike Steinberg (2019), Dhingra et al. (2017), and other papers, I look at additional two possible post-Brexit scenarios apart from the soft- and hard-Brexit. That is, 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. 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. To match these moments, I calibrate distinct iceberg trade costs for intermediate input and final goods. This allows matching the model to the 2015 Eora input-output matrix perfectly. Finally, I assume that NTBs constitute about 10 percent of the iceberg trade cost.

With the model calibrated, I solve the equilibrium of the four post-Brexit scenarios to quantify the effect of Brexit by comparing these scenarios to the no-Brexit state. Overall, hard-Brexit is the worst-case scenario, and soft-Brexit is the best-case scenario relative to the former. 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 0.005 to 0.4385 percent in total consumption of households, with an average welfare loss of 0.2166 percent for all countries except India and EU27 in hard Brexit. Aside from the UK, the most affected countries are Japan, Kenya, and China. UK-USA FTA leads to a welfare gain for the USA and a loss of 0.0367 percent for the UK, while UK-EU-USA FTA reduces welfare for the UK and USA by 0.0313 and 0.0539 percent. The EU27 gains in welfare or remain unaffected in all the possible post-Brexit.

This paper aims to quantify the effect of these post-Brexit scenarios on GVC participation and positioning. 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 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 on production stages upstream from the final demand of the sector

The findings indicate that hard- and soft-Brexit will produce higher percent changes in forward participation than backward participation. These post-Brexit scenarios hit countries that are well involved in forward participation the hardest. The USA is not well integrated into GVCs even with a 5.7 and 5.2 percent move in the upstream and downstream positioning following soft- and hard Brexit. Japan stands out as a country that records a significant increase in its production staging according to both upstream and downstream positioning after Brexit.

Related Literature: This paper builds upon several strands of literature for 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), Dhingra et al. (2016b); 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 many sectors to analyze the effects of Brexit quantitatively. Third, this paper contributes to recent expansive literature on GVC participation and positioning measures (Yi (2003); Yi (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 the UK and EU's participation and positioning on the value chains due to post-Brexit trade policies? Does this produce a spillover effect on other countries that trade with the UK and the EU? This section summarizes data and provides more detailed information on changes in trade cost that may emerge due to Brexit and how open the UK is to trade with the rest of the world aside from the EU.

2.1 Trade Openness and Production

GVC changes that will result from post-Brexit are not dependent on changes in trade policy only, but also on the openness of trade between the UK, EU, and countries that trade with the most. Sectoral production may also be a critical factor in how positioning on the value chain may change. 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. To illustrate trade flow pattern, sectoral production, and intermediate input and final good trade 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.

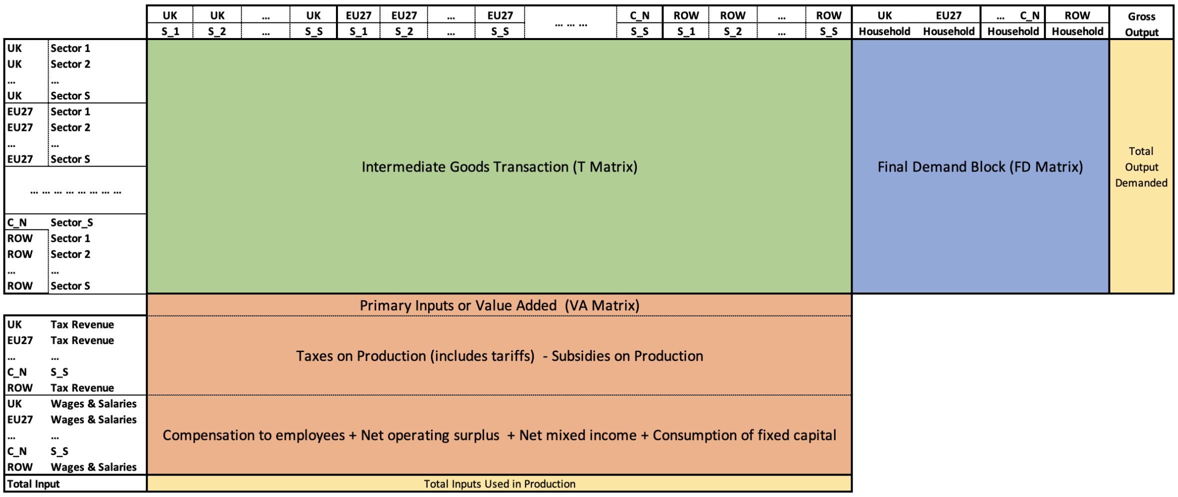
2.1.1 Input-Output Data

I use the Eora26 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 accepted to be less reliable than the World Input-Output Database (henceforth, WIOD), a source deemed to provide high-quality and reliable data for 43 samples of countries and the rest of the world. I avoid using this data because most of the 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's goal is to find the impact of Brexit on more countries in which 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. (2016b).

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 non-tradable 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, 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 non-tradable, which are aggregated into a single service sector. The regional aggregation of the data is presented in table 4.

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. Figures 1 to 3 provide a visual illustration of trade flows by country and by sector and intermediate and final production; all values are expressed as a proportion of each country's total GDP.

Figure 1: Eora MRIO Input-Output Table Structure



2.1.2 Aggregate Trade Openness

To be completed

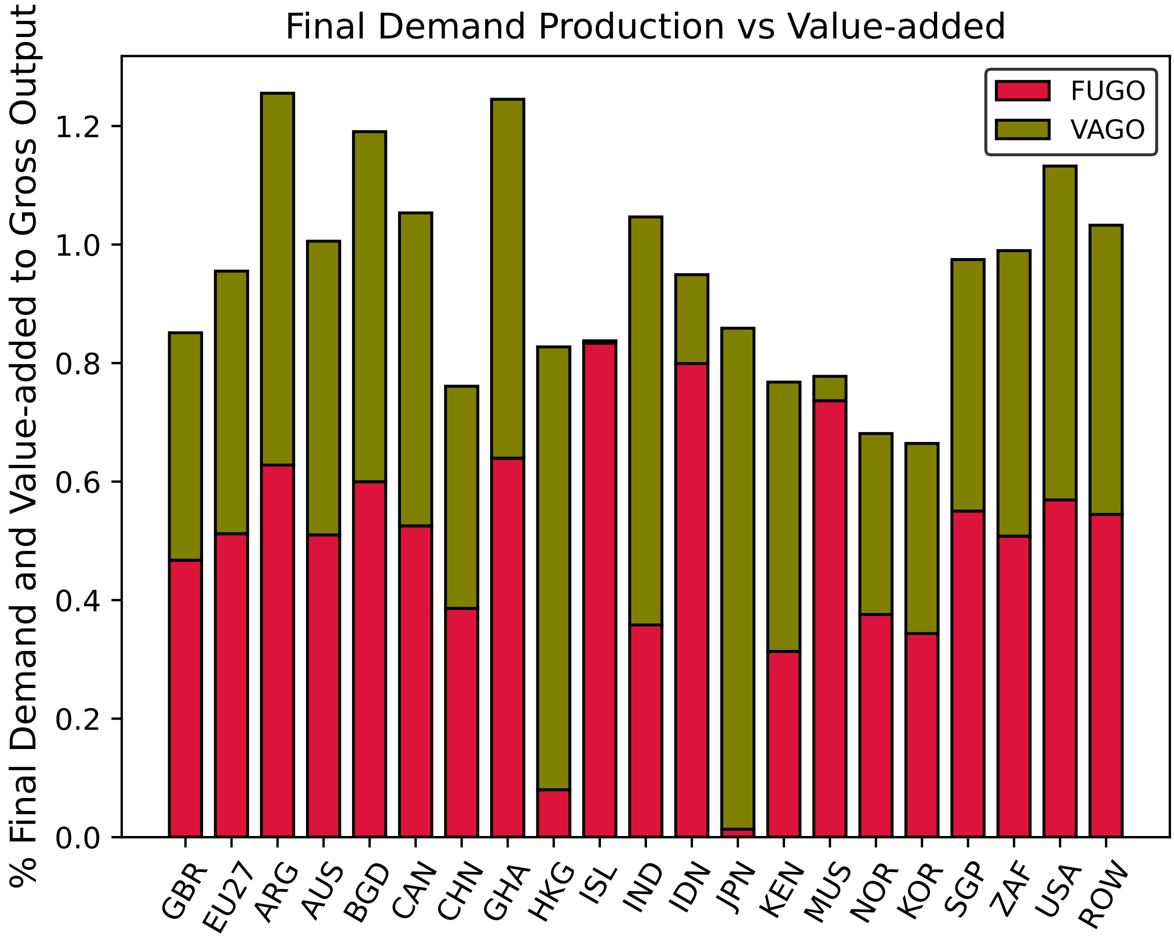
2.1.3 Sector-Level Trade and Production

To be completed

2.1.4 Final-use and Value-added to Gross Output

Table 6 in the appendix reports the ratio of final demand use to gross output and that of value-added to gross production for the 33 countries sample for this paper.

Figure 2: Country-Level Final-use and Value-added Shares



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 globe 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 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:

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

α_j^s is the share of total expenditure spend 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.[1] 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[2] 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 $s \in S$ across all countries the input can be purchased from:

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

where $\rho^s > 1$ is the elasticity of substitution for intermediate goods between the countries of origin within sectors s, and $\sigma^s = \rho^s$ 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.

[1] I assume the sector-specific elasticity of substitution is the same across all countries j, for simplicity.

[2] Roundabout input production, where input is either used for final consumption and as intermediate input

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 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,[3] and P_i^s is the CES price index in country i of composite intermediate good from sector s.

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

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.

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

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

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

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 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:

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

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

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

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

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

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

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:

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

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

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 value of final goods from country j sector s by country i and intermediate input value from country j sector s use in country i sector r. Labor market clears, with total labor supplied $\bar{L}_j$ equals labor demand l_j^s by country i sector s.

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

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

Equilibrium: Given parameters $\{\alpha_i^s, \gamma_i^{rs}, \beta_i^s, \sigma^s, A_i^s, \tau_{ij}^s, d_{ij}^s\}$ and exogenous variable L_i, an equilibrium is a collection of prices $\{w_i, p_i^s, p_{ij}^s, P_i^s, P_i\}$, aggregate quantities $\{C_j^s, M_i, Y_j, T_j\}$, consumption $\{c_{ij}^s\}$, production $\{q_i^s\}$, and input allocations $\{l_i^s, m_{ij}^s\}$ 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 four 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.[4] The appendix discuss further on how prices and quantities are determined and how equilibrium is constructed.

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.

[4] According to walras' law

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/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 $\{\alpha_i^s, \gamma_i^{rs}, \beta_i^s, \sigma^s, A_i^s, \tau_{ij}^s, d_{ij}^s\}$ and exogenous variable L_i, an equilibrium is a collection of prices $\{w_i, p_i^s, p_{ij}^s, P_j^{sr}, P_j^r, P_j\}$, aggregate quantities $\{C_j^s, M_i, Y_j, T_j\}$, consumption $\{c_{ij}^s\}$, production $\{q_i^s\}$, and input allocations $\{l_i^s, m_{ij}^s\}$ 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 four system of equations: (11), (13), (14), (15), (15), (16), (17), (18), and (19). I normalized wages to one for all countries at the no-Brexit equilibrium state.[5] The appendix discuss further on how

[5] According to walras' law

prices and quantities are determined and how equilibrium is constructed.

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 $\xi_{ji}^{sr} = (1 + \tilde{\xi}_{ji}^{sr})$ and $\xi_{ji}^{r} = (1 + \tilde{\xi}_{ji}^{r})$ 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:

$$\text{Price index for input:} \quad P_j^{sr} = [\sum_{i=1}^{N} \{(\tau_{ji}^r)(\xi_{ji}^{sr})(d_{ji}^{sr} - \xi_{ji}^{sr}) p_i{}^r)\}^{1-\sigma^r}]^{\frac{1}{1-\sigma^r}} \tag{22}$$

$$\text{Price index final good:} \quad P_j^{r} = [\sum_{i=1}^{N} \{(\tau_{ji}^r)(\xi_{ji}^{r})(d_{ji}^{r} - \xi_{ji}^{r}) p_i{}^r)\}^{1-\sigma^r}]^{\frac{1}{1-\sigma^r}} \tag{23}$$

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. I estimate the impact of Brexit from this no-Brexit equilibrium state.

Second, I construct four potential post-Brexit trade policy schemes using external data and calibrated trade cost parameters. These schemes include Hard Brexit, in which the UK leaves the EU and loses its' single market access; 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); UK-USA FTA, where UK and United States of America (henceforth, USA) forms a free trade agreement(hence, FTA); and UK-EU-USA FTA, in which the UK, EU, and the USA forms FTA. These schemes involve two main exogenous effects resulting from: (i) changes in iceberg trade costs and (ii) changes in import tariffs. The focal point of this paper is on the rest of the world, so the cost of trade between the UK, EU, selected countries, and the remaining rest of the world does change.

Third, I solve for the equilibrium that arises from each of these potential Brexit schemes and then estimates the impact of Brexit by comparing this new equilibrium with the no-Brexit equilibrium state.

4.1 Data for Quantitative Analysis

Trade is unbalanced in the aggregated regional data; the UK, EU, 20 other countries have trade deficits. The remaining countries, such as China, Japan, Hong Kong, India, Indonesia, Singapore, 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 to treat 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 data.

4.2 Calibration

I now describe how I calibrate the model for this paper. I calibrated two versions of the model, the baseline model with 33 countries and 12 sectors,[6] and the aggregate model with 33 countries and two sectors, a single tradable sector[7] and the non-traded 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 shares and expenditure shares directly from the EORA data. Third, I calibrate the technology parameter from the input-output matrix together with the calibrated shares. Finally, given the assigned parameters and the data calibrated parameters, I

[6] 11 tradable sectors and 15 non-tradable aggregated to one non-tradable sector.
[7] All tradable sectors from the benchmark are aggregated to one tradable sector

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. For agricultural, fishing, mining, and the petroleum sector, I use CP estimates, all other sectors, I use Giri 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 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, which range from 3.27 in the electrical and machinery sector to 15.72 in the mining and quarrying 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

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 measured in 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 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). Table 2 presents the key parameters of the model averaged across countries.

Table 2: Parameters Calibrated from data and Exogenous Variables

Parameter	**Definition**	**Moment**
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[8] schedules for 6-digit HS industries[9], for all the countries represented in the data; and COMTRADE data on trade flows between UK, EU27, selected countries, and the rest of the world, for these same industries. I have 26 sectors, 11 tradable sectors, and 15 non-tradable sectors aggregated into a single service sector. First, I computed average applied effective tariffs for trade between each country using UNCTAD and COMTRADE data. After, I weighted each average tariff by its imports from other countries to obtain weighted average applied tariffs. These estimated weighted average tariffs are the tariffs in the no-Brexit equilibrium state based on tariffs at which countries were trading before Brexit happened.

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}. I choose to match two key targeted data moments in the 2015 Eora matrix: (i) the intermediate input values and (2) the final demand values. To match these data moments I use, the assigned and calibrated 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}. 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.

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 four possible Brexit scenarios. Table 4 provides a sector-level tariff for applied

[8]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 base on MFN tariffs

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

Table 3: Calibrated Iceberg Trade Cost from Model

Sector	Final Demand	Input
AG	22.336	25.433
FSH	31.526	79.015
MINQ	4.475	4.557
FDB	47.767	151.513
TWAP	15.030	45.490
WOPA	12.564	15.968
PECH	7.673	8.388
METP	5.782	3.703
EMCH	36.199	36.675
TPEQ	17.166	12.021
OTHM	18.691	70.562
SERV	44.979	94.400
Moments	Final demand	Intermediate Input

and MFN aggregated across countries.

4.3.1 Tariffs

Soft Brexit: Import tariffs do not change in the soft Brexit scenario because the UK retains single market access to the EU. So, there is a zero tariff between the UK and EU, and no-Brexit state tariff remains the same for all countries

Hard Brexit: Tariff changes and is estimated based on two data sources: EU's most-favored-nation (MFN) tariff schedule for 6-digit HS goods industries;[10] and 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 similar to that in section (3.3). First, I calculated average MFN tariffs between the UK and EU, between the UK and selected countries, and the rest of the world goods trade using WTO and COMTRADE data. I then computed weighted average MFN's 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 Japan tariff on UK goods is weighed by imports from Japan and UK import from Japan is weighed by UK's import. 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

[10] MFN is sourced from World Trade Organization (WTO) - Integrated Database (IDB)

exports since there are no tariffs in services trade. I assume tariff between the EU27 and other countries and between different countries remains at the no-Brexit state tariff.

UK-USA FTA: The UK and USA negotiate on 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 5 percent for trade between the UK and the USA and assume that all other tariff remains at the no-Brexit state.

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 tariff between all other countries remains at the no-Brexit state tariff.

Table 4: No-Brexit and MFN Tariff Estimates

	APP Tariff	**MFN Tariff**
AG	1.0494	1.0481
FSH	1.0427	1.0458
MINQ	1.0480	1.0550
FDB	1.0488	1.0574
TWAP	1.0400	1.0581
WOPA	1.0474	1.0447
PECH	1.0452	1.0488
METP	1.0439	1.0453
EMCH	1.0444	1.0468
TPEQ	1.0433	1.0454
OTHM	1.0525	1.0493
SERV	1.0427	1.0449

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 my non-tariff trade barriers based on the calibrated iceberg trade cost in section (4). So, I assume 80 percent of the iceberg trade cost are NTBs, and the remaining are its other components.

Soft Brexit: The UK will face NTBs in trade with the EU27, so I assume NTBs increase by 10 percent for trade between UK-EU27 and between the UK and other countries. Yet, it remains the same for trade between EU27 and other countries and between other countries.

Hard Brexit: NTBs for trade between the UK and EU27 will increase by a larger amount than in the case of soft Brexit. Therefore, I assume a 20 percent increase in NTBs for trade between the UK and EU, and between the UK and other countries.

UK-USA FTA: UK-USA NTBs is assumed to fall, and this may also raise the UK-EU27 NTBs. I assume a 5 percent decrease in NTBs between UK and USA trade, and a 5 percent increase in NTBs for trade between the UK and EU27 and trade between the UK and other countries.

UK-EU-USA FTA: In this scenario NTBs for trade between these three countries reduces considerably. I assume a 5 percent reduction in NTBs for trade between these countries, ceteris paribus.

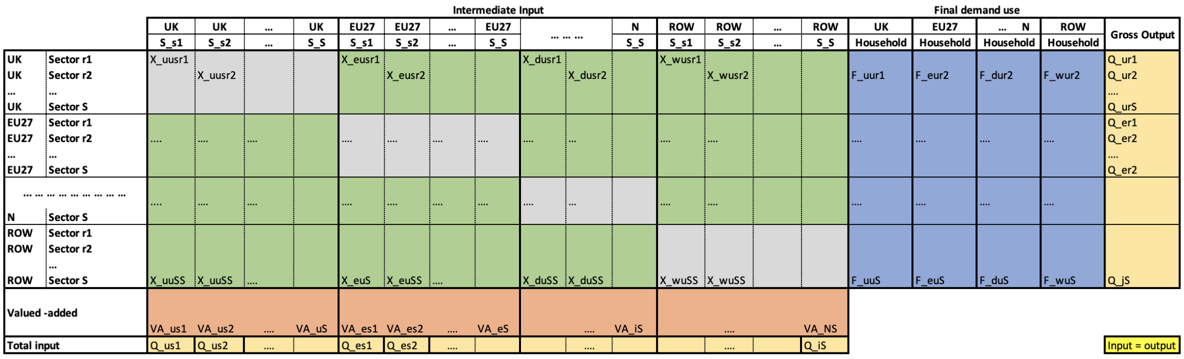
5 Unpacking Measures of GVC

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,[11] 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 2 considers a world economy with N countries and S sectors.[12] 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}. The final demand block, which is to the right of the input 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 use from sector r in a country j and column-wise shows the value-added and intermediate input used in production by sector s in country i. The value-added of country i is $1 \times N$ row vector. The sum of columns $N \times S + N$ in each row of the table gives the gross output Q_j^r, which is equal to the sum of rows in each column.

[11] Industries and sectors are used interchangeably

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

Figure 3: Visual Representation of Model in Eora Table



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

$$Q_i^s = \sum_{r=1}^{S} \sum_{j=1}^{N} X_{ij}^{sr} + VA_i^s \tag{26}$$

The following two subsections elaborate on estimating the measures of GVC participation and positioning from the Eora data.

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:

$$\text{Backward Participation Index} = \frac{\text{FVA}}{\text{Gross Exports}} \tag{27}$$

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 embodied in those same 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 that are exported globally and are consumed by both domestic and foreign firms. This measure excludes domestic value-added included in final goods that are shipped directly to consumers. Mathematically specified as:

$$\text{Forward Participation Index} = \frac{\text{DVA}}{\text{Gross Exports}} \tag{28}$$

The larger the ratio of the backward and forward participation of a particular country, 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.

Figures 2 presents a straightforward measure of upstreams, 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 upstreamness 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 upstreamness of country-sector pairs beyond how the output is directly sold to final consumers or other sectors, and VAGO does not account for a country-sector pair variation in the upstreamness of inputs used in production.

There are other different measures of upstreamness 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:

$$a_{ij}^{sr} = \frac{X_{ij}^{sr}}{Q_j^s} \tag{29}$$

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 and divided all by Q_j^s.

$$U_i^r = 1 * \frac{F_i^r}{Q_i^r} + 2 * \frac{\sum_{s=1}^{S} \sum_{j=1}^{N} a_{ij}^{sr} F_j^s}{Q_i^r} + 3 * \frac{\sum_{s=1}^{S} \sum_{j=1}^{N} \sum_{t=1}^{S} \sum_{k=1}^{N} a_{ij}^{sr} a_{jk}^{st} F_k^t}{Q_i^r} + \ldots\ldots \tag{30}$$

Where $U_i^r \geq 1$ and lower values implies that final demand, on average, occurs less on production stages upstream from final demand of sector r in 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:

$$b_{ij}^{sr} = \frac{X_{ij}^{sr}}{Q_i^s} \tag{31}$$

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 divided each by Q_j^s.

$$D_j^s = 1 * \frac{VA_j^s}{Q_j^s} + 2 * \frac{\sum_{s=1}^{S}\sum_{j=1}^{N} b_{ij}^{sr} VA_i^r}{Q_j^s} + 3 * \frac{\sum_{r=1}^{S}\sum_{i=1}^{N}\sum_{t=1}^{S}\sum_{k=1}^{N} b_{ki}^{tr} b_{ij}^{sr} VA_k^t}{Q_j^s} + ... \tag{32}$$

As in the first measure, $D_j^s \geq 1$, and lower values means 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

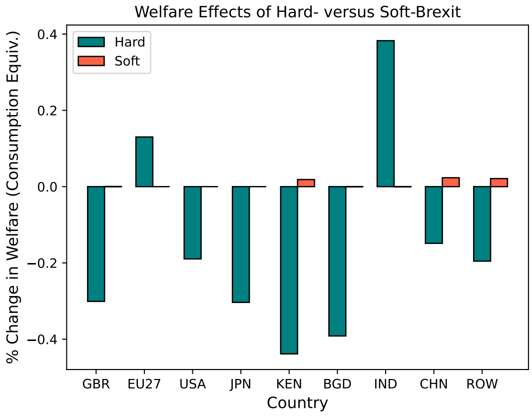
I measure welfare effects in total consumption equivalence by a backward-looking method using the utility function in equation (1). This measure compares the welfare in the no-Brexit equilibrium state to the welfare in the different potential post-Brexit scenarios. It is expressed as a percent of their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

$$\hat{W} = \frac{C'}{C} \tag{33}$$

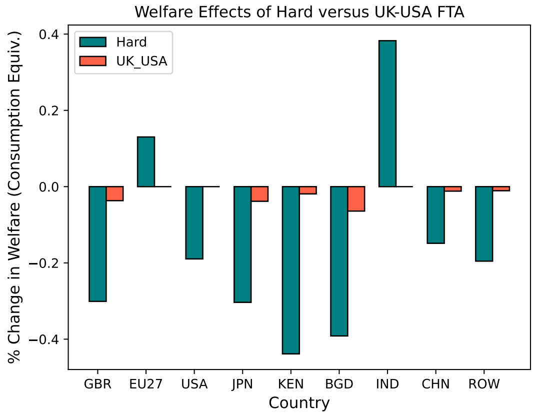
The baseline case that all other post-Brexit scenarios were compared to is the hard-Brexit equilibrium state. Table 7 in appendix reports the welfare implications from the changes resulting from hard-Brexit, soft-Brexit, UK-USA FTA, and UK-EU-USA. Hard Brexit leads to welfare losses for all countries except for India and EU27. These losses range from 0.005 to 0.4385 percent, with an average welfare loss of 0.2166 percent. Soft-Brexit was more on the gain side of welfare, with only two countries (Iceland and Mauritius) having losses in this state of Brexit. However, the magnitude of gains was somewhat smaller compared to the losses in the hard-Brexit state. The average increase across countries for soft Brexit is 0.0204.

Figure 4, depicts the welfare changes of the different scenarios for eight of the countries, with hard Brexit compared to all other scenarios. The UK-USA and UK-EU-USA states produce

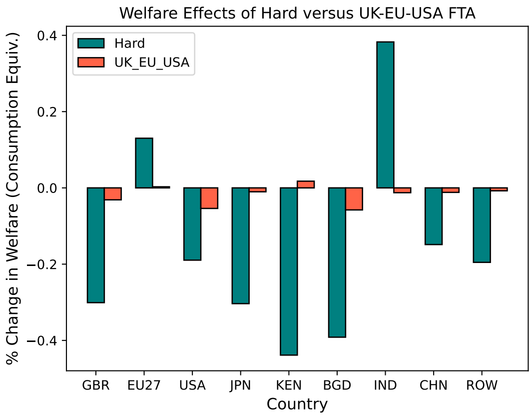
Figure 4: Welfare Changes from Brexit Scenarios



(a) Hard vs Soft



(b) Hard vs UK-USA FTA



(c) Hard vs UK-EU-USA FTA

similar results with more welfare losses than gains in welfare. The magnitude of losses and gains are almost the same for both UK-USA and UK-EU-USA FTA's. The UK and USA forming a bilateral agreement led to a gain for the USA and a loss of 0.0367 percent for the UK. However, if these three big economies start a trilateral deal (UK-EU-USA), both the UK and the USA will face welfare losses of 0.0313 and 0.0539 percent. The EU27 either gains in welfare or remains unaffected in all the possible scenarios analyzed. China will face a more significant gain in soft-Brexit, 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 compared to the losses in hard Brexit. Japan will face a loss in all scenarios except in soft Brexit, where it remains unaffected. In the case of Kenya, it will face a significant loss in the form of hard Brexit but gains in soft Brexit and UK-EU-USA FTA states.

Overall, hard Brexit is the worst-case scenario 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 (0.0015) and Mauritius (0.0011) were minimal. The welfare losses for this paper are more minor compared to estimates by (Steinberg, 2019), that find a welfare loss of 0.4 percent 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., 2016b) more significant estimates for both soft and hard Brexit. However, these estimates are more significant than CP estimates of 0.1 percent for US gains from NAFTA. Other papers compared to in literature are Di Giovanni et al. (2014) with welfare gain of 0.4 percent from trade with China.

7 Results: GVC Impact of Brexit

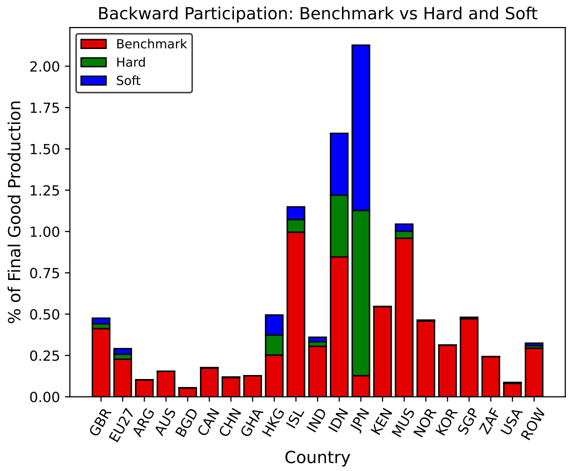
I focus only on Hard- and Soft-Brexit scenarios to estimate the effects on GVC participation and positioning of countries in the Eora database. This is because the impact arising from the UK-USA and UK-EU-USA FTA were minute, and other countries are somewhat unaffected. Also, for the change in tariff, I use the MFN tariff for trade between the UK and EU only in hard-Brexit, whereas all other trading interactions remain at the no-Brexit state tariff. Therefore, the changes in the GVC participation and positioning have to do more with changes in NTBs. I increased NTB by 20 percent for hard Brexit and 10 percent for soft Brexit, making the two less comparable as the changes were minimal.

7.1 GVC Participation Implications

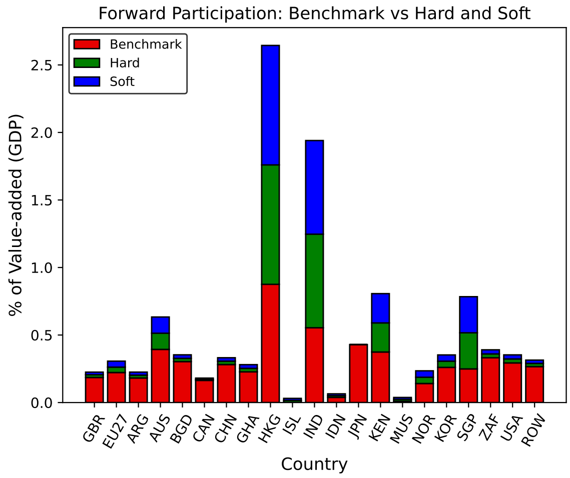
I begin in Figure 5 by plotting the changes in backward and forward GVC participation indexes for 20 of the selected countries and the remaining rest of the world in the Eora data sample. As earlier discussed, the backward GVC participation index measures the extent to which a country's final demand production uses imported inputs. The forward GVC participation index measures the proportion of domestic value-added exported embodied in intermediate input.

Figure 5 indicates a fall in backward participation for all countries in all scenarios except for Japan. But its forward participation falls drastically. At the benchmark equilibrium, Japan is integrated less at the backward participation than at the forward participation. But, the country will move farther downstream and remain less affected at upstream after Brexit. Indonesia has

Figure 5: GVC Participation Changes from Brexit Scenarios



(a) FVA



(b) DVA

a lower fall in backward participation for both hard- and soft Brexit. Hard- and soft-Brexit produces similar changes in GVC participation for both forward and backward involvement. This may be due to the minor difference of 0.1 percent increment of NTBs between hard- and soft-Brexit scenarios. After both hard- and soft-Brexit, India and Hong Kong, which are more upstream in GVCs, will remain more actively engaged in GVCs.

At the benchmark equilibrium, most countries are more actively engaged in backward participation (downstream) than forward participation (upstream). Some countries like Canada, Ghana, Kenya, Norway, Singapore, South Korea, the USA, etc., have minimal change in backward participation. The USA, the world's largest economy, is the least integrated into backward participation, followed by Bangladesh. But the two countries are unparalleled considering the economy and population size. The USA is also less integrated into forward participation but more actively engaged than in backward participation. Both 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 Table 3 in the appendix.

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, it is imperative to estimate the position index in conjunction with the participation index to get a holistic view of how it is integrated into global production.

Table 5: GVC Positioning Measure: Upstreamness and Downstreamness

Country	Calibrated	Hard	Soft	Calibrated	Hard	Soft
	Upstream	Upstream	Upstream	Downstream	Downstream	Downstream
GBR	2.0767	3.5614	3.5820	2.2087	3.4657	3.4587
EU27	1.9605	4.6445	4.6453	2.1227	4.6946	4.6987
USA	1.7793	1.8806	1.8806	1.7892	1.8818	1.8818
JPN	2.9129	7.8055	7.8059	1.3464	9.0476	9.0483
KEN	2.1091	3.7299	3.7292	1.7345	1.0004	1.0004
BGD	1.6811	1.6938	1.6944	1.7079	1.6301	1.6300
IND	2.0181	1.8725	1.8706	1.5739	1.0988	1.0993
CHN	2.5399	2.7239	2.7240	2.5964	2.7026	2.7026

Table 5 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 Table 9 in the appendix. Both hard- and soft-Brexit produce similar results due to the tiny difference of 0.1 percent in NTBs. In general, the pattern of changes in positioning is the same for all the countries, with an increase in production staging distance, following Brexit. The USA is not well integrated into GVCs even with a 5.7 and 5.2 percent move upstream and downstream after soft- and hard Brexit. Japan stands out as a country that records a significant increase in its production staging according to upstream and downstream positioning after Brexit.

8 Conclusion

This paper builds a quantitative model of trade policy shock with input-output linkages to examine the effect of Brexit not limited to the UK and EU only. The impact of Brexit is quantify on welfare and global value chain participation and positioning measures. The model features four potential outcomes for Brexit: soft Brexit, in which tariff is free, but non-tariff trade barriers increase between the UK and the EU, all other countries trading with the UK; hard Brexit, in which both tariff and non-tariff trade barriers substantial increase; UK-USA FTA, tariff and non-tariff are reduced for trade between the UK and EU. and finally UK-EU-USA FTA, no tariff between these three countries and non-tariff trade barrier falls.

The model predicts that Brexit will have a significant impact on the welfare of other third countries, with more losses in the hard-Brexit scenario and more minor losses in the soft-Brexit scenarios. The findings indicate that hard Brexit is the worst-case scenario, with losses ranging from 0.005 to 0.4385 and an average loss of 0.2166. On the other hand, soft Brexit is the best case. Finally, this paper contributes to knowledge on the participation and positioning of countries and sectors in GVCs. The results show that GVC participation and positioning changes following soft and hard Brexit, with a considerable difference on countries other than UK and EU27. Countries most impacted are Japan, India, Hong Kong, etc. The USA is less integrated into GVC participation both in the no-Brexit and post-Brexit scenarios state.

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Appendix A Tables

Table 6: Eora Data: Final Demand and Value-added Shares in Gross Output

Country	Final Demand to Gross Output	Value-added to Gross Output
GBR	0.4673	0.3838
EU27	0.5121	0.4430
ARG	0.6279	0.6274
AUS	0.5101	0.4955
BGD	0.5998	0.5907
BRA	0.5044	0.5022
KHM	0.5306	0.5144
CAN	0.5253	0.5281
CHN	0.3861	0.3748
EGY	0.6556	0.5841
GHA	0.6395	0.6056
HKG	0.0801	0.7472
ISL	0.8336	0.0040
IND	0.3582	0.6884
IDN	0.7992	0.1500
JPN	0.0134	0.8454
KEN	0.3134	0.4545
MUS	0.7365	0.0411
MAR	0.5824	0.5750
NZL	0.4874	0.4478
NOR	0.3757	0.3054
PAK	0.5454	0.4302
KOR	0.3436	0.3208
RUS	0.4850	0.5012
SGP	0.5502	0.4245
ZAF	0.5080	0.4818
LKA	0.6921	0.6524
THA	0.5009	0.4372
TUR	0.7034	0.6878
ARE	0.5836	0.5219
USA	0.5691	0.5633
VNM	0.5382	0.5708
ROW	0.5446	0.4880

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

Country	Hard	Soft	UK-US	UK-EU-US
GBR	-0.3009	0.0004	-0.0367	-0.0313
EU27	0.1302	0.0000	0.0000	0.0029
ARG	-0.2899	0.0382	-0.0390	-0.0337
AUS	-0.2944	0.0005	-0.0160	-0.0114
BGD	-0.3915	0.0001	-0.0641	-0.0578
BRA	-0.2752	0.0001	-0.0471	-0.0446
KHM	-0.0048	0.0581	-0.0004	0.0111
CAN	-0.2209	0.0526	-0.0533	-0.0432
CHN	-0.1486	0.0233	-0.0118	-0.0118
EGY	-0.1931	0.0318	-0.0320	-0.0262
GHA	-0.1631	0.0404	-0.0411	-0.0330
HKG	-0.1409	0.0000	-0.0019	0.0074
ISL	-0.2838	-0.0015	0.0008	0.0010
IND	0.3827	0.0001	0.0000	-0.0126
IDN	-0.0614	0.0244	-0.0128	-0.0345
JPN	-0.3035	0.0000	-0.0384	-0.0102
KEN	-0.4385	0.0186	-0.0190	0.0176
MUS	-0.0845	-0.0011	0.0071	0.0023
MAR	-0.3970	0.0334	-0.0410	-0.0345
NZL	-0.1791	0.0561	-0.0572	-0.0438
NOR	-0.1085	0.0209	-0.0124	-0.0186
PAK	-0.2538	0.0405	-0.0408	-0.0303
KOR	-0.2139	0.0107	-0.0207	-0.0131
RUS	-0.1094	0.0521	-0.0532	-0.0505
SGP	-0.1920	0.0255	-0.0263	-0.0186
ZAF	-0.3195	0.0009	-0.0270	-0.0244
LKA	-0.0428	0.0383	-0.0388	-0.0310
THA	-0.1037	0.0209	-0.0207	-0.0138
TUR	-0.4353	0.0235	-0.0355	-0.0290
ARE	-0.1948	0.0227	-0.0231	-0.0174
USA	-0.1895	0.0000	0.0000	-0.0539
VNM	-0.1854	0.0207	-0.0083	-0.0011
ROW	-0.1953	0.0211	-0.0107	-0.0076

Table 8: Change in GVC Participation Indexes from Post-Brexit Scenarios

	Backward GVC Participation			**Forward GVC Participation**		
Country	**Benchmark**	**Hard**	**Soft**	**Benchmark**	**Hard**	**Soft**
GBR	0.412683	0.028691	0.034384	0.185645	0.019983	0.019597
EU27	0.227229	0.031103	0.033019	0.222304	0.039856	0.044391
ARG	0.102205	0.000223	0.000223	0.181863	0.020992	0.022513
AUS	0.154037	0.000270	0.000270	0.393483	0.119889	0.120022
BGD	0.053322	0.000021	0.000021	0.303360	0.023666	0.026294
BRA	0.075787	0.000145	0.000145	0.243824	0.018800	0.020098
KHM	0.130583	0.000018	0.000018	0.220267	0.019215	0.021095
CAN	0.173637	0.001515	0.001515	0.163935	0.008384	0.008664
CHN	0.116551	0.001691	0.001692	0.281460	0.024677	0.025600
EGY	0.178872	0.000017	0.000018	0.312465	0.026862	0.029393
GHA	0.126910	0.000018	0.000018	0.227327	0.025756	0.027549
HKG	0.252459	0.121306	0.121335	0.875366	0.884461	0.884452
ISL	0.996023	0.076579	0.076662	0.001108	0.014837	0.014839
IND	0.305094	0.027551	0.027682	0.553943	0.692839	0.693386
IDN	0.846430	0.373743	0.373743	0.038159	0.013158	0.013169
JPN	0.127702	1.000000	1.000000	0.429402	0.000000	0.000000
KEN	0.545521	0.000043	0.000043	0.374295	0.215380	0.216879
MUS	0.958916	0.043055	0.042852	0.010044	0.013724	0.013839
MAR	0.117471	0.000092	0.000093	0.253529	0.020989	0.022931
NZL	0.204131	0.000621	0.000621	0.210652	0.027931	0.029473
NOR	0.458479	0.002915	0.002884	0.141007	0.046268	0.047529
PAK	0.279244	0.000007	0.000007	0.255299	0.021339	0.023978
KOR	0.311489	0.000914	0.000918	0.260358	0.045950	0.046183
RUS	0.121950	0.000642	0.000642	0.324538	0.041702	0.042449
SGP	0.471676	0.004707	0.004708	0.249088	0.267354	0.267361
ZAF	0.242470	0.000368	0.000376	0.331728	0.028290	0.030387
LKA	0.119574	0.000054	0.000054	0.240910	0.036528	0.041184
THA	0.268145	0.000456	0.000456	0.209711	0.030764	0.031661
TUR	0.125514	0.000197	0.000199	0.219273	0.024312	0.026619
ARE	0.220645	0.000156	0.000156	0.345594	0.039451	0.039760
USA	0.080890	0.003018	0.003018	0.293415	0.029358	0.030164
VNM	0.143015	0.000113	0.000113	0.344479	0.032547	0.033979
ROW	0.294009	0.015216	0.015301	0.266159	0.023555	0.024573

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

	Upstream Position			Downstream Position		
Country	**Benchmark**	**Hard**	**Soft**	**Benchmark**	**Hard**	**Soft**
GBR	2.0767	3.5614	3.5820	2.2087	3.4657	3.4587
EU27	1.9605	4.6445	4.6453	2.1227	4.6946	4.6987
ARG	1.6309	1.6760	1.6756	1.6297	1.4938	1.4938
AUS	1.9887	1.9988	1.9988	1.9854	1.9879	1.9879
BGD	1.6811	1.6938	1.6944	1.7079	1.6301	1.6300
BRA	1.9841	1.9389	1.9389	1.9878	1.9083	1.9083
KHM	1.9049	1.8789	1.8791	1.9255	1.7929	1.7928
CAN	1.9049	1.8467	1.8467	1.8913	1.8238	1.8238
CHN	2.5399	2.7239	2.7240	2.5964	2.7026	2.7026
EGY	1.5627	1.5038	1.5036	1.6660	1.4507	1.4507
GHA	1.5968	1.7610	1.7604	1.6479	1.4750	1.4750
HKG	2.2337	2.0453	2.0453	1.5480	1.2838	1.2839
ISL	1.3365	1.0302	1.0303	2.6161	1.1874	1.1878
IND	2.0181	1.8725	1.8706	1.5739	1.0988	1.0993
IDN	1.5600	1.4540	1.4540	2.4451	1.5694	1.5695
JPN	2.9129	7.8055	7.8059	1.3464	9.0476	9.0483
KEN	2.1091	3.7299	3.7292	1.7345	1.0004	1.0004
MUS	1.5926	1.2527	1.2546	2.5277	1.0537	1.0534
MAR	1.7448	2.0389	2.0386	1.7687	1.5769	1.5768
NZL	2.0581	2.3436	2.3434	2.1579	2.0214	2.0213
NOR	2.4191	3.0341	3.0338	2.6163	2.5779	2.5774
PAK	1.8558	2.0009	2.0030	2.0625	1.7896	1.7884
KOR	2.7236	2.8930	2.8930	2.7746	2.8705	2.8706
RUS	2.0642	1.9161	1.9161	1.9931	1.9098	1.9098
SGP	1.8440	1.6107	1.6108	2.1632	1.5707	1.5707
ZAF	1.9877	1.8712	1.8715	1.9853	1.7993	1.7992
LKA	1.4847	1.5312	1.5349	1.5531	1.3965	1.3959
THA	2.0061	2.1478	2.1478	2.1724	2.0710	2.0710
TUR	1.4795	1.5242	1.5242	1.5208	1.3093	1.3092
ARE	1.7884	1.7499	1.7499	1.8449	1.7378	1.7378
USA	1.7793	1.8806	1.8806	1.7892	1.8818	1.8818
VNM	1.9106	1.7906	1.7904	1.7983	1.7150	1.7150
ROW	1.8817	2.3469	2.3468	1.9338	2.3331	2.3334