# UK Industry and Welfare Effects of a 'Brexit Trade Cost Shock'

Kurt Kratena, CESAR
Fuhrmannsgasse 2a, A-1080 Vienna (Austria)
www.cesarecon.at (kurt.kratena@cesarecon.at)

***Abstract***:

The substitution between different sources of origin of goods either in Armington or in gravity equations is the core of trade models used in welfare analysis of trade. The recent trade literature (Costenot and Claire-Rodriguez, 2014; and Caliendo and Parro, 2015) emphasizes the importance of disaggregation by industries/goods and of international linkages via trade in intermediates. These two features introduce substitution between different goods in total goods and factor demand of users (households and firms) that substantially increases the welfare impacts of trade. This paper uses a one region model (UK) based on Caliendo and Parro (2015) with different sources of origin of imports and of destination of exports for analyzing the welfare impact of trade cost shocks. The core of the model is an input-output framework that integrates (i) substitution between capital, labour and intermediates in production, (ii) substitution between different goods in household consumption, and (iii) substitution between domestic goods and different sources of imports for each user. In contrast to models like Caliendo and Parro (2015) the economy is not in full employment equilibrium and macroeconomic closure can include fixed trade balances or not. The specification for substitution in production and consumption goes beyond the standard Cobb-Douglas function by applying an AIDS model in consumption and a Translog function in production. The trade cost shock in a ‚hard Brexit‘ scenario (Dhingra et al, 2017) leads to a welfare loss for UK households of 1.8%. Trade effects are smaller than in the existing literature. Trade diversion results in an import shift towards imports from non-EU countries (+ 8%), whereas exports to non-EU contries also suffer (- 5%) from the UK price increase.

## Introduction

The trade literature of the last decades has significantly changed our concept of the basics of international trade. Especially the increase in intra-industry trade has been dominated by an increase in trade of intermediate products (Feenstra, et al., 2005). That led in a first step to the formulation of trade models with international outsourcing and fragmentation and in a second step to the concept of global value chains. In parallel to these developments in trade theory, significant progress in building multi-regional trade databases has been achieved. Especially, the construction of multi-regional input-output (MRIO) databases has been enforced. One of the most widely used MRIO databases in trade analysis is the World Input-Output Database WIOD (for example in: Costenot and Rodriguez-Clare, 2014, Caliendo and Parro, 2015). The basic idea of the value chain concept is based on the international or multi-regional input-output (MRIO) linkages, where all flows from each user in each country to all the other users in all countries are accounted for. The IO linkages are treated as fixed relationships in value added chains, where substitution on the side of users between different sources of production does not take place. Nevertheless, the MRIO model can be extended to incorporate substitution elasticities between domestic and imported products, and between production factors and consumption goods as well, as Vandenbussche, et al. (2017, 2018) have recently shown.

In CGE models substitution in trade between domestic and imported products as well as different countries of import origin, is a standard feature. In most standard CGE models it is captured via the Armington assumption (Armington, 1969) at the level of goods. The Armington elasticity values inserted in most models stem from a limited number of sources (e.g. Reinert and Roland-Holst, 1992) and – as for example Turner, et al., (2012) have shown - not much effort has been put into econometric estimation of relevant (for the model in question) and statistically sound elasticity values. Another line of research about substitution in trade is the estimation of gravity equations and their integration into CGE models (Baier et al., 2008; Balistieri, et al., 2011; Di Giovanni and Levchenko, 2009; and Caliendo and Parro, 2015). These models are based on the theory of the seminal work by Eaton and Kortum (2002) and on the empirics of numerous recent studies applying advanced econometric estimation methodology for deriving trade elasticities. As Caliendo and Parro (2015) as well as Vandenbussche, et al. (2017) emphasize, superficially the Armington function and the gravity equation of the Eaton and Kortum model have almost the same specification. Costenot and Rodriguez-Clare (2014) formulate a general ‚gravity equation‘ that can be further specified in detail as an Armington function or as a function of trade flows and expenditure shares in the spirit of the Ricardian model, designed by Eaton and Kortum (2002). The main difference is that the Ricardian model of Eaton and Kortum makes the source country of the origin of imports endogenous, according to the extensive margin of prices for goods from different countries, whereas in the Armington model goods from different origins are different goods and only the intensive margin of prices governs the allocation. Two relevant recent application of gravity models to the issue of Brexit, fully integrated into a simple CGE framework, are Vandenbussche, et al. (2017) and Pfaffermayr and Oberhofer (2019). As Costinot and Clare-Rodriguez (2014) have pointed out, the most relevant extensions in many of these new models is extending the one good (aggregate) perspective to a model with production of intermediates and IO linkages and firm entry. This is done by adding the features of intermediate production with many industries and the resulting IO linkages to a comparative static model with multi-regional trade. An important result of this extension is that these additional features tend to increase the estimates of welfare impacts of free trade. At the same time, these features introduce additional levels of substitution between goods in household consumption and factors in production and therfore additional sensitivity of the results on the values of elasticities. For consumers' preferences and factor-substitution in the production of intermediates these models usually apply Cobb-Douglas functions. The elasticity of substitution in trade is usually based on a CES functional form (Armington or gravity). As already Eaton and Kortum (2002) have shown, these models incorporate several channels of price spillovers and simultaneuously explain the distribution of output prices, composite good prices and trade flows across countries.

In this paper, the modelling features of substitution (i) between different sources (countries) of imports and domestic flows for each single user, (ii) between different goods in consumption and (iii) between different factors of production have been integrated into an IO framework for one region (UK). The main difference in this approach to the existing literature is that we add functions that allow for substitution at different levels to the IO framework and not the other way round, i.e. adding IO linkages to a standard trade model. In that sense, this study is in line with the work of Vandenbussche, et al. (2017, 2018). Theoretically, this study is strongly based on the Eaton and Kortum model, as recently applied in Caliendo and Parro (2015), but without the Ricardian feature of the extensive margin of prices. The relevance of having the IO framework as the core of the model is that important feedback mechanisms from trade cost shocks on production structures become explicit. First, the structure of the IO price model is kept and is combined with a flexible production function. The price feedback from output prices on input prices is in fact also considered in Caliendo and Parro (2015), as far as the production of intermediates is concerned (their equation (2), p. 7). In this study, this is extended to the production of capital goods, as capital is also a factor of production in our model. Second, the substitution effects between labour, capital and intermediates has an important explicit repercussion on the IO system, both on final demand (capital formation) and on the matrix of IO coefficients (intermediates). The impact on intermediates together with substitution in trade exerts a feedback on domestic input-output coefficients in our model and thereby on domestic output. The feedback mechanism works on input-output coefficients, because the substitution in trade is implemented at the level of each industry. This is a different type of feedback from the one present in other CGE models or models of the Eaton and Kortum-type (e.g. Caliendo and Parro, 2015), where domestic output is not an explicit variable, and labour input is derived from the side of labour supply, thereby implicitly assuming full employment. In this study, the IO equation determines domestic output by letting the substitution mechanisms operate on domestic IO coefficients. Changes in outputs by industry have an impact on employment and income generated in production, and also determine the welfare effects of trade.

Besides this important issue of capital goods and trade substitution at the level of users, this study goes beyond the existing literature by using two different specifications for substitution elasticities in production as well as in consumption. Therefore, we can test for the sensitivity of aggregate and industry impacts on substitution parameters others than the trade elasticities. One specification applies the standard Cobb-Douglas function applied in the literature, whereas the alternative specification integrates a Translog function in production and an Almost Ideal Demand System (AIDS) in consumption.

The most important shortcoming in this study compared to the existing literature, is that it only uses a one-country perspective for the UK with imports from and exports tothe EU27 and the Rest of World (RoW), instead of a MRIO model. This is based on a 'small country assumption' in the sense that changes in UK output and prices do not have an important impact in the total EU27 economy and the RoW. This assumption introduces biases of overestimation as well as of underestimation of the welfare effects of trade. The most important potential underestimation stems from omitting all kinds of feedback effects from outside the UK on the UK price system. That includes the direct feedback via trade flows as well as indirect effects stemming from price spillovers between different countries outside the UK. A potential overestimation could occur, as we use the UK price effect as the signal for other countries to substitute imports from the UK by goods from other sources of origin. In the logic of our model it is the relative price of UK goods to the composite goods price of the importers that determines substitution in trade flows. In the setting of the model used in this study, one cannot correct for the bias of underestimation, as the other countries are not modelled at the same level of detail as the UK. Comparing the results of this study to those of a study that actually uses the same regional structure, but in a fully multi-regional specification (Pfaffermayr and Oberhofer, 2019), one can nevertheless draw some conclusions about the magnitude and importance of the omissions. The implicit bias of an overestimation of the reaction in UK exports resulting from not considering the relative price effect (UK price/importer composite price) is corrected by adjusting the trade elasticities in the case of exports.

The comparative static model is then used for simulating a 'hard Brexit' trade cost shock, using the data from Dhingra et al. (2017) for tariffs on exports and imports, non-tariff barriers as well as trade cost dynamics for EU-members in the case of a 'hard Brexit'. The aggregate results obtained are slightly higher than those in Dhingra et al. (2017) for trade cost-shocks in the same scenario (‚hard Brexit‘), with consumer welfare effects between -1.8% and -3.7%, and GDP effects ranging from -1.9% to -3.0%. The aggregate effects are slightly lower, if instead of Cobb-Douglas functions with unity elasticities more flexible functional forms with heterogenous elasticities are introduced in the production and consumption parts of the model.

In general, the trade effects in this study are smaller than those from comparable studies like Dhingra et al. (2017) and Pfaffermayr and Oberhofer (2019). This might partly be due to a different specification of the gravity model (Pfaffermayr and Oberhofer, 2019) and to additional macroeconomic restrictions (balanced trade) in Dhingra et al. (2017), which are absent in this study. Another important difference in results is that positive trade diversion effects (shift from trade with the EU to RoW) can only happen for UK imports but not for UK exports in the model used here. This is due to the gravity equation used here, where mainly price effects govern substitution in trade flows. UK prices will always rise more than prices in other countries in a ‚Brexit scenario‘, thereby unambigously dampening exports to the RoW as well (not only to EU).

## 1.The IO modelling framework with trade

Starting point is an IO model for the UK (the domestic economy, *d*) with a disaggregation of the import matrix (goods * users) between the EU27 and the RoW. In general, *i,j* denote goods/industries, and *n* countries with *d* as the domestic economy, *EU* as the EU 27 without the UK, and *RoW* as the rest of the world (*n = d, EU, RoW*). The country index is used for variables of trade flows, in general. No country index is used for those variables (production and consumption) that are only defined for the UK. Besides that, the notation closely follows the model of Caliendo and Parro (2015) and covers household demand, production and demand of intermediate goods (IO linkages), trade flows, and equilibrium conditions for the economy.

The country index only plays a role for demand and substitution between different sources of goods demand (domestic and imports from the two different regions). The relevant trade flows are UK imports from *EU* and *RoW*, as well as exports to *EU* and *RoW*. The full model of consumption and production is only defined for the UK economy. Total output by industry *j* in the UK is given from the supply side (columns of the IO matrix) by:

$$Q^j = \sum_{i,n} X_n^{i,j} + w^j L^j + p^{j,K} K^j \tag{1}$$

The output is the sum of intermediate inputs of all goods *i* $X^{ij}$ from all countries *n* plus wages with wage rate *w* and employment *L* plus capital income with capitalk price $p^K$ (user costs) and capital stock *K*.

Total output by industry *i* in the UK (rows of the domestic part of the IO matrix) is given from the demand side by:

$$Q^i = \sum_j a_d^{i,j} Q^j + F_d^i \tag{2}$$

That represents the $i^{th}$ row of the IO equation $\mathbf{q} = \mathbf{A}_d\,\mathbf{q} + \mathbf{F}_d$, where **q** is the column vector of output and $\mathbf{A}_d$ and $\mathbf{F}_d$ are the matrix of domestic input coefficients ($a_d^{i,j}$) and domestic final demand respectivly. The *n* parts of the final demand matrix **F** comprise vectors of private consumption (**c**), public consumption (**g**), gross fixed capital formation (**cf**), changes in inventories (**st**), and exports to EU and RoW ($\mathbf{ex}_{EU}$, $\mathbf{ex}_{RoW}$). Substitution between intermediates and other production factors (labour and capital) takes place, and the bundle of total intermediates is defined by fixed technologies (Leontief). UK output is always determined by equation (2) and substitution in trade and in production operates on the domestic IO coefficients, $a_d^{i,j}$. It is only possible to use this specification, when one allows for substitution in trade at the level of each user (industry and final demand component). Standard CGE models and models of the Eaton and Kortum-type deal with trade substitution at the level of total demand for a good. This aggregate treatment of demand leaves IO linkages in the determination of domestic output out. In general, in the model presented here, the standard IO coefficients (input per unit of output) of intermediates from region *n*, $a_n^{i,j}$, can be decomposed into several parts:

$$a_n^{i,j} = s^{i,j}\, r^{jM}\, \pi_n^{i,j} \left(\frac{P^i}{P_n^i}\right) \tag{3}$$

The first multiplicative term ($s^{ij}\ r^{jM}$) represents the fixed input structure of intermediates ($s^{ij}$) combined with variable input coefficient $r^{jM}$, described in section 3. The $s^{ij}$ are the coefficients of a fixed input structure matrix **S** of intermediates representing the total technology ($\frac{X^{i,j}}{\sum_i X^{i,j}}$) of producing the intermediate bundle. This technology is fixed, but within this structure, substitution between different countries of origin producing these inputs, takes place. The bundle of intermediates can be substituted in production by labour and capital, therefore the input coefficient $r^{jM}$ (= $\frac{\sum_i X^{i,j}}{Q^j}$) is variable. The second multiplicative term ($\pi_n^{i,j}\ \left(\frac{P^i}{P_n^i}\right)$) represents substitution in trade. Deflating the expenditure share of industry *i*'s inputs for industry *j* from region *n* ($\pi_n^{i,j}$) with the corresponding prices ($P^i$ = composite good price and $P_n^i$ as the price of *i* purchased from region *n*) gives the volume shares of inputs by region in industry *j*.

Each user in the UK, i.e. each industry *j* and each final demand component *k* demands a composite good that is a CES aggregator over the the three regions (*d*, *EU*, *RoW*), where the good can be purchased from. The composite good $D$ is defined from the supply as well as from the demand side. The demand side equation is defined in analogy to equation (2). Total expenditure for good $j$ is the product $X^j = P^jD^j$ with $P^j$ as the composite price of $j$, but is determined in detail by users as in equation (2). The supply is the sum of all suppliers of good $j$ inside and outside the UK.

Prices of production in industry $i$ and region $n$, $p_{q,n}{}^i$, are augmented by specific iceberg transport costs ($d_n{}^i \geq 1$) and tariffs $\tau_n{}^i = (1 + tr_n{}^i) \geq 1$:

$$\kappa_n^i = \tau_n^i d_n^i \qquad (4)$$

The composite price of good $i$ for the UK is defined for each user (industry $j$ and final demand component $k$), including trade costs as:

$$P^{i,j} = P^{i,k} = A^i[\sum_{n=1}^{N} \left(p_{q,n}^i \kappa_n^i\right)^{-\vartheta^i}]^{-1/\vartheta^i} \quad ; \qquad n = d \qquad (5)$$

Where $\theta^i$ is the trade elasticity. The gravity equation of our model defines the expenditure shares of each user $j$ or $k$ for good $i$ from n, $\pi_n{}^{i,j} = X_n{}^{i,j}/X^{i,j}$ as a function of prices only:

$$\pi_n^{i,j} = \pi_n^{i,k} = \Pi^i \frac{\left(p_{qn}^i \kappa_n^i\right)^{-\vartheta^i}}{\sum_{n=1}^{N} \left(\left(p_{qn}^i \kappa_n^i\right)\right)^{-\vartheta^i}} \quad ; \qquad n = d \qquad (6)$$

The specifications in (5) and (6) differentiate by user, but still apply the same good-specific trade elasticity - measured by $\theta^i$ - across users. For UK exports, it is assumed that trade flows react to UK price changes (including trade costs) with adjusted parameters $\vartheta^{*i}$ to take into account that export tariffs on UK products also change the composite price in the other regions (*EU* and *RoW*), so that the relative price change is smaller than the change in UK prices.

## 2. Households

For households, two different specifications of preferences and of expenditure functions are used alternatively in the model. In the case of Cobb-Douglas preferences, UK consumers maximize their utility

$$u(C) = \prod_{j=1}^{J} C^{j^{\alpha^j}} \qquad (7)$$

with $C^j$ as the consumption composite good $j$ and - given Cobb-Douglas – with the restriction $\Sigma\alpha^j = 1$. Disposable income is fully spent on consumption $CP$ and is the sum of labour income, a part $s_y$ of capital income distributed to households, and of lump-sum distributed tariff revenues $Tr$:

$$YD = wL + s_y p_K K + Tr \qquad Tr = \sum_{j,m} \tau_m^j X_m^j \quad ; m = EU, RoW \qquad (8)$$

Income is in this study determined from the demand side. The level of output together with the input coefficient of labour (see below) determines labour income, and the same holds fore capital income. This is different from models like the one in Caliendo and Parro (2015), where labour is given from the supply side and domestic output is not a relevant variable. Macroeconomic closure in these models is not achieved by an income multiplier, but by an exogenously given total trade deficit and by total expenditure by regions $n$ and industry $j$ goods.

The alternative specification for consumer preferences assumes that consumers minimize their expenditure according to an indirect utility function (AIDS demand system) and combines that with the same income equation and consumption function. This AIDS model is defined at an aggregate level of few consumption categories (AIDS), that are defined by aggregation from the *j* goods:

$$p^{AIDS}C^{AIDS} = \left(\alpha^{AIDS} + \beta^{AIDS} log\left(\frac{CP}{P^{C}}\right) + \sum_{k=1}^{AIDS} \gamma^{AIDS,k}\, logp^{AIDS}\right) CP \tag{9}$$

The value shares for splitting up volume as well as price data from the *AIDS* categories tothe final level of *j* goods ($w^{j,AIDS}$) are aggregated via a Cobb-Douglas function. For the prices of the AIDS categories, that gives (with as $\Omega^{AIDS}$ a constant):

$$P^{AIDS} = \Omega^{AIDS} \prod_{j=1}^{J} P^{j,C^{w^{j,AIDS}}} \tag{10}$$

The consumption by *AIDS* category is finally split up into the *j* goods by applying the volume shares: $w^{j,AIDS}/P^{AIDS}$.

In both cases, total consumption in volumes. *C*, is defined by deflating consumption expenditure *CP* by the aggregate consumer price $P^C$, using expenditure shares and the composite goods prices of consumer goods, $p^{j,C}$, as defined in (5). The aggregate consumer price is in the Cobb-Douglas case given by:

$$P^{C} = \prod_{j=1}^{J} \left(\frac{p^{j,C}}{\alpha^{j}}\right)^{\alpha^{j}} \tag{11}$$

In the AIDS model, the price approximation formula of the Stone-price index is used:

$$P^{C} = e^{\left(\sum_{j} w^{j} logp^{j,C}\right)} \tag{12}$$

where $w^j$ are the expenditure shares ($p^{j,C}C^j/CP$) and $p^{j,C}$ are the composite goods prices. The expenditure shares in (12) are defined by: $w^{j} = \frac{p^{AIDS}C^{AIDS}}{CP} w^{j,AIDS}$.

## 3.Intermedate goods and prices

Intermediate goods are produced in all *n* regions and are used as a factor of production, together with labour and capital. Including capital is an important difference to other models, as it augments price and therefore welfare effects of trade. Production of intermediate and final goods is explicitely only defined for UK firms, by the unit costs of production that determine the output price $p_q^j$ in the UK, the other output prices are normalized and exogenous. In the Cobb-Douglas case that reads:

$$p_{q}^{j} = \Gamma^{j} w^{\gamma^{j,L}} p_{K}{}^{\gamma^{j,K}} \prod_{i=1}^{J} P^{i\gamma^{i,j}} \tag{13}$$

Here, $\Gamma^j$ is a constant and the Cobb-Douglas function implies: $\gamma^{j,L} + \gamma^{j,K} + \Sigma_i \gamma^{j,j} = 1$. Once the output prices, including trade and transport costs are given, the composite good price $P_n^j$ is derived from equation (5). In the Translog case, firms produce intermediate and final goods, based on the correesponding cost function. Factor demand is defined by value shares of inputs $v^j$:

$$v^{j.K} = \alpha^{j,K} + \gamma^{j.KK} log\left(p^{j,K}/p^{j,L}\right) + \gamma^{j.MK} log\left(p^{j,M}/p^{j,L}\right)$$

$$v^{j.M} = \alpha^{j,M} + \gamma^{j.MM} log\left(p^{j,M}/p^{j,L}\right) + \gamma^{j.MK} log\left(p^{j,K}/p^{j,L}\right)$$

$$v^{j,L} = 1 - v^{j,K} - v^{j,M} \tag{14}$$

The corresponding output price equation using the same notation as in (13) is:

$$logp^{j} = \Gamma^{j} + v^{j,K} logp^{j,K} + v^{j,L} logp^{j,L} + v^{j,M} logp^{j,M} \tag{15}$$

Note that price equation (15) is equivalent to (13), as the parameters $\gamma$ in the Cobb-Douglas function are identical to the value shares of the factors. The price of the total intermediate input $p^{j,M}$ in (15) is equivalent to the term $\prod_{i=1}^{J} P^{i}$ in (13). The input coefficient of intermediates in equation (3) $r^{jM}$ (= $\frac{\sum_i X^{i,j}}{Q^j}$) is derived by dividing the value share $v^{jM}$ by the bundle price of intermediates, $p^{jM}$. The latter is defined as the result of the loop of the IO price model:

$$\mathbf{p}^{j,M} = \mathbf{p}_{n}^{i} \mathbf{S}_{n}^{i,j} \tag{16}$$

The row vector of prices for goods *i* from region *n* ($\mathbf{p}_n^i$) contains the elements $\left(p_{q,n}^{i} \kappa_{n}^{i}\right)$ and the input structure matrix ($\mathbf{S}_n^{i,j}$) consists of the elements $s^{i,j}\ \pi_{n}^{i,j}\ \left(\frac{P^i}{P_n^i}\right)$. Substitution in trade leading to changes in expenditure shares for each user ($\pi_n{}^{i,j}$) therefore exerts a feedback mechanism on the vector of input prices, $\mathbf{p}^{j,M}$.

The second feedback stems from the price of capital goods

$$\mathbf{p}^{j,K} = \mathbf{p}_{n}^{i} \mathbf{B}_{n}^{i,j,K} \tag{17}$$

In (17) $\mathbf{B}_n^{i,j,K}$ is the investment coefficient matrix, depicting the structure of goods that enter intothe gross capital formation of each industry. The price $\mathbf{p}^{j,K}$ is defined as a normalized price in the base solution - like all other prices - and as a user cost of capital $\mathbf{p}^{j,K}(r + \delta)$ with $\delta$ as the industry-specific depreciation rate and *r* as the internal rate of return.

In (14), the parameters $\gamma^{j,KK}$, $\gamma^{j,LL}$ and $\gamma^{j,KL}$ determine the own and cross price elasticity of substitution between factors. The parameters $\gamma$ for intermediates (*j*,*M*) are given as residuals from the homogeneity restriction of the Translog model. The price elasticities are a combination of parameters and factor shares, the own and cross price elasticity for the factors *f* and $\phi$ are given with:

$$\epsilon^{j,ff} = \frac{\gamma^{j,ff + \left(v^{j,f}\right)^{2} - v^{j,f}}}{v^{j,f}} \quad ; \quad \epsilon^{j,f\varphi} = \frac{\gamma^{j,f\varphi + v^{j,f}\ v^{j,\varphi}}}{v^{j,\varphi}} \tag{18}$$

The only remaining exogenous prices are the trade cost augmented output prices of the other regions $p_{q,m}^{i} \kappa_{m}^{i}$ for *m* = *EU*, *RoW*, and the price of labour. The latter is given as the wage rate in equation (1) and is normalized for the Translog model. These price of labour can be seen as the numeraire of the model.

## 4. Welfare analysis

The complete model is made up of the equations for total UK expenditure, for UK output, composite goods prices and the gravity equation, as well as price, factor demand and consumption equations.

Total expenditure for good *j* is the product $X^j = P^j D^j$ and can be expressed by:

$$X^j = \sum_{i,n} a_n^{j,i} P^{j,i} Q^i + P^{j,k}\left(C^j + G^j + CF^j + EX_{EU}^j + EX_{ROW}^j\right) \tag{19}$$

with prices $P^{j,i}$ and $P^{j,k}$:

$$P^{i,j} = P^{i,k} = A^i \left[\sum_{n=1}^{N} \left(p_{q,n}^i \kappa_n^i\right)^{-\vartheta^i}\right]^{-1/\vartheta^i} \quad ; \qquad n = d$$

Total output for good *j* is

$$Q^j = \sum_i a_d^{j,i} Q^i + C_d^j + G_d^j + CF_d^j + EX_{d,EU}^j + EX_{d,ROW}^j \tag{20}$$

If re-exports are ruled out by the data set used (as in the case of this study), $EX_{EU}{}^j = EX_{d,EU}{}^j$ and $EX_{ROW}{}^j = EX_{d,ROW}{}^j$. The demand side of total expenditure for industry *j* goods is always defined in detail with intermediate demand ($\sum_{i,n} a_n^{j,i} P^{j,i} Q^i$ and $\sum_i a_d^{j,i} Q^i$ ) and final demand, as in other CGE models and Eaton and Kortum-type models. The difference between those models and the framework in this study is that domestic (UK) output is explicitly defined and together with factor demand (equation (13) or (14)) determines labour and capital income. Disposable household income, therefore, is a function of output changes that operate via domestic input-output coefficients $a_d^{j,i}$.

The full model that is used for welfare analysis additionally comprises the following equations:

Expenditure shares $\quad \pi_n^{i,j} = \pi_n^{i,k} = \Pi^i \dfrac{\left(p_{qn}^i \kappa_n^i\right)^{-\vartheta^i}}{\sum_{n=1}^{N}\left(\left(p_{qn}^i \kappa_n^i\right)\right)^{-\vartheta^i}} \quad ; \qquad n = d$

Output prices, Cobb-Douglas $\quad p_q^j = \Gamma^j w^{\gamma^{j,L}} p_K{}^{\gamma^{j,K}} \prod_{i=1}^{J} P^{i\gamma^{i,j}}$

Output prices, Translog $\quad logp^j = \Gamma^j + v^{j,K} logp^{j,K} + v^{j,L} logp^{j,L} + v^{j,M} logp^{j,M}$

Factor prices $\quad \mathbf{p}^{j,M} = \mathbf{p}_n^i \mathbf{S}_n^{i,j} \; ; \qquad \mathbf{p}^{j,K} = \mathbf{p}_n^i \mathbf{B}_n^{i,j,K}$

Factor demand (*M*, *K*), Cobb-Douglas $\quad r^{j,M} = \sum_i \gamma^{j,i} / p^{j,M} \quad ; \qquad r^{j,K} = \gamma^{j,K} / p^{j,K}$

Factor demand (*M*, *K*), Translog $\quad r^{j,M} = v^{j,M} / p^{j,M} \quad ; \qquad r^{j,K} = v^{j,K} / p^{j,K}$

Income $\quad CP = YD = wL + s_y p_K K + Tr \qquad Tr = \sum_{j,m} \tau_m^j X_m^j \quad ; m = EU, RoW$

Consumer price, Cobb-Douglas $\quad P^C = \prod_{j=1}^{J} \left(\frac{p^{j,C}}{\alpha^j}\right)^{\alpha^j}$

Consumer price, AIDS $\quad P^C = e^{\left(\sum_j w^j logp^{j,C}\right)}$

Consumption, Cobb-Douglas $\quad C^j = \dfrac{\alpha^j CP}{p^{j,C}}$

Consumption, AIDS $\quad C^j = \dfrac{w^j CP}{p^{j,C}} \quad ; \qquad w^j = \dfrac{p^{AIDS} C^{AIDS}}{CP} w^{j,AIDS}$

This must be complemented by the explicit share equations of the Translog and of the AIDS model (equation (9) and (14)). As has been already stated above, the output prices of *m* regions (*EU* and *RoW*), $p_{qm}{}^i$, the trade costs, $\kappa_{in}$, and the wage rate $w^j$ (respectively the price of labour,

$p^{j,L}$) are the only exogenous price variables in the model. This is different from Caliendo and Parro (2015), where the wage rate is set in order to fulfill all equilibrium conditions of the multi-regional trade model in the baseyear. Domestic trade costs are levied on exports, whereas all other trade costs are on products from *m* regions (*EU* and *RoW*). At the expenditure side, the only exogenous variable is public consumption ($G^j$). Gross capital formation is endogenous, as the optimal capital stock by industry $K^j$ changes with the changes in factor demand, expressed by $r^{j,K}$ and the changes in industry output, $Q^j$: $K^j = r^{j,K}\, Q^j$. It is not assumed, however, that the change in the optimal capital stock fully transforms into additional gross capital formation, i.e. that capital stock adjustment is perfect, not even in this comparative static setting. Rather, a fixed relationship (from the baseyear data) of replacement plus new capital formation in relation to the capital stock by industry is assumed and applied in order to calculate the new capital formation by industry, $CF^j$. Writing the capital formation by good (in equation (19)) by $CF^i$, this can be found by converting capital formation by industry into capital formation by goods, applying the investment coefficients matrix:

$$\mathbf{cf}^{i} = \mathbf{B}_{n}^{i,j,K}\ \mathbf{cf}^{j} \tag{21}$$

Export flows to the *m* regions are endogenized in a similar way as the import flows from the *m* regions by defining log-linear equations:

$$\log\left(EX_{m}^{j}\right) = log\left[A^{j}\left[\lambda_{d}^{j}\left(p_{q}^{j}\kappa_{dm}^{j}\right)^{-\vartheta^{*j}}\right]^{-1/\vartheta^{*j}}\right] \tag{22}$$

In (22), $k_{dm}^{j}$ are trade costs on exports to region m and $\theta^{*j}$ is the adjusted trade elasticity. The adjustment corrects for the bias of not calculating price effect for UK exports relative to the composite good prices in *EU* and *RoW*. The next step of extension would have been calculating this change in the composite pricve effect from UK products by extending the data base. The final modelling step would consist of setting up a full MRIO framework where all varaibles are modelled for *EU* and *RoW* as well.

The changes induced by the trade cost shock change UK production structures in several ways. Besides substitution in trade, determined by the trade elasticities, it is the substitution in production that impacts on the input coefficient for intermediates ($r^{j,M}$) and thereby on input coefficients for all intermediates, according to equation (2) and (3). These output effects in turn induce important changes in disposable household income, *YD*. Welfare is calculated as the change in the real income: $YD/P^C$ and is composed by income as well as price changes. The initial shock in trade costs, $\kappa_{in}$, induces price changes that further trigger income effects, so that both *YD* and $P^C$ change simultaneously and the feedback from the price side on production structures is important. This aspect has not been highlighted by the existing literature.

The main equilibrium condition in this model is that consumption expenditure equals disposable income $CP = YD$ and an income/consumption multiplier is in place. That implicitly does not assume full employment. In Caliendo and Parro (2015), the condition of an exogenously given trade balance for each region *n* as well as a zero trade balance for the whople system are enforced. As labour is given from the supply side, a baseline equilibrium that fulfills all conditions has to be constructed by setting the wage rate in a way that this condition holds. In this study, no condition is imposed on the trade balance. This could be easily done and enforced by changing the transfer term in disposable income, until the baseyear trade balance or a zero balance is achieved. The trade balance in this model is given with:

$$TB = \sum_j \sum_m P_m^{k,EX} EX_m^j - \sum_j \sum_m X_m^j \tag{23}$$

with $P_m^{k,EX} = A^j [\lambda_d^j \left(p_q^j \kappa_{dm}^j\right)^{-\vartheta^{*j}}]^{-1/\vartheta^{*j}}$.

Adding such a mechanism to our model would limit the potential of the built-in income/consumption multiplier.

## 5. Data and calibration

The data set is derived from a combination of the ONS Supply-Use table for 2016 and the WIOD International Supply-Use table (http://www.wiod.org/database/int_suts16). The ONS table for 2016 does not contain a full supply table, but only vectors of output by industries and by goods. Therefore, we have directly constructed a symmetric IO table with output by industry as matrix margin and by bridging the gap between goods and industry output with a statistiscal difference vector in final demand. An import matrix has been constructed by applying the import share by good from the ONS table and allowing for heterogeneity across the row of users in the import share, according tothe WIOD SUTs. The import table has finally been balanced by RAS. In a second step, the import table has been disaggregated intotwo import tables, one for the EU and another – as a residual – for the rest of the world (RoW). This has also been carried out based on the WIOD SUTs by applying average import shares of the EU in total imports by good. All calculations have been done at the level of 30 industries (see the Appendix) and ONS as well as WIOD data have been aggregated to this classification in the first place. The result of the data construction procedure is a symmetric UK IO table for 30 industries with a differentiation of exports and imports by the two regions (EU and RoW). In the case of imports this is available at the full detail of import matrices.

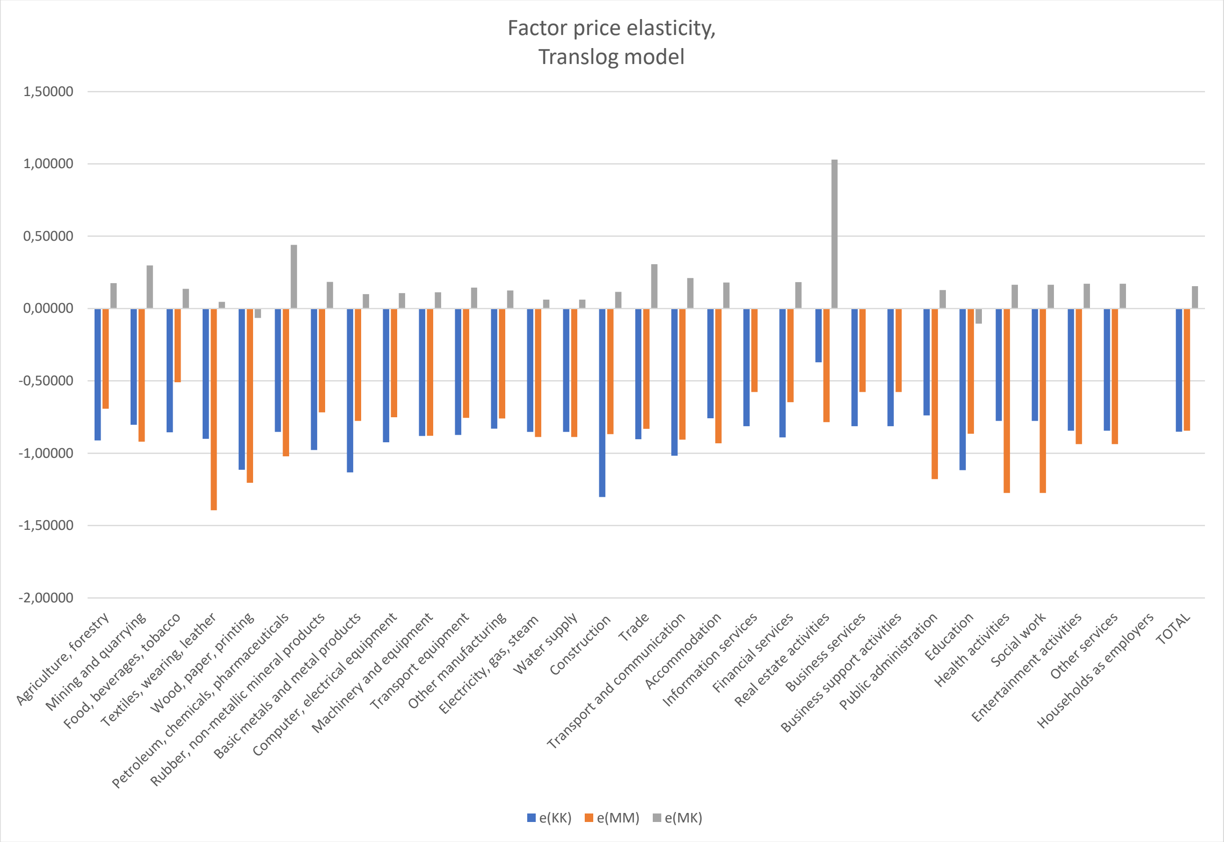
Once the data set has been constructed, the calibration of the functions was implemented in the model. The parameters that had to be determined, cover the trade elasticity, $\theta^j$, and factor price elasticities according to (18), respectively parameters $\gamma^{jf}$ according to (14) for the Translog model, as well as parameters $\gamma^{jk}$ and $\beta^j$ according to (9) for the AIDS model in consumption. Once the parameters are given, all constants ($A^i$, $\Pi^j$, $\Gamma^j$, $\alpha^{AIDS}$, $\alpha^{j,K}$, $\alpha^{j,M}$ ) are derived from the calibration exercise. A large body of literature on trade elasticities exists (for a review see: Costinot and Claire-Rodriguez (2014)). As many studies describe trade between countries at the aggregate level (e.g. Pfaffermayr and Oberhofer (2018), they only present aggregate trade elasticities. Therefore, Costinot and Claire-Rodriguez (2014) put the emphasis on studies that include industry disaggregation, firm entry, and intermediate goods with IO linkages, such as Balistieri et al. (2011), Di Giovanni and Levchenko (2009), and Simonovska and Waugh (2013). The latter study closely follows the estimation strategy in Eaton and Kortum (2002), correcting for biases of overestimation and presents a ‘preferred’ value of 4.12. This study mainly builds on Caliendo and Parro (2015) concerning methodology and on and Dhingra et al. (2017) concerning the simulation design. As Dhingra et al. (2017) also apply Caliendo and Parro’s elasticities and we want to refer our results to their work, we use the same elasticities, as shown in Table 1. For service sectors we set the trade elasticity equal to 5, as in Dhingra et al. (2017). These elasticity values are available in classification of the WIOD database and had to be aggregated to the 30 industries used here. Due to ample research evidence on that issue, we also refrain from undertaking sensitivity analysis with respect to the trade elasticity. The values in Table 1 have been used in the model for substitution between domestic flows and imports from the two regions. The values have been multiplied with a factor of 0.8 for export demand (equation (22)) to correct for the bias stemming from omission of the relative price effect in countries importing from the UK.   This is clearly a second best- methodology. The most simple and immediate improvement over that is to include data for UK imports of Europe and RoW, so that the change in the composite price in these regions, induced by the UK price changes, could be calculated and the trade elasticity without adjusting could be applied.

*Table 1: Trade elasticities ($\dot{\theta}$), based on Caliendo and Parro (2015)*

| | |
|---|---|
| Agriculture, forestry | 8,11 |
| Mining and quarrying | 15,72 |
| Food, beverages, tobacco | 2,55 |
| Textiles, wearing, leather | 5,56 |
| Wood, paper, printing | 9,50 |
| Petroleum, chemicals, pharmaceuticals | 4,75 |
| Rubber, non-metallic mineral products | 2,20 |
| Basic metals and metal products | 7,99 |
| Computer, electrical equipment | 10,60 |
| Machinery and equipment | 1,52 |
| Transport equipment | 0,37 |
| Other manufacturing | 5,00 |
| Electricity, gas, steam | 5,00 |
| Water supply | 5,00 |
| Construction | 5,00 |
| Trade | 5,00 |
| Transport and communication | 5,00 |
| Accommodation | 5,00 |
| Information services | 5,00 |
| Financial services | 5,00 |
| Real estate activities | 5,00 |
| Business services | 5,00 |
| Business support activities | 5,00 |
| Public administration | 5,00 |
| Education | 5,00 |
| Health activities | 5,00 |
| Social work | 5,00 |
| Entertainment activities | 5,00 |
| Other services | 5,00 |

In the Cobb-Douglas case no calibration is necessary,as all elasticities are equal to unity and the value shares simply do not change with price changes in that case. For the Translog case in production, relevant elasticity values have been taken from panel data estimations (pooling across 27 EU countries) based on the WIOD database (www.wiod.org) that have been carried out in the context of the second version of the FIDELIO model (Kratena, et al., 2017). Graph 1 contains selected own- and cross-price elasticities for capital and materials in the classification of the 30 industries used in this study. The cross price-elasticity between capital and materials is – with exception of one industry – significantly lower that unity. The own price elasticities of capital and materials is on average about -0.8 with some industries that show values higher than unity. The elasticities for labour (not shown here) implicitly follow from the elasticities shown in Graph 1 and are slightly below -0.5. The fact that own price elasticities are on average lower than unity, *ceteris paribus* leads to less flexibility in substitution and therefore higher price and welfare effects of trade costs. The *ceteris paribus*-constraint is essential in this context, as this function interacts with substitution in consumption and trade and all other general equilibrium feedbacks inherent in the model. The final outcome in terms of the impact of trade costs can therefore not directly be inferred from the elasticities in one block. The calibration uses the inverted formula from equation (18) to calculate the parameters $\gamma^{jf}$.

*Graph 1: Factor price elasticity (capital, materials), Translog model*



Source: own calculations from FIDELIO (Kratena, et al., 2017) background material

For the AIDS model in consumption, panel data (pooling across 27 EU countries) and cross section (UK Household Budget Survey) estimation results from FIDELIO (Kratena, et al., 2017) have been taken that are representative for the UK (Table 2). The nine categories of the AIDS model comprise the eight shown in Table 2 and a residual category 'Others' (not shown), that are aggregates of the 30 goods/industries classification.

*Table 2: Price and expenditure elasticities, AIDS model*

| | ***price elasticity*** | | | | Transport/ | | | | ***expenditure*** |
|---|---|---|---|---|---|---|---|---|---|
| | Food, bev. | Clothing | Housing related | Health | Communication | Education | Accommodation | Financial serv. | ***elasticity*** |
| Food, beverages, tobb. | **-1.15** | 0.05 | -0.05 | 0.41 | 0.31 | 0.25 | 0.41 | 0.16 | 0.59 |
| Clothing | -0.43 | **-0.53** | -0.03 | 0.10 | -0.20 | -0.02 | 0.13 | -0.24 | 1.19 |
| Housing related | -1.44 | -0.02 | **-1.45** | -0.14 | 0.21 | 0.43 | 0.99 | 0.19 | 1.32 |
| Health | 1.62 | 0.25 | -0.14 | **-1.30** | -0.04 | -0.15 | -0.28 | -1.16 | 1.00 |
| Transport/Communication | 0.89 | -0.32 | 0.27 | 0.01 | **-0.62** | -0.68 | -0.52 | 0.14 | 0.45 |
| Education | 0.48 | 0.02 | 0.47 | -0.13 | -0.74 | **-0.73** | -0.75 | 0.27 | 1.00 |
| Accommodation | 0.39 | 0.04 | 0.25 | -0.12 | -0.21 | -0.26 | **-1.39** | -0.09 | 1.09 |
| Financial services | -0.08 | -0.37 | 0.21 | -0.93 | 0.12 | 0.26 | -0.09 | **-0.04** | 0.45 |

Source: own calculations from FIDELIO (Kratena, et al., 2017) background material

The expenditure elasticity in Table 2 is based on estimation results with individual household data and reveals important heterogeneity of the elasticity across broad consumption categories with the majority of the values equal to unity or higher values. In the case of own price elasticities, half of the values are higher than unity. These high elasticities in the AIDS model *ceteris paribus* alleviate adjustment on the side of consumers to trade cost shocks, compared to the model with Cobb-Douglas preferences. As already noted above, that only holds from a *ceteris paribus* perspective and the final results depend on the interplay of the consumption block with the other model parts. As in the case of the Translog model, for calibration the elasticity values had to be converted into the parameters of the AIDS model ($\gamma^{jk}$ and $\beta^{j}$) by inverting the elasticity formulas (see: Kratena, et al., 2017).

## 7. Impacts of a 'Brexit trade cost shock'

The simulation design for the trade cost shock is directly taken from Dhingra et al. (2017). Their study additionally analyses effects of Brexit scenarios on FDI and on long-run productivity growth. This is not considered here, but the inclusion of capital as a factor production in this study renders effects on investment, that are not included into the trade cost-effects in Dhingra et al. (2017).

The simulation focuses on the ‚hard Brexit'-scenario described in Dhingra et al. (2017). Table 3 shows the expected most favourite nation (MFN) tariffs for UK imports and exports from and tot he EU in this case, which correspond with the WTO rules. Quantitatively more important, especially for service sectors, are the non-tariff barriers, also taken from the Dhingra et al. study and shown in Table 3 as well. For the ‚hard Brexit'-scenario it is assumed that ¾ of the reducible share of non-tariff barriers will be in place. Additionally, we also take the dynamic trade cost effects from Dhingra et al. (2017) into account. This effect measures the lack of reduction in the reducible share of non-tariff barriers, that would probably occur for EU members. Total trade costs in the ‚hard Brexit' scenario are the sum of all these categories in the case of imports. For exports only tariffs are considered as Brexit trade costs. In order totest for sensitivity, two different model versions are used: one with Cobb-Douglas functions in consumption and production and the other with an AIDS model in consumption and a Translog function in production.

Table 4 compares the aggreagte results of the ‚hard Brexit'-scenario of both models. The price impacts for exporters and consumers are quite similar in both model versions. The indicator for welfare in this study is the change in the real disposable income *YD/PC,* that changes due to changes in nominal income and in the consumption deflator. As can be seen from Table 4, the change in welfare in the Translog/AIDS model version is almost half of the one in the Cobb-Doglas version. i.e. -1.8% instead of -3.7%. It is not possible, to fully decompose this effect. What could be done, alternatively is further splitting up the model versions and change the Cobb-Douglas specification for production and for consumption separately. This difference in impacts is also visible for GDP, though less pronounced: -1.8% (Translog/AIDS model) instead of -2.9% (Cobb-Douglas model).

Looking at the sectoral results, one can observe that the substitution effects in production are in general higher in the Translog model than in the Cobb-Douglas case. Though the price elasticities are below unity on average, there are important industries like construction with considerably higher elasticities in the Translog case (Graph 1). In other industries the opposite holds and we even get positive substitution effects in the Translog case, e.g. for capital in the transport equipment industry. In general, the higher substitution away from capital and intermediates in the Translog case benefits labour and thereby dampens the negative income effect. This is one channel of feedback that is responsible for the difference in results. The other one, obviously is the better adjustment of consumption to price and income shocks in the AIDS model, also visible from the significantly lower consumption impact in the Translog/AIDS model (-0.8% vs. -2.7%). Costinot and Claire- Rodriguez (2014) have been arguing that overcoming the unitary elasticity approach of Cobb-Douglas might possibly lead to higher welfare effects of trade, because elasticities might be well below unity. This view cannot be confirmed by our sensitivity analysis. Table 7 clearly reveals the significantly lower negative consumption effect in the AIDS case, compared tot he Cobb-Douglas specification. That holds especially for imprtant consumption goods like food and beverages, transport equipment as well as many services.

*Table 3: Trade costs for a Brexit-scenario*

| | MFN tariffs imports | MFN tariffs exports | non-tariff barriers | reducible share | trade cost dynamics |
|---|---|---|---|---|---|
| Agriculture, forestry | 0.059 | 0.0563 | 0 | 0 | 0 |
| Mining and quarrying | 0 | 0 | 0 | 0 | 0 |
| Food, beverages, tobacco | 0.073 | 0.050 | 0.568 | 0.430 | 0.023 |
| Textiles, wearing, leather | 0.096 | 0.097 | 0.192 | 0.500 | 0.009 |
| Wood, paper, printing | 0.023 | 0.036 | 0.113 | 0.600 | 0.006 |
| Petroleum, chemicals, pharmaceuticals | 0.027 | 0.025 | 0.239 | 0.630 | 0.014 |
| Rubber, non-metallic mineral products | 0.054 | 0.040 | 0 | 0 | 0 |
| Basic metals and metal products | 0.021 | 0.019 | 0.119 | 0.620 | 0.007 |
| Computer, electrical equipment | 0.020 | 0.016 | 0.065 | 0.410 | 0.003 |
| Machinery and equipment | 0.021 | 0.021 | 0 | 0 | 0 |
| Transport equipment | 0.081 | 0.072 | 0.221 | 0.530 | 0.011 |
| Other manufacturing | 0.017 | 0.017 | 0 | 0 | 0 |
| Construction | 0 | 0 | 0.046 | 0.380 | 0.002 |
| Trade | 0 | 0 | 0.044 | 0.370 | 0.002 |
| Transport and communication | 0 | 0 | 0.117 | 0.700 | 0.008 |
| Accommodation | 0 | 0 | 0 | 0 | 0 |
| Information services | 0 | 0 | 0.044 | 0.370 | 0.002 |
| Financial services | 0 | 0 | 0.113 | 0.490 | 0.005 |
| Real estate activities | 0 | 0 | 0 | 0 | 0 |
| Business services | 0 | 0 | 0.149 | 0.510 | 0.007 |
| Business support activities | 0 | 0 | 0.149 | 0.510 | 0.007 |
| Entertainment activities | 0 | 0 | 0.044 | 0.370 | 0.002 |
| Other services | 0 | 0 | 0.044 | 0.370 | 0.002 |

Source: Dhingra, et al. (2017)

*Table 4: Welfare, trade and demand effects of a 'Brexit trade cost shock'*

| | Cobb-Douglas model | Translog/AIDS model |
|---|---|---|
| Consumer price | 1.09% | 1.07% |
| Welfare (households) | -3.72% | -1.84% |
| Consumption | -2.66% | -0.78% |
| Capital formation | -3.11% | -3.07% |
| Export price, EU | 2.61% | 2.59% |
| Export price, ROW | 1.21% | 1.19% |
| Exports, EU | -9.11% | -9.05% |
| Exports, ROW | -5.01% | -4.95% |
| Imports, EU | -14.58% | -14.38% |
| Imports, ROW | 7.57% | 8.45% |
| GDP | -2.93% | -1.77% |

*Table 5: Substitution effects (capital and intermediates) of a 'Brexit trade cost shock', Cobb-Douglas model*

| | Capital/Output | Intermed./Output |
|---|---|---|
| **AVERAGE** | **-1.38%** | **-0.14%** |
| Agriculture, forestry | -2.59% | 0.44% |
| Mining and quarrying | -1.46% | 0.55% |
| Food, beverages, tobacco | -3.26% | -0.03% |
| Textiles, wearing, leather | -2.75% | 0.62% |
| Wood, paper, printing | -2.89% | -0.04% |
| Petroleum, chemicals, pharmaceuticals | -1.58% | 0.09% |
| Rubber, non-metallic mineral products | -3.21% | -0.05% |
| Basic metals and metal products | -3.48% | -0.31% |
| Computer, electrical equipment | -0.68% | -0.59% |
| Machinery and equipment | -0.84% | -0.53% |
| Transport equipment | -1.01% | -0.77% |
| Other manufacturing | -1.18% | -0.24% |
| Electricity, gas, steam | -1.68% | -0.18% |
| Water supply | -0.59% | 0.04% |
| Construction | -2.09% | 0.38% |
| Trade | -0.30% | -0.28% |
| Transport and communication | -1.29% | -0.19% |
| Accommodation | -0.86% | -0.21% |
| Information services | -1.20% | -0.33% |
| Financial services | -0.60% | -0.35% |
| Real estate activities | -0.77% | -0.09% |
| Business services | -0.08% | 0.06% |
| Business support activities | -0.85% | -0.19% |
| Public administration | -0.99% | -0.10% |
| Education | -0.74% | -0.46% |
| Health activities | -0.86% | -0.57% |
| Social work | -0.97% | -0.49% |
| Entertainment activities | -0.49% | -0.20% |
| Other services | -0.77% | -0.19% |

*Table 6: Substitution effects (capital and intermediates) of a 'Brexit trade cost shock', Translog/AIDS model*

| | **Capital/Output** | **Intermed./Output** |
|---|---|---|
| **AVERAGE** | **-1.67%** | **-0.81%** |
| Agriculture, forestry | -3.56% | -0.32% |
| Mining and quarrying | -2.14% | -0.13% |
| Food, beverages, tobacco | -2.70% | -0.20% |
| Textiles, wearing, leather | -3.97% | -1.41% |
| Wood, paper, printing | -5.74% | -2.64% |
| Petroleum, chemicals, pharmaceuticals | -0.67% | -0.03% |
| Rubber, non-metallic mineral products | -3.25% | -0.26% |
| Basic metals and metal products | -5.06% | -1.31% |
| Computer, electrical equipment | -0.62% | -1.16% |
| Machinery and equipment | -1.09% | -1.49% |
| Transport equipment | 1.34% | -1.82% |
| Other manufacturing | -0.77% | -1.05% |
| Electricity, gas, steam | -2.36% | -1.26% |
| Water supply | -1.20% | -0.82% |
| Construction | -4.74% | -0.81% |
| Trade | 0.04% | -0.74% |
| Transport and communication | -1.71% | -0.54% |
| Accommodation | -0.58% | -0.60% |
| Information services | -1.75% | -0.74% |
| Financial services | -0.90% | -0.47% |
| Real estate activities | 1.60% | 0.95% |
| Business services | -0.91% | -0.58% |
| Business support activities | -1.37% | -0.60% |
| Public administration | -1.00% | -0.68% |
| Education | -2.00% | -1.18% |
| Health activities | -0.62% | -0.97% |
| Social work | -0.76% | -1.20% |
| Entertainment activities | -0.87% | -0.74% |
| Other services | -1.18% | -0.68% |

*Table 7: Effects in private consumption of a 'Brexit trade cost shock'*

| | Cobb-Douglas model | Translog/AIDS model |
|---|---|---|
| **TOTAL** | **-2.66%** | **-0.78%** |
| Agriculture, forestry | -4.08% | -2.87% |
| Mining and quarrying | -2.27% | -0.99% |
| Food, beverages, tobacco | -3.39% | -2.19% |
| Textiles, wearing, leather | -2.31% | -0.37% |
| Wood, paper, printing | -4.06% | -2.74% |
| Petroleum, chemicals, pharmaceuticals | -3.40% | -0.93% |
| Rubber, non-metallic mineral products | -3.74% | -2.48% |
| Basic metals and metal products | -4.80% | -3.53% |
| Computer, electrical equipment | -3.44% | -2.18% |
| Machinery and equipment | -2.47% | -1.19% |
| Transport equipment | -10.88% | -8.60% |
| Other manufacturing | -2.77% | -1.50% |
| Electricity, gas, steam | -2.36% | -1.07% |
| Water supply | -2.68% | -1.37% |
| Construction | -3.24% | -1.92% |
| Trade | -2.75% | -1.13% |
| Transport and communication | -2.54% | -0.04% |
| Accommodation | -2.26% | 1.02% |
| Information services | -2.53% | -0.92% |
| Financial services | -2.59% | 1.23% |
| Real estate activities | -2.39% | -1.12% |
| Business services | -2.66% | -1.03% |
| Business support activities | -2.69% | -1.08% |
| Public administration | -1.95% | -0.33% |
| Education | -2.34% | 0.53% |
| Health activities | -1.97% | 0.57% |
| Social work | -2.27% | 0.27% |
| Entertainment activities | -2.50% | -0.88% |
| Other services | -2.44% | -0.82% |

The trade effects in our ‚hard Brexit‘-scenario are in general smaller than in comparable studies like Dhingra, et al. (2017) and Pfaffermayr and Oberhofer (2018). They are either closer to the effects of ‚soft‘ scenarios in both studies or at the lower level of the confidence interval. This can be due to several differences. Both other studies use an aggregate approach, only partially taking intermediates and IO linkages into account (Dhingra, et al., 2017). They also apply a different version of the gravity equation (Pfaffermayr and Oberhofer, 2018) and introduce trade balance restrictions. The solution algorithm of Dhingra, et al. (2017), where the equilibrium wages are determined, is completely different from the approach in this study that treats the price of labour as a normalized varaible. An important result in our study ist hat due to the pronounced role of relative prices in trade, no trade diversion effect in exports can be identified. The UK prices unambiguously rise and therefore, importers of UK products in the RoW also substitute these goods by goods from other countries.

Table 8 and 9 reveal the industry effects of both models. The most affected industries (‚mining and quarrying‘. ‚textile, wearing, leather‘, and ‚computer, electrical equipment) are exposed to high trade cost changes or high trade elasticities or a combination of both. The opposite holds for the transport equipment industry that shows a relatively low negative impact. Several service sectors reduce their output more than the average, which is a mixed effect from direct impacts of trade costs and IO linkages. Graph 2 shows that the difference in output effects between the Translog/AIDS model and the Cobb-Douglas model is concentrated in the service sectors.

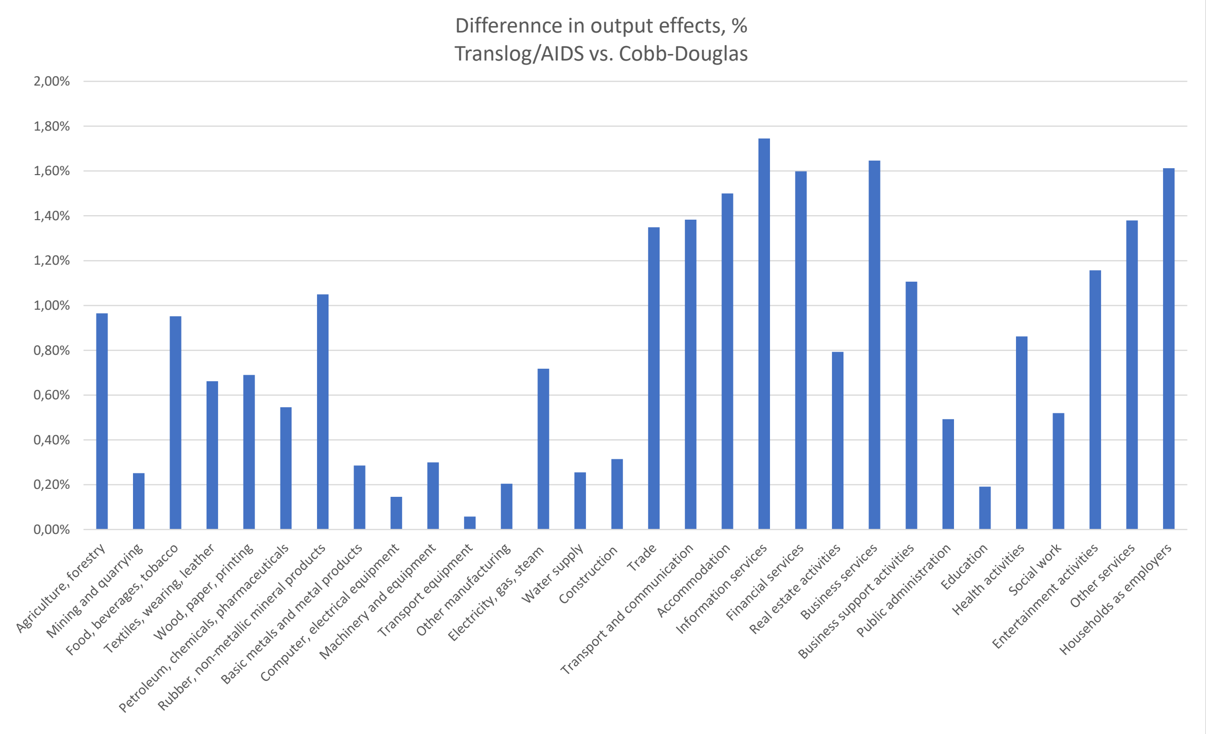
*Table 8: Industry effects (prices and output) of a 'Brexit trade cost shock', Cobb-Douglas model*

| | **Output price** | **Output** |
|---|---|---|
| **TOTAL** | 0.98% | -3.29% |
| Agriculture, forestry | 2.11% | -3.62% |
| Mining and quarrying | 1.72% | -20.03% |
| Food, beverages, tobacco | 1.74% | -3.53% |
| Textiles, wearing, leather | 1.78% | -27.03% |
| Wood, paper, printing | 1.90% | 3.02% |
| Petroleum, chemicals, pharmaceuticals | 1.45% | -8.01% |
| Rubber, non-metallic mineral products | 1.56% | -3.36% |
| Basic metals and metal products | 2.11% | -2.73% |
| Computer, electrical equipment | 1.23% | -19.46% |
| Machinery and equipment | 1.48% | -3.24% |
| Transport equipment | 2.29% | -1.22% |
| Other manufacturing | 1.63% | -6.73% |
| Electricity, gas, steam | 1.47% | -7.33% |
| Water supply | 1.10% | -3.17% |
| Construction | 1.82% | -3.34% |
| Trade | 1.17% | -3.80% |
| Transport and communication | 0.94% | -3.36% |
| Accommodation | 0.76% | -3.76% |
| Information services | 0.95% | -3.63% |
| Financial services | 0.79% | -2.32% |
| Real estate activities | 0.87% | -3.43% |
| Business services | 1.05% | -2.76% |
| Business support activities | 0.83% | -2.42% |
| Public administration | 0.66% | -4.34% |
| Education | 0.73% | -0.44% |
| Health activities | 0.36% | -1.05% |
| Social work | 0.67% | -0.58% |
| Entertainment activities | 0.85% | -2.23% |
| Other services | 0.84% | -2.48% |
| Households as employers | 0.00% | -1.61% |

*Table 9: Industry effects (prices and output) of a 'Brexit trade cost shock', Translog/AIDS model*

| | **Output price** | **Output** |
|---|---|---|
| **TOTAL** | 1.26% | -2.27% |
| Agriculture, forestry | 2.08% | -2.66% |
| Mining and quarrying | 1.70% | -19.78% |
| Food, beverages, tobacco | 1.73% | -2.58% |
| Textiles, wearing, leather | 1.75% | -26.36% |
| Wood, paper, printing | 1.83% | 3.71% |
| Petroleum, chemicals, pharmaceuticals | 1.45% | -7.47% |
| Rubber, non-metallic mineral products | 1.55% | -2.31% |
| Basic metals and metal products | 2.08% | -2.44% |
| Computer, electrical equipment | 1.22% | -19.31% |
| Machinery and equipment | 1.46% | -2.94% |
| Transport equipment | 2.26% | -1.16% |
| Other manufacturing | 1.61% | -6.53% |
| Electricity, gas, steam | 1.45% | -6.61% |
| Water supply | 1.07% | -2.91% |
| Construction | 1.76% | -3.03% |
| Trade | 1.15% | -2.45% |
| Transport and communication | 0.93% | -1.98% |
| Accommodation | 0.76% | -2.26% |
| Information services | 0.94% | -1.88% |
| Financial services | 0.78% | -0.72% |
| Real estate activities | 0.88% | -2.64% |
| Business services | 1.02% | -1.11% |
| Business support activities | 0.83% | -1.31% |
| Public administration | 0.65% | -3.85% |
| Education | 0.72% | -0.25% |
| Health activities | 0.35% | -0.19% |
| Social work | 0.66% | -0.06% |
| Entertainment activities | 0.83% | -1.08% |
| Other services | 0.83% | -1.10% |
| Households as employers | 0.00% | 0.00% |

*Graph 2: Difference in output effects of trade cost shocks (Translog/AIDS model minus Cobb-Douglas model)*



## Conclusions

This study replicates the Dhingra et al. (2017) study by applying the same simulation design for trade costs, but a slightly different modelling framework. It complements the existing literature by including capital as a factor of production and testing for the sensitivity of results to specifications in consumption (AIDS model) and production (Translog model) that are different from Cobb-Douglas. In these alternative specifications, elasticities differ from unity in both directions and are not systematically much smaller. Price effects of a ‚hard Brexit'-scenario are similar in both models, but welfare and consumption effects are significantly smaller in the Translog/AIDS-model. The IO framework where labour and disposable income are determined from the demand side, makes repercussions from the price side to the production structures explicit. These feedbacks comprise the negative impact on investment from susbstitution in production due to capital price effects and the impact on domestic intermediate inputs from substitution in production and trade. The latter changes the IO coefficients, as trade substitution is modelled at the level of users.

The aggregate results on welfare are between -1.8% and -3.7% and therefore within the range of recent studies on the same issue (Dhingra, et al., 2017; Pfaffermayr and Oberhofer, 2018). The trade effects are significantly smaller than in the literature, which might have to do with small but relevant differences in modelling design. These differences in modelling also lead to a clear negative impact on UK exports to the RoW due to higher UK output prices.

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