Estimating the Trade and Welfare Effects of Brexit: A Panel Data Structural Gravity Model[⋆]

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Abstract

This paper proposes a new panel data structural gravity approach for estimating the trade and welfare effects of Brexit. Assuming different counterfactual post-Brexit scenarios, our main findings suggest that UKs exports of goods to the EU are likely to decline within a range between 7.2% and 45.7% six years after the Brexit has taken place. For the UK, the negative trade effects are only partially offset by an increase in domestic trade and trade with third countries, inducing a decline in UKs real income between 0.3% and 5.7%. The estimated welfare effects for the EU are not different from zero but some members like Ireland are expected to also experience welfare losses.

Keywords: Constrained Poisson Pseudo Maximum Likelihood Estimation; Panel Data; International Trade; Structural Gravity Estimation; Trade Policy; Brexit

JEL: F10; F15; C13; C50

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1 Introduction

On Thursday, 26th of June 2016 the United Kingdom (UK) held a "Brexit-referendum" and the majority of the participating electorate voted in favor of the "leave choice". As a consequence David Cameron resigned as prime minister and Theresa May took over office. On the 29th of March 2017, the government of the UK officially handed in a letter in Brussels notifying the country's withdrawal from the European Union (EU) triggering Article 50 of the "Treaty on European Union". This initiated a two year time window for the conclusion on a withdrawal agreement. Since then the UK and EU are negotiating the terms for UK's withdrawal. On the 14th December 208, both parties announced the conclusion of UK's withdrawal agreement and moved on working on a political declaration which outlines the main issues which should govern the future bilateral relationships. Ever since then, the government of the UK failed to convince a parliamentary majority for the withdrawal agreement and, as a consequence, none of the politically discussed potential outcomes can be ruled out by the end of February 2019.

During the period of political campaigning prior to (and also after) the referendum, the likely economic costs and benefits induced by Brexit for both the UK and the EU have been highly debated. Given the fact that the negotiators are still far away from reaching a final agreement on all involved issues, an (ex-ante) estimation of the involved costs and benefits is naturally surrounded by substantial policy uncertainty. Nevertheless, some economic studies tried to provide estimates on the costs and benefits by focusing on different economic issues. Thereby, the potential effects of Brexit for bilateral trade between UK and the EU and domestic welfare in both economic areas attracted the most attention among economists and policy makers alike. With only one exception, all available analyses point to a (maybe substantial) reduction in bilateral trade between the remaining 27 EU member states and the UK as a consequence of Brexit. This decline in economic interactions would be accompanied by negative domestic welfare effects for both economic areas. The magnitude of these estimates differ depending on the estimation approaches applied, the data used and, most importantly, the counterfactual post-Brexit scenarios assumed.[1]

This paper applies a novel approach for identifying the bilateral trade and welfare effects stemming from Brexit in a unifying framework in the spirit of Allen, Arkolakis and Takahashi (2018). In particular, we extend the Constrained Poisson Pseudo Maximum Likelihood Estimator (CPPMLE) as suggested by Pfaffermayr (2017) for panel data and account for full endowment general equilibrium effects as suggested by Yotov, Permantini, Monteiro and Larch (2016). The panel data CPPMLE features some advantageous properties which are useful for trade policy evaluation.

First, the panel data CPPMLE avoids the estimation of a large set of dummy variable parameters by exploiting the restrictions imposed by the system of multilateral resistances also for estimation purposes (see French, 2016 and the technical appendix for more details) and at the same time concentrates out bilateral fixed effects. In effect, CPPMLE

[1] A more detailed account of the findings from other Brexit studies applying (structural) gravity models is offered in Section 2.

treats all bilateral, exporter-time and importer-time dummies as functions of the structural parameters of the bilateral, time varying trade friction indicators and the observed data. Thus it is able to accurately address and solve the incidental parameter problem[2] and allows to fully control for unobserved heterogeneity across country-pairs. This an important property for the calculation of consistent effects from counterfactual scenarios in a (follow-up) general equilibrium analysis.

Second, this approach delivers unbiased estimates for the standard errors of the slope parameters and allows reliable inference. In contrast, and as demonstrated by Pfaffermayr (2019), PPMLE with many dummies suffers from downward biased estimates of the standard errors. The reason lies in the high leverage found in gravity data and the number of parameters increasing in sample size.

Third, CPPMLE allows to apply the delta method for calculating trade theory consistent confidence intervals which are important for accurately assessing the uncertainty involved when applying various alternative post-Brexit trade policy scenarios. Monte Carlo simulations provided in the technical appendix and in Pfaffermayr (2018) indicate that the estimated standard errors of panel data CPPMLE for both the structural parameters and the counterfactual general equilibrium predictions do not suffer from finite sample bias and that coverage rates of the confidence intervals are correct in the panels with a minimum country coverage of about 60 economies. The panel data CPPMLE approach might be preferable as compared to routinely applied bootstrapping procedures. In the context of gravity models, bootstrapping the system of multilateral resistance terms together with the parameter estimates is computationally intensive and theoretical results on the reliability of the obtained confidence intervals seem to be yet unavailable.

The empirical specifications of the gravity model suggested in this paper allow for phasing-in effects in counterfactual policy scenarios such as e.g., the conclusion of new bilateral free trade agreements by the UK. For this purpose, we follow Bergstrand, Larch and Yotov (2015) and apply a distributed lag structure as only considering contemporaneous trade policy effects likely only allows to identify lower bound estimates. Further, we allow for time trends in border effects. The paper also investigates the sensitivity of the obtained Brexit effects with respect to the empirical identification of the parameter estimates associated with trade policy measures. In the previous literature trade effects of EU membership are either identified by means of an average effect stemming from all existing regional trade agreements (RTAs) or by accounting for EU membership indicators. The former measure might be too broad in its definition as RTAs substantially differ in their respective depths concerning the degree of trade liberalization. In datasets capturing only recent time periods, the effects from EU membership seem to be driven by its eastern enlargement which might not allow to obtain good estimates for UKs (additional) trade costs induced by Brexit. As an alternative, this paper suggests to use information on customs unions for identifying the (direct) trade effects of Brexit and empirically com-

[2] The incidental parameter problem arises because only a small number of observations is available to estimate bilateral fixed effects, while exporter-time and importer-time fixed effects can be estimated consistently. However, even if one concentrates out the bilateral fixed effects, the estimation has to account for the fact that the number of parameters increase in sample size. Concise econometric results on this issue seem yet to be unavailable.

pares this specification with the more commonly used one involving RTA indicators (only).

Most of the previous literature dealing with the trade effects from Brexit relies on different versions and time periods of the World Input-Output Database (WIOD) for estimating direct trade policy effects (see, e.g., Brakman, Garretsen and Kohl 2018; Dhingra, Huang, Ottaviano, Pessoa, Sampson and Van Reenen 2017; Felbermayr, Gröschl and Steininger 2017; Vandenbussche, Connell and Simons 2017). The WIOD mainly contains the most developed economies around the world which are very actively engaged in free trade policies. As a consequence, this data source lacks exploitable (time-) variation in policy indicators which makes it difficult to identify the causal trade effects of free trade agreements and/or customs unions. Furthermore, input-output tables are technically constructed in a way that the sum of the residuals for all trade relationships is zero. This is a very useful property for the representation of input-output relationships but constitutes a drawback for statistical inference as it puts specific restrictions on the error terms of any econometric model applied. For this reason, we rely on a different and unique dataset which combines various sources for bilateral trade, domestic trade and total production of manufacturing goods.[3]

For assessing the trade and welfare effects we apply four different counterfactual scenarios. As mentioned above, we run two alternative empirical specifications of the gravity model using either customs union data together with information on free trade agreements (FTAs) or pool these two together into one single RTA indicator. These alternatives aim at assessing potential heterogeneity in the trade creating effects of custom unions versus FTAs. The usage of a single RTA indicator is more common in the Brexit literature, and thus the alternative specifications provide insights into the sensitivity of the obtained trade and welfare effects based on the choice of the empirical specification.

With regard to the potential outcomes of the Brexit negotiations we distinguish between a "hard-" and "soft-Brexit" scenario. For the former, we assume that the UK will not only leave the EU but also loses all current free trade agreements with third countries. Furthermore, this scenario assumes that no new free trade agreement between the EU and UK could be established. As a consequence, UK would trade with all countries in the world based on the World Trade Organization regulations. In our data the UK would be the only country not trading under any preferential agreements in force. The "soft-Brexit" scenario assumes that all existing trade agreements with third countries are inherited from the EU and remain in force. In the first empirical specification, the UK leaves the EU as a member of the customs union, but would trade with the EU under a newly established FTA. This scenario closely mimics the "Global Britain" strategy proposed by the current government of the UK and since recently is its official negotiating position[4]. Since the second specification does not distinguish between customs unions and FTAs, the RTA indicator is set to zero for all bilateral trade relationships between the UK and any EU27 member state while the RTAs with third countries remain in force. For the hard Brexit scenario these bilateral trade agreements are additionally also set to zero.

[3]The data sources are discussed in detail in the Appendix A.1

[4]See, e.g., `https://www.theguardian.com/politics/2018/jul/07/brexit-summit-how-the-papers-saw-theresa-mays-deal`.

Our estimation results reveal the following main findings: The trade distorting border effects substantially decline over time pointing to the importance of using panel data for trade policy evaluation. The cumulative RTA trade enhancing effect is qualitatively in line with the results offered by Bergstrand et al. (2015) but in quantitative terms somewhat smaller. This can be explained by the shorter time span covered in our data lasting from 1994 to 2012. A differentiation between customs unions and FTAs seems to be important as the former increases bilateral trade by a significantly larger amount as compared to the latter. As a consequence, relying on RTAs as a empirical combination of both customs unions and FTAs might not deliver a very accurate estimate for the trade effects stemming from Brexit.

The conducted counterfactual scenario analysis suggests that Brexit reduces EU-UK trade across all scenarios. This effect is substantially more pronounced for UK exports to the EU as compared to its imports from the EU. Not very surprising the largest negative trade effect would be induced by a hard-Brexit and when differentiating between customs unions and FTAs. In this scenario, our model predicts an expected decrease in UK (EU) exports to the EU (UK) by 35.5% (29.4%). In addition, our theory-consistent estimates also reveal substantial uncertainty involved in the estimation of Brexit effects. For the worst case scenario, the reduction in exports from UK to EU varies in a range between 25.3% and 45.7%. Furthermore, Brexit is estimated to exhibit "positive" trade diversion effects by increasing domestic trade in the UK and also from trade with third countries. Our model also identifies small but positive effects for intra-EU trade among the remaining EU27 economies. The total net effect stemming from "negative" trade creation and "positive" trade diversion is calculated via a standard measure for overall welfare effects.[5] Or results suggest that, as a consequence of Brexit, real income in the UK will decline in a range between (statistically significant) 0.3% and 5.7% while for the EU the estimated welfare effects are statistically never different from zero. This finding points to an asymmetry of the Brexit induced net costs to be borne by the UK and the EU, respectively.

The remainder of the paper is structured as follows: Section 2 summarizes the methodological approaches and findings from previous studies on the trade and welfare effects of Brexit. For comparability, we limit the discussion to contributions which rely on (structural) gravity model estimation. Section 3 presents the panel data structural gravity model while Section 4 discusses the empirical specification, details on the panel data CPPMLE, presents the data used and reports the estimation results from the gravity model. Section 5 details the findings from the alternative counterfactual Brexit scenarios assumed. In Section 6 we offer some concluding remarks and discuss the main policy implications.

[5] The changes in welfare are based on the approach suggested by Costinot and Rodríguez-Clare (2014) and can be interpreted as Brexit induced changes in real income.

2 The trade and welfare effects of Brexit: A brief review of the literature

The scheduled referendum on UK's future membership status in the EU triggered a series of economic analyses which aimed at identifying the various costs and benefits of a potential win of the leave campaign. A detailed account of various potentially relevant economic dimensions such as e.g., trade, investment and productivity is offered by Baldwin (2016), Van Reenen (2016) and Sampson (2017). In the following, this section concentrates on scientific contributions which put the trade and welfare effects of the Brexit at the center of the respective investigations and applies (structural) gravity model estimation for studying counterfactual Brexit scenarios. Table 1 provides a brief overview of the reviewed studies displaying the various methodological approaches applied, the data sources utilized and the main findings reported.

The first series of ex-ante investigations into the potential trade and welfare effects of a leave vote in the Brexit referendum has been provided by national and international (governmental) institutions including the HM Treasury (2016), Kierzenkowski, Pain, Rusticelli and Zwart (2016) and the International Monetary Fund (2016). These studies are reviewed in more detail in Gudgin, Coutts, Gibson and Buchanan (2017). The estimated trade effects from Brexit are commonly based on ad-hoc formulations of gravity models which do not take any type of general equilibrium effects explicitly into account. The report prepared by HM Treasury (2016), for example, relies on aggregated bilateral trade flow data (in logs) from the Glick and Rose database covering 200 countries for the years from 1948 to 2013 and (mainly) applies simple fixed-effects estimators to gravity type specifications. The trade effects of Brexit are modeled using two dummy variables for trade creation and trade diversion due to the formation of the EU together with a single market membership (EEA) dummy variable indicator and information on FTAs with the EU. Other standard gravity variables capturing export demand and other trade costs are included for isolating the trade effects stemming from EU membership. Applying this very simple (atheoretical) gravity approach and assuming that WTO trade rules would be applied in the aftermath of UKs withdrawal from the EU, the Treasury identifies potential trade reductions amounting to approximately -20% in this case. Under a soft Brexit scenario in which Brexit would be accompanied by the signing of a bilateral FTA between the EU and the UK the negative trade effect would be smaller and add up to approximately -17%. The investigations by Kierzenkowski *et al.* (2016) and the International Monetary Fund (2016) deviate slightly in their modeling approaches and the time periods captured for estimating the gravity models but, in quantitative terms, identified similar negative trade effects stemming from Brexit.

Gudgin *et al.* (2017) comprehensively investigate the robustness of the findings from the above mentioned national and international institutions (i) by closely mimicking the approach taken by HM Treasury (2016) and (ii) varying the sample composition, the time span considered and the estimators applied. With regard to the latter, the authors alternatively also run their specifications relying on the Pseudo Poisson Maximum Likelihood (PPML) estimator which avoids biased estimates by explicitly accounting for zero trade flows and the inherently observed heteroscedasticity in bilateral trade flow data (San-

Table 1: Summary of previous Brexit studies (gravity models)

Authors/Year	**Estimation**	**Main Brexit scenarios**	**Data**	**Main findings**
Brakman *et al.* (2018)	Structural gravity Full endowment GE	**Hard Brexit**: No third country TAs **Soft Brexit**: Third country TAs	WIOD 2014 Total VAX 43 countries	**Hard Brexit**: Drop in UK's VAX of 18% **Soft Brexit:** VAX drop by 14%
Dhingra *et al.* (2017)	Quantitative trade model	**Hard Brexit**: WTO rules **Soft Brexit:** EEA membership	WIOD 2011 31 sectors 35 regions	**Hard Brexit**: UK's direct welfare loss -2.7% **Soft Brexit**: UK's direct welfare loss -1.3% Dynamic productivity effects are important
Felbermayr *et al.* (2017)	Structural gravity Quantitative Ifo trade model	**Hard Brexit**: WTO rules **Soft Brexit**: Comprehensive agreement Global Britain, Fiscal transfer	WIOD 2000-14 50 sectors 43 countries + ROW	**Hard Brexit**: Welfare loss in UK between 0.8 and 2.9% **Soft Brexit**: Welfare loss in UK might be zero
Graham *et al.* (2017)	Gravity models	HM treasury specification	Glick and Rose	Brexit effects are sensitive
HM Treasury (2016)	Simple gravity models	WTO rules: 4 TA indicators	Glick and Rose	≈ 20% export drop for UK
Oberhofer & Pfaffermayr (2017)	Panel data structural gravity	**Hard Brexit**: No third country TAs **Soft Brexit**: Third country TAs	STAN, UNIDO CEPII, WIOD 1994-2012, total manufacturing 65 countries	**Hard Brexit**: Decline in UK (EU) exports) 35.5 (29.4)% **Soft Brexit**: Decline in UK (EU) exports 16.3 (13.2)% Welfare effects: for UK -3.5%, zero for EU
Vandenbussche *et al.* (2017)	sector-level input-output model	**Hard Brexit**: WTO rules plus 8.31% non-tariff barriers (NTBs) **Soft Brexit**: EEA membership plus 2.77% NTBs	WIOD 2014 56 sectors 43 countries + ROW	**Hard Brexit**: value added production declines by 4.47% **Soft Brexit**: value added production declines by 1.21% Absolute job losses in EU27 are larger

tos Silva and Tenreyro 2006). The findings of their robustness checks suggest that the quantitative trade effects from Brexit identified by the HM Treasury (2016) should be considered as upper bound estimates. However, all different sensitivity analyses carried out by Gudgin *et al.* (2017) also indicate negative trade effects Brexit for both the EU as well as for the UK.

A more structural approach for understanding both the short- and long-run welfare effects of Brexit has been proposed by a research team working at the London School of Economics and Political Science based Centre for Economic Performance (Dhingra, Huang, Ottaviano, Pessoa, Sampson and Van Reenen 2017). The authors apply a standard quantitative general equilibrium trade model as suggested by Costinot and Rodríguez-Clare (2014) for simulating total welfare effects of alternative post-Brexit scenarios. The paper calibrate this model using trade in value added data stemming from the World Input-Output Database (WIOD) for the year 2011 capturing 40 economies and 35 industrial sectors. Accordingly, the resulting average welfare losses would be smallest, amounting to -1.3%, in case of a soft Brexit in which the UK would remain in the EU single market. Under the application of standard WTO rules, the average welfare losses for households would be more than doubled amounting to -2.7%. Using reduced form regressions, Dhingra *et al.* (2017) furthermore document severe setbacks for UKs productivity (and thus competitiveness) due to Brexit induced reductions in foreign direct investments (FDI). Accordingly, the negative income effects for UK households would be tripled and spread almost evenly across the whole income distribution.

Vandenbussche *et al.* (2017) develop a gravity model with sector-level input-output linkages in production and separately study the impact of UKs withdrawal from the EU for value added production and employment in the UK and for each EU member state. The trade effects of Brexit are inferred by means of sectoral trade elasticities obtained from Imbs and Méjean (2017). This study also differentiates between a hard and soft Brexit scenario closely following Dhingra *et al.* (2017). A hard Brexit would imply the application of WTO rules together with high non-tariff barriers (NTBs). The soft Brexit is defined as EEA membership including some NTBs (see Table 1 for further details on the scenarios). The 2014 input-output data from WIOD are used for estimation. The main findings of Vandenbussche *et al.* (2017) suggest that value added production in UK would decrease between 1.21% (soft Brexit) and 4.47% (hard Brexit), inducing job losses in the UK of around 140,000 to 530,000 jobs. In absolute terms a larger number of jobs would be lost in the EU27 ranging between 280,000 and 1.2 million jobs.

The recent contributions by Brakman *et al.* (2018) and Felbermayr *et al.* (2017) are most closely related to the work carried out in this paper. The former apply a structural gravity model for bilateral trade flows taking account for full endowment general equilibrium effects as proposed by Yotov *et al.* (2016). For this purpose, Brakman *et al.* (2018) estimate the gravity equation via PPML together with an iterative procedure which allows to estimate and counterfactually change both the multilateral resistance (MLR) terms and a country's income level (i.e., full endowment general equilibrium effects). The estimated parameters for calculating counterfactuals is based on information on bilateral trade agreements. This paper also investigates two alternative Brexit scenarios. The soft

Brexit scenario assumes that UK trades with the EU only under WTO rules, but retains all bilateral trade agreements with third countries with which the EU has agreements in force. Under the hard Brexit alternative, Brakman *et al.* (2018) assume that UK is able to only trade under WTO regulation with all trading partners around the world. Empirically, this study also relies on cross-sectional trade in value added data from the 2014 WIOD covering 43 countries. Their findings suggest that value added exports would drop by 18% for the UK under the hard Brexit scenario and by about 14% under the alternative soft Brexit. Furthermore, the results suggest that the "Global Britain" strategy in which the UK signs bilateral trade agreements with all non-EU economies included in the WIOD database would still not be sufficient to offset UK's post-Brexit losses in trade with the EU.

In a similar vein, Felbermayr *et al.* (2017) also estimate a structural gravity model. This paper, however, exploits the time-variation by using data from WIOD spanning the years from 2000 to 2014, allow for heterogeneous trade effects of Brexit and also provide a detailed analysis at both the sectoral- and country-level of disaggregation, respectively. Similar to Dhingra *et al.* (2017), the identified trade effects enter as inputs for various counterfactual scenario analyses in a new quantitative multi-country, multi-sector trade model which has been developed at the Ifo Institute for Economic Research. This paper's main findings suggest that a hard Brexit scenario under which UK would trade only under WTO regulation, would induce a welfare loss in the UK by approximately 2%. Within the EU, welfare losses might be asymmetrically distributed and trade in services is estimated to be most negatively affected by the Brexit. Under the alternative soft Brexit scenarios the welfare effects are smaller and in many cases not statistically different from zero for the EU27 economies.

Our papers reconsiders the estimation of potential Brexit effects in a unifying framework applying a panel data estimator which exploits the general equilibrium constraints imposed by the system of multilateral resistances. The contributions of the paper to the existing literature on trade policy analysis, in general, and the estimation of Brexit effects, in specific, are the following: In the comparative static analysis we account for full endowment general equilibrium effects and explicitly assesses uncertainty in the estimated Brexit effects for each counterfactul policy scenario using theory consistent confidence intervals.

This is an important property as it allows to provide a bandwidth of potential Brexit trade effects for alternative post-Brexit scenarios and to formulate more accurately policy conclusions. The previous literature either ignores this uncertainty or calculates confidence intervals by applying different bootstrapping methods. In our view, there are no papers available that justify the usage of bootstrapped standard errors for predictions in gravity models. In fact, the work of Bickel and Freedman (1983) suggest that bootstrapping does not work for models where the number of parameters increase in sample size as in gravity models.[6] By contrast, the delta method proposed in this paper is consistent with standard trade theory and does not suffer from a bias. The latter point is illustrated

[6]Monte-Carlo evidence provided in Pfaffermayr (2018) confirms this view and shows that robust standard errors of PPML estimates are typically downward biased so that parametric bootstrap procedures do no yield reliable confidence intervals.

in a small-scale Monte Carlo analysis presented in the technical Appendix D.

Furthermore, we apply two alternative specifications of the underlying gravity model based on different trade policy indicators, i.e., customs unions and FTAs versus RTAs. We utilize a tailor-made dataset based on OECD's STAN and UNIDO's production database for 65 economies for a time period spanning the years from 1994 to 2012. As compared to the previously mentioned studies based on WIOD data, our data source accounts for a larger number of newly formed free trade agreements facilitating the identification of the potential trade effects from Brexit which, in turn, are used for the counterfactual policy scenario analysis. Finally, our econometric specification of the gravity model differs from previous work in that we empirically assess the impact of trade policies on border effects for bilateral cross-border trade flows. Such a specificity and the inclusion of domestic trade flows as the "frictionless" trade counterpart to cross-border trade most closely mimics the findings from trade theory and allows for a clear identification and interpretation of the trade and welfare effects of trade policies.

3 The structural panel data gravity model and comparative static analysis

3.1 The specification of the structural panel data gravity model

Following of Anderson and van Wincoop (2003) and Yotov et al. (2016), we write demand of country j for goods produced in country i in period t, x_{ijt}, as

$$x_{ijt} = Y_w \left(p_{it} b_{it} t_{ijt}\right)^{1-\sigma} \theta_{jt} P_{jt}^{\sigma-1}, \quad P_{jt} = \left(\sum_{j=1}^{C} \left(p_{it} b_{it} t_{ijt}\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}},$$

where b_{it} is a preference parameter or may be determined by another isomorphic gravity model. p_{it} denotes the mill price in country i with corresponding trade elasticity $1-\sigma$. $t_{ijt} > 1$ captures barriers to trade and P_{jt} defines the CES-price index in importer country j. Lastly, κ_{it} stands for country $i's$ share in the value of world production, while θ_{jt} refers to the share of expenditures of country j in world income $Y_{t,w}$. In the empirical analysis below we allow these two figures to differ and thus for exogenously determined multilateral trade imbalances at the country level. For each country i the market clearing conditions implicitly defines the outward resistance term as

$$\kappa_{it} = \left(p_{it} b_{it}\right)^{1-\sigma} \underbrace{\sum_{j=1}^{C} t_{ijt}^{1-\sigma} \theta_{jt} P_{jt}^{\sigma-1}}_{\Pi_{it}^{1-\sigma}} \rightarrow p_{it} = \tfrac{1}{b_{it}} \left(\kappa_{it} \Pi_{it}^{\sigma-1}\right)^{\frac{1}{1-\sigma}}. \quad (1)$$

and thus the system of multilateral resistances. For econometric estimation, the structural gravity model is specified for normalized trade flows $s_{ijt} = x_{ijt}/Y_{t,W}$ so that $\sum_{i=1}^{C} \sum_{j=1}^{C} s_{ijt} =$

1 (see Allen et al. 2018):

$$s_{ijt} = t_{ijt}^{1-\sigma}\kappa_{it}\Pi_{it}^{\sigma-1}P_{jt}^{\sigma-1}\theta_{jt}e^{\mu_{ij}}\eta_{ijt} := e^{z'_{ijt}\alpha+\beta_{it}(\alpha,\mu)+\gamma_{jt}(\alpha,\mu)+\mu_{ij}}\eta_{ijt}.$$

Time varying trade frictions are modelled as $t_{ijt}^{1-\sigma} = e^{z'_{ijt}\alpha}$, while the country-pair fixed effects μ_{ij} capture time invariant unobserved bilateral barriers to trade. Multilateral trade resistances enter the model in normalized form as $e^{\beta_{it}(\alpha,\mu)} = \kappa_{it}\Pi_{it}(\alpha,\mu)^{\sigma-1}$ and $e^{\gamma_{jt}(\alpha,\mu)} = \theta_{jt}P_{jt}(\alpha,\mu)^{\sigma-1}$ and depend on the parameter vector α referring to trade barriers, the pair specific fixed effects and on the number of countries in the sample. For $i,j = 1,...,C$ and period t the reparameterized system of trade resistances can be compactly written as

$$\kappa_{it} = \sum_{j=1}^{C} e^{z'_{ijt}\alpha+\beta_{it}(\alpha,\mu)+\gamma_{jt}(\alpha,\mu)+\mu_{ij}}, \; i = 1,...,C-1, \tag{2}$$

$$\theta_{jt} = \sum_{i=1}^{C} e^{z'_{ijt}\alpha+\beta_{it}(\alpha,\mu)+\gamma_{jt}(\alpha,\mu)+\mu_{ij}}, \; j = 1,...,C. \tag{3}$$

Since the solutions of the system of trade resistances are unique up to a constant[7], without loss of generality we set $\beta_{Ct} = 0$, $t = 1,..,T$ and do not include a constant in our econometric model. In addition, we have to account for the collinearity of the exporter-time and importer-time specific dummies with the bilateral fixed effects, since unilateral exporter and importer fixed effects are nested in the set of bilateral fixed effects. Following Anderson and Yotov (2016) we drop $2C-1$ bilateral fixed effects, namely those for internal trade ($i = j$, $\mu_{ii} = 0$) and those for $i = C$ ($\mu_{Cj=0}$). In effect, this implies that all international fixed effects with $i \neq j$ measure time invariant bilateral trade costs relative to (i) domestic trade and (ii) relative to the US as exporting country for each importing country j".

The normalization of trade flows by $Y_{t,W}$ implies that there is no constant in the model and without further structural assumptions on the DGP the value of world production denoted by $Y_{t,W}$ remains unspecified. For estimation the countries' production and expenditure figures are assumed to be exogenously given. Finally, the disturbances are denoted by η_{ij}, with $E[\eta_{ijt}|z_{ijt}] = 1$ and can be heteroskedastic or arbitrarily correlated in the exporter-time, importer-time and country-pair dimensions, respectively (Egger and Tarlea, 2015).

3.2 Full endowment general equilibrium and comparative static analysis

To obtain the full endowment general equilibrium effects of counterfactual changes in trade barriers, their impact on factory gate prices and on the value of production has to be considered, in addition to their direct effect and the impact on multilateral resistances. The value of production Y_{it} may be written as

$$Y_{it} = p_{it}\tfrac{Y_{it,0}}{p_{it,0}},$$

[7] In the absence of any trade barriers (i.e., $\alpha = 0$, $\mu_{ij} = 0$), one may set $\Pi_{it}(0) = c_t$ and $P_{jt}(0) = 1/c_t$, where c_t is a time-specific constant so that $e^{\beta_{it}(\alpha,\mu)} = c_t\kappa_{it}$ and $e^{\gamma_{jt}(\alpha,\mu)} = \theta_{jt}/c_t$.

where the index 0 refers to the initially observed values in the baseline situation.[8] Using the equilibrium condition (1) yields $p_{it} = b_{it}^{-1} e^{\frac{\beta_{it}(\alpha,\mu)}{1-\sigma}}$. The production and expenditure shares observed in the counterfactual scenario can thus be written as

$$\kappa_{it} = \frac{\frac{p_{it}}{p_{it}^0}\frac{Y_{it}^0}{Y_{t,W}}}{\sum_{k=1}^{C}\frac{p_{kt}}{p_{kt}^0}\frac{Y_{kt}^0}{Y_{t,W}}} = \frac{e^{\frac{\beta_{it}(\alpha,\mu)-\beta_{it}^0(\alpha,\mu)}{1-\sigma}}\kappa_{it.0}}{\sum_{k=1}^{C} e^{\frac{\beta_{kt}(\alpha,\mu)-\beta_{kt}^0(\alpha,\mu)}{1-\sigma}}\kappa_{kt}^0} \quad (4)$$

$$\theta_{jt} = \kappa_{jt}\frac{\theta_{jt}^0}{\kappa_{jt}^0}. \quad (5)$$

This specification holds initial trade deficits constant, which remain unexplained and are taken as given. In order to obtain the full endowment general equilibrium effects in the spirit of Yotov et al. (2016), we insert (4) and (5) into the system of multilateral resistances (2) and (3) to account for endogenous adjustments of gross production and expenditures as a response to counterfactual changes in mill prices. Allen et al. (2018) prove that under a set of low level assumptions the equilibrium exits and is unique under a proper normalization of the model. Hence, the multilateral resistance terms as well a the counterfactual production and expenditure shares are uniquely determined by the finite set of the structural parameters α.

The estimated counterfactual change is based on the expected value of the trade vector $m_t(\alpha) = E[s_t(\alpha)]$ and the diagonal matrix of baseline predictions $M_t^0(\alpha) = diag(m_{ijt}^0(\alpha))$. For a group of country pairs selected by a matrix R with dimension smaller than the number of structural slope parameters[9] the counterfactual changes are calculated as $RM_t^0(\alpha)^{-1}m_t(\alpha)$. Since the multilateral resistance terms are unique functions of the structural slope parameters, one can apply the delta method to obtain the variance of the estimated counterfactual changes.

The delta method is based on the first order Taylor series approximation[10] of $RM_t^0(\alpha)^{-1}m_t(\alpha)$ with respect to the structural slope parameters α. Thereby the functional dependence of the multilateral resistance on the structural parameters α is fully accounted for. Under a standard set of regularity conditions one can show that its limit distribution is given as

$$CR\left(M_t^0(\widehat{\alpha})^{-1}m_t(\widehat{\alpha}) - M_t^0(\alpha_0)^{-1}m_t(\alpha_0)\right) \xrightarrow{d} N(0, R\left(\Upsilon_t - \Upsilon_t^0\right)V_\alpha\left(\Upsilon_t - \Upsilon_t^0\right)' R'),$$

where α_0 denotes the vector of true structural parameters and V_α the limiting variance of a root-n consistent estimator of α_0. The matrices of the derivatives, Γ_t and Γ_t^0, are given

[8] In an endowment economy $\frac{Y_{it}^0}{p_{it}^0}$ denotes country i's the endowment.

[9] This condition ensures that the limiting distribution of the estimated counterfactual changes is properly defined.

[10] Details are provided in technical appendix, Sections B and C.

as

$$\Gamma_t(\alpha) = M_t^0(\alpha)^{-1}M_t(\alpha)\left(\left(I_{C^2} - D_t\left[D_t'M_t(\alpha)D_t - H_t(\alpha)\right]^{-1}D_t'M_t(\alpha)\right)Z_t + D_t\left[D_t'M_t(\alpha)D_t - H_t(\alpha)\right]^{-1}H_t(\alpha)\left(D_t'M_t^0(\alpha)D_t\right)^{-1}D_t'M_t^0(\alpha)Z_t^0\right)$$

$$\Gamma_t^0(\alpha) = M_t^0(\alpha)^{-1}M_t(\alpha)\left(Z_t^0 - D_t\left(D_t'M_t^0(\alpha)D_t\right)^{-1}D_t'M_t^0(\alpha)Z_t^0\right)$$

with $R\left(\Upsilon_t - \Upsilon_t^0\right) = \lim_{C\to\infty} R\left(\Gamma_t(\alpha_0) - \Gamma_t^0(\alpha_0)\right)$. Thereby D_t denotes the design matrix for the exporter and importer dummies at period t and $H_t(\alpha)$ comprises the derivatives of κ_t and θ_t with respect to the $\beta_{it}'s$

$$H_t(\alpha) = \left[\begin{array}{cc} \frac{1}{1-\sigma}\left(diag(h_{x,t}) - h_{x,t}h_{x,t}'\right) & 0 \\ \frac{1}{1-\sigma}\left(diag(h_{m,t}) - h_{m,t}h_{x,t}'\right) & 0 \end{array}\right],$$

with $h_{it} = e^{\frac{\beta_{it}-\beta_{it}^0}{(1-\sigma)}}\kappa_{it}\left(\sum_{k=1}^n e^{\frac{\beta_{kt}-\beta_{kt}^0}{(1-\sigma)}}\kappa_{kt}\right)^{-1}$, $h_{x,t} = (h_{1t}, ..., h_{C-1,t})'$, $h_{m,t} = \left(h_{1t}\frac{\theta_{1t}^0}{\kappa_{1t}^0}, ..., h_{C-1,t}\frac{\theta_{C-1,t}^0}{\kappa_{C-1,t}^0}, \frac{\theta_{Ct}^0}{\kappa_{Ct^0}}\right)$ and $h_t = (h_{x,t}'h_{m,t}')'$. One can be show that the resulting variance covariance matrix of comparative static effects can be estimated consistently, since $R(\Gamma_t(\widehat{\alpha}) - \Upsilon_t) = o_p(1)$ as well as $R(\Gamma_t^0(\widehat{\alpha}) - \Upsilon^0) = o_p(1)$.

Section D of the technical appendix offers a small-scale Monte Carlo simulation exercise that illustrate the performance of the delta method based confidence intervals for counterfactual predictions in finite samples. The results demonstrate that in case of robust standard errors and standard errors clustered by country pairs the estimated standard errors of counterfactual effects come close to the simulated ones and the confidence intervals exhibit approximately correct coverage rates. If standard errors are clustered by country-pair, exporter-year and importer-year, the estimated variance-covariance matrix of $\widehat{\alpha}$ turned out negative definite in a substantial number of Monte Carlo runs. This phenomenon is well documented in the literature (Cameron, Gelbach and Miller, 2011) and is prevalent in models with dummy designs sharing the same dimensions of the clusters. In the valid Monte Carlo runs the simulated coverage ratios turned out too small by a margin of approximately 5 percentage points across the board.

4 Econometric model, data and estimation results

The specification of the structural gravity model follows Yotov (2012), Bergstrand *et al.* (2015) and Heid, Larch and Yotov (2015) who argue that the impact of (bilateral) trade policies are best identified in a model that includes domestic trade flows (i.e., from country i to i), comprises a border dummy (B_{ij}) taking the value 1 if $i \neq j$ and 0 else which is interacted with a time trend (t) to allow the (international) border effects to change over time, and captures the evolution of international trade that may be different for more distant trading partners and for neighboring countries. Hence, the border-trend variable is additionally interacted with $log(dist_{ij})$ and a dummy for contiguity $contig_{ij}$, respectively. The inclusion of domestic trade flows allows to identify the parameters associated with these three international trade related covariates. With regard to the counterfactual scenario analysis, this empirical approach enables us to extrapolate secular globalization trends beyond the estimation period for predicting short- and medium-run Brexit effects. Furthermore, we include a dummy, D_{GR}, which only takes on a value of 1 for the year 2009 and is zero otherwise. This variable is interacted with the border dummy and controls for the short-run international trade reducing impact of the Great Recession.

Regional trade agreements, in general, reduce tariffs and possibly also non-tariff barriers to international trade, but by definition do not affect domestic trade. Conceptually, regional trade agreements may thus be thought of yet another determinant that reduces (international) border effects. Following this reasoning, the dummy variables indicating the presence of alternative types of international trade agreements are likewise interacted with the border dummy. Moreover and in line with Bergstrand *et al.* (2015, p. 313), these interaction terms additionally enter the specification with 3-year and 6-year lags, respectively, to account for phasing-in effects and sluggish adjustment of trade flows over time.

The resulting empirical specification of the gravity model identifies the change of border effects over time, but not their level, which is absorbed by the country-pair fixed effects. It thus provides a clean measurement for the impact of changing trade barriers on bilateral trade over time, since domestic trade flows serve as the base and are fully described by the fixed country-pair effects and the trade resistance terms. For estimating the Brexit induced trade effects, we apply two alternative specifications of the gravity equation. Specification (1) differentiates between the impact of customs unions (such as the EU) and FTAs, while Specification (2) subsumes CUs and FTAs in a single RTA indicator variable. Formally these two specifications read as

$$\begin{aligned} s_{ijt} &= \exp\left(\alpha_1 B_{ij} t + \alpha_2 B_{ij} contig_{ij} t + \alpha_3 B_{ij} \log(dist_{ij}) t + \alpha_4 B_{ij} D_{GR}\right) \\ &\quad * \exp\left(\sum_{k=0}^{2} \alpha_{5+k} B_{ij} CU_{ij,t-3k} + \sum_{k=0}^{2} \alpha_{8+k} B_{ij} FTA_{ij,t-3k} + \mu_{ij} + \beta_{it} + \gamma_{jt}\right) + \varepsilon_{ijt}, \end{aligned} \tag{6}$$

$$\begin{aligned} s_{ijt} &= \exp\left(\alpha_1 B_{ij} t + \alpha_2 B_{ij} contig_{ij} t + \alpha_3 B_{ij} \log(dist_{ij}) t + \alpha_4 B_{ij} D_{GR}\right) \\ &\quad * \exp\left(\sum_{k=0}^{2} \alpha_{5+k} B_{ij} RTA_{ij,t-3k} + \mu_{ij} + \beta_{it} + \gamma_{jt}\right) + \varepsilon_{ijt.} \end{aligned} \tag{7}$$

The estimation applies the panel data CPPML estimator derived in Pfaffermayr (2017), which assumes that gross production and expenditures are given and the system of multilateral resistances holds in expectation. Furthermore, the estimation procedure eliminates country-pair fixed effects like the standard panel PPML. The estimation uses a zig-zag Gauss-Seidel algorithm, which is described in more detail in Section A of the technical appendix. The main advantage of constrained panel data PPML is that it delivers predictions that adhere to the restrictions imposed by the system of trade resistances even in case of missing trade flow data and this estimator is unaffected by the incidental parameters problem. The estimated standard errors of the parameter estimates of the structural parameters α account for these restrictions and are derived in more details in Pfaffermayr

(2017). As shown in Section 3.2 in this setting the delta method is applicable for the calculation of the confidence intervals of counterfactual scenario predictions.

Moreover, this estimation procedure allows for three-way clustering across country-pairs, exporter-time and importer time, respectively, as suggested by Egger and Tarlea (2015). Since the multilateral resistances are functions of the estimated structural parameters, the delta method can be applied to obtain standard errors for percentage changes in trade flows and welfare based on the assumed counterfactual Brexit scenarios.

We use data on bilateral goods trade as well as compatible data on gross production, total exports and imports for total manufacturing for 65 countries. The bilateral trade flow data and the unilateral data are consistent in the sense that the total value of exports of a single country adds up to its production value and the value of all imports to its expenditures, when accounting for domestic trade flows. Thereby, domestic trade is defined as gross production minus total exports.[11]

The database covers the time period from 1994 to 2012 in three-year intervals and is described in more detail the Appendix A.1. Trade flow data are taken from OECD's STAN database and Nicita and Olarreaga's (2007) database. The data on gross production, total exports and imports are collected from several sources (OECD-STAN, UNIDO, CEPII and WIOD). These figures have been carefully checked to be consistent with the trade data and it is ensured that none of them is missing. Thereby, a few data points have been interpolated.[12] A detailed description on the applied imputation procedures for bilateral trade flows, gross production and expenditures is offered in Appendix A.1. Population weighted distances and the dummy for contiguity is taken from Mayer and Zignago (2011).[13]

The information on regional trade agreements stems from Mario Larch's Regional Trade Agreements Database (Egger and Larch 2008). This database provides dummy variables indicating the presence of a customs union, a free trade agreement (FTA) and a regional trade agreement (RTA). The RTA dummy covers both customs unions and FTAs and is coded as 1 if either a customs union or a FTA is in force and zero otherwise. In Specification (1) we separately estimate the bilateral trade effects of custom unions and FTAs, respectively while Specification (2) pools all trade policy agreements together and estimates average RTA effects. The second specification more closely follows the empirical Brexit literature discussed above. Specification (1) aims at identifying potentially heterogeneous trade effects stemming from trade policy measures with varying depths in their respective scope.

Table 2 reports the panel data CPPML estimation results from Specifications (1) and (2),

[11] This adding up property might be violated, however, under missing trade flows and unobserved random measurement errors.

[12] In a robustness analysis, we check for the impact of data interpolation on the estimation results by excluding these observations from the sample. The corresponding results are reported in Table A2 in Appendix A.2.

[13] All data and the software codes of the imputation procedures are available from the authors upon request.

respectively. In our data only 4% of bilateral trade flows are missing and thus CPPML and the standard PPML deliver rather similar parameter estimates. Overall, we find a pronounced downward trend in the size of trade distorting border effects as indicated by the positive border-time interaction effects. Furthermore, these estimates imply that, on average, the share of international trade in world trade expands by 3.5% (Specification 1) and 4.5% (Specification 2) per year.[14] Yet, these are the estimated direct border effects which neglect the associated changes in multilateral resistances. This finding, however, is also well in line with the observed pattern in the data. Table A1 in Appendix A.2 shows that the shares of domestic trade flows in the UK, the EU and the rest of the world (ROW) (substantially) declined from 1994 to 2012. Accordingly, domestic trade has been increasingly substituted by international imports and exports. The interaction of the border dummy with log distance indicates that the identified global trend of falling international trade barriers is weaker for more distant trading partners. For neighboring countries this trend is reinforced but not significantly so as can be inferred from the parameter estimates associated with the contiguity-time interaction term.

Table 2: Parameter estimates from panel data CPPML

	Specification (1)		**Specification (2)**	
	Parameter-estimate	t-value	Parameter-estimate	t-value
Border*time	0.17	4.75***	0.20	5.48***
Border*contiguity*time	0.02	1.20	0.02	1.53
Border*(log) distance*time	−0.01	−1.82*	−0.01	−2.50**
Border*Great recession 2009	−0.19	−4.87***	−0.19	−4.55***
Border*Customs union	0.13	1.99**		
Border*Customs union (t-3)	0.33	4.24***		
Border*Customs union (t-6)	0.03	0.45		
Border*FTA	−0.07	−1.36		
Border*FTA (t-3)	0.25	3.64***		
Border*FTA (t-6)	0.11	1.67*		
Border*RTA			−0.06	−1.24
Border*RTA (t-3)			0.25	3.49***
Border*RTA (t-6)			0.14	1.90*
Total customs unions effect	0.50	5.39***		
Total FTA effect	0.29	3.90***		
Total RTA effect			0.33	4.31***

Notes: The panel comprises 7 periods of 3 years and 65 countries with with 1,138 out of 28,353 missing trade flows. Standard errors are clustered over country-pairs, importer-years and exporter-years. *, **, *** ... Significant at 10%-, 5%- and 1%-level.

Further, the estimates suggest that customs unions substantially promote international

[14] Recall, that the negative impact of international borders is fully absorbed by the fixed country-pair effects and that the positive parameter estimates indicate the "lessening' of border effects over time.

trade. Their impact on bilateral goods trade accumulates to an increase of 64.2% after 6 years as indicated by the total trade effect parameter which amounts to 0.5 and is reported in the lower part of Table A3.[15] Interestingly the formation of a FTA initially induces an insignificant negative impact and its total accumulated bilateral trade effect after six years amounts to only 33.3%. The findings from Specification (1) thus point to the relevance of distinguishing between customs unions and FTAs for trade policy analysis (Baier, Bergstrand and Feng 2014). Specification (2) finds that RTAs exhibit an accumulated trade enhancing effect of 38.7%. Given that FTAs are a more common trade policy tool as compared to the establishment of customs unions, the estimate stemming from the RTA indicator unsurprisingly is closer to the one from FTAs. All these estimation results only refer to the measured direct effects of international trade agreements and do not yet take general equilibrium effects into account. Overall, the estimated direct effects are well in line with those in the literature and point to pronounced phasing-in effects of trade agreements (see, e.g., Baier, *et al.* 2014; Bergstrand *et al.* 2015).

In Table A2 in Appendix A.2 we provide a detailed robustness analysis for the bilateral trade effects stemming from trade policies. Accordingly, we re-estimate Specifications (1) and (2) for modified and alternative data sources and apply some alternative specifications. First we exclude all imputed trade flows and obtain very similar estimation results. Second, we alternatively use 3 year averages from the WIOD data spanning the years 2000 to 2012 and estimate gravity models for 42 mainly developed economies. This allows to compare our findings more directly with the available literature as most other Brexit studies rely on trade data based on input-output tables collected in the WIOD project (see Table 1). Specification (1) yields a very similar estimate for the long-run impact of customs unions, while the cumulative direct effect of FTAs and RTAs turns substantially lower (0.12 and 0.13, respectively). Furthermore, the cumulative impact of FTAs is insignificant in the WIOD sample. This finding indicates that WIOD data might not be most useful for identifying accurate trade policy effects. Prior to the year 2000, the 42 included countries have already been very active in implementing free-trade policies which result in small time-variation exploitable for estimation purposes. Table A4 in Appendix A.2 documents this phenomena descriptively. The overall share of any free trade agreement as captured by the RTA indicator shows substantially more time-variation in our data as compared to the WIOD database. In 1994 only 18% of all bilateral trade relationships profited from favorable market excess. Until 2012 this share increased to 38% in our dataset. The share of RTA-affected trade relationships in the WIOD amounted to 44% in 2000 and increased to 57% in 2012. For the UK as an historically free-trade policy active country, the share of RTAs is larger and especially in the WIOD database only increases by 5 percentage points from 2000 until 2012.

The next two robustness checks modify the empirical specification with regard to the time-trend assumed for the changing nature of border effects. The third set of columns reported in Table A2 additionally includes an interaction term of the border dummy variable with squared time. This allows the border effects to change non-linearly over time.

[15] We use the approach of van Gardaren and Sha (2002) who suggest to estimate percentage changes based on a parameter associated with a dummy variable in a semi log-specification, say c, by $\widehat{p}_c = 100(e^{\widehat{c}-0.5*\widehat{\sigma}_c} - 1)$.

As indicated by the parameter estimates, this effect is zero which allows us to rule out misspecification in the border-time effects. The last set of results corresponds to a specification close to the one applied by Bergstrand *et al.* (2015). Accordingly, the border dummy is not interacted with time assuming a time-constant trade distorting effect for international versus domestic trade. The parameter estimate associated with the common border dummy is positive capturing the average increase in international versus domestic trade. The total effects steeming from trade policies are, however, only marginally affected. The customs union effect increase from 0.5 (Table 2) to 0.54 while the FTA and RTA effects are reduced by 0.01, respectively.

In Table A3 we provide additional robustness checks by examining potentially heterogeneous trade policy effects for the UK. For this purpose we additionally interact the suggested trade policy indicators including CUs and FTAs in Specification (1) and RTAs in Specification (2) with an indicator variable which marks trade flows where the UK is one of the trading partners. This approach allows to investigate whether past trade policy effects are different for the UK as compared to the remaining EU member states. In Specification (1) the effects of a customs union membership and from FTAs is smaller in the UK only 6 years after these agreements went into force. For the more contemporaneous effects, we are not able to identify statistically significant differences between the UK and the other members of such policy agreements. When calculating the overall trade effects over the 6 years, the customs union effects are not statistically different from each other, while the FTA effects are smaller for the UK. As a consequence, the Hard Brexit scenario estimates would not change while the Soft Brexit scenarios would be somewhat worse for the UK under this empirical specification. In Specification (2) we estimate more heterogeneous effects. Until the first three years, RTA effects are smaller for the UK which, however, is compensated with a larger effect for the 6 years lag effect. On overall, the RTA effect is not statistically significantly different from all other countries signing any RTAs.

In general, the results provided in Tables A2 and A3 point to the robustness of our baseline estimates and further shed some light on potential identification issues when relying on the WIOD for evaluating the impact of trade policies on bilateral trade. In our case, the trade enhancing effects of FTAs and more generally RTAs are substantially lower when applying WIOD data. As a consequence, any counterfactual scenario which relies on these parameters would identify smaller trade and welfare effects as compared to data provided in OECD's STAN database.

5 The trade and welfare effects of Brexit

The two alternative empirical specifications of the gravity model allow us to define four counterfactual Brexit scenarios, two of which we classify as soft Brexit and two refer to a hard Brexit. With the data at hand, we proceed as if Brexit materialized in 2012 (last year of available observations) for identifying the short-run effects of the Brexit and calculate out-of-sample predictions for $t+3$ and $t+6$ for obtaining medium-run effects.

The first scenario refers to the determination of UK's membership in the customs union formed be the EU countries. For the soft Brexit it is assumed that a free trade area with the remaining EU member countries is established instead, while all trade agreements of UK with non-EU countries remain unaffected by Brexit. The scenario thus assumes that the UK gets its post-Brexit FTA which since July 2018 is the official negotiating position of the UK government headed by Theresa May. The hard Brexit scenario based on Specification (1) also abandons the membership of UK in the existing customs union established by the EU. However, it is further assumed that a new arrangement of UK with the EU countries cannot be established. In addition, this scenario also abolishes all existing trade agreements of UK with third countries. As a consequence, in this scenario the UK would not take part in any trade agreements and would trade under WTO rules.

Specification (2) subsumes all existing trade agreements into the single RTA indicator. For the soft Brexit scenario this dummy variable is set to zero for the bilateral UK-EU trade relationships, while the trade policy relationships of UK with all non-EU member states would remain unaffected. As in Specification (1), the hard Brexit version of this scenario additionally switches off all RTAs that the EU has established with third countries. In all experiments we change the respective current and lagged dummies for the trade agreements so that the trade impact of Brexit is immediately realized and the alternative counterfactual scenarios account for phasing in effects in case UK would be able to negotiate a new FTA with the EU. This implies that the immediate effect of a new FTA is zero and only after three years a significant trade enhancing effect could be materialized (see Specification 1 in Table 2).

Tables 3 to 5 report the full endowment general equilibrium effects of Brexit that account for changes in multilateral trade resistances, in gross production and incomes, respectively. Besides the estimated general equilibrium effects the tables also report 95-confidence intervals (in square brackets) that are based on the delta method and the panel data CPPML as discussed in Pfaffermayr (2017). The tables document unweighted averages for groups of bilateral trade combinations. In Table 3, the rows depict the Brexit induced changes in bilateral exports from the first to the second economic region mentioned. The estimation results corresponding to the rows denoted by UK-EU, for example, indicate the changes in UK's exports to the EU. Overall, we observe moderate changes in the Brexit effects over time due to the secular trends in globalization. Thus, in our discussion we focus on the estimated consequences of Brexit for the $t+6$ out of sample predictions.

5.1 The soft Brexit scenario

As shown above, the estimated long-run impact of customs unions on bilateral trade is much higher than that of FTAs. Even if UK would be able to successfully negotiate a new FTA with the EU member states a significant reduction in bilateral trade has to be expected. Table 3 reports that under the soft Brexit scenario and Specification (1) the structural gravity model predicts a reduction in UK-EU trade by -16.8% [-26.4%, -7.2%] six years after the Brexit will take place and one of -13.8% [-21.7%, -5.9%] for the corre-

Table 3: Brexit impact on international trade, full endowment general equilibrium

		Soft Brexit			Hard Brexit		
		%-change	CI lower	CI upper	%-change	CI lower	CI upper
Specification 1							
UK-EU	t	-18.06	-27.68	-8.44	-37.40	-47.59	-27.21
	t+3	-17.19	-26.96	-7.41	-36.26	-46.54	-25.98
	t+6	-16.81	-26.41	-7.21	-35.53	-45.71	-25.34
EU-UK	t	-14.42	-22.04	-6.80	-30.28	-38.89	-21.67
	t+3	-13.87	-21.80	-5.93	-29.55	-38.33	-20.76
	t+6	-13.78	-21.69	-5.88	-29.41	-38.19	-20.62
EU-EU	t	0.39	-0.08	0.85	1.13	0.51	1.75
	t+3	0.40	-0.08	0.89	1.17	0.54	1.81
	t+6	0.43	-0.07	0.92	1.23	0.58	1.88
UK-ROW	t	2.21	0.71	3.71	-3.21	-5.81	-0.62
	t+3	2.64	0.86	4.41	-3.88	-6.65	-1.11
	t+6	3.07	1.03	5.12	-2.84	-5.64	-0.04
ROW-UK	t	5.83	1.91	9.74	5.79	2.14	9.45
	t+3	5.88	1.93	9.83	4.64	0.97	8.31
	t+6	5.99	1.98	10.00	4.86	1.12	8.59
EU-ROW	t	0.73	0.27	1.19	1.60	0.96	2.25
	t+3	0.71	0.26	1.17	1.51	0.89	2.13
	t+6	0.71	0.26	1.15	1.50	0.89	2.11
ROW-EU	t	-0.14	-0.19	-0.08	-0.20	-0.36	-0.05
	t+3	-0.11	-0.16	-0.06	0.06	-0.15	0.27
	t+6	-0.08	-0.13	-0.03	0.12	-0.10	0.35
Specification 2							
UK-EU	t	-26.12	-36.02	-16.23	-25.57	-35.28	-15.87
	t+3	-25.56	-35.30	-15.81	-24.95	-34.47	-15.43
	t+6	-25.00	-34.59	-15.41	-24.33	-33.68	-14.99
EU-UK	t	-20.91	-29.19	-12.63	-20.36	-28.34	-12.39
	t+3	-20.80	-29.05	-12.55	-20.23	-28.17	-12.28
	t+6	-20.67	-28.89	-12.44	-20.06	-27.96	-12.15
EU-EU	t	0.71	0.17	1.25	0.67	0.14	1.20
	t+3	0.75	0.19	1.31	0.71	0.16	1.25
	t+6	0.79	0.22	1.36	0.74	0.18	1.29
UK-ROW	t	3.15	1.26	5.05	-4.42	-6.41	-2.44
	t+3	3.88	1.64	6.12	-3.67	-5.47	-1.87
	t+6	4.61	2.02	7.20	-2.91	-4.58	-1.25
ROW-UK	t	9.07	4.62	13.51	1.01	0.03	1.98
	t+3	9.22	4.70	13.73	1.19	0.10	2.28
	t+6	9.40	4.79	14.01	1.41	0.19	2.64
EU-ROW	t	1.06	0.54	1.57	1.11	0.58	1.64
	t+3	1.04	0.54	1.55	1.10	0.57	1.63
	t+6	1.03	0.53	1.53	1.09	0.57	1.62
ROW-EU	t	-0.20	-0.26	-0.13	-0.07	-0.22	0.07
	t+3	-0.15	-0.22	-0.08	-0.02	-0.18	0.13
	t+6	-0.11	-0.19	-0.04	0.02	-0.15	0.19

Notes: Confidence intervals are calculated by the delta method. CI lower and CI upper denote the estimates for the two-sided 95% confidence interval. The rows depict the Brexit induced changes in bilateral exports from the first to the second economic region mentioned. UK-EU, for example, denotes the changes in UK's exports to the EU.

Table 4: Brexit impact on domestic trade, full endowment general equilibrium

		Soft Brexit			Hard Brexit		
		%-change	CI lower	CI upper	%-change	CI lower	CI upper
Specification 1							
UK	t	7.94	2.44	13.45	19.66	10.91	28.42
	t+3	8.46	2.58	14.34	21.60	12.05	31.15
	t+6	9.03	2.77	15.30	23.17	12.92	33.42
EU	t	-0.03	-0.11	0.05	1.14	0.51	1.76
	t+3	-0.04	-0.12	0.05	1.18	0.54	1.82
	t+6	-0.04	-0.12	0.04	1.23	0.58	1.89
ROW	t	0.21	0.19	0.22	0.27	0.14	0.39
	t+3	0.20	0.18	0.23	0.39	0.23	0.56
	t+6	0.20	0.17	0.23	0.39	0.23	0.56
Specification 2							
UK	t	12.34	5.79	18.89	14.00	6.40	21.59
	t+3	13.30	6.25	20.35	15.11	6.91	23.30
	t+6	14.30	6.72	21.89	16.26	7.44	25.09
EU	t	0.71	0.17	1.26	0.67	0.14	1.20
	t+3	0.75	0.19	1.32	0.71	0.16	1.26
	t+6	0.79	0.22	1.37	0.74	0.18	1.30
ROW	t	0.05	0.04	0.05	0.37	0.24	0.50
	t+3	0.05	0.04	0.05	0.37	0.24	0.50
	t+6	0.05	0.04	0.06	0.38	0.25	0.50

Notes: Confidence intervals are calculated by the delta method. CI lower and CI upper denote the estimates for the two-sided 95% confidence interval.

sponding flows from the EU to UK.[16] The negative bilateral trade effects stemming from the soft Brexit scenario are the largest in the year the Brexit will take place (most likely in 2019) and the phasing-in effects of a potential EU-UK FTA will reduce the negative trade effects by about 1.2 percentage points over six years. To a small extent, the UK will be able to compensate this decline by an increase in trade with third countries (UK-ROW 3.0% [1.0%, 5.1%] and ROW-UK 6.0% [2,0%, 10.0%], respectively). The latter effects indicate a positive trade diversion effect implied by UK's withdrawal from the single market. Imports from the ROW will become relatively cheaper (due to an increase in trade costs for EU exports to the UK) and thus the ROW will gain from a Brexit via a 6% (average) increase in its exports. In the long-run this might also have implications for UKs trade balance with the ROW as exports from UK to the ROW are only increasing by about 3%. Trade flows within the EU and also that of EU member states with the ROW can be expected to be hardly affected by Brexit. Six years after the Brexit, the full endowment general equilibrium model suggests an increase of within-EU27 bilateral trade flows of about 0.4% which, however, is statistically not different from zero as indicated by the lower bound of the confidence interval which takes on a value of -0.1%. Exports from

[16] In the following discussion square brackets indicate the boundaries of the 95% confidence intervals obtained from the delta method.

Table 5: Welfare effects of Brexit, full endowment general equilibrium

		Soft Brexit			Hard Brexit		
		%-change	CI lower	CI upper	%-change	CI lower	CI upper
Specification 1							
UK	t	-1.29	-2.29	-0.28	-3.05	-4.85	-1.24
	t+3	-1.37	-2.45	-0.29	-3.32	-5.33	-1.32
	t+6	-1.46	-2.61	-0.30	-3.55	-5.73	-1.36
EU	t	-0.03	-0.11	0.05	-0.12	-0.22	-0.01
	t+3	-0.04	-0.12	0.05	-0.12	-0.23	-0.02
	t+6	-0.04	-0.12	0.04	-0.13	-0.24	-0.02
ROW	t	0.05	0.05	0.05	0.04	0.02	0.07
	t+3	0.05	0.04	0.05	0.04	0.02	0.07
	t+6	0.05	0.04	0.05	0.05	0.02	0.07
Specification 2							
UK	t	-1.96	-3.22	-0.71	-2.21	-3.69	-0.74
	t+3	-2.11	-3.47	-0.75	-2.38	-3.99	-0.77
	t+6	-2.26	-3.74	-0.78	-2.55	-4.31	-0.79
EU	t	-0.07	-0.16	0.02	-0.07	-0.15	0.02
	t+3	-0.08	-0.17	0.02	-0.07	-0.16	0.02
	t+6	-0.08	-0.18	0.01	-0.08	-0.17	0.02
ROW	t	0.05	0.04	0.05	0.00	0.00	0.00
	t+3	0.05	0.04	0.05	0.04	0.02	0.07
	t+6	0.05	0.04	0.06	0.04	0.02	0.07

Notes: Welfare calculations based on the Costinot and Rodríguez-Clare (2014) formula. The value of σ is chosen as 6.858 following Bergstrand *et al.* (2013, Table 1). Confidence intervals are calculated by the delta method. CI lower and CI upper denote the estimates for the two-sided 95% confidence interval.

the EU to the ROW are estimated to increase by 0.7% under the soft Brexit scenario when applying the direct trade effects stemming from Specification (1). This effect is statistically significantly different from zero. The some holds true for the negative but very small EU import effect from the ROW which, on average, amounts to -0.08%.

As hoped for by Brexit supporters in the UK, the soft Brexit scenario of Specification (1) fosters domestic trade by 9.3% [2.8%, 15.3%] six years after the Brexit as indicated in Table 4. Again, the immediate effect is very large and the adjustment over time is relatively small. Furthermore, the reported confidence intervals document substantial uncertainty in the domestic trade effect. The true effect most likely lies somewhere between 2.8% and 15.3% where actual realizations close to one or the other boundary of the interval would provide very different implications for the UK economy. This domestic trade effect is again driven by relative increases in costs for goods provided from the EU. The increase in relative costs induces a substitution of imports from the EU by relatively expensive but domestically produced goods.

In line with standard trade theory such a substitution will induce a welfare loss as consumers are faced with higher (average) prices after the Brexit has taken place. We calculate the welfare effects of Brexit by applying the approach suggested by Costinot and Rodríguez-Clare (2014). The results are reported in Table 5. Accordingly, when applying the soft Brexit scenario to Specification (1) the welfare effects from UK's leaving of the EU are most likely in the range of -1.5% [-2.6%, -0.3%]. For this calculation we assume an elasticity of substitution of 6.98, the preferred estimate reported by Bergstrand, Egger and Larch (2013, Table 1). The results suggest that under a soft Brexit scenario, in which the UK would be able to negotiate a post-Brexit FTA with the EU, the welfare losses from leaving the single market might not be too severe. Accordingly, UKs GDP would be about 1.5% lower six years after the Brexit as it would be in the hypothetical scenario in which the UK would have voted to remain within the EU. Table A4 in Appendix A.2 provides a robustness analysis for the calculated welfare losses. In particular, we are varying the elasticity of substitution such that it can take on values of 3 and 9, respectively. Table A4 documents that the obtained welfare effects change to some extent depending on the assumed elasticity of substitution. A smaller assumed σ induces larger negative welfare effects for the UK and in the worst case implies a reduction of real income in the magnitude up to minus 7% even in a soft Brexit scenario. When assuming $\sigma = 9$ the negative welfare consequences are substantially smaller and again might only be marginally negative in the best case scenario. For the EU and ROW the welfare effects are not very sensitive to changes in the assumed elasticity of substitution and are economically hardly significant.

5.2 The hard Brexit scenario

When focusing on the hard Brexit scenario, the Brexit induced consequences for bilateral goods trade and welfare are much more pronounced for the UK. Specification (1) predicts a decrease in UK exports to the EU by -35.5% [-45.7%, -25.3%]. Imports from the EU are expected to decline by -29.4% [-38.2%, -20.6%]. In other words, in the worst case UKs exports to the EU could drop by almost one half while the EU might also export about 40% less manufacturing goods to the UK. In this scenario, UK will also not be able to maintain its trade preferences with all non-EU countries and thus it would be substantially harmed by trading under WTO rules only. The counterfactual scenario results thus further suggest a reduction of UK-ROW trade by -2.9% [-5.6%, -0.04%] but the UK imports from the ROW would increase by 4.9% [1.1%, 8.6%]. The hard Brexit scenario thus would imply a substantial worsening in UKs trade balance with all other countries around the world including the remaining EU member states and would definitely make the UK a much more closed economy as it is today.

This fact is underlined by the tremendous increase in domestic trade induced by a hard Brexit which is reported in Table 4. Accordingly, six years after the Brexit has taken place domestic trade would be increased by 23.2% [12.9%, 33.4%], which is more than twice the number estimated for the soft Brexit scenario using the same empirical specification. Similar to the soft Brexit scenario, the EU27 economies are in total only marginally affected in terms of domestic trade and welfare effects although the trade conditions would be significantly worsened. The large increase in domestic trade of relatively expensive goods in the UK also translates into larger welfare losses to be expected. Six years after the Brexit has taken place UKs GDP is thus estimated to be about -3.5% [-5.7%, -1.4%]

lower under the hard Brexit scenario. Based on our estimates, a hard Brexit would more than double the economic costs stemming from Brexit via trade in manufacturing goods only.

5.3 The regional trade agreements specification

As compared to the results obtained from Specification (1), the differences in the effects between hard and soft Brexit are smaller when applying Specification (2), which estimates a significant direct long run RTA effect of 38.7% (see discussion above). Applying an estimator which is based on a weighted average of custom unions and FTAs for studying Brexit delivers larger (smaller) effects for the soft (hard) Brexit scenario. Six years after a Brexit bilateral exports from the UK to the EU are estimated to decline by -25.0% [-34.6%, -15.4%] in the soft Brexit scenario while under a hard Brexit the effects would be smaller -24.3% [-33.7%, -15.0%]. Domestic trade is estimated to increase by 14.3% [6.7%, 21.9%] after a soft Brexit and by 16.3% [7.4%, 25.1%] in case of a hard Brexit. This would translate into corresponding welfare losses of -2.3% [-3.7%, -0.8%] and -2.6% [-4.3%, -0.8%], respectively. The estimated welfare effects for the EU member states are again economically negligible and statistically not different from zero.

The estimated impact of Brexit on trade and welfare compares well to the findings available from the literature which are reported in Table 1. The results support the need for the UK to establish trade agreements with non-EU economies in order to at least partially compensate for the reduction in trade with single market member states. Given the geographic location of UK and the still prevalent burden of large distances for international trade, trade agreements with non-EU countries will most probably become not as economically successful as UKs integration into the European single market. Against this backdrop, Brexit will most likely come with some economic costs stemming from a (substantial) decline in trade with the remaining EU27 economies.

However another important aspect to note is that we observe considerably large confidence intervals of the estimated full endowment general equilibrium effects despite the fact that most of the parameters are estimated with high precision as indicated by the large t-values (in absolute numbers) attached to most of them. This implies that the uncertainty induced by the estimation of the structural gravity model is substantial and documents the need to apply a theory-driven approach for estimating and predicting the trade and welfare effects of trade policy measures. It also reveals that the provision of some average effects based solely on the parameter estimates might not be very informative for policy makers, as the broad bandwidth of possible effects provides important additional information on the likely impacts stemming from alternative post-Brexit scenarios.

5.4 Welfare effects for individual EU member states

The average welfare effects from Brexit for the EU are relatively small across both empirical specifications of the gravity model and across the different Hard and Soft Brexit scenarios considered. This finding might be driven by the aggregation of the individual effects at the EU level. In order to assess the maybe heterogeneous welfare consequences for the individual member states Table 6 reports welfare effects at the country-level for both the Hard and Soft Brexit scenarios and using Specifiction (1).

Again the findings support the view that a Hard Brexit will be more harmful in general. Ireland will be most strongly affected but is expected to experience a welfare loss under any Brexit scenario. In the case of a Soft Brexit this effect could limited to a reduction of real incomes below 0.2% while the lower bound estimate for the Hard Brexit scenario amounts to -2.66% 6 years after UK's leaving of the EU. Our best estimates for Ireland suggest a reduction of around 0.7% under the Soft Brexit and 1.7% under the Hard Brexit scenarios, respectively. When comparing these numbers for the estimated welfare effects for the UK, the full endowment general equilibrium model still suggests that the UK will be hit most strongly by its leaving of the EU irrespective of wheather a Soft or Hard Brexit would take place.

For another group of countries, the individual estimates also suggest some negative welfare implications especially in case of a Hard Brexit. Among these are Benelux countries Belgium, Netherlands and Luxembourg and some Scandinavian EU member states including Denmark and Sweden. From the new member states Cyprus and Latvia could suffer the most in case of a Hard Brexit. As compared to the effects for UK and Ireland, the effects for all these economies are, however, rather not very sizable in economic terms.

Finally, for the remaining EU member states reported in Table 6 and based on our model for estimating the trade and welfare effects of Brexit we do expect relatively small and in many cases no statistically significant negative welfare effects stemming from the Brexit. To sum up and in line with e.g., Felbermayr *et al.* (2017) one should expect somehow heterogeneous welfare effects for the remaining EU member states stemming from the Brexit which, however, are economically less pronounced as compared to the welfare implications estimated for the UK.

Table 6: Welfare effects of Brexit for the EU27 without Croatia and Malta, full endowment general equilibrium. Specification (1)

		Soft Brexit			**Hard Brexit**		
		%-change	CI lower	CI upper	%-change	CI lower	CI upper
Austria	t	0.01	-0.01	0.04	-0.02	-0.05	0.02
	t+3	0.01	-0.02	0.04	-0.02	-0.05	0.02
	t+6	0.01	-0.02	0.04	-0.02	-0.05	0.01
Belgium and Luxembourg	t	-0.16	-0.30	-0.02	-0.40	-0.57	-0.22
	t+3	-0.17	-0.31	-0.02	-0.41	-0.59	-0.23
	t+6	-0.17	-0.32	-0.02	-0.42	-0.60	-0.24
Bulgaria	t	0.00	-0.02	0.03	-0.01	-0.04	0.02
	t+3	0.02	0.00	0.05	0.00	-0.03	0.03
	t+6	0.02	0.00	0.05	0.00	-0.03	0.03
Cyprus	t	-0.12	-0.24	0.00	-0.30	-0.46	-0.14
	t+3	-0.13	-0.25	0.00	-0.31	-0.48	-0.15
	t+6	-0.13	-0.26	-0.01	-0.33	-0.50	-0.16
Czech Republic	t	0.00	-0.04	0.04	-0.05	-0.10	0.00
	t+3	0.00	-0.04	0.04	-0.05	-0.10	0.00
	t+6	0.00	-0.04	0.04	-0.06	-0.11	-0.01
Denmark	t	-0.10	-0.21	0.00	-0.26	-0.39	-0.13
	t+3	-0.11	-0.21	0.00	-0.27	-0.41	-0.14
	t+6	-0.11	-0.22	0.00	-0.29	-0.42	-0.15
Estonia	t	-0.02	-0.07	0.03	-0.09	-0.16	-0.03
	t+3	-0.02	-0.07	0.03	-0.09	-0.16	-0.03
	t+6	-0.02	-0.07	0.03	-0.09	-0.16	-0.03
Finland	t	-0.03	-0.09	0.03	-0.11	-0.19	-0.03
	t+3	-0.03	-0.10	0.03	-0.12	-0.20	-0.04
	t+6	-0.04	-0.10	0.02	-0.13	-0.22	-0.05
France	t	-0.05	-0.11	0.02	-0.15	-0.24	-0.05
	t+3	-0.05	-0.12	0.02	-0.16	-0.25	-0.06
	t+6	-0.06	-0.13	0.02	-0.17	-0.27	-0.07
Germany	t	-0.03	-0.08	0.03	-0.10	-0.18	-0.03
	t+3	-0.03	-0.09	0.03	-0.12	-0.19	-0.04
	t+6	-0.04	-0.10	0.03	-0.13	-0.21	-0.05
Greece	t	0.00	-0.03	0.04	-0.04	-0.09	0.01
	t+3	0.00	-0.04	0.04	-0.05	-0.10	0.00
	t+6	0.00	-0.04	0.04	-0.05	-0.11	0.00
Hungary	t	-0.01	-0.06	0.03	-0.08	-0.13	-0.02
	t+3	-0.01	-0.06	0.03	-0.08	-0.13	-0.02
	t+6	-0.01	-0.06	0.03	-0.08	-0.14	-0.02
Ireland	t	-0.73	-1.28	-0.18	-1.63	-2.51	-0.76
	t+3	-0.75	-1.31	-0.19	-1.68	-2.58	-0.77
	t+6	-0.77	-1.34	-0.19	-1.72	-2.66	-0.78
Italy	t	0.01	-0.03	0.04	-0.03	-0.08	0.01
	t+3	0.00	-0.03	0.04	-0.04	-0.09	0.01
	t+6	0.00	-0.04	0.04	-0.05	-0.10	0.00
Latvia	t	-0.08	-0.18	0.01	-0.23	-0.35	-0.11
	t+3	-0.09	-0.18	0.01	-0.24	-0.36	-0.12
	t+6	-0.09	-0.18	0.01	-0.24	-0.36	-0.12
Lithuania	t	-0.01	-0.05	0.04	-0.06	-0.12	-0.01
	t+3	-0.01	-0.05	0.04	-0.07	-0.13	-0.01
	t+6	-0.01	-0.06	0.03	-0.08	-0.13	-0.02
Netherlands	t	-0.17	-0.32	-0.02	-0.42	-0.61	-0.22
	t+3	-0.18	-0.34	-0.02	-0.44	-0.64	-0.23
	t+6	-0.19	-0.35	-0.03	-0.46	-0.67	-0.25
Poland	t	0.01	-0.02	0.04	-0.03	-0.08	0.01
	t+3	0.01	-0.03	0.04	-0.04	-0.08	0.01
	t+6	0.00	-0.03	0.04	-0.04	-0.09	0.00
Portugal	t	-0.03	-0.08	0.03	-0.11	-0.18	-0.03
	t+3	-0.03	-0.09	0.03	-0.12	-0.19	-0.04
	t+6	-0.03	-0.10	0.03	-0.12	-0.20	-0.04
Romania	t	-0.02	-0.05	0.02	-0.05	-0.09	-0.01
	t+3	0.01	-0.02	0.04	-0.03	-0.07	0.01
	t+6	0.01	-0.03	0.04	-0.03	-0.08	0.01
Slovakia	t	0.02	-0.01	0.05	-0.01	-0.05	0.02
	t+3	0.02	-0.01	0.04	-0.01	-0.05	0.02
	t+6	0.02	-0.01	0.04	-0.02	-0.05	0.02
Slovenia	t	0.03	0.00	0.05	0.00	-0.02	0.03
	t+3	0.03	0.00	0.05	0.00	-0.02	0.03
	t+6	0.03	0.00	0.05	0.00	-0.02	0.03
Spain	t	-0.02	-0.07	0.03	-0.08	-0.15	-0.02
	t+3	-0.02	-0.07	0.03	-0.09	-0.16	-0.02
	t+6	-0.02	-0.08	0.03	-0.10	-0.18	-0.03
Sweden	t	-0.07	-0.16	-0.01	-0.20	-0.31	-0.09
	t+3	-0.08	-0.17	-0.01	-0.22	-0.33	-0.10
	t+6	-0.09	-0.18	-0.01	-0.23	-0.35	-0.11

Notes: Welfare calculations based on the Costinot and Rodríguez-Clare (2014) formula. The value of σ is chosen as 6.858 following Bergstrand *et al.* (2013, Table 1). Confidence intervals are calculated by the delta method. CI lower and CI upper denote the estimates for the two-sided 95% confidence interval.

6 Conclusions

This paper studies the Brexit induced welfare effects stemming from trade in manufacturing goods by applying an estimation approach which allows to estimate counterfactual scenario outcomes consistent with structural trade theory and to exploit the system of multilateral resistances for calculating confidence intervals. In this regard, the suggested approach naturally takes the uncertainty surrounding the Brexit negotiations explicitly into account and allows to present a meaningful bandwidth for the possible general equilibrium trade effects for the UK, the EU and the ROW, respectively. Furthermore, this approach enables us to estimate both immediate and medium-run trade effects stemming from Brexit by exploiting the panel structure in the data which allows to model phase-in effects in the counterfactual trade policy scenarios. Furthermore, by combining the proposed panel data structural gravity estimator with the full endowment general equilibrium model suggested by Yotov *et al.* (2016) we are able to assess the manufacturing trade induced welfare effects from Brexit.

The estimation results suggest that the largest adverse trade and welfare effects are to be expected in case of a hard Brexit in which UK would only trade under WTO rules. The formation of free trade agreements with other countries as suggested in the Global Britain strategy and the conclusion of a similar agreement with EU as indicated in the current negotiating position of UKs government would most likely be able to dampen these negative effects but would not fully compensate for the withdrawal from the European single market. Across all different scenarios, the negative trade effects of Brexit are accompanied by a substantial increase in domestic trade within UK and with some minor increase in trade with third countries. Thereby, the imports from the ROW will increase by more as the exports from UK to ROW. In the long-run this can also have important implications for UKs trade balance with all non-EU member states. In contrast, intra-EU trade is estimated to only marginally increase after UKs leaving of the EU.

The estimated (positive and mainly domestic) trade diversion effects are not sufficient to fully compensate for the losses stemming from reduced trade with the EU. Our calculations for the welfare effects suggest a Brexit induced decrease in UKs real income (real GDP) in a range between 0.3% and 5.7%. This effect is driven by a substitution of relatively cheap imports of manufacturing goods from the EU27 by relatively expansive domestic production. EU27s welfare, by contrast, is not statistically significantly affected by UKs withdrawal from the EU. For the whole EU the trade relationships with the UK are not as important as these economic ties are for the UK. As a consequence, our estimates suggest substantial costs likely to be triggered by Brexit which have to be borne by both economic areas. However, the expected decline in bilateral trade flows of manufacturing goods will be much more damaging for the UK.

Furthermore, our findings should be considered as a lower bound estimates of the potential overall economic costs involved in the Brexit. In this paper we are not considering other channels of bilateral economic relationships such as migration, trade in services and FDI. The main reason for this lies in the data requirement necessary for the proposed estimation procedure. We do need consistent data on trade and production in order to identify the border effects. Such data are not readily available in the necessary quality for services trade and FDI. Furthermore, for trade in services and FDI there is a lack in suitable policy indicators. Many FTAs, for example, might exempt some forms of services trade and FDI which makes it difficult to estimate accurate effects for these other channels of bilateral economic relationships.

However and similar to the trade effects, it is very likely that bilateral FDI flows between both economic areas are also declining with potential adverse effects on UK's productivity (Dhingra *et al.* 2016). Furthermore, due to data limitations we are only able to investigate the Brexit effects for manufacturing goods trade. According to Felbermayr *et al.* (2017), the trade distorting effects of Brexit might be even more pronounced for the services sectors. Thus, the negative welfare effects stemming from reduced bilateral trade of services might be larger as the ones identified from manufacturing goods. The welfare effects identified based on trade in manfacturing goods are thus one component of and a lower bound of the potential costs from Brexit associated with UK's withdrawal from the EU.

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Appendix

A Data base

The empirical analysis focuses on trade of manufacturing goods observed over periods of 3 years during 1994-2012. The panel is based on several data sources. The primary data source is OECD's-STAN data base that reports consistent figures for bilateral trade flows, total exports, total imports and gross production, however the latter three figures only for OECD economies. Trade flows are measured in nominal cif-values as reported by the importing country. To obtain a larger group of countries and more observations on trade flows, the trade data had been augmented by Nicita and Olarreaga's (2007) Trade, Production and Protection database. This database comprises consistent data on bilateral trade flows including mirrored ones for a large set of countries. Missing bilateral trade flows from the STAN database have been imputed from this database using bilateral STAN trade flows as the dependent variable in a PPML framework. Explanatory variables are the log trade flows of Nicita and Olarreaga (2007), the log of mirrored values interacted with a missing dummy for World Bank data as well as exporter, importer and time effects. This procedures allows to impute 1,184 annual missing trade flows to the STAN-Data. Note, not all observations on trade flows can be used due to missing data on gross production. The robustness section thus re-estimates the structural gravity model considering all imputed trade flows as missing (see Table A2 in Appendix A.5).

STAN'S data on gross production have been augmented by UNIDO's and CEPII's data bases (De Sousa, Mayer and Zignago 2012), respectively, again using PPML to regress gross production on the log of its counterparts in UNIDO and CEPII along with interactions of log production with country and year dummies as well as country and year dummies themselves. Overall 277 observation on gross production have been imputed from CEPII and the 279 from UNIDO. In a few cases (CYP, BEL, EST, NLD, IRL, LUX, LTU, SVK, SVN) these production data turned inconsistent with trade flow data and information from WIOD has been used instead. In this way the set of countries with consistent trade and production data could be expanded to 65. The same imputation procedure has been applied for total exports and imports. Here additional data sources are aggregates from the Nicita and Olarreaga (2007) database and 478 values for total exports and 556 for total imports had been imputed. Finally, a in a few cases data have been interpolated.

The data on trade flows, x_{ijt}, production, Y_{it}, and expenditures, E_{it}, are corrected for trade with the rest of the world as well as for trade imbalances which have been taken as given. The total production value of country i at time t is given as $x_{i.t} = \sum_{j=1}^{C} x_{ijt} + x_{i,ROW,t}$, while total expenditures can be derived as $x_{.it} = \sum_{j=1}^{C} x_{jit} + x_{ROW,i,t}$. This implies the trade balance of a country i are defined as $d_{it} = x_{i.t} - x_{.it}$. Since data are available for 65 countries, exports to the rest of the world (ROW) and imports from ROW of country i at time t have been aggregated in $x_{i,ROW,t}$ and $x_{ROW,i,t}$. Domestic shipments are implicitly defined as

$$\kappa_{it} = \frac{x_{it.} - x_{i,ROW,t}}{Y_{t,W}} = s_{iit} + \sum_{j \neq i}^{C} s_{ijt},$$

while expenditures net of imports to ROW are given as.

$$\theta_{jt} = \frac{x_{.jt} - d_{it} - x_{ROW,j,t}}{Y_{t,W}} = s_{iit} + \sum_{h \neq i}^{C} s_{hit}.$$

Thereby, $Y_{t,W}$ denotes overall (world) production or expenditures for the 65 countries. Note that $\sum_{i=1}^{C} d_{it} = 0$ holds per definition and that $\sum_{i=1}^{C} \kappa_{it} = \sum_{j=1}^{C} \theta_{jt} = 1$.

The dataset includes the following 65 countries: Albania, Australia, Austria, Belgium with Luxembourg, Brazil, Bulgaria, Canada, China, Colombia, Costa Rica, Cyprus, Czech Republic, Denmark, Egypt, Estonia, Ethiopia, Finland, France, Germany, Greece, Hungary, Iceland, India, Indonesia, Ireland, Israel, Italy, Japan, Jordan, Kazakstan, Kenya, Korea, Kyrgyzstan, Latvia, Lithuania, Macedonia, Malawi, Malaysia, Mauritius, Mexico, Moldova, Morocco, Netherlands, New Zealand, Norway, Panama, Peru, Philippines, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Tanzania, Turkey, Ukraine, United kingdom, United States of America and Uruguay.

B Additional tables and robustness results

Table A1: Share of trade flows in world trade by country-pair group

Country-pair group	1994	1997	2000	2003	2006	2009	2012
UK, domestic	0.027	0.029	0.025	0.023	0.020	0.012	0.011
EU, domestic	0.183	0.172	0.154	0.170	0.148	0.126	0.092
ROW, domestic	0.581	0.554	0.548	0.517	0.524	0.585	0.575
UK-EU	0.007	0.009	0.009	0.008	0.008	0.006	0.006
UK-ROW	0.004	0.005	0.005	0.005	0.004	0.004	0.005
EU-UK	0.009	0.011	0.011	0.012	0.011	0.009	0.009
ROW-UK	0.005	0.007	0.007	0.007	0.007	0.005	0.007
EU-EU	0.057	0.065	0.068	0.081	0.084	0.077	0.075
EU-ROW	0.025	0.030	0.031	0.035	0.037	0.035	0.043
ROW-EU	0.024	0.026	0.031	0.034	0.038	0.036	0.038
ROW-ROW	0.077	0.094	0.112	0.109	0.119	0.105	0.139

Table A2: Robustness of the parameter estimates from constrained panel PPML

	No imputed trade flows				Wiod (2000-2012)				Non-linear border time trend				Bergstrand *et al.* (2015)			
	Spec. (1)		Spec. (2)		Spec. (1)		Spec. (2)		Spec. (1)		Spec. (2)		Spec. (1)		Spec. (2)	
	Par.-est.	t-val.	Par.-est.	t-val.	Par.-est.	t-val.	Par.-est.	t-val.	Par.-est.	t-val.	Par.-est.	t-val.	Par.-est.	t-val.	Par.-est.	t-val.
Border*time	0.17	4.75***	0.20	5.57***	−0.01	−0.24	0.01	0.12	0.16	3.43***	0.19	3.98***				
Border*time^2									0.00	0.23	0.00	0.25				
Border													0.10	7.72***	0.11	7.94***
Border*contiguity*time	0.02	1.24	0.02	1.54	0.01	0.33	0.01	0.26	0.02	1.20	0.02	1.53	0.00	0.13	0.00	0.38
Border*(log) dist.*time	−0.01	−1.81*	−0.01	−2.54**	0.01	0.91	0.00	0.58	−0.01	−1.83*	−0.01	−2.52**	0.00	0.25	0.00	−0.26
Border*Great recession	−0.19	−4.85***	−0.19	−4.56***	−0.07	−1.96**	−0.07	−1.66*	−0.19	−4.88***	−0.19	−4.56***	−0.19	−4.72***	−0.19	−4.32***
Border*Customs u.	0.13	1.92**			0.27	2.69**			0.13	1.96**			0.14	2.11**		
Border*Customs u. (t-3)	0.34	4.21***			0.16	2.02**			0.34	4.21**			0.35	4.34***		
Border*Customs u. (t-6)	0.04	0.51			0.08	1.31			0.04	0.48			0.05	0.61		
Border*FTA	−0.07	−1.43			−0.01	−0.07			−0.07	−1.39			−0.08	−1.71*		
Border*FTA (t-3)	0.25	3.57***			0.06	0.88			0.25	3.57***			0.25	3.69***		
Border*FTA (t-6)	0.11	1.69*			0.06	1.44			0.11	1.73*			0.11	1.56		
Border*RTA			−0.06	−1.33			−0.01	−0.19			−0.06	−1.27			−0.07	−1.63
Border*RTA (t-3)			0.25	3.49***			0.05	0.72			0.25	3.43***			0.26	3.50***
Border*RTA (t-6)			0.14	1.91*			0.09	1.77*			0.14	1.98**			0.14	1.77*
Total customs unions	0.51	5.34***			0.52	3.52***			0.50	5.40***			0.54	5.96***		
Total FTA	0.29	3.84***			0.12	1.34			0.29	3.85***			0.28	3.79***		
Total RTA			0.33	4.31***			0.13	1.39***			0.33	4.27***			0.32	4.31***

Notes: The panel used for estimation as described in the text comprises 7 periods of 3 years and 65 countries with 2,273 out of 27,169 missings trade flows . Wiod data cover the period 2000-2012 in three years intervals and comprise 42 countries. Thus there are 8,820 observations. All variables including trade flows are fully observed. Standard errors are clustered over country-pairs, importer-years and exporter-years. *, **, *** ... Significant at 10%-, 5%- and 1%-level.

Table A3: Robustness: Heterogeneous trade policy effects for the UK

	Specification (1)		Specification (2)	
	Parameter-estimate	t-value	Parameter-estimate	t-value
Border*time	0.16	4.99***	0.20	6.12***
Border*contiguity*time	0.01	1.01	0.02	1.71*
Border*(log) distance*time	−0.01	−1.80*	−0.01	−2.87***
Border*Great recession 2009	−0.20	−14.97***	−0.19	−14.38***
Border*Customs union	0.17	3.41***		
Border*Customs union (t-3)	0.30	8.60***		
Border*Customs union (t-6)	0.19	4.5***		
Border*Customs union*UK	0.08	0.96		
Border*Customs union*UK (t-3)	−0.01	−0.1		
Border*Customs union*UK (t-6)	−0.26	−4.41***		
Border*FTA	0.03	0.49		
Border*FTA (t-3)	0.20	8.06***		
Border*FTA (t-6)	0.26	9.78***		
Border*FTA*UK	−0.12	−1.60		
Border*FTA*UK (t-3)	0.07	1.15		
Border*FTA*UK (t-6)	−0.23	−5.09***		
Border*RTA			−0.05	−1.07
Border*RTA (t-3)			0.26	5.25***
Border*RTA (t-6)			0.13	2.96***
Border*RTA*UK			−0.21	−2.71***
Border*RTA*UK (t-3)			−0.16	−2.32**
Border*RTA*UK (t-6)			0.24	2.61***

Notes: The panel comprises 7 periods of 3 years and 65 countries with with 1,138 out of 28,353 missing trade flows. Standard errors are clustered over country-pairs, importer-years and exporter-years. *, **, *** ... Significant at 10%-, 5%- and 1%-level.

Table A4: Share of trade flows covered by international trade agreements

	Stan database			WIOD database		
	Customs Unions	FTAs	RTAs	Customs Unions	FTAs	RTAs
All country-pairs						
1994	0.05	0.14	0.18			
1997	0.07	0.16	0.23			
2000	0.07	0.19	0.25	0.15	0.29	0.44
2003	0.07	0.21	0.27	0.15	0.32	0.47
2006	0.14	0.18	0.33	0.34	0.19	0.53
2009	0.16	0.17	0.34	0.40	0.14	0.54
2012	0.16	0.22	0.38	0.40	0.18	0.57
UK						
1994	0.19	0.23	0.42			
1997	0.23	0.25	0.48			
2000	0.23	0.28	0.51	0.39	0.31	0.70
2003	0.23	0.31	0.54	0.39	0.34	0.72
2006	0.36	0.20	0.56	0.58	0.14	0.72
2009	0.39	0.17	0.56	0.63	0.10	0.72
2012	0.39	0.20	0.59	0.63	0.12	0.75

Notes: In Mario Larch's Regional Trade Agreements Database RTAs are defined as the sum of customs unions and FTAs.

Table A5: Robstness analysis: Welfare effects of a soft Brexit, full endowment general equilibrium. Specification (1)

		$\sigma = \mathbf{3}$			$\sigma = \mathbf{9}$		
		%-change	CI lower	CI upper	%-change	CI lower	CI upper
UK	t	-3.55	-6.39	-0.71	-0.97	-1.73	-0.21
	t+3	-3.72	-6.71	-0.72	-1.04	-1.85	-0.22
	t+6	-3.90	-7.06	-0.75	-1.11	-1.98	-0.23
EU	t	-0.03	-0.26	0.21	-0.03	-0.08	0.03
	t+3	-0.04	-0.28	0.20	-0.03	-0.09	0.03
	t+6	-0.05	-0.30	0.19	-0.03	-0.09	0.03
ROW	t	0.11	0.04	0.18	0.04	0.03	0.04
	t+3	0.11	0.05	0.18	0.04	0.03	0.04
	t+6	0.11	0.05	0.17	0.04	0.03	0.05

Notes: Welfare calculations based on the Costinot and Rodríguez-Clare (2014) formula. The values of σ are chosen as 3 and 9, respectively. Confidence intervals are calculated by the delta method. CI lower and CI upper denote the estimates for the two-sided 95% confidence interval.