CPB Netherlands Bureau for
Economic Policy Analysis

Trade policy analysis with a gravity model

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The gravity model can predict the impact of changes in trade policy on export flows well over the medium term (3-6 years). Therefore, we argue that the baseline gravity model would be a valuable addition to the CPB toolbox.

CPB Background Document

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Abstract

In this CPB background document we investigate the use of the standard structural gravity model for trade policy analysis at the CPB. The model is intended for long term analyses of trade policy changes and is based on a simple general equilibrium framework. The model is useful despite its simplicity, because it has a good empirical fit. We investigate it by applying the gravity model to both a US trade war scenario and different Brexit scenarios. We compare the latter results to those reported in the literature and find that they are comparable. In addition, the model produces reasonably good out-of-sample forecasts of trade flow developments 3 to 6 years in the future. Hence, the gravity model can predict the impact of changes in trade policy on export flows well over the medium term. Given these results, we argue that the baseline gravity model would be a valuable addition to the CPB toolbox. However, CPB's analysis of the impact of trade policy on trade would benefit from supplementary tools, for example, to better model short-run trade flows. We conclude our report by discussing potential extensions to the gravity model.

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1 Introduction

The main objective of this report is to investigate whether a standard version of the gravity model can be used to empirically analyze the impact of changes in trade costs on trade flows. Recent examples are lower trade costs resulting from trade deals, for example CETA (between the EU and Canada), or higher trade costs resulting from trade conflicts, for example between the US and China (e.g. Bekkers (2019)), or Brexit (Brakman *et al.*, 2018; Bollen *et al.*, 2016; Treasury, 2016).

The empirical gravity model (Tinbergen (1962), and a theoretical underpinning based on micro foundations Anderson & Van Wincoop (2003)) revolve around changes in trade costs relative to other countries, such as changes in bilateral tariffs or product prices. These relative changes cause shifts and mutations in trade flows, so-called trade diversion or trade creation/destruction and can be properly mapped by the gravity model. Additionally, using the theoretical underpinning, we can do simple general equilibrium analysis of a change in trade costs.

We start with the gravity equations and use production and bilateral trade data at the sector level to estimate the key parameters of the model. Next, we use these parameters to find the new general equilibrium due to a change in trade cost using a method developed by Anderson *et al.* (2018). In accordance with this method, we extend the gravity equation with the equations from the micro founded theoretical underpinning: exporter and importer multilateral trade resistance, a market clearing condition, equilibrium prices and a balanced trade condition. With the results we can show that the structural gravity model can simulate economic impacts of changes in trade costs on exports and real income under the strong assumption of unaffected endowments.

It is relevant for policymakers to know which sectors will be affected by changing trade costs as a result of, for example, Brexit. Therefore, we investigate for each sector separately what the consequences of changing trade costs are. This allows identification of potentially affected sectors and for trade policy to be adjusted accordingly. To estimate the impact at the macro level we aggregate the sectoral impacts. We find that the simulated impacts of Brexit and the US-China conflict are in the range of those found it the literature. We illustrate the robustness of the results by investigating how changing key parameters and the time range of our sample affect our results.

Key to our estimates is the data that we use. The dataset is constructed from CEPII's BACI data, which is based on recorded bilateral import and exports of goods (UN Comtrade), production statistics estimated by the OECD STAN team, and tariffs from the Worldbank (World integrated trade solution or WITS). The resulting data set stretches from 2000 to 2015 covering 16 industrial sectors and 51 countries.

The setup of the report is as follows. First, we start in section 2 by describing the micro-founded standard gravity model based on Anderson & Van Wincoop (2003). Then, we present in section 3 how the model can be used to estimate the impacts of changes in trade costs. In section 4 we describe our dataset underlying the estimation procedure. Section 5 analyzes our main results, with emphasis on the elasticity of substitution and simulation results for both the US trade conflict and Brexit. We also compare our various findings with the literature, to see if our estimates are comparable. Furthermore, we do an out-of-sample forecast of the entry by Central and Eastern European countries to the EU in 2004 to evaluate the accurateness of our simulations. Finally, we will conclude in section 6 by discussing the applicability of the model for the CPB and possible extensions to enrich the gravity model further.

2 The theoretical gravity model

The gravity model has become a workhorse model for explaining bilateral trade flows. Tinbergen (1962) was one of the first who proposed to use the gravity equation from physics, which describes the force that two objects exercise on each other, to explain the magnitudes and directions of bilateral international trade flows. The intuition to apply the gravity equation to trade is straightforward. The further two countries are apart the less they trade because it is more costly to do so. Distance can both be physical as well as economical, for instance, consider economic integration as a way to reduce economic distance. Additionally, the larger two countries are the more they trade, where size is measured typically by GDP. If countries are larger, they produce more, making their products relatively cheaper for other countries.[1]

Although the gravity equation is successful in explaining trade flows empirically, it took economists some time to find theoretical foundations for its use. Anderson (1979) and Bergstrand (1985) both made important contributions towards this goal. More recently Anderson & Van Wincoop (2003) further improved the theoretical model, by incorporating third country effects into the model via a weighted trade cost term for both the exporter and importer, the so-called multilateral trade resistance (MTR) terms. They showed that accounting for these terms solved the McCallum (1995) border puzzle. Using the simple gravity model without MTR terms, McCallum estimated that the border between the US and Canada reduces trade by, an unrealistically high, 2200 percent. Incorporating third country effects, Anderson and Van Wincoop find a more realistic border effect of 44 percent. This new theoretical structural gravity model became the baseline model for many extensions and gave a substantial boost to the gravity literature. Our method will be based on this model as well.[2]

[1] And/or they make a larger variety of products, though we abstract away from this in our gravity model.

[2] See for extensive overviews on the gravity literature Anderson (2011) and Head & Mayer (2014).

The structural gravity model is based on several basic assumptions. On the supply side, each country produces only one distinguishable good and its real endowment is fixed. This last assumption is very restrictive because it does not allow an increase in trade to impact productivity. This will especially impact the size of the effect on output due to changes in trade cost. The demand side assumptions feature identical and homothetic consumers preferences given by a CES utility function, all countries import for consumption use only, and trade is balanced.

Given these assumptions, consumers in some importing country j wants to maximize their utility subject to the budget constraint

$$\max_{x_{ijt}} c_{jt} = \left(\sum_i \lambda_{it}^{\frac{1}{\sigma}} x_{ijt}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \tag{1}$$

$$\sum_i p_{ijt} x_{ijt} = E_{jt} \tag{2}$$

where $c_{jt} = E_{jt}/P_{jt}$ is the aggregate consumption index, x_{ijt} is the quantity of country's good i imported by country j (note that x_{jjt} is the quantity country j consumes of its own good, and each country produces only one good, also indexed by i), σ is the elasticity of substitution typically assumed to be larger than one but not approaching infinity (so all goods are gross substitutes and imperfect substitutes), λ_{it} is a taste parameter for good i (where $\sum_i \lambda_{it} = 1$ and it is independent of j due to identical preferences), E_{jt} is the nominal expenditure of country j, P_{jt} is the consumer price index, $p_{ijt} = p_{it} t_{ijt}$ is the price country j pays for good i, p_{it} is the domestic producer price of good i and t_{ijt} the bilateral trade cost factor.

The system of general equilibrium equations that describe exports in equilibrium is derived in three steps. First, we solve for the consumer maximization problem and obtain the exports demand equation for good i by consumers in country j

$$X_{ijt} = \lambda_{it} \left(\frac{p_{ijt}}{P_{jt}} \right)^{1-\sigma} E_{jt}, \tag{3}$$

where $X_{ijt} = p_{ijt} x_{ijt}$ is the nominal value of exports and

$$P_{jt} = \left[\sum_i \lambda_{it} \left(p_{ijt} \right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}. \tag{4}$$

This last expression is the consumer price index of country j.

Next, we derive equilibrium prices from the fact that markets clear in equilibrium:

$$Y_{it} = \sum_j X_{ijt} = p_{it} Q_{it}, \tag{5}$$

where Q_{it} is the real endowment of country i. By substituting the export demand equation (3) into the market clearing condition we obtain an expression for the domestic producer prices in equilibrium

$$p_{it} = \left(\frac{w_{it}^y}{\lambda_{it}}\right)^{\frac{1}{1-\sigma}} \frac{1}{\Pi_{it}}, \tag{6}$$

where

$$\Pi_{it} = \left(\sum_j \left(\frac{t_{ijt}}{P_{jt}}\right)^{1-\sigma} w_{jt}^e\right)^{\frac{1}{1-\sigma}} \tag{7}$$

and $w_{it}^y = Y_{it}/Y_{Wt}$ is the share of country i in global output and $w_{jt}^e = E_{it}/Y_{Wt}$ is the share of country j in global expenditure (realize that $Y_{Wt} = E_{Wt}$).

In the gravity literature Π_{it} is defined as the multilateral trade resistance (MTR) of the exporter. This is the weighted trade cost relative to the cost of one consumption basket over all importers and therefore is a measure for how hard it is for country i to export; or, in other words, an inverted competitiveness measure. This helps us to get a better understanding for the expression of equilibrium prices (6). If Π_{it} increases, country i becomes less competitive and demand for good i declines, leading to a decrease in the equilibrium price. Similarly, equilibrium prices will fall if supply of good i rises relative to the rest of the world (RoW). Finally, if the taste λ_{it} for good i increases, demand increases and the equilibrium price rises.

The equilibrium prices can also be substituted into the consumer price index (4) such that we arrive at

$$P_{jt} = \left(\sum_i \left(\frac{t_{ijt}}{\Pi_{it}}\right)^{1-\sigma} w_i^y\right)^{\frac{1}{1-\sigma}}. \tag{8}$$

This is the MTR of the importer.

Finally, in the last step we substitute the equilibrium prices (6) into the export demand equation (3) to arrive at the gravity equation:

$$X_{ijt} = w_{it}^y \left(\frac{t_{ijt}}{\Pi_{it} P_{jt}}\right)^{1-\sigma} E_{jt}. \tag{9}$$

In line with Tinbergen's intuition, the structural gravity equation (9) shows that trade-flows from i to j depend both on economic distance (i.e. trade cost) t_{ijt} and economic size of the importer E_{jt} and exporter w_{it}^y, where output from the exporter is measured relative to total world output. However, the inclusion of the MTR terms changes the interpretation slightly.

The structural gravity equation is all about relative instead of absolute changes in the trade cost. If t_{ijt} increases, it becomes more expensive for country j to import from country i and country j will substitute its consumption towards goods from other countries which are relatively cheaper now. In addition, if the trade cost with another trade partner of j, say k, increases, country k becomes more expensive. Hence, it becomes relatively cheaper for country j to import from country i. Similarly, if t_{ikt} increases, it becomes more expensive for country k to import from country i, so country i becomes less competitive. A decrease in demand from country k decreases equilibrium price p_i and therefore it becomes cheaper for country j to import from country i. Note that, if the trade cost between all country pairs changes by the same factor, export will not change because P_{jt} and Π_{it} are homogeneous of degree one in t_{ijt} and therefore (9) is homogeneous of degree zero.[3]

As a final remark it is important to note the assumption of balanced trade in the gravity model. This assumption is not realistic as we can see from the persistent current account deficit of the US. Anderson *et al.* (2018) propose to relax this assumption to balanced trade up to a constant factor ϕ_{it}

$$Y_{it} = \phi_{it} E_{it}. \tag{10}$$

Given the characteristics of the gravity model ϕ_{it} is exogenous; it cannot change due to a shock in trade cost. As we describe in the next section, we calibrate it in the general equilibrium analysis using existing trade deficits.

3 General equilibrium analysis in the gravity model

Since the structural gravity model is based on consumers maximizing their utility in each country, it is possible to do a general equilibrium analysis of a change in trade policy.[4] There are six endogenous variables: X_{ijt}, Y_{it}, E_{jt}, Π_{it}, P_{jt} and p_{it}, so we need the six equations described in Section 2 to solve for the six unknowns. There is the gravity equation (9) itself, subject to the exporter (7) and importer (8) MTR. In addition, we have the market clearing condition (5), the equilibrium price condition (6) and finally the balanced trade (up to a factor) condition (10). We assume that λ_{it}, Q_{it}, Y_{Wt} and ϕ_{it} are exogenous.

We follow a method developed by Anderson *et al.* (2018) to solve for these six endogenous variables allowing us to do the general equilibrium analysis. This is done in three steps, where in each step more of the six endogenous variables (X_{ijt}, Y_{it}, E_{jt}, Π_{it}, P_{jt} and p_{it}) are allowed to react to a change in trade cost, ending in the last step where all variables are free to react. In the first step we only let a change in trade cost directly affect exports all else equal: the partial effect. In the second step we also allow both MTRs to change conditional on income, expenditure and producer prices remaining fixed: the conditional effect. Finally, in the last step, we also allow

[3]To see this, divide both sides of (7) by Π_{it}. The right-hand-side of the resulting expression is homogeneous of degree zero in t_{ijt}, so for the left-hand-side to be homogeneous of degree zero, $P_{jt}\Pi_{it}$ must be homogeneous of degree one in t_{ijt}.

[4]This section is based on an appendix from Teulings (2017), which describes the method by Anderson *et al.* (2018) to do general equilibrium analysis for the gravity equation in nominal terms.

these last three variables free to react: the full endowment effect. Each step introduces more realism, but also more uncertainty via estimation errors. The estimated percentage change in exports from the partial effect differs considerably from that of the conditional and full effect. This is consistent with findings from Anderson & Van Wincoop (2003), who show that not accounting for the MTR leads to strongly overestimated impacts of trade cost changes on exports (as can be seen for example in the McCallum border puzzle). Compared to the partial effect, the estimates in the conditional and full effect are much closer to each other, although in absolute terms the latter is on average typically at least a factor 2 larger than the former.[5]

For this section we introduce some new notation. To indicate actual data, estimated variables (or parameters) and constructed variables, we use the variable itself X_{ijt}, the variable with a hat $\widehat{X}_{ijt}$ and the variable with a tilde $\widetilde{X}_{ijt}$, respectively.

3.1 Estimate the baseline model

First, we use the market clearance condition (5) to derive income and expenditure and subsequently derive ϕ_{it}

$$\begin{aligned} \widetilde{Y}_{it}^{b} &= \sum_{j} X_{ijt}, \\ \widetilde{E}_{jt}^{b} &= \sum_{i} X_{ijt}, \\ \widetilde{\phi}_{it} &= \frac{\widetilde{Y}_{it}}{\widetilde{E}_{it}}, \end{aligned} \tag{11}$$

where the b in the superscript indicates that these variables are produced in the baseline scenario.

Next, we estimate the trade cost elasticities using the baseline model, or the elasticity of substitution between different varieties. The standard procedure is to estimate this model with Poisson pseudo maximum likelihood (PPML), but other routines like OLS or gamma pseudo maximum likelihood (GPML) are also possible. In our analysis we will use PPML and the estimation equation becomes

$$X_{ijt} = \exp(t_{ijt}^{b\prime}\beta + \alpha_{ij} + \theta_{it}^{x} + \theta_{jt}^{m})\eta_{ijt}, \tag{12}$$

where α_{ij} are country-pair FE (see Baier & Bergstrand (2007) for a motivation to add country-pair FE) and θ_{it}^{x} and θ_{jt}^{m} are exporter- and importer-time FE, respectively.[6] This estimation

[5] It is difficult to put a general rule on the average width of the confidence bands with respect to the estimated percentage change in exports, but it typically increases by approximately a factor 2 from the partial to the conditional effect. From the conditional to the full endowment effect the uncertainty does not increase that much anymore (if it increases at all) and it is not possible to derive a general rule of thumb.

[6] Bun & Klaassen (2007) show that it might also be important to add country-pair trend FE. In Section 5 we add this FE-type as a robustness check.

suffers from multicollinearity, so we need normalizations to be able to estimate the equation.[7] Post-estimation we construct predicted exports $\widehat{X}_{ijt}^b$ using the baseline model. It is possible to set some or all trade cost elasticities β to a pre-specified value[8], for example, to ensure comparability with previous literature. In this case we need to estimate (12) with a restricted estimation method, where we restrict some or all βs to a pre-specified value.

The estimated country-time FE capture all country-time specific variation, among which, the MTRs. Hence, using (9), we derive estimates for the MTR terms in the baseline model

$$\widetilde{\Pi}_{it}^{(1-\sigma),b} = \frac{\widetilde{Y}_{it}^b}{\exp(\widehat{\theta}_{it}^x)} \widetilde{E}_{Kt}^b, \tag{13}$$

$$\widetilde{P}_{jt}^{(1-\sigma),b} = \frac{\widetilde{E}_{jt}^b}{\exp(\widehat{\theta}_{jt}^m)} \frac{1}{\widetilde{E}_{Kt}^b}, \tag{14}$$

where $\widetilde{E}_{Kt}^b$ is expenditure from the normalized country. We omit Y_{Wt} everywhere because in the end we will present our results in ratios of change, so Y_{Wt} will drop out.

Finally, the baseline trade cost is constructed using the estimated elasticities

$$\widetilde{t}_{ijt}^{(1-\sigma),b} = \exp(t_{ijt}^{b\prime}\widehat{\beta} + \widehat{\alpha}_{ij}), \tag{15}$$

where we assume that the country-pair FE are part of the trade cost.

3.2 Constructing the counterfactual

In the second step the counterfactual trade cost $\widetilde{t}_{ijt}^{(1-\sigma),c}$ is constructed, where the c indicates that this is the counterfactual trade cost scenario. For example, think of an increase in import tariffs by some country with respect to its neighboring countries. We use (15) and replace the bilateral trade cost matrix t_{ijt}^b by the counterfactual scenario $\widetilde{t}_{ijt}^c$ while keeping the elasticities fixed:

$$\widetilde{t}_{ijt}^{(1-\sigma),c} = \exp(\widetilde{t}_{ijt}^{c\prime}\widehat{\beta} + \widehat{\alpha}_{ij}). \tag{16}$$

3.3 Estimate partial and conditional effect

In the third step, we estimate the partial effect and the conditional effect of this counterfactual scenario.

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[7]We normalize θ_{Kt}^m and α_{ij} for all country-pairs, where either $i = K$ or $j = K$ to zero. K is a country of the researcher's choice. We choose to use Switzerland because it is a small open economy that is not a member of the EU, not the most important trading partner of the Netherlands and its economic data is considered to be relatively reliable. Our results are not dependent on choice of the base country: robustness checks with Austria or Canada as base countries yield similar results.

[8]Therefore, among others, the elasticities of substitution σ via the trade cost elasticity of the ad valorem import tariffs, see Section 5.1 for more details

3.3.1 Partial effect

The partial effect is the effect of the change of bilateral trade cost on bilateral exports, while all else remains equal. Hence, we do not account for changes in the multilateral resistances, expenditure, income and producer prices, which all affect exports as well. The partial effect is given by

$$\widetilde{X}^{p}_{ijt} = \widetilde{Y}^{b}_{it} \left(\frac{\widetilde{t}^{c}_{ijt}}{\widetilde{\Pi}^{b}_{it} \widetilde{P}^{b}_{jt}} \right)^{1-\sigma} \widetilde{E}^{b}_{jt}, \tag{17}$$

where the p in the superscript indicates that this is the partial effect.

3.3.2 Conditional effect

For the conditional effect we allow the MTRs to change due to the counterfactual trade cost, while keeping expenditure, income and producer prices fixed. Therefore, we re-estimate the baseline estimation equation (12) using actual exports X_{ijt}, while we fix the trade cost to the counterfactual trade cost $\widetilde{t}^{(1-\sigma),c}_{ijt}$

$$X_{ijt} = \widetilde{t}^{(1-\sigma),c}_{ijt} \exp(\theta^{x}_{it} + \theta^{m}_{jt}) \eta_{ijt}. \tag{18}$$

Postestimation we construct predicted exports $\widehat{X}^{cnd}_{ijt}$, where *cnd* refers to the conditional effect. Next, we use the reestimated country-time FE to derive the new MTR terms as a result from the change in trade cost: $\widetilde{\Pi}^{(1-\sigma),cnd}_{it}$ and $\widetilde{P}^{(1-\sigma),cnd}_{jt}$ using (13) and (14), respectively.

3.4 Estimate full endowment effect

In the fourth step. we allow nominal income, expenditure, and producer prices to change as well due to a change in trade cost, so we arrive at the new general equilibrium in the counterfactual scenario. This is also called the full endowment case. Producer prices are affected by the change in the exporter MTR (see (6)). In turn they affect nominal income via (5). The balanced trade relation (10) implies that a change in income also changes expenditure. Since we assume that every country has a fixed endowment, the actual number of produced goods does not change in the counterfactual.

To derive the full endowment case, we use an iteration procedure, where the equilibrium price ratios serve as convergence criteria[9]. Hence, the procedure starts by deriving the equilibrium

[9] The iteration procedure converges if either the standard deviation or the maximum absolute value of the difference in the price ratio is smaller than some pre-specified threshold value. If no convergence is reached in this way, we use values of the iteration that come closest to satisfying convergence and we check whether the difference between $\widetilde{Y}^{full}_{it}$ and $\sum_j \widetilde{X}^{full}_{ijt}$ is acceptably small.

price ratio for both the exporter and importer

$$\begin{aligned}\frac{\widetilde{p_{it}^{full(n-1)}}}{p_{it}^{full(n-2)}} &= \left(\frac{\exp(\widehat{\theta}_{it}^{x,n-1})}{\exp(\widehat{\theta}_{it}^{x,n-2})}\frac{\widetilde{E}_{Kt}^{n-2}}{\widetilde{E}_{Kt}^{n-1}}\right)^{\frac{1}{1-\sigma}}, \\ \frac{\widetilde{p_{jt}^{full(n-1))}}}{p_{jt}^{full(n-2)}} &= \left(\frac{\exp(\widehat{\theta}_{jt}^{x,n-1})}{\exp(\widehat{\theta}_{jt}^{x,n-2})}\frac{\widetilde{E}_{Kt}^{n-2}}{\widetilde{E}_{Kt}^{n-1}}\right)^{\frac{1}{1-\sigma}},\end{aligned} \tag{19}$$

where $full$ indicates that this is the full endowment case and n is the n-th iteration.

Next, we use these ratios and the estimated MTR to update the new bilateral export flows using the following expression

$$\widetilde{X}_{ijt}^{full(n-1)} = \frac{\widetilde{p_{it}^{full(n-1)}}}{p_{it}^{full(n-2)}}\frac{\widetilde{p_{jt}^{full(n-1)}}}{p_{jt}^{full(n-2)}}\left(\frac{\widetilde{\Pi}_{it}^{full(n-2)}}{\widetilde{\Pi}_{it}^{full(n-1)}}\frac{\widetilde{P}_{jt}^{full(n-2)}}{\widetilde{P}_{jt}^{full(n-1)}}\right)^{1-\sigma}\widehat{X}_{ijt}^{full(n-1)}. \tag{20}$$

This expression is derived from (9), using that $Y_{it} = p_{it}Q_{it}$, such that $\widetilde{Y}_{it}^{full(n-1)}/\widetilde{Y}_{it}^{full(n-2)} = \widetilde{p_{it}^{full(n-1)}/p_{it}^{full(n-2)}}$, under the assumption that Q_{it} is exogenous and drops out when taking ratios.

We use the updated exports and the counterfactual trade barrier to estimate

$$\widetilde{X}_{ijt}^{full(n-1)} = \widetilde{t}_{ijt}^{(1-\sigma),c}\exp(\theta_{it}^{x,full(n)} + \theta_{jt}^{m,full(n)})\eta_{ijt} \tag{21}$$

and construct predicted exports $\widehat{X}_{ijt}^{full(n)}$ post-estimation. Together with the market clearance condition (5) we use the latter to update income

$$\widetilde{Y}_{it}^{full(n)} = \sum_j \widehat{X}_{ijt}^{full(n)}, \tag{22}$$

where we exploit the special property of our PPML estimation that the sum of the predicted value of the dependent variable adds up to the sum of the actual value of the dependent variable. This holds as long as we include exporter-time and importer-time FE, as is shown by Fally (2015) and Arvis & Shepherd (2013). Other estimation routines, like for example LSDV or GPML, will consistently overestimate income due to Jensen's inequality.

Finally, expenditure $\widetilde{E}_{jt}^{full(n)}$ follows from (10). The MTRs are updated using the estimated $\hat{\theta}_{it}^{x,full(n)}$ and $\hat{\theta}_{jt}^{m,full(n)}$, income $\widetilde{Y}_{it}^{full(n)}$, expenditure $\widetilde{E}_{jt}^{full(n)}$ and (13)-(14). We update equilibrium price ratios $\widetilde{p_{it}^{full(n)}/p_{it}^{full(n-1)}}$ and $\widetilde{p_{jt}^{full(n)}/p_{jt}^{full(n-1)}}$ using $\hat{\theta}_{it}^{x,full(n)}$, $\hat{\theta}_{jt}^{m,full(n)}$ and (19). We continue until we reach convergence.[10]

[10]For this iteration procedure we need starting values. For the equilibrium price ratios we use $\frac{\widetilde{p_{it}^{full(2)}}}{p_{it}^{full(1)}} = \frac{\widetilde{p_{it}^{cnd}}}{p_{it}^{b}}$ and

3.5 Derive full endowment GE effect

Finally, in the fifth step, we derive the equilibrium price ratio using (19) between the counterfactual and the baseline $\widetilde{p_{it}^{full}/p_{it}^{b}}$. This price ratio is used to calculate income in the new equilibrium

$$\widetilde{Y}_{it}^{full} = \frac{\widetilde{p_{it}^{full}}}{p_{it}^{b}} \widetilde{Y}_{it}^{b}. \tag{23}$$

Expenditure $\widetilde{E}_{jt}^{full}$ follows from the balanced trade condition (10). Now we have all we need to derive the MTR terms using the estimated $\widehat{\theta}_{it}^{x,full}$, $\widehat{\theta}_{jt}^{m,full}$, income $\widetilde{Y}_{it}^{full}$, expenditure $\widetilde{E}_{jt}^{full}$ and (13)-(14). Finally, we use the gravity equation (9) to derive the export flows in the new equilibrium

$$\widetilde{X}_{ijt}^{full} = \widetilde{Y}_{it}^{full} \left(\frac{\widetilde{t}_{ijt}^{c}}{\widetilde{\Pi}_{it}^{full} \widetilde{P}_{jt}^{full}} \right)^{1-\sigma} \widetilde{E}_{jt}^{full}. \tag{24}$$

3.6 Measuring changes in real income

In a general equilibrium analysis, it is important to know how welfare and real income of the counterfactual scenario compare with the actual values. The structural gravity model by Anderson & Van Wincoop (2003) is not the best model to get a definitive answer on real income since it does not take many effects of changes in trade cost into account, consider the impact on productivity (which is assumed away due to the fixed endowment assumption), global value chains, intermediate sector inputs or labor markets. Furthermore, the model is static and not dynamic. In general, the impact on real income of a counterfactual scenario in the structural gravity model will be small (Arkolakis *et al.*, 2012) because it does not take all these effects into account. However, it can give us a good first order approximation, see for an extensive analysis Bekkers (2019) and Bekkers & Rojas-Romagosa (2019).

The impact on real income can be measured in three different ways. First, we can calculate it directly by calculating the change in real income Y_{it}/P_{it} between the baseline and the counterfactual scenario. Second, we can use the expression proposed by Arkolakis *et al.* (2012) to calculate the percentage change in the domestic expenditure share. Finally, we can approximate the change in real income by subtracting the percentage change in consumer prices P_{it} from the percentage change in producer prices p_{it}. To arrive at this approximation, we use that $Y_{it} = p_{it}Q_{it}$ and that $y_{it} = Y_{it}/P_{it}$. Recognizing that Q_{it} is exogenous, we know that

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$\frac{\widetilde{p_{jt}^{full(2)}}}{p_{jt}^{full(1)}} = \frac{\widetilde{p_{jt}^{cnd}}}{p_{jt}^{b}}$. Other starting values are $\widehat{X}_{ijt}^{full(2)} = \widehat{X}_{ijt}^{cnd}$, $\widehat{\theta}_{it}^{x,full(2)} = \widehat{\theta}_{it}^{x,full(1)} = \widehat{\theta}_{it}^{x,cnd}$, $\widehat{\theta}_{jt}^{m,full(2)} = \widehat{\theta}_{jt}^{m,full(1)} = \widehat{\theta}_{jt}^{m,cnd}$ and the ratios $\left(\widetilde{\Pi}_{it}^{full(1)}/\widetilde{\Pi}_{it}^{full(2)}\right)^{1-\sigma} = \left(\widetilde{\Pi}_{it}^{cnd}/\widetilde{\Pi}_{it}^{cnd}\right)^{1-\sigma}$ and $\left(\widetilde{P}_{jt}^{full(1)}/\widetilde{P}_{jt}^{full(2)}\right)^{1-\sigma} = \left(\widetilde{P}_{jt}^{cnd}/\widetilde{P}_{jt}^{cnd}\right)^{1-\sigma}$.

$dY_{it}/Y_{it} = dp_{it}/p_{it}$. The first order approximation of the percentage change is then given by:

$$\frac{dy_{it}}{y_{it}} = \frac{dp_{it}}{p_{it}} - \frac{dP_{it}}{P_{it}}. \tag{25}$$

The first two approaches result in the same outcome and the third gives very similar results when the changes in real income are small.

Calculating the impact on real income at the macro level in these ways yield relatively accurate approximations, however, on a sectoral level this might be less so. This is because import and export shares of value added and the differences between them vary strongly across sectors. However, if we take an aggregated level, this error is likely small.

3.7 Comparing this method to solving the non-linear structural model

Anderson *et al.* (2018) show that the results obtained with the method described above are identical to those they obtain when they solve the non-linear structural gravity model (using Matlab). They also show that their results are identical to the method proposed by Dekle *et al.* (2007). The advantage of the above method is that it is a linearized problem and therefore less computationally intensive compared to a non-linear solver.

Finally, one note of caution: both approaches, the one presented above and the non-linear method assume that the gravity model is the true underlying data generating process. If this is not the case, the estimates are biased. This will, among other things, affect our bilateral trade cost and FE estimates. Especially our country-time FE might capture more than the MTRs. Hence, despite its remarkable empirical fit, the theoretical gravity model probably does not hold empirically, even though we assume it does (see also Anderson (2011) and Head & Mayer (2014) for a more extensive discussion).

4 The data

4.1 Manufacturing goods trade data

The dataset is constructed using international manufacturing goods trade-flow data from CEPII's BACI dataset. The BACI dataset is based on UN Comtrade data, but has reconciled recorded bilateral import and export flows. This dataset contains over 200 countries and records trade-flows using 6-digit 1996 version of the harmonized System (HS '96) product categories. We use a set of 51 countries (among which 6 separate rest-of-the-world (RoW) regions) and aggregate the data into 16 2-digit ISIC rev. 4 manufacturing industries. To translate the HS product codes to ISIC industries we use a concordance created by the OECD STAN team.[11] The resulting

[11] Available from the OECD website.

Table 1: Industries covered by the data (ISIC rev.2), global trade shares and top importer and exporter

Code	Global trade share	Average non-zero tariff	Largest exporter	Largest importer	Name
10t12	6.86%	10.5%	USA	USA	Food products, beverages and tobacco
13t15	6.63%	6.9%	CHN	USA	Textiles, wearing apparel, leather and related
16	0.82%	5.1%	CHN	USA	Wood and of products of wood and cork
17t18	1.64%	3.8%	USA	USA	Paper products and printing
19	4.36%	2.3%	USA	Asia^{RoW}	Coke and refined petroleum products
20t21	13.84%	4.1%	USA	USA	Chemicals and pharmaceutical products
22	3.09%	6%	CHN	USA	Rubber and plastics products
23	1.32%	4.1%	CHN	USA	Other non-metallic mineral products
24	8.37%	2.8%	CHN	Asia^{RoW}	Manufacture of basic metals
25	2.99%	4.9%	CHN	USA	Fabricated metal products
26	16.22%	3.9%	CHN	Asia^{RoW}	Computer, electronic and optical products
27	5.75%	5.2%	CHN	USA	Electrical equipment
28	9.02%	3.8%	CHN	USA	Machinery and equipment n.e.c.
29	10.73%	5%	DEU	USA	Motor vehicles, trailers and semi-trailers
30	4.18%	3.7%	USA	USA	Other transport equipment
31t33	4.18%	5.4%	CHN	USA	Other manufacturing

Values presented are for 2015

dataset stretches from 2000 to 2015 covering the sectors listed in Table 1.

4.2 Domestic trade data

For our gravity model, the data requires domestic trade flows, or the flows of goods produced, traded (and consumed) within each country. Therefore, we need data on production for each country and industry.[12] Fortunately, starting in 2005, the OECD input-output (I-O) tables contain production and export data for each of the industries in our dataset. We use the share of total exports over production from the I-O tables and apply them to the BACI trade data. This yields the implied production data for each industry in each country, given the BACI trade data. Subtracting total exports from total production leaves us with the domestic trade flow, or the production of goods that is traded domestically.[13]

For domestic trade flows before 2005 however, we have to use a different source. We backcast the OECD I-O table's export share using production data from the UNIDO's IndStat database. This database contains production statistics for all the countries and industries in our dataset.

[12]See Zylkin (2016) for an extensive discussion on how to construct domestic trade. Baier *et al.* (2019) present a different way of going about it by using data based on the TradeProd database. Unfortunately, this dataset is no longer updated.

[13]We assume all exports are domestically produced, and domestically produced goods that are not exported are therefore consumed. This yields domestic trade is set to zero for certain products in several countries. Fortunately, PPML, the estimation method we will use in our applications, can deal with zero trade values, LSDV however is not suited in dealing with zero trade flows.

We extend the implied export shares backward to 2000, with the 2000-2006 trend of the UNIDO production data.[14]

4.3 Tariff data

The tariff data that we use comes from World integrated trade solution (WITS) of the World-bank. This data contains information on the tariffs applied to bilateral trade-flows of detailed product categories. These tariff data include tariffs, taking bilateral relations (Bilateral or regional trade agreements/WTO rates) into account.

The data is available in the HS combined product classification system. To link it to our trade-flows data, we have to transfer it to the HS 1996 system. Fortunately, the WITS website provides suitable concordance files to translate the data to the HS '96 system.

We aggregate the tariff to the industry level by taking the (unweighted[15]) average product-level tariff within every 2-digit ISIC rev. 4 industry. Note that we implicitly assume that any missing tariff data is assumed to be equal to the average of the non-missing tariff data in the industry.[16] For several countries, the tariff data is imputed if it is consistently missing across years. This is done by assuming that the reported tariff in year t is valid for all subsequent n years until a new tariff is reported in $t + n + 1$. Finally, the tariffs for each of the six RoW categories is an average of the tariffs applied by the constituent countries.

4.4 Other data

We obtain other variables from Baier *et al.* (2018). These data contain indicators of distance between countries and inter-country relations like free trade agreements. Because the data are only available until 2012, we extend the trade agreement indicators for the missing years and adjust the indicators where necessary for new trade/integration agreements.

In addition to the data on inter-country relations and tariff, we use estimates on the ad valorem equivalents of non-tariff trade barrier. We use estimates from Bollen *et al.* (2016) and apply them in our counterfactual Brexit analyses.

4.5 Descriptives

Finally, we present some statistics borne out by the data to illustrate the dataset. First, Table 1 lists for each industry it's importance in international trade, globally. There are large differences between different industries. The largest manufacturing industries in terms of trade flows are

[14] The UNIDO data contains gaps and are at times inconsistent with the other data. To remedy most of the issues, we use a procedure akin to Zylkin (2016), see the appendix for more details.

[15] To avoid the tariffs being dominated by large trade flows.

[16] This often corresponds to missing trade flows.

Table 2: Industry export shares by country

Industry	AUS	CAN	CHN	DEU	FRA	GBR	IRL	NLD	USA
10t12	25.9%	8.8%	1.8%	5.3%	10.5%	6.6%	9.8%	14.7%	6.6%
13t15	1.1%	1.0%	14.5%	2.5%	4.2%	2.9%	0.6%	3.2%	1.4%
16	1.3%	3.9%	0.7%	0.6%	0.5%	0.1%	0.3%	0.3%	0.5%
17t18	1.5%	5.2%	0.8%	1.8%	1.6%	1.2%	0.4%	1.6%	2.1%
19	1.7%	4.8%	0.7%	1.1%	2.0%	3.9%	0.4%	10.8%	6.4%
20t21	13.5%	12.7%	5.7%	16.2%	19.8%	18.4%	62.2%	22.8%	17.9%
22	1.0%	3.3%	3.4%	3.8%	3.0%	2.8%	0.9%	2.4%	3.1%
23	0.3%	0.7%	1.9%	1.2%	1.2%	0.8%	0.3%	0.7%	1.0%
24	34.7%	13.9%	4.2%	5.3%	5.8%	14.1%	0.4%	5.5%	5.4%
25	1.1%	2.5%	4.2%	3.7%	2.3%	2.1%	0.6%	2.1%	2.5%
26	3.8%	3.9%	33.2%	8.3%	6.0%	8.2%	11.9%	16.9%	12.6%
27	1.3%	2.1%	9.8%	6.5%	4.4%	3.9%	2.1%	2.8%	4.5%
28	4.4%	7.0%	8.0%	14.3%	8.2%	9.7%	2.7%	7.4%	10.9%
29	3.2%	21.8%	2.5%	21.7%	11.7%	14.4%	0.3%	4.5%	10.7%
30	2.2%	6.0%	1.7%	4.9%	15.5%	7.8%	1.3%	1.6%	10.3%
31t33	3.0%	2.4%	6.6%	2.9%	3.5%	3.2%	6.0%	2.8%	4.1%

computers, chemical & pharmaceuticals, and motor vehicles. Paper and wood manufacturing are the least important industries in global trade.

The next column shows for each industry the average non-zero tariff levied, many instances of zero tariffs are not considered for this average. For most trade flows the average non-zero tariffs are between 3 and 6%, food products clearly stand out with the highest tariff value.

The table furthermore shows the largest global importer and exporter for each industry. China is usually the largest exporter and the USA the largest importer. However, in several industries other Asian countries (combined) import more than the USA. This likely concerns trade in intermediate goods.

Table 2 shows industry export distributions for a selection of countries. For most of these countries exports of food products are relatively important. Other important exporter industries in most countries are chemical & pharmaceuticals, basic metals, computers, and transport equipment. For China, the important industries tend to be different. Apparel, computers and electrical equipment are the largest Chinese exporting sectors.

5 Counterfactual scenarios: results

In this section we discuss the results for different counterfactual scenarios and compare the results with the literature. We start in Section 5.1 by discussing the estimated elasticities for each sector. In Section 5.2 we investigate the first counterfactual scenario: an escalating trade war between the US and all OECD countries and China. This simple counterfactual scenario helps us to get a better intuition of the model. Next, we study four different Brexit scenarios in

Section 5.3 and compare the results with existing literature. This helps us to judge whether the applied method produces realistic results and where it might potentially under- or overestimate effects. Finally, we do an out-of-sample forecast of the entry by Central and Eastern European countries to the EU in 2004 in Section 5.4, to see if simulated exports and real GDP converge to the actual data and in what time span.

The overall method for the different counterfactual scenarios is the same, only the scenario changes. We estimate the baseline equation using PPML.[17] We apply the counterfactual scenario to each sector separately and calculate the general equilibrium effects. Next, we calculate the aggregate effects by adding up the effects for each sector. To obtain confidence bands for the general equilibrium effects we use a residual block bootstrap, where we use the residuals from the sector specific baseline regression (12). We assume that the errors are not correlated across sectors and draw the residuals within each country-pair. This allows us to construct a new export variable for each sector and redo the whole analysis. To obtain 95% confidence bands we perform 500 bootstraps.

5.1 Estimating elasticities of substitution

For the general equilibrium analysis described in Section 3 the elasticity of substitution σ is a key parameter. We can either use sector specific parameters from the literature or estimate it. We will go for the latter approach.

The most common way to estimate elasticities is to use ad valorem import tariffs. The import tariff is part of bilateral trade costs t_{ijt}, but because it is a direct price-shifter it does not have an elasticity of its own. Other trade costs, for example whether or not two countries have a free trade agreement, tend to have their own elasticities. Using tariffs allows us to directly identify σ from the estimated coefficient of the import tariffs. When we introduce tariffs, the structural gravity equation becomes (see for example Heid & Larch (2016) for a derivation)

$$X_{ijt} = w_{it}^{y} \left(\frac{t_{ijt}}{\Pi_{it} P_{jt}} \right)^{1-\sigma} \tau_{ijt}^{-\sigma} E_{jt}, \tag{26}$$

$$\Pi_{it} = \left(\sum_{j} \tau_{ijt}^{-\sigma} \left(\frac{t_{ijt}}{P_{jt}} \right)^{1-\sigma} w_{jt}^{e} \right)^{\frac{1}{1-\sigma}}, \tag{27}$$

$$P_{jt} = \left(\sum_{i} \left(\frac{\tau_{ijt} t_{ijt}}{\Pi_{it}} \right)^{1-\sigma} w_{i}^{y} \right)^{\frac{1}{1-\sigma}}, \tag{28}$$

where τ_{ijt} indicates ad valorem tariffs, that is, 1 plus the import tariff on imports from country

[17] We use a new command developed by Correia *et al.* (2019a). This command is much faster than other existing methods in estimating PPML with many FE (for more information see also Correia *et al.* (2019b)).

i by country j. Hence, to be able to estimate σ we substitute the log of the ad valorem tariffs into our model equation (12). The corresponding parameter estimate is equal to $-\sigma$.

In Table 3, Model 1, we display the estimated elasticities for the different sectors in the baseline model. We estimate these elasticities in a model equation that, besides the FE in (12), only includes the log of ad valorem tariffs. We find that for values of σ below 4, the iteration procedure to find the new general equilibrium no longer converges.[18] A low elasticity of substitution implies that equilibrium prices have to change more to bring supply and demand back into equilibrium after a change in trade policy. Hence, prices become more volatile making it more difficult for the iteration procedure to converge. For three sectors, 10t12, 20t21 and 28, we find estimates below 4 (for the last two this is significantly below 4) and therefore set the elasticity of substitution to 4. This is the lowest value for which the iteration procedure still converges, while σ remains reasonably close to the actual estimates.

The estimated elasticities are comparable with the literature. Head & Mayer (2014) show in their literature survey that the mean and median of all the estimated elasticities of substitution by the collection of papers that use ad valorem tariffs is 6.0 and 7.7, respectively, with a standard deviation of 9.3. The mean and median from our estimates are somewhat larger but still within range. Anderson & van Wincoop (2004) also review different studies and find that the estimates of the elasticities of substitution are usually somewhere between 5 and 10. Both the mean and median of our estimates fall within this range. Important is to take the level of disaggregation into account Ossa (2015). Felbermayr *et al.* (2018) perform an analysis on a very similar disaggregate sector level. They find slightly lower, but still comparable elasticities to our own.

The robustness checks we perform in Table 3 give widely varying results for different reasons. If we split the sample in two, a period before (Model 2) and a period during and after the financial crisis (Model 3), we find very similar estimates in the period before the financial crisis. The estimated elasticities of substitution in the period during and after the crisis are substantially lower for almost all sectors. Considering that the global markets were in tremendous turmoil from the financial crisis followed by the euro crisis, this might not be too surprising. Hence, we do de-emphasise these outcomes. In Model 4 we include a trend-pair FE, as proposed by Bun & Klaassen (2007), this more or less halves our estimated elasticities. However, our general equilibrium findings in the counterfactual scenarios are not influenced too much by this. Finally, we exclude country-pair FE in Model 5. This leads to unrealistically high estimates. This is not surprising because Baier & Bergstrand (2007) show that omitting country-pair FE can lead to substantial biases.

[18] This finding is not unique to our model. Felbermayr & Larch (2013) face a similar problem and replace the σ for those sectors they fail to find suitable estimates.

Table 3: Estimated tariff elasticities per sector for different models

Model	1	2	3	4	5	6
Description	Baseline	2000-2007	2008-2015	Trend-pair FE	No α_{ij}	WorldScan
10t12	−2.9	−4.5*	−1.1**	−2.2**	−17.0**	6.0
	(1.7)	(2.1)	(0.4)	(0.6)	(2.0)	
13t15	−7.7**	−6.8**	−2.5**	−3.2**	−27.9**	8.0
	(1.0)	(1.4)	(0.5)	(0.7)	(2.4)	
16	−28.0**	−21.6**	−1.3	−7.7**	−59.5**	7.0
	(6.1)	(5.0)	(1.3)	(2.3)	(7.5)	
17t18	−8.8	−14.0*	−1.9	−7.8*	−48.8**	7.0
	(6.0)	(6.7)	(1.3)	(3.3)	(6.6)	
19	−26.8**	−27.3**	1.2	−2.9	−82.2**	5.0
	(8.9)	(7.8)	(6.3)	(3.5)	(13.2)	
20t21	−1.8**	−1.3	−2.2**	−1.5**	−32.7**	8.0
	(0.6)	(0.6)	(0.6)	(0.5)	(3.6)	
22	−8.6**	−10.6**	0.1	−3.7*	−33.6**	8.0
	(2.3)	(3.1)	(0.3)	(1.5)	(3.8)	
23	−17.8**	−15.2**	−2.4	−5.4**	−31.7**	7.0
	(4.3)	(4.6)	(1.2)	(1.8)	(4.2)	
24	−6.9**	−1.8	−13.3**	−3.7**	−59.4**	8.0
	(2.4)	(1.7)	(5.1)	(1.4)	(7.4)	
25	−5.9**	−6.7**	−1.3*	−3.2**	−29.3**	9.0
	(1.3)	(2.0)	(0.6)	(1.0)	(3.0)	
26	−5.7*	−6.3**	0.9	−3.5*	−31.1**	8.0
	(2.5)	(2.4)	(1.1)	(1.4)	(5.1)	
27	−6.5**	−7.7**	−0.5	−3.7**	−23.9**	9.0
	(1.7)	(2.7)	(0.5)	(1.0)	(3.6)	
28	−2.0*	−1.5	−0.6	−0.8	−32.2**	8.0
	(0.8)	(1.1)	(0.6)	(0.7)	(5.1)	
29	−4.4	−3.8*	−2.1*	−2.1*	−50.5**	5.0
	(2.3)	(1.9)	(0.9)	(1.0)	(6.6)	
30	−12.5**	−15.2**	−3.9	−4.9**	−43.1**	5.0
	(3.2)	(4.2)	(2.9)	(1.9)	(5.0)	
31t33	−12.8**	−10.5*	−0.4	−5.7*	−37.7**	8.0
	(2.5)	(4.3)	(0.6)	(2.2)	(3.6)	
Average	−9.9	−9.7	−2.0	−3.9	−40.0	7.3
Median	−7.3	−7.3	−1.3	−3.6	−33.1	8.0

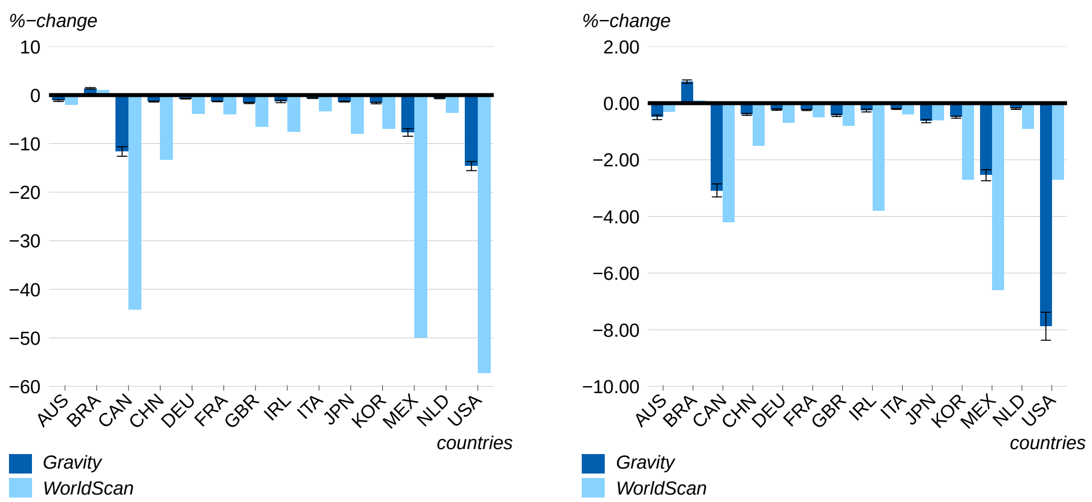
The tariff elasticity is equal to minus the elasticity of substitution (σ). The latter is set to 4 in case it is estimated to be lower than 4 to ensure convergence of the general equilibrium iteration procedure. In the baseline model we estimate the elasticity for each sector using a data set with 51 countries or regions and a time period ranging from 2000-2015; this results in 41,616 observations. We report the results for six different models: (1) the baseline model, (2) for a time period ranging from 2000-2007, (3) for a time period ranging from 2008-2015, (4) including trend-pair FE, (5) without country-pair FE and (6) the elasticities of substitution (- the tariff elasticity) from WorldScan. In the baseline model the pseudo-R^2 for the different sectors ranges between 97-100%. We report clustered standard errors on a country-pair level between brackets. * and ** indicate significance at the 5% and 1% level.

Finally, overall the elasticities compare on a sector level relatively well with the elasticities used in WorldScan (Lejour *et al.*, 2006; Rojas-Romagosa, 2017). Only for the sectors 16, 19, 23 and 30 do our estimated elasticities deviate substantially from those used by WorldScan. For the sectors 20t21 and 28 the estimated elasticities are also much lower than those of WorldScan, but they are set to 4. A possible explanation for these differences might be that the elasticities from WorldScan are based on a much higher aggregated sector classification and estimated using a cross-section from 1992 which does not overlap with our time period (Hummels, 1999; Hertel & Mensbrugghe, 2016). Felbermayr *et al.* (2018) perform an analysis on a very similar disaggregate sectoral level. They find lower elasticities than we do resulting in bigger differences between our results compared to WorldScan. However, they use value added data from the WIOD, possibly explaining the difference. We leave the investigation of this difference for future research.

5.2 Escalating trade war with the US

We now study the counterfactual scenario of an escalating trade war between the US and all OECD countries and China. In the counterfactual scenario we assume that the US increases import tariffs by 10%-point for all goods from the OECD countries and China. These countries, in turn, retaliate by also increasing import tariffs by 10%-point for all goods from the US.

Figure 1: The impact of a trade war with the US analyzed with a gravity model and WorldScan



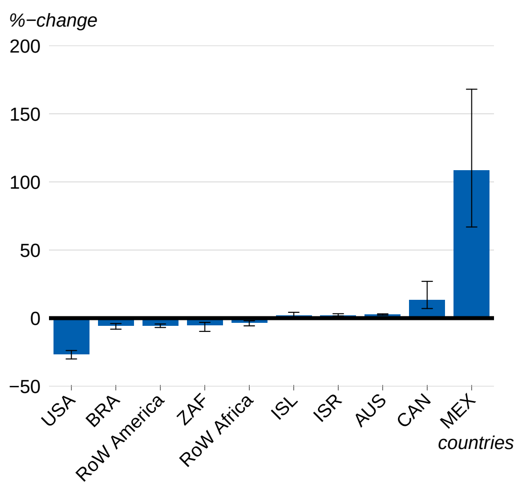
(a) Percentage change nominal exports (b) Percentage change real GDP

The whiskers display 95% confidence bands that are created using a residual block-bootstrap method, where we redraw the residuals within each country-pair. The confidence bands are based on 500 draws. The bootstrap is performed for each sector separately, so we assume that the errors are not correlated between sectors. It is not possible to create confidence bands for sector 30 due to problems with convergence for some of the draws.

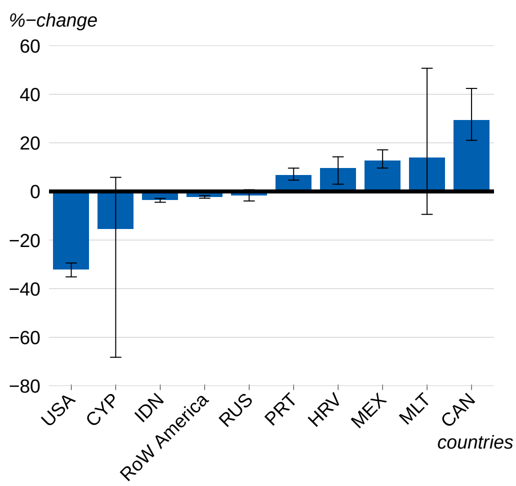
Figure 1 shows that aggregate nominal exports reduces for almost all countries. Exceptions are countries like Brazil. They are not targeted by the trade war and gain from the trade war because their products become relatively cheap compared to the countries that are involved in the trade war. The latter countries see a rise in their importer MTR due to the trade war making importing from, for example, Brazil relatively cheap. The US, Canada and Mexico are hit the hardest by the trade war. These neighboring countries have deep trade relations with each other and an escalating trade war between these countries will therefore hurt these countries exceptionally hard. Other OECD countries and China are also affected but they have more opportunities for trade diversion. There is no trade diversion between sectors within each country because the model does not feature intermediate sector linkages. In section 6 we discuss the possibility of extending the model to include this.

The Netherlands experiences overall a decrease in total exports by 0.6%, but the reduction in exports with the US is partially undone by trade diversion to other countries, like Mexico and Canada (see Figure 2). The exports diversion estimate to Mexico stands out. The reason for this high value is sector 19 - refined petroleum products etc -, which is one of the largest bilateral export flows. Dutch exports of this sector to Mexico are estimated to rise sharply due to the trade war. This strong rise inflates the total diversion estimate to Mexico. The Netherlands also diverts its imports from the US to, among others, Canada and Mexico.

Figure 2: Trade diversion for the Netherlands due to a trade war with the US



(a) Top five winners and losers in percentage change of total exports



(b) Top five winners and losers in percentage change of total imports

See the figure note in Figure 1 for more information on the confidence bands.

Most countries experience small reductions in real GDP of around 0.5%, except for the US, Canada and Mexico (see Figure 1b). These countries are hit the hardest in terms of losses in exports, so it is not surprising that their loss in real GDP stands out. For Canada and Mexico losses are large but still surmountable with 3.1% and 2.45%, respectively. The loss for the US, being 7.8%, is more than twice as large and larger than one might expect solely on the reduction in exports. However, the loss of real GDP consists of two effects: the loss of income from exports and the loss in purchasing power due to the increase in import prices. A quick back-on-the-envelope calculation shows that the later effect dominates and that the total loss in real GDP is not unrealistic. The loss of income from exports is around 1.2% of nominal GDP[19], while the weighted average increase of consumer prices is around 5.4%.[20] Together this results in a decrease of 6.6%, reasonably close for a back-on-the-envelope calculation. The fact that the loss in purchasing power dominates the loss of income from exports is not surprising given that the US runs a persistent trade deficit. Overall the large decrease in GDP is in line with the intuition from the gravity model. If a country places itself far away from all other countries, say, by increasing import tariffs it will be hit exceptionally hard because it cannot divert trade to other countries. Still, intuitively a loss of 7.8% for the US might be an overestimation of the true effect.

Comparing our results from the gravity model with those of WorldScan[21] shows that the signs of the effects are similar, but that the size of the effects differ, especially for exports. The effects of the trade war on exports in the WorldScan model are much larger.[22] This is partly because the gravity model is a less extensive description of the economy, for example it does not have sector linkages. However, decreases in exports of more than 40% for Canada, Mexico and the US due to the trade war, as WorldScan results suggest, are likely an overestimation. Also, for other countries, WorldScan export effects are much larger than those estimated with the gravity model. The real GDP effects are more in line with the gravity model, although there are substantial deviations for specific countries. Part of these differences might be because we estimate different elasticities of substitution than WorldScan does. However, using the same elasticities does not fully reconcile the results.[23]

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[19]Based on IMF Direction of Trade Statistics data exports is 8% of GDP. Multiplying this with a decrease in exports of 15% (see Figure 1a) we find a 1.2% fall in nominal GDP.

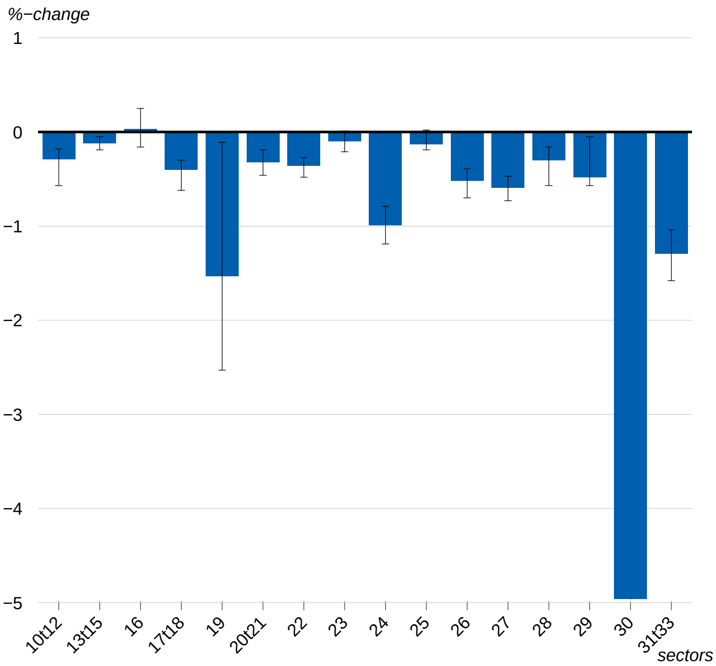
[20]This is based on a weighted average over all sectors of the increase in consumer prices we find in our simulation.

[21]The WorldScan model is based on input-output tables linking different sectors with each other. Goods are produced using sector specific production functions with multiple factors of production, such as different types of labor and capital. It is a general equilibrium model and it takes dynamic and productivity effects into account. The results presented here are under the assumption of perfect competition to make it more comparable with the gravity model.

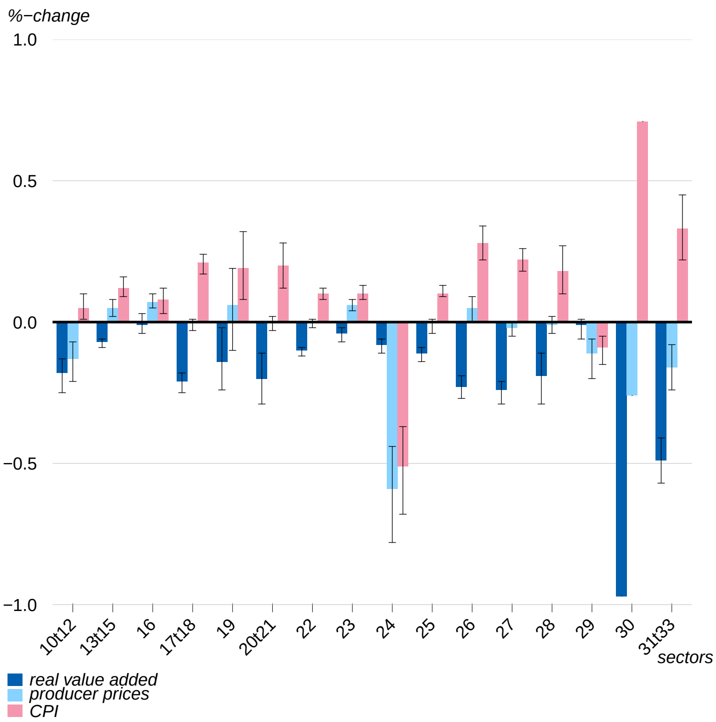
[22]Though in the GE trade model of the WTO, the export effects are closer to our gravity estimates Bekkers & Schroeter (2020)

[23]Jackson & Shepotylo (2018) find smaller welfare effects in their gravity specification than we do. However,

Figure 3: The impact of a trade war with the US on sector-level for the Netherlands



(a) Percentage change nominal exports



(b) Percentage change in real value added

In Figure 3b the percentage change in exporter prices minus the percentage change in CPI is an approximation for the change in real value added also displayed in this figure (see (25) in Section 3.6). For more information on the confidence bands see Figure 1. See table 1 for a description of the different sectors.

All sectors in the Netherlands lose from a trade war (see Figure 3). For sector 30 and 31t33 exports decrease the most percentage-wise, but sector 19 loses the most in absolute numbers followed by 30. Other hard-hit sectors in absolute numbers are 26 and 20t21. The largest percentage-wise decreases in real value added are for sectors 30 and 31t33. However, these sectors are small in absolute size and therefore in absolute numbers the sectors 20t21, 26 and 10t12 (from large to small) lose the most. The reasons for the loss in real value added differ per sector. It can be approximated by the percentage change in producer prices minus that in CPI (see equation (25)) and this gives an indication for the underlying reasons of the loss in real value added. Some sectors, like 10t12, see both a decrease in producer prices as well as an increase in consumer prices. Hence, Dutch producers earn less from selling their products due to a fall in worldwide demand, while at the same time Dutch consumers have to pay more for the goods in these sectors because of higher trade frictions. In other cases, like 13t15, producer prices go up, but consumer prices go up even more resulting in a net loss. Finally, in some sectors, like 24, consumer prices go down, but producer prices even more resulting in a net loss.

5.3 Brexit

This section presents the results of our counterfactual Brexit analysis. We present aggregate results for a set of countries and examine the Netherlands and the UK in more detail at sector level. We use four different scenarios to analyze the consequences of Brexit. Each scenario uses a different counterfactual trade cost for trade flows involving the UK. Table 4 lists the scenarios in order of expected impact. The WTO scenario would imply the UK trading with the EU on purely WTO-Most Favored Nation (MFN) basis, where in the Norway scenario, the UK would retain a close trading relationship.[24]

Figure 4 shows the percentage change in exports and real GDP for several countries around the world. As with the trade war analysis, we find that the country instituting additional trade costs, in this case the UK, is most affected. Across scenarios, the UK loses most in terms of exports and real GDP[25], far more than any other country. Ireland is also set to lose from Brexit, but relatively little compared to the UK. Other European countries generally lose too, but less than Ireland. For countries outside the EU, Brexit appears to have little, or even a very small

due to differences in specifications and data, they end up using a much smaller trade elasticity.

[24]We assume in all scenarios that the UK is able to 'roll over' all trade agreements that the European Union currently has with third countries. This assumption may seem strong, but the UK has already secured half of all such trading agreements after Brexit, at the time of writing.

[25]As we did for the US in the trade war counterfactual, we can do a back-on-the-envelope calculation to see if we can match the loss in real GDP. The loss in income of exports for the UK is around 3.0% in the WTO-scenario (exports-to-GDP share is around 16% and the loss in exports is 19%), while the loss in purchasing power is around 6.7%. This results in a back-on-the-envelope estimate of 9.7%. This is somewhat larger than we find in our simulations but still reasonably close. Just as for the US, the loss in purchasing power dominates the loss of income from exports. This is not surprising considering the UK runs a trade deficit.

Table 4: Post-Brexit EU-UK trading relationship scenarios

Scenario	Implementation strategy
"WTO"	The trade costs for trade between EU-members and the UK are increased to the MFN rates that the EU currently applies. This is further increased by NTM ad valorem-equivalents (Based on Egger & Larch (2012)) imposed by both sides that reflect those currently in force on imports from outside the EU.
"Canada"	The trade costs for trade between EU-members and the UK are increased to the rates current applied by Turkey. This is further increased by NTM ad valorem-equivalents imposed by both sides that reflect those currently in force on imports from outside the EU. Because the data only runs until 2015, the actual Canada rates likely do not reflect the level of integration in 2020, for this reason we use the Turkey rates in the Canada scenario.
"Turkey"	The trade costs for trade between EU-members and the UK are increased to the rates current applied by Turkey. This is further increased by NTM ad valorem-equivalents imposed by both sides that reflect *half* those currently in force on imports from outside the EU, as Turkey is more integrated with the EU.
"Norway"	The trade costs for trade between EU-members and the UK are increased to the rates current applied by Norway. No additional NTM related costs are added because Norway is part of the single market. In this situation very little would change compared to the UK being in the EU.

positive impact in some cases due to trade diversion.

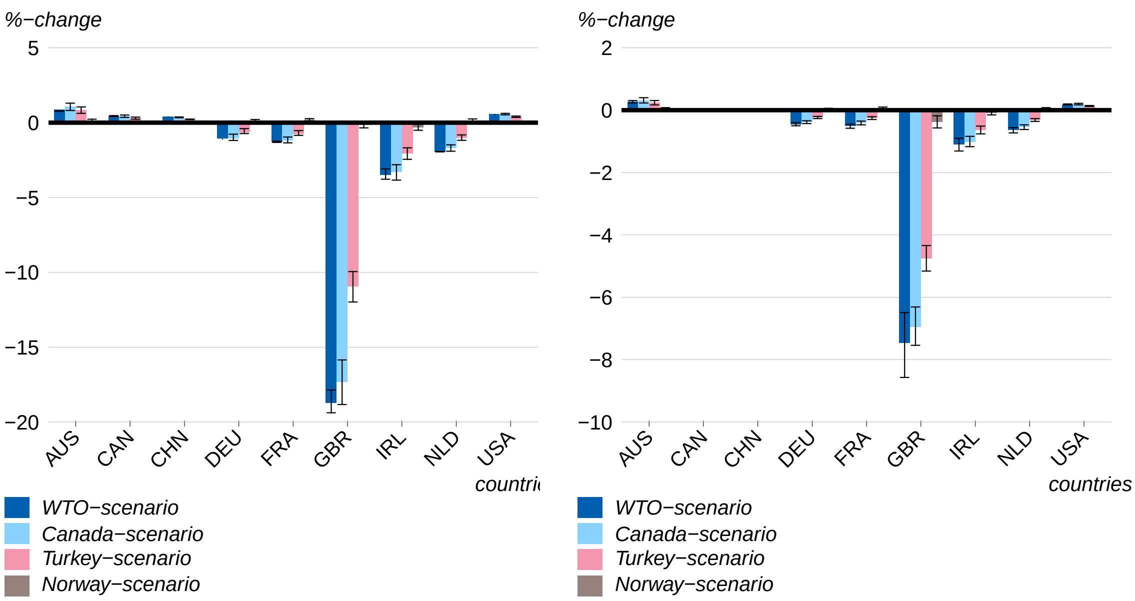
The differences across the scenarios are large. Clearly, a WTO type scenario would be most costly in terms of exports and real GDP, to the UK but also to other European countries. Moving down the list of scenarios, reducing their severity also reduces the impact of Brexit, as expected. Our estimates indicate that Brexit under the Norway scenario would have only minor impacts on exports and real GDP. The other two scenarios are in between but tend to be closer to the WTO scenario. This result indicates that starting from a Norway-type relationship, reducing trade-integration further, might rapidly increase the cost in terms of exports and real GDP.

In Figure 5, we take a more in-depth look at the outcomes for the Netherlands and the UK. Figure 5a clearly shows that exports in the UK are reduced across the board in almost all scenarios. The differences between sectors are large, however. For several sectors, the estimated decline is small, but for most we estimate exports to decline by over 20% in WTO- and Canada-type scenarios.[26] Here again, the same differences between scenarios are apparent.

The exports results for the Netherlands are less severe. In most sectors, the estimated drop in exports in a WTO-type scenario is around or less than 2%. For the other Brexit scenarios, the estimated decline in Dutch exports tend to be smaller. In fact, in the Norway-type scenario, sector-level exports might increase by up to 1% (in the motor-vehicle industry). This rise is due to trade-diversion effects, shifting trade between countries in the Norway-type scenario.

[26]Note once again that our results are based on exports of manufactured goods only; the impact of Brexit on exports could very well be more sever in service sectors. See for example IJtsma *et al.* (2018), who find services are increasing in the export composition of the U.K.

Figure 4: Aggregate impact of Brexit analyzed with different scenarios



(a) Percentage change nominal exports

(b) Percentage change real GDP

See the figure note in Figure 1 for more information on the confidence bands.

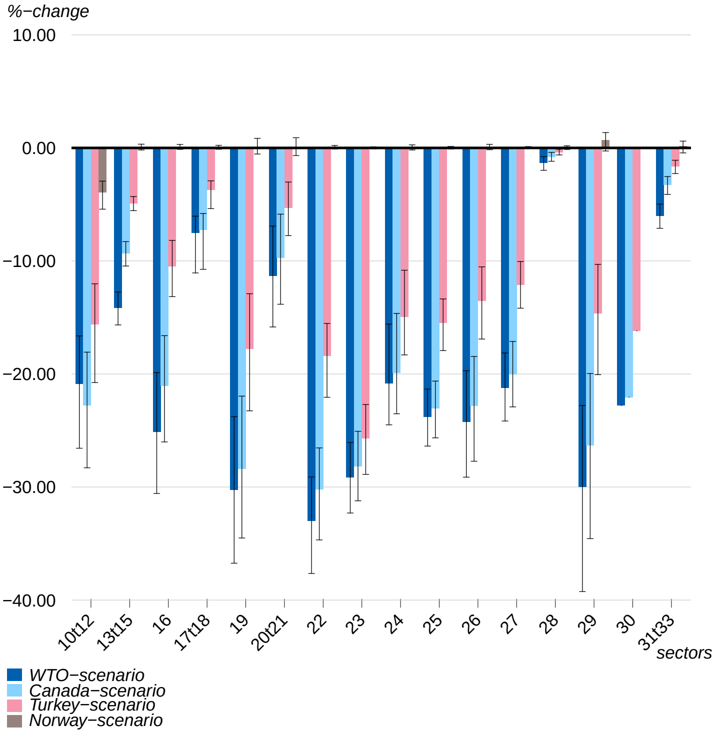
The patterns of export-change across sectors are similar for both countries. Three sectors - paper and printing (17t18), machinery (28), and other machinery (31t33) - are affected much less than others. For the Netherlands, computers and electronics (26) is most heavily affected. For the UK petroleum products (19), rubber and plastics (22), and mineral products (23) are most heavily affected. All these sectors are estimated to lose more than 30% of exports. These patterns hold across all scenarios.

Finally, we compare our Brexit analysis results with previous analyses in the literature to explore how our results measure up. Table 5 shows several Brexit analyses from the literature, listing the estimated changes in exports and real GDP. For the Netherlands, we compare our results to those from WorldScan (Bollen *et al.* (2016)). Note that each study uses different methods and parameters, which is why results vary between studies. Therefore, we are going to investigate whether the results are in the same ballpark.

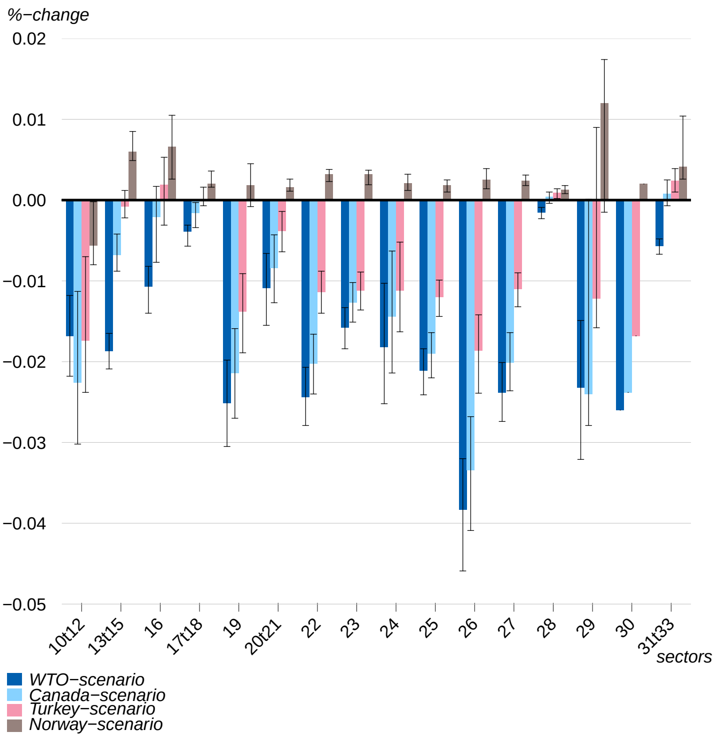
For the UK, our WTO-scenario export-change estimate appears somewhat on the high side compared to the other results. However, it is by no means the highest estimate. The FTA-scenario estimate for UK sits right in the middle of other estimates. The same pattern holds for the real GDP change estimates; our WTO-scenario result tends to be on the high side of other results and the FTA-scenario result is around the average.

Comparing the Brexit results for the Netherlands to the WorldScan results, we seem to

Figure 5: Impacts of Brexit on Dutch and British sector exports analyzed with different scenarios



(a) The United Kingdom



(b) The Netherlands

See the figure note in Figure 1 for more information on the confidence bands and Table 1 for a description of the different sectors.

Table 5: Percentage change in exports and GDP; comparing with other studies

	Exports		GDP	
UK	WTO-scenario	Turkey-scenario	WTO-scenario	FTA-scenario
Our Results	-18.0	-11.5	-7.5	-4.5
Bollen *et al.* (2016)	-23.2	-13.2	-4.4 (-8.7 / -2.7)	-3.4(-5.9 / -2)
Kierzenkowski *et al.* (2016)	-8.1	-6.4	-5.1(-7.7 / -2.7)	NA
Treasury (2016)	-24(total trade)	-18(total trade)	-7.5(-9.5 / -5.4)	-6.2(-7.8 / -4.6)
Carreras *et al.* (2016)	-29 / -21	NA	-9.2 / -2.4	NA
Dhingra *et al.* (2016)	NA	-12.5	-2.6(-9.5 / -1)	-1.3(-9.5 / 1)
Brakman *et al.* (2018)	-18 / -13	-8	NA	NA
NL				
Our results	-2.6	-1.7	-1.2	-0.7
Bollen *et al.* (2016)	-3.2	-1.9	-0.9	-0.2

estimate smaller export declines, but larger real GDP declines, as was also the case in the trade war comparison. As mentioned before, the WorldScan model is a more fully-fledged general equilibrium model. One of the key elements responsible for the differences is likely that WorldScan takes sector linkages into account. This means that dependencies and relations between sectors can be considered. In WorldScan, each sector is specified with its own production function, which allows relations between sectors to be specified. This yields a more dynamic model, where shocks in one sector are allowed to influence other sectors' outcomes. Our current gravity model is not capable of taking these dynamics into account. However, previous literature shows that it is possible to set up a gravity model which can take sector linkages into account. We discuss this in section 6.

5.4 Out-of-sample forecast

Finally, we check how well the model performs in predicting developments in export flows and real GDP outside the sample used to estimate the parameters and perform the simulations. Furthermore, we can investigate in what time span the actual out-of-sample realizations of the data will converge to our simulated results. To do this, we examine how well the model predicts the effects of entry into the European Union by Central and Eastern-European countries in 2004.[27] The aim of this exercise is to check how well the model predicts the developments in exports and real GDP of these countries, after 2004, when entry into the EU has occurred.

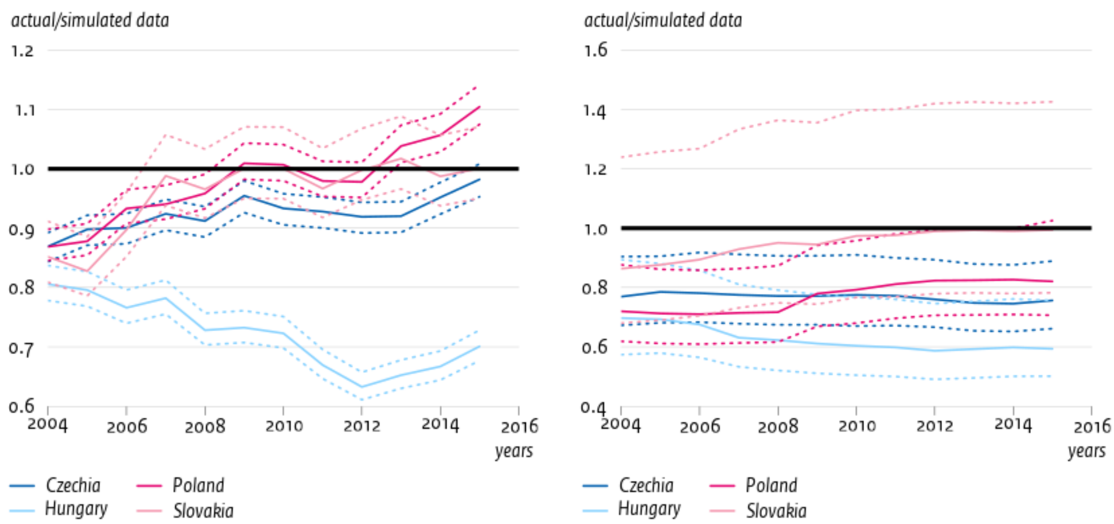
The analysis requires two steps. First, we need estimated coefficients for the EU-effect: the change in export flows associated with EU-membership. We take the estimated coefficients from Felbermayr *et al.* (2018), who estimate them in a model similar to our own. Subsequently, we incorporate these coefficients and estimate our baseline model using the data up to and including

[27] In May 2004 10 countries entered the EU: Cyprus, Czechia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, and Slovenia.

2004, assuming the EU-effect for the new entrants to kick in from 2005 onwards.[28] We then specify our counterfactual by "switching on" the EU-membership for the new entrants. Using this counterfactual, the model predicts the changes in the export flows and real GDP due to the accession of the new members into the EU.

The second step is to compare the predicted change in exports and real GDP due to the EU-effect with the actual developments in exports and real GDP in the subsequent years. We make this comparison for several of the newly acceded countries in Central and Eastern Europe. Many developments (besides EU-accession) have influenced exports and real GDP in the years after 2004, which make the comparison difficult. We attempt to correct for these developments by correcting the actual trade and real GDP data for the average trend of all Central and Eastern European countries in our sample.[29] Having filtered the trends from the actual trade data, we compare them with the predictions of the model.

Figure 6: Actual over simulated data in out-of-sample forecast



(a) Nominal exports (b) Real GDP

These figures compare actual exports and real GDP data of four Eastern European countries in the period 2004-2015 to the simulated data for the entry of Central and Eastern European countries to the EU in 2004 using an out-of-sample forecast. See the figure note in Figure 1 for more information on the confidence bands.

[28]This choice is justified since the Eastern-European countries enter the EU only in May 2004 and there most likely is a considered phase-in period of the accession agreement.

[29]Bulgaria, Czechia, Estonia, Greece, Croatia, Hungary, Lithuania, Poland, Latvia, Romania, Slovakia, Slovenia, and the Rest of the world Europe category, which mostly consists of countries in Eastern Europe.

Figure 6 compares the development of actual exports (left panel) and real GDP[30] (right panel) to the estimated counterfactual. If the counterfactual scenario is a good prediction of the actual developments in the data, we expect the lines to gradually converge to the black reference line at 1. We make the comparison for the largest four new members: Poland, Hungary, Czechia, and Slovakia.

The actual exports data for three of the countries are in line with our simulations, they gradually converge to our estimates. The speed at which this happens is also a useful indication of the time-span at which point the gravity estimates become valid. We show that actual exports data converge to predicted exports in roughly 3 to 6 years, although for Czechia full convergence is only reached in the last year. This is a much shorter time span than prior beliefs in the literature, which are closer to 10 to 15 years (see for example the phase-in estimates of an FTA by Baier & Bergstrand (2007)). Hungary is the big exception, showing declining (adjusted) exports compared to the out-of-sample forecast results. Most likely, some Hungary-specific developments are responsible.

The story is more complicated for real GDP. The actual data is less in line with the out-of-sample forecasts than for exports. Two countries show convergence, taking the 95% confidence bands into account, although for Poland this is only after 10 years. However, real GDP of both Czechia and Hungary move away from our estimate. Confidence bands are also much broader for these results. This reflects that the real GDP estimates of the gravity model are less precise and most likely do not fully capture the impact of a change in trade costs.

The results indicate that the model overall successfully captures medium term out-of-sample export developments. The model is therefore suitable to make predictions about the development of trade flows in 3-6 years, given changes in trade costs today. The model appears less suitable to do the same for real GDP. A more fully fledged CGE model might yield better results when it comes to this aspect. See the next section for further discussion on this.

6 Discussion and Conclusion

In this report we show how to use a simple gravity model for trade policy analysis and arrive at estimates that are comparable to the literature. Our scenario of an escalating trade war between the US and all other OECD countries and China shows that the gravity results are intuitive and the estimated impact on exports are in line with our expectations. However, the estimated impact on US real GDP seems to be on the large side. Compared to the WorldScan CGE analysis,

[30] We compare our real GDP estimate to data from the Penn World table (PWT) 9.1. The levels of estimated real GDP are sometimes not in line with the actual external data. Furthermore, we are more interested in the developments over time of real GDP, rather than the levels of our estimates. For these reasons we scale the actual GDP (from PWT) in Figure 6 to reflect the level of our baseline estimates in 2003.

our gravity estimates for changes in exports are much smaller but appear more realistic as WorldScans estimates are often improbably large. In addition, we evaluate four different Brexit scenarios and reach similar conclusions, that is, the estimated impact on exports are in line with expectations, but the impact on UK real GDP seems on the large side. Comparing two of these scenarios shows that our estimates are in line with the literature. Finally, our out-of-sample forecasts predicts the development in exports rather well, but less so for real GDP.

The main advantage of using the gravity model is its simplicity. The simplicity of the model makes the results more tractable and intuitive compared to larger CGE-models like WorldScan. However, enriching the model with additional features might yield even better results, though reduce tractability. For example, Bekkers & Rojas-Romagosa (2019) show that extending a simple marco model to one that tracks intermediate deliveries produces more realistic macro impacts of trade tariff-simulations. Adding intermediate linkages to a simple macro model might significantly change the GDP effects of increased trade costs. Further extensions might include the endogenization of both capital and labor, though doing this would by itself almost yield a full-fledged CGE model. Something we want to avoid to ensure tractability of the model

Caliendo & Parro (2015) present a gravity model which features sector linkages. Compared to a full-fledged CGE model - like WorldScan - this model is still simple, but it would allow us to decompose the amplifying impacts of intermediate goods and sectoral linkages when trade tariffs are changed. Furthermore, the model can distinguish many sectors, while the models parameters are limited and can still be estimated. However, incorporating this extension into our current linearized solving method is not straight forward and might not even be possible. The reason is that equations on costs of production and expenditure depend on cross-sectoral arguments, which considerably complicates the equations presented in this report. As such, we leave this, and other potential extensions to future work.

Overall, the gravity model is a useful tool for trade policy analysis that is relatively easy and swift to use. The model focusses on the medium-to-long term: 3 to 6 years, as our out-of-sample forecast implies. Due to its features, it is likely desirable to supplement the gravity model with different frameworks or models to address questions or analyze mechanisms that lie outside its focus, such as trade dynamics, impacts on productivity, labor markets, capital markets and global value chains. Despite this, the gravity model performs well at what it is meant to do, yielding useful insights about changes in trade policy on the medium-to-long term.

References

Anderson, James E. 1979. A Theoretical Foundation for the Gravity Equation. *The American Economic Review*, **69**(1), pp. 106–116.

Anderson, James E. 2011. The Gravity Model. *Annual Review of Economics*, **3**, pp. 133–160.

Anderson, James E., & Van Wincoop, Eric. 2003. Gravity with gravitas: a solution to the border puzzle. *American Economic Review*, **93**(1), 170–192.

Anderson, James E., & van Wincoop, Eric. 2004. Trade Costs. *Journal of Economic Literature*, **42**(3), pp. 691–751.

Anderson, James E., Larch, Mario, & Yotov, Yoto V. 2018. GEPPML: General equilibrium analysis with PPML. *The World Economy*, **41**(10), 2750–2782.

Arkolakis, Costas, Costinot, Arnaud, & Rodrguez-Clare, Andrs. 2012. New Trade Models, Same Old Gains? *American Economic Review*, **102**(1), 94–130.

Arvis, Jean Franois, & Shepherd, Ben. 2013. The Poisson quasi-maximum likelihood estimator: a solution to the 'adding up' problem in gravity models. *Applied Economics Letters*, **20**(6), pp. 515–519.

Baier, Scott L., & Bergstrand, Jeffrey H. 2007. Do free trade agreements actually increase members' international trade? *Journal of International Economics*, **71**(1), pp. 72–95.

Baier, Scott L, Bergstrand, Jeffrey H, & Clance, Matthew W. 2018. Heterogeneous effects of economic integration agreements. *Journal of Development Economics*, **135**, 587–608.

Baier, Scott L., Yotov, Yoto V., & Zylkin, Thomas. 2019. On the widely differing effects of free trade agreements: Lessons from twenty years of trade integration. *Journal of International Economics*, **116**(Jan.), 206–226.

Bekkers, Eddy. 2019. *The welfare effects of trade policy experiments in quantitative trade models: The role of solution methods and baseline calibration.* WTO Staff Working Papers ERSD-2019-02. World Trade Organization (WTO), Economic Research and Statistics Division.

Bekkers, Eddy, & Rojas-Romagosa, Hugo. 2019. The welfare effects of free trade agreements in quantitative trade models: A comparison of studies about Transatlantic Trade and Investment Partnership. *The World Economy*, **42**(1), 87–121.

Bekkers, Eddy, & Schroeter, Sofia. 2020. *An economic analysis of the US-China trade conflict.* Tech. rept. WTO Staff Working Paper.

Bergstrand, Jeffrey H. 1985. The Gravity Equation in International Trade: Some Microeconomic Foundations and Empirical Evidence. *The Review of Economics and Statistics*, **67**(3), pp. 474–481.

Bollen, Johannes, Meijerink, Gerdien, & Rojas-Romagosa, Hugo. 2016 (July). *Nederlandse kosten Brexit door minder handel*. CPB Policy Brief. Centraal Panbureau.

Brakman, Steven, Garretsen, Harry, & Kohl, Tristan. 2018. Consequences of Brexit and options for a Global Britain. *Papers in Regional Science*, **97**(1), 55–72.

Bun, Maurice J. G., & Klaassen, Franc. 2007. The Euro Effect on Trade is not as Large as Commonly Thought. *Oxford Bulletin of Economics and Statistics*, **69**(4), pp. 473–496.

Caliendo, Lorenzo, & Parro, Fernando. 2015. Estimates of the Trade and Welfare Effects of NAFTA. *The Review of Economic Studies*, **82**(1), 1–44.

Carreras, Oriol, Ebell, Monique, Kirby, Simon, Meaning, Jack, Pigott, Rebecca, & Warren, James. 2016 (May). *The Long and the Short of it: What price UK Exit from the EU?*

Correia, Sergio, Guimares, Paulo, & Zylkin, Thomas. 2019a. ppmlhdfe: Fast Poisson Estimation with High-Dimensional Fixed Effects. Mar.

Correia, Sergio, Guimares, Paulo, & Zylkin, Thomas. 2019b. Verifying the existence of maximum likelihood estimates for generalized linear models. Mar.

Dekle, Robert, Eaton, Jonathan, & Kortum, Samuel. 2007. Unbalanced Trade. *American Economic Review*, **97**(2), 351–355.

Dhingra, Swati, Ottaviano, Gianmarco I. P., Sampson, Thomas, & Van Reenen, John. 2016. *The UK Treasury analysis of "the long-term economic impact of EU membership and the alternatives" : CEP commentary*. CEP Brexit analysis. London : Centre for Economic Performance, London School of Economics and Political Science.

Egger, Peter, & Larch, Mario. 2012. Estimating Consistent Border Effects in Gravity Models with Multilateral Resistance. *The World Economy*, **35**(9), pp. 1121–1125.

Fally, Thibault. 2015. Structural gravity and fixed effects. *Journal of International Economics*, **97**(1), pp. 76–85.

Felbermayr, Gabriel, Grschl, Jasmin Katrin, & Heiland, Inga. 2018. *Undoing Europe in a New Quantitative Trade Model*. ifo Working Paper Series 250. ifo Institute - Leibniz Institute for Economic Research at the University of Munich.

Felbermayr, Gabriel J., & Larch, Mario. 2013. The Transatlantic Trade and Investment Partnership (TTIP): Potentials, Problems and Perspectives. *CESifo Forum*, **14**(2), pp. 49–60.

Head, Keith, & Mayer, Thierry. 2014. Gravity Equations: Workhorse,Toolkit, and Cookbook. *Pages 131–195 of: Handbook of International Economics*, vol. 4. Elsevier.

Heid, Benedikt, & Larch, Mario. 2016. Gravity with unemployment. *Journal of International Economics*, **101**(July), 70–85.

Hertel, Thomas, & Mensbrugghe, Dominique van der. 2016. Behavioral Parameters. *In:* G, Badri Narayanan, Aguiar, Angel, & McDougall, Robert (eds), *Global Trade, Assistance, and Production: The GTAP 9 Data Base*. Department of Agricultural Economics, Purdue University, West Lafayette, IN: Global Trade Analysis Project (GTAP).

Hummels, David. 1999. *Toward a Geography of Trade Costs*. GTAP Working Papers. Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University.

IJtsma, Pieter, Levell, Peter, Los, Bart, & Timmer, Marcel P. 2018. The UK's Participation in Global Value Chains and Its Implications for PostBrexit Trade Policy. *Fiscal Studies*, **39**(4), 651–683.

Jackson, Karen, & Shepotylo, Oleksandr. 2018. Trade Wars: Are Good and Easy to Win? *SSRN Electronic Journal*, Jan.

Kierzenkowski, Rafal, Pain, Nigel, Rusticelli, Elena, & Zwart, Sanne. 2016 (Apr.). *The Economic Consequences of Brexit: A Taxing Decision*. OECD Economic Policy Papers No. 16. OECD.

Lejour, A. P., Veenendaal, G., & Leeuwen, N. 2006. *WorldScan: A Model for International Economic Policy Analysis*. CPB Document 111. CPB Netherlands Bureau for Economic Policy Analysis.

McCallum, John. 1995. National Borders Matter: Canada-U.S. Regional Trade Patterns. *The American Economic Review*, **85**(3), pp. 615–623.

Ossa, Ralph. 2015. Why trade matters after all. *Journal of International Economics*, **97**(2), 266–277.

Rojas-Romagosa, H. 2017. Potential economic effects of TTIP for the Netherlands. *De Economist*, **165**(3), 271–294.

Teulings, Rutger. 2017 (Aug.). *Brexit and The Impact of Gradual Economic Integration on Export*. Tinbergen Institute Discussion Papers 17-075/VI. Tinbergen Institute.

Tinbergen, J. 1962. *Shaping the World Economy; Suggestions for an International Economic Policy*. Twentieth Century Fund, New York.

Treasury, HM. 2016. *HM Treasury analysis: the long-term economic impact of EU membership and the alternatives*. Cm, no. 9250. United Kingdom: HM Treasury.

Zylkin, Thomas. 2016. Feeding Chinas Rise: The Growth Effects of Trading with China, 1993-2011. *The World Bank Economic Review.*

A Appendix

A.1 Interpolation in UNIDO data

We apply a method for reconciling the UNIDO production and trade data inspired by Zylkin (2016) to construct suitable (positive) measures of domestic trade with some slight adaptations. This reconciliation prioritize the integrity of the trade data, and adjusts production where necessary. First, for some countries the production value is missing (for some industries, some of the time). Secondly, if the production value of a country's 2-digit industry is lower than its exports, we change the production value to missing. The procedure then follows four steps to impute the production data based on the STAN and UNIDO IndStat datasets, and the total exporter and imports of countries. These steps are:

1. Interpolate missing values
   - In case the values for production are in two years, with missing values in between, we linearly impute the missing values. This covers the vast majority of missing values
2. Extrapolate missing values
   - In case missing values are at the start or end of the period for a particular country-industry, the value of production needs to be extrapolated, to do this we use the internal trade-to-import ratio ($\epsilon_{mst} = (int_{mst})/(imp_{mst})$, int is internal trade, imp is imports)
   - To do this we use internal trade-to-import ratios at the level of the country (ϵ_{mt}), at the level of the world-wide industries (ϵ_{st}), and globally (ϵ_t).
   - We thus extrapolate the internal trade-to-imports (ϵ_{mst}):

$$\epsilon_{mst} = \epsilon_{mst-1} \left(\frac{\epsilon_{mt-1}\epsilon_{st-1}}{\epsilon_{t-1}} \right) / \left(\frac{\epsilon_{mt}\epsilon_{st}}{\epsilon_t} \right) \tag{A.1}$$

3. Deal with missing industries
   - In rare cases, industries have all missing values and need the production values need to be inferred. The values are inferred using the same country, industry, and world averages used above:

$$\epsilon_{mst} = \frac{\epsilon_{mt}\epsilon_{st}}{\epsilon_t} \tag{A.2}$$

4. Deal with missing years

- In very rare cases, some countries have no production data before certain years.
- In this case data needs to extrapolated from the available years back, without using the country specific industry internal trade-to-imports ratios (ϵ_{mt}) As such, we substitute them with the average for all other countries (ϵ_{mt}^{sub}), and use:

$$\epsilon_{mst} = \epsilon_{mst-1} \left(\frac{\epsilon_{mt-1}^{sub}\epsilon_{st-1}}{\epsilon_{t-1}} \right) / \left(\frac{\epsilon_{mt}^{sub}\epsilon_{st}}{\epsilon_t} \right) \tag{A.3}$$