CPB Netherlands Bureau for Economic Policy Analysis

Value chain research tools

We present two novel tools to enhance our comprehension of international trade dynamics.
Firstly, the trade cost index computes the total trade costs of a value chain.
Secondly, a new gravity model that includes trade in intermediate goods, which allows us to map the effects of trade policies.

These two tools can work in tandem to analyse trade policy shifts effectively.
This synergy enables us to scrutinize the comprehensive impact of trade policy changes on the entire value chain.

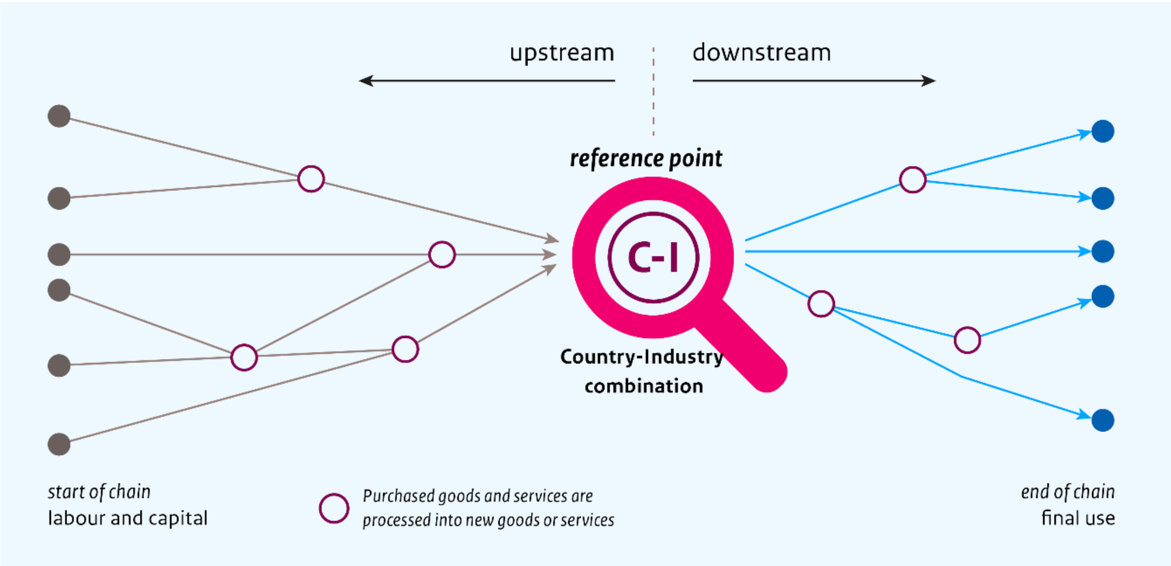
CPB - April 2023

Stefan Boeters,
Daan Freeman, Gerrit Hugo van Heuvelen,
Gerdien Meijerink, Rutger Teulings

1 Introduction

Value chains play an increasingly important role in international trade. In the past, a product, for example a car, was (almost) entirely manufactured in one country before being sold to a domestic or foreign end-user. Today, production chains are highly fragmented. Different parts of a product are made in many different countries and intermediate products cross borders several times before reaching the end user. Because value is added in each step of this production chain, we also refer to it as a 'value chain'. Figure 1 is a schematic representation of a value chain from the perspective of a country-industry combination. It receives intermediate goods upstream in the value chain, then produces a partial product which is shipped on to another industry at home or abroad. This continues until eventually a consumer good reaches the end user.

Figure 1 Value chain from the perspective of a country-industry combination



To better understand international trade, value chains should be included. In the standard gravity model in the tradition of Anderson and Van Wincoop (2003) it is often assumed that all trade takes place in final goods. This can lead to an underestimation of the welfare effect of trade. The welfare gains from trade can be up to twice as large if value chains are included (Costinot and Rodríguez-Clare, 2014). To this end, CPB has developed two new tools based on existing literature.

First, we develop a trade cost index along the lines of Miroudout and Nordström (2020). By weighting trade costs with the associated trade flows, this index maps the total trade costs of a value chain from the perspective of a country-industry combination. In doing so, we can study different trade costs in the value chain, e.g. tariff costs as in Teulings et al. (2023). By breaking down the trade cost index into different components, we can understand the differences in the value of the trade cost index between countries or industries. Is the trade cost index high because a value chain is very international and intermediate supplies are relatively often imported from countries subject to import tariffs? Or because average import tariffs are high in a value chain? This information gives us a better understanding of how trade costs within value chains work. The trade cost index can be used both to look at the existing situation and the consequences of a change in trade costs.

Second, we replace the current CPB gravity model based on Anderson and Van Wincoop (2003) with a gravity model of Caliendo and Parro (2015) that does consider value chains. The current model considers each industry in isolation. Industries are not interconnected through intermediate supplies, so changes in trade costs of one industry cannot affect other industries through value chains. The new model does include trade in intermediate goods and can therefore analyse how a change in trade policy for an industry feeds through to the rest of the value chain.

These two new tools do not stand alone, but complement each other in analysing changes in trade policy. The trade cost index uses trade flows to sum trade costs weighted along the value chain. As a result of a change in trade policy, prices will change and trade flows will shift between countries. The model of Caliendo and Parro (2015) captures these changes and the results may serve as a basis for new weights in the trade cost index. In this way, it is possible to map not only the impact of a change in trade policy on trade flows, prices and welfare, but also on trade costs along the value chain. This completes the picture.

This new set of tools is mainly suitable for identifying the medium-term effects of changes in trade policy. It takes time for prices and trade flows to adjust to the new situation following a change in trade costs. Bollen et al. (2020) show that this takes around three to five years. Like most trade models, the Caliendo and Parro trade model does not incorporate this adjustment lag and is therefore not suitable for short-term analysis. We therefore interpret the model results as medium-term effects. In the long run, foreign direct investment may also adjust due to a change in trade costs. Again, this affects trade flows (see, for example, Helpman et al., 2004). However, the role of capital is not included in this trade model. For the trade cost index, this is somewhat more nuanced. It is possible to look only at the change in trade costs themselves while leaving the trade flows used for weighting unchanged. This gives a good approximation of the very short-term impact on total trade costs in the value chain. For the medium term, changing trade flows should also be considered. There are also issues beyond the scope of the toolbox. For example, it cannot be used to examine the impact of trade policies on the labour market, capital flows or specific firms within a value chain.

In chapter 2 we describe the construction of the trade cost index and in chapter 3 the trade model of Caliendo and Parro (2015)**.** This publication is intended as a reference work and will be updated over time with additional sensitivity analyses and new knowledge gained about the tools.

2 Construction of trade cost index

The purpose of the trade cost index[1] is to determine the trade costs incurred along the entire value chain of a product. We can focus here on either the upstream or the downstream chain. The upstream index captures the sum of trade costs incurred in the production of a good on the intermediate supply value chain as a share of the value of the good produced. The downstream index summarises the trade costs associated with a good before it becomes part of final consumption. These indices can be calculated using standard methods from input-output analysis. In doing so, we follow the setup of Miroudot and Nordström (2020).

2.1 Upstream

For the case of an aggregate industry per country, let the upstream (u) trade cost index be TCI_j^u for imports of intermediate products from country j which can be calculated as:

[1] We discuss here the construction of the trade cost index in a general sense. The tariff cost and distance index are a special case of the trade cost index. Apart from tariffs, there are other forms of trade costs: trade and transport margins, non-tariff trade measures (NTMs). These are more complicated, partly due to data availability reasons. Therefore, we leave them aside for now.

$$TCI_j^u = \sum_k \alpha_{kj} t_{kj} + \sum_k \alpha_{kj} \sum_l \alpha_{lk} t_{lk} + \sum_k \alpha_{kj} \sum_l \alpha_{lk} \sum_m \alpha_{ml} t_{ml} + \cdots.$$

TCI_j^u thus shows the cumulative trade costs of country j on all intermediate products as a percentage of the value of gross production. The bilateral trade costs for exports from country k to country j (as a percentage of the underlying trade value) are given by t_{kj}. The value share α_{kj} is the input coefficient,[2] which indicates how many inputs from country k in country j is needed to produce one good, where $\sum_k \alpha_{kj} < 1$. The first term in the sum then indicates the trade cost on direct intermediate supplies, the second term the intermediate supplies in the second step and so on.

The above equation can be rewritten in matrix notation:

$$TCI^u = W^\alpha + A'W^\alpha + A'^2W^\alpha + \cdots.$$

The upstream trade cost index TCI^u then summarises all countries and is a $K \times 1$ vector containing K the number of countries. W^α is the $K \times 1$ vector of weighted trade costs in which element j is given by $\sum_k \alpha_{kj} t_{kj}$, and A the $K \times K$ matrix with input coefficients. For all bilateral matrices, the exporting country can be found in the rows and the importing country in the columns. Using the Leontief inverse, this infinite sum can be rewritten to:

$$TCI^u = [I - A']^{-1} W^\alpha,$$

where I the $K \times K$ identity matrix is. Using this formula, it is possible to calculate the upstream trade cost index for each country in one step.

So far, we have assumed an economy aggregated to a single industry, but now we generalise to a Q-industry economy:

$$TCI_j^{r,u} = \sum_{k,s} \alpha_{kj}^{sr} t_{kj}^{sr} + \sum_{k,s} \alpha_{kj}^{sr} \sum_{l,u} \alpha_{lk}^{us} t_{lk}^{us} + \sum_{k,s} \alpha_{kj}^{sr} \sum_{l,u} \alpha_{lk}^{us} \sum_{m,v} \alpha_{ml}^{vu} t_{ml}^{vu} + \cdots.$$

Now, upstream trade costs for production in country j and industry r are given by $TCI_j^{r,u}$. All variables contain two additional indices for the supplying and receiving industry. α_{kj}^{sr} is the input coefficient for deliveries from industry s in country k to industry r in country j, and t_{kj}^{sr} are the associated trade costs.[3] Again, we may describe this in the same matrix form as above with the difference that now the matrices have the dimensions $KQ \times KQ$ where the rows contain exporting country k all Q industries and the columns contain importing country j all Q industries.

2.2 Downstream

The downstream (d) trade cost index of industry q in country i can be calculated analogously to the upstream index, only with a different type of value shares for aggregation:

[2] In the international literature, these are also *called direct requirement coefficients*.
[3] In practice, trade costs will not vary by receiving industry in most cases. Nevertheless, for symmetry, we add a second industry index *s* here.

$$TCI_i^{q,d} = \sum_k \left(\varphi_{ik}^q t_{ik}^{qC} + \sum_s \beta_{ik}^{qs} t_{ik}^{qs}\right) + \sum_{k,s} \beta_{ik}^{qs} \sum_l \left(\varphi_{kl}^s t_{kl}^{sC} + \sum_t \beta_{kl}^{st} t_{kl}^{st}\right) +$$

$$\sum_{k,s} \beta_{ik}^{qs} \sum_{l,t} \beta_{kl}^{st} \sum_m \left(\varphi_{lm}^t t_{lm}^{tC} + \sum_u \beta_{lm}^{tu} t_{lm}^{tu}\right) + \cdots.$$

The value share β_{ik}^{qs} is the output coefficient,[4] which is the share of the output of industry q from country i to industry s from country k, φ_{ik}^q is the output coefficient for final demand in country k. All output coefficients of a good add up to 1: $\varphi_{ik}^q + \sum_{k,s} \beta_{ik}^{qs} = 1$. The corresponding tariff rates are t_{ik}^{qs} and t_{ik}^{qC}.

The equation for the downstream index can also be rewritten in matrix notation:

$$TCI^d = W^\beta + BW^\beta + B^2 W^\beta + \cdots.$$

TCI^d is a $QK \times 1$ vector, W^β is the $QK \times 1$ weighted trade cost vector in which the element W_{iq}^β is given by $W_{iq}^\beta = \sum_k (\varphi_{ik}^q t_{ik}^{qC} + \sum_s \beta_{ik}^{qs} t_{ik}^{qs})$. Finally, B is the $QK \times QK$ matrix with output coefficients. Using the Ghosh inverse, this sum can be rewritten to:

$$TCI^d = [I - B]^{-1} W^\beta.$$

Using this formula, it is possible to calculate the downstream trade cost index for each country-industry combination.

2.3 Trade cost decomposition index

To understand why the upstream or downstream trade cost index differs between country-industry combinations, it is useful to pull apart the different components that make up the trade cost index. For example, two country-industry combinations may have the same trade cost index, but there may be different underlying reasons for this. The trade cost index for a country-industry combination may be low because the value chain in question is largely national or because trade costs in the value chain in question are low. In this section, we deal with the decomposition of the upstream true index. On the downstream index, the decomposition can be applied in the same way.

The trade cost index for a country-industry combination will, *ceteris paribus*, be higher when: (*i*) value chains are longer, (*ii*) the number of country border crossings in the value chain increases, (*iii*) a country is less likely to participate in FTAs and thus pays more often at border crossings (taxed part), and (*iv*) if average tariff costs at taxed border crossings increase. To capture the relative importance of these determinants for the trade cost index, we calculate a set of auxiliary indicators. The calculation of the indicators is very similar to the calculation of the trade cost index itself. Combined, these indicators lead to the trade cost index.

First, the length of the value chain (D^{lng}) of the country-industry combination equals the value-weighted sum of all intermediate supplies required for production for this and all previous production steps:

$$D^{lng} = [I - A']^{-1} W^{lng}.$$

[4] In the international literature, these are also called *allocation coefficients*.

The calculation corresponds to the trade cost index itself, except for the W-vector. The element of W^{lng} with the indices r, j is given by $\sum_{k,s} \alpha_{kj}^{sr}$. Compared with W^{α} of the trade cost index, the trade cost percentage t_{kj}^{sr} falls away. This measure is equal to the *embodied production stages* minus 1 of Fally (2012). The difference arises from the fact that Fally takes into account all stages of production up to and including the combination itself, while we only take into account all stages of production gone through up to the combination.

For the second indicator, the number of country border crossings in the value chain (D^{int}), only value flows that cross the border are included:

$$D^{int} = [I - A']^{-1} W^{int}.$$

Again, the only difference in the calculation is in the W-vector. The element of W^{int} with the indices r, j is given by $\sum_{k,s} \alpha_{kj}^{sr}\, \iota_{kj}^{sr}(k \neq j)$. $\iota_{kj}^{sr}(k \neq j)$ is an indicator varia bele that has the value 1 if $k \neq j$ and 0 otherwise. Miroudot and Nordström (2020) have a similar measure called *foreign production stages*.

The third indicator is the number of border crossings where trade costs are incurred in the value chain (D^{cst}). Here, only the value flows for which trade costs are incurred are still included:

$$D^{cst} = [I - A']^{-1} W^{cst},$$

The element of W^{cst} with the indices r, j is given by $\sum_{k,s} \alpha_{kj}^{sr}\, \iota_{kj}^{sr}(t_{kj}^{sr} > 0)$. The indicator variable is now equal to 1 if the trade cost associated with the value stream is positive, otherwise the indicator is 0.

Finally, the average nominal trading costs across all value streams with trading costs ($\bar{T}^{nom}$), the fourth indicator, are by definition equal to

$$\bar{T}_j^{r,nom} = TCI_j^{r,u} / D_j^{r,cst},$$

where $\bar{T}_j^{r,nom}$ and $D_j^{r,cst}$ are the country-industry average nominal trade costs and the country-industry number of taxed trade flows, respectively. With these definitions and the decomposition by country-industry combination results in:

$$TCI_j^{r,u} = \bar{T}_j^{r,nom} \cdot D_j^{r,lng} \cdot d_j^{r,int} \cdot d_j^{r,cst}.$$

The trade cost index for a country-industry combination results from the average nominal trade cost ($\bar{T}_j^{r,nom}$), the length of the value chain ($D_j^{r,lng}$), the relative international openness of the country-industry combination ($d_j^{r,int}$) and the taxed trade flows relative to free trade flows ($d_j^{r,cst}$).

2.4 Scenario analysis with a trade cost index

As a result of a change in trade policy, the upstream and downstream trade cost index may change. For example, if two countries sign a new free trade agreement, the number of taxed border crossings, D^{cst}, decrease and possibly the average nominal trade costs also change, $\bar{T}^{nom}$. With this, the trade cost index itself also changes. But this is only the first-order effect of the change in trade policy and does not yet take into account any trade diversion due to relative price changes. This first-order effect can also be interpreted as the short-term consequence of a change in trade costs on total trade costs in the value chain.

Entering into a trade agreement makes it cheaper to trade with each other. This can cause shifts in value chains. Value chains that used to be entirely located in one country or instead passed through a third country may move wholly or partially when two countries conclude a free trade agreement. This affects not only the number of taxed border crossings and average nominal trade costs, but also the number of border crossings D^{int} and the length of the value chain D^{lng}. We call this the second-order effect. This effect captures the medium-term impact of a change in trade costs on total trade costs in the value chain.

To derive the first-order effect, a new bilateral trade cost matrix $T'$is needed with elements $t_{ij}^{qr\prime}$. This can then be used to derive the new $W^{\alpha\prime}$, $W^{\beta\prime}$ and $W^{cst\prime}$ can be calculated. Using the formulas from section 2.1, 2.2 and 2.3, we can calculate the new upstream ($TCI^{u,1}$) and downstream ($TCI^{d,1}$) trade cost index and the number of taxed border crossings ($D^{cst,1}$) can be calculated. From this, the new average nominal trade cost over all taxed border crossings in the value chain ($\bar{T}^{nom,1}$).

The second-order effect requires not only a new bilateral trade cost matrix T' also requires a new input-output table. This reflects the volume of all new trade flows and intermediate supplies. From this, new input and output coefficients can be derived and thus the new A'- and B'-matrices. The second-order effects $TCI^{u,2}$, $TCI^{d,2}$, $D^{lng,2}$, $D^{int,2}$, $D^{cst,2}$ and $\bar{T}^{nom,2}$ can then be derived using the formulas above. To derive new input-output tables due to a change in trade policy, we need a trade model that takes value chains into account. In section 3 we introduce the model of Caliendo and Parro (2015).

3 The trade model with value chains by Caliendo and Parro (2015)

3.1 Model structure

The ambition of the trade model of Caliendo and Parro (2015) (henceforth C&P) is to include trade in intermediate goods, which is not the case in the literature consistent with the gravity model of Anderson and Van Wincoop (2003). The latter model is the basis for CPB's previous trade model (Bollen et al., 2020). However, this extension with value chains will be modelled as simply as possible, avoiding the black box effect of a fully computable general equilibrium model (CGE).

Many elements of C&P are standard for trade models. Consumers maximise a utility function over a set of industry-defined composite goods. These goods consist of domestically produced and imported varieties. Choosing among possible suppliers of the varieties is done on the basis of lowest price ('Ricardian trade' à la Eaton and Kortum (2002), see further below in this section). Labour (as the only primary input) and intermediate supplies are used in the production of each variety. Intermediate supplies use the same composite goods by industry, so domestic demand can be summed from final demand and intermediate demand.

The structure of international trade is then determined by relative prices and these in turn are determined by costs consisting of wages, intermediate input prices and stochastic productivity parameters. The equation for bilateral trade shares can be formulated as a gravity equation with the following elements: exporter size, importer size and trade costs. This makes it possible to match the estimation of substitution parameters in the gravity literature (see section 3.3). By closing the income circuit (consumption expenditure equal to wage income plus tariff revenue plus trade deficit), trade balances are controlled. Starting point trade surpluses/deficits are thereby held constant.

By including intermediate supplies, the C&P trade model begins to resemble CGE models, such as WorldScan which was used by CPB in the past. In certain aspects, simplifications have been included that allow solving the model for a large number of countries and industries:

- Value shares in final consumption are constant (Cobb-Douglas).
- Product-level value shares in intermediate supplies are constant (Cobb-Douglas).
- All industries of the importing country (and final consumption) use the same mix from domestically produced and imported varieties. In reality, an international input-output table contains differences in the import mix by industry.

International trade by industry is modelled as trade in varieties à la Eaton and Kortum (2002). Domestic demand (intermediate plus final demand) thereby relates to a continuum of varieties. Each country is in principle capable of producing every variety, but there are differences in productivity levels by industry and country for the different varieties. These productivity levels are stochastic and are drawn from a Fréchet distribution. Each country buys the necessary varieties from the cheapest supplier, taking trade costs into account. Because of the random element in productivity and the infinite number of varieties, each country's demand is then still spread over a large number of sources.

The model is formulated in relative differences from a starting point. The advantage of this is that the model can be calibrated to an international input-output table (in our case FIGARO, see section 3.2) and that country- and industry-specific productivity parameters do not need to be given a numerical value because they are constant and fall out of the equations when determining the effect of a shock. The only parameters we still need are different value shares and the dispersion parameters of the productivity distribution. We can derive the former from the input-output table (see section 3.2) and the latter are directly related to the substitution elasticities estimated in the gravity literature using tariff data (see section 3.3).

With 46 countries and 63 industries from FIGARO's input-output table, the model is too large to be solved simultaneously with standard tools, despite the simplifications. Therefore, C&P introduced an iterative solution method. The effect of a shock in bilateral trade costs is first translated into a consistent set of supply and demand prices while holding trade shares constant. From this, new trade shares are then calculated. In the final step of an iteration, a consistent set of value flows (including income by country) is calculated with the new shares. These value flows imply trade surpluses and deficits by country that differ from the observed trade balance balances. C&P assume that the trade balance balances remain the same even in the simulated situation, and adjust wages by country so that the balances change in the desired direction. This provides the new input for the next iteration, until convergence is achieved. Separating a price system from a value flow system reduces the number of simultaneous variables and hence the size of the calculations required.

3.2 Trade data

As mentioned above, the model is based on FIGARO data.[5] The 2022 version of this dataset includes input-output (IO) tables for the years 2010-2020. These tables map value added, output and trade flows between them for 64 industries in 46 countries. Trade flows can be divided into intermediate use supplies, such as intermediate goods, and final use supplies, mainly consumption and investment.

[5] For further details on the FIGARO database, see. Rémond-Tiedrez and Rueda-Cantuche (2019) and ec.europa.eu/eurostat/web/esa-supply-use-input-tables/figaro.

The dataset is a complete matrix of trade flows. Thus, the data on intermediate supplies contains four dimensions (supplier country and industry, and user country and industry) and that of final demand contains three dimensions (supplier country and industry, and user country). The crucial construction step of an IO table such as FIGARO is the consistent merging of trade data and national IO tables. Both types of information are needed to properly model the choice between domestically produced goods and services and imports.

The data in an IO table are arranged in two accounting identities. The gross production value of a country-industry is equal to the value of all intermediate deliveries to all country-industry combinations (including to itself) plus deliveries to all countries for final use (including domestic use). In addition, the value added of a country-industry is always equal to its gross production value minus the value of all intermediate supplies of all country-industry combinations.

Some parameters of the model were calibrated directly to the FIGARO data so that the model exactly reproduces the data in the absence of a further shock:

- input coefficients of intermediate supplies by supplying country and industry,
- trade shares by industry and country,
- shares of final consumption by country.

Given that C&P's model works with three dimensions, as opposed to the four dimensions of the dataset, this calibration includes an aggregation step (see also section 3.1 for a description of the model and section 3.5 for deriving a new IO table). Intermediate and final use imports are enumerated for each exporter. From these, average import shares are calculated, and these are applied to each recipient industry and final demand.

3.3 Substitution elasticities

The substitution elasticity of each industry is a crucial parameter for determining the general equilibrium effects due to a change in trade costs. For each industry, the substitution elasticity shows how sensitive the demand for products from a particular country is to a change in relative international prices. Here, we are particularly interested in price changes induced by change in trade costs. For example, if the Netherlands starts levying tariffs on imports from Germany, Germany becomes more expensive for the Netherlands. The elasticity of substitution then determines how Dutch demand shifts and the more expensive German products are replaced by cheaper products from all other countries, including the Netherlands itself. If other countries also impose tariffs on imports from Germany and there is also more demand for Dutch products from these countries because of the more expensive German products, the price of Dutch products will also rise. Again, the elasticity of substitution then determines how much demand will shift away from Dutch products.

The C&P trade model has no substitution elasticity but an industry-dependent dispersion parameter (see section 3.1). This determines the dispersion of productivity within an industry and thus the varieties in which a country has a comparative advantage. This parameter plays a similar role to the substitution elasticity in the Armington-CES gravity models, such as those of Anderson and Van Wincoop (2003) and the CPB gravity model. Therefore, we set the dispersion parameter equal to the substitution elasticity minus 1.

Conceptually, the two models do differ. In the C&P model, trade takes place on the basis of the lowest price, while in an Armington-CES gravity model it takes place on the basis of preferences for national varieties. Consumers switch to a variety from another country only if they are compensated by price. See also footnotes 20 and 35 in Caliendo and Parro (2015) for a detailed discussion.

We use the estimated substitution elasticities from Freeman et al. (2022a) (see table 6.1). The substitution elasticity estimate is based on import tariffs causing a one-to-one change in price. The substitution elasticity is then equal to minus the partial tariff elasticity.[6] We choose not to estimate the substitution elasticities with FIGARO data because FIGARO only covers the most recent period (2010-2019). In this period, rates are generally low and there is little variation over time. This complicates the accurate estimation of the partial rate elasticity and hence the substitution elasticity. In contrast, Freeman et al. (2022a) use long-term WIOD(LTWIOD) data.[7] These cover a much longer time period in which the tariff data show much more country and time variation. This gives us a period from 1988-2011 for which substitution elasticities can be accurately estimated.[8] The industry breakdown of the LTWIOD for goods is at a slightly more aggregate level than that of FIGARO. In some cases, we therefore need to assign the same elasticity of substitution to several FIGARO industries.

For services, it is not possible to estimate substitution elasticities because no import tariffs are levied on services. To still obtain a value of substitution elasticities in service industries for the model, we follow the literature (Freeman et al., 2021) by using 1.5 times the average of the trade elasticity of goods.[9] This implies a substitution elasticity of 10.6 for all service industries.

To estimate partial rate elasticities and hence substitution elasticities, Freeman et al. (2022a) use a standard gravity equation (see their note for more details on the estimation method and the underlying estimation equation). In the following, we discuss the main elements of their method. In the note, they estimate the gravity equation using the *Poisson pseudo maximum likelihood* (PPML) estimation method (see Santos Silva and Tenreyro, 2006), as is common in the gravity literature. The estimating equation consists of the following components:

$$X_{ijt}^{q} = \exp\left(\ln\left(Tariffs_{ijt}^{q}\right)\beta_1^{q} + Z_{ijt}^{q}\beta_5^{q} + \alpha_{ij}^{q} + \theta_{it}^{x,q} + \theta_{jt}^{m,q}\right)\eta_{ijt}^{q}\,.$$

The dependent variable X_{ijt}^{q} is the exports in industry q from i to j at time t. To estimate the partial tariff elasticity β_1^{q} we define $Tariffs_{ijt}^{q}$ as 1 plus the country pair industry-specific ad-valorem *rate*.[10] The estimated partial rate elasticities and corresponding standard errors are shown in table 6.1. The necessary substitution elasticity is equal to minus the partial tariff elasticity.

Several control variables Z_{ijt}^{q} that are important for explaining exports were added to the estimating equation by Freeman et al. (2022a). First, they add variables controlling for European Union (EU) economic integration because EU countries tend to trade relatively more with each other than non-EU countries. In doing so, they distinguish between different stages of EU economic integration, such as the free trade agreement and the customs union or single market. They also check for trade diversion from third countries to EU member states as a result of the EU. Finally, they check for the difference between trade within a country and trade between two countries. In the latter case, trade barriers are almost always much higher than within a country. For a detailed explanation of all the control variables they include, see the appendix of Freeman et al. (2022b).

Table 6.1 Estimated partial rate elasticities from Freeman et al. (2022a)

Industry sector	Partial rate elasticity	Standard error
Agriculture	-4,1*	1,0

[6] The tariff elasticity is partial because it only includes the direct effect of tariffs on exports and not the indirect effect of tariffs through the multilateral trade costs of the importer and exporter.
[7] See Woltjer et al (2021).
[8] The LTWIOD covers a period from 1965-2011 and the tariff dates from 1988-2011.
[9] Freeman et al. (20222022a) use a substitution elasticity of 4 for service industries, consistent with Egger et al. (2012) and Felbermayr et al. (2021)
[10] Tariff data are from the UNCTAD TRAINS database.

Forestry	-4,1*	1,0
Fisheries	-4,1*	1,0
Mineral extraction	-6,8*	1,2
Food industry	-3,2*	0,7
Textile industry	-4,8*	0,8
Wood Industry	-3,2*	0,7
Paper industry	-3,2*	0,7
Graphics industry	-3,2*	0,7
Petroleum industry	-7,0*	2,2
Chemical industry	-7,2*	1,1
Pharmaceutical industry	-7,2*	1,1
Rubber and plastics industry	-6,0*	1.0
Other non-metallic industry	-5,4*	1,7
Primary metal industry	-5,9*	0,7
Metal products	-5,9*	0,7
Electrical industry	-12,1*	1,8
Electronic appliance industry	-12,1*	1,8
Machinery industry	-13,2*	2,0
Automotive industry	-8,1*	1,7
Other transport equipment industry	-8,1*	1,7
Furniture industry	-12,1*	1,3
Other industry and repairs	-12,1*	1,3
All service industries	-10,6	

Table note: The estimated partial rate elasticity equals minus the substitution elasticity. The * indicates that the estimate is significant at a 95% significance level. Industries in italics are estimated together with the industry directly above as one industry and therefore have the same partial tariff elasticity. Service industries have a partial tariff elasticity of 1.5 times the average of all goods industries. See Freeman et al. (2022a) for more information on the estimation method.

Finally, it is important to correct for unobserved heterogeneity in the data by adding different types of *fixed effects* (FE). First, it is important to add the industry-dependent country pair FE, α_{ij}^{q} to be added as Baier and Bergstrand (2007) show. Country pair-specific factors that do not change over time, such as whether two countries share a common border or language, can affect the level of exports. Second, industry-dependent exporter time-, $\theta_{it}^{x,q}$, and importer time-, $\theta_{jt}^{m,q}$ FE are added. These correct for unobserved multilateral trade costs that play an important role in gravity models.

3.4 Scenario analyses with the gravity model

To estimate the effects of a change in trade policy, we use scenario analysis. In a scenario analysis, we compare the existing situation with an alternative one. An example of an alternative scenario is where the EU does not exist and all EU member states trade with each other based on World Trade Organization (WTO) rules (Freeman et al., 2022a). This allows us to identify the impact of the alternative scenario on export values and prices while all other factors, such as global economic growth, remain the same.

In a scenario analysis with a gravity model, we take into account not only the partial effects of, say, EU membership on two member states but also the general equilibrium effects. This means that we take into account trade diversion from or to third countries as they become relatively more expensive or cheaper, respectively. In this example, this means that trade between one EU member state and another in the actual situation shifts to a third non-EU country in the alternative scenario because it is relatively cheaper in the absence of the EU.

For a scenario analysis, we firstly need trade volume effects of the trade policy in question. Estimates of these effects can be generated by, for example, adding trade policy variables to the gravity estimation equation in section 3.3, such as for example an EU dummy equal to 1 if the exporting and importing country are both EU members and 0 in other cases. For an extensive discussion on estimating trade volume effects, we refer, for example, to Freeman et al. (2022a).

Finally, a scenario analysis requires a good alternative scenario. The choice of scenario should be tailored to the research question to be answered. Some examples of different alternative scenarios are: there is no EU and all member states trade with each other on the basis of WTO rules, there is no internal market within the EU and all member states trade with each other on the basis of a free trade agreement and an economic union (Freeman et al., 2022a), sanctions are imposed with a tariff equivalent of 100% between Russia and a bloc of Western countries, (Meijerink et al., 2022) and reciprocal import tariffs are imposed between the EU and China that are 25% higher, as was the case in the 1990s (Freeman et al., 2022a).

3.5 Deriving a new input-output table

As an output of the scenario analysis with the Caliendo-Parro model, we get a three-dimensional trade structure (importer × exporter × exporting industry). This is not a complete international IO table because information on the import intensity and import sources of each recipient industry is missing. In the C&P model, for the sake of numerical tractability of the model, the import structure by country is assumed to be the same for all recipient industries and final consumption.

It is not informative to compare this raw model output with its homogeneous structure for all importing industries directly with the original FIGARO data (the starting point before the shock in the scenario analysis). Such a comparison would confusingly mix the simulation output (effect of the shock) and the model assumption of a homogeneous input structure. It would then no longer be clear which changes in the new IO table are due to the shock and which are due to the model assumptions. In particular, it would lead to unclear results if we use the raw model output to estimate second-order effects (shift of the trade structure) on the trade cost index (see section 2.4). Therefore, we further process the raw model output in a follow-up step and try to decompose it to the level of recipient industries (and final demand) in a plausible way.

For this purpose, we apply a RAS procedure for balancing matrices (see Eurostat 2014). Since the countries are connected only by trade flows and these are determined by the model, the different countries can be considered separately in the procedure. We start with the ex-ante matrix of country-specific value flows for country j from the original IO table: $\overline{W}_{ij}^{qr}$ with exporting country i, supplying industry q and receiving industry (including final demand) r from importing country j. In two dimensions and for a dataset with K countries and Q industries, this is a national IO matrix with KQ rows and $Q+1$ columns. Each row indicates a country-industry combination as the origin of the goods/services, the columns contain the national industries plus final consumption. The interior of the matrix is not determined by the model, but the edge totals are: the total expenditure per supplying country-industry combination (D_{ij}^{q}), the sum of the row and total spending by recipient industry (D_{j}^{qr}, including final demand) as well as the sum of the columns. This imposes the following constraints on the rows and columns of the matrix for country j:

$$\sum_{r} W_{ij}^{qr} = D_{ij}^{q}$$

$$\sum_{i} W_{ij}^{qr} = D_{j}^{qr}$$

The RAS procedure starts from the starting values $\bar{W}_{ij}^{qr}$ and then modifies the interior of the IO matrix through iterative row and column multiplications such that all constraints are met. In the process, the structure of the original IO table is preserved as much as possible. Indeed, the shocks that we are able to analyse in our scenario analysis do not give rise to the assumption that the distribution of imports across and within the receiving industries would shift beyond what is required for reproducing the edge totals.

4 Literature

Anderson, J.E. and E. Van Wincoop, 2003, Gravity with gravitas: a solution to the border puzzle, *American Economic Review*, vol. 93, no. 1, pp. 170-192 (link).

Baier, S.L. and J.H. Bergstrand, 2007, Do free trade agreements actually increase members' international trade?, *Journal of International Economics*, vol. 71, no. 1, pp. 72-95. (link).

Bollen, J., R. Teulings and D. Freeman, 2020, *Trade policy analysis with a gravity model*, CPB Background paper, The Hague: Centraal Planbureau. (link).

Caliendo, L. and F. Parro, 2015, Estimates of the Trade and Welfare Effects of NAFTA, *The Review of Economic Studies*, vol. 82, no. 1, pp. 1-44 (link).

Costinot, A. and A. Rodríguez-Clare, 2014, Trade Theory with Numbers: Quantifying the Consequences of Globalisation, in: *Handbook of International Economics*, Elsevier, vol. 4, pp. 197-261 (link).

Eaton, J. and S. Kortum, 2002, Technology, Geography, and Trade, *Econometrica*, vol. 70, no. 5, pp. 1741 - 1779. (link).

Egger, P.H., M. Larch and K.E. Staub, 2012, Trade preferences and bilateral trade in goods and services: A structural approach, CEPR Discussion Papers 9051. (link)

Eurostat, 2014, Method: RAS, in: *Memobust Handbook on Methodology of Modern Industry Statistics* (link).

Fally, T., 2012, *Production staging: Measurements and facts* (link) .

Felbermayr, G.J., S. Gans, H. Mahlkow and A. Sandkamp, 2021, *Decoupling Europe*, Kiel Policy brief 153, Kiel: IfW Kiel Institute for the world economy. (link).

Freeman, R., M. Larch, A. Theodorakopoulos and Y.V. Yotov, 2021, *Unlocking new methods to estimate country-specific trade costs and trade elasticities*, Staff working paper 951, London: Bank of England. (link).

Freeman, D., G. Meijerink and R. Teulings, 2022a, *Trade benefits of the EU and the internal market*, CPB Notitie, The Hague: Centraal Planbureau (link).

Freeman, D., G. Meijerink, R. Teulings, M. van 't Riet, T. Notten, K.F. Wong, N. Aerts and O. Lemmers, 2022b, *Economic interwovenness with China through trade: two sides of the same coin*, CPB/CBS note, The Hague: Netherlands Bureau for Economic Policy Analysis and Statistics Netherlands (link).

Helpman, E., M.J. Melitz and S.R. Yeaple, 2004, Exports Versus FDI with Heterogeneous Firms, *The American Economic Review*, vol. 94, no. 1, pp. 300-316 (link).

Meijerink, G., D. Freeman, R. Teulings and M. van 't Riet, 2022, Analysis of international trade sanctions against Russia, CPB Note, The Hague: Centraal Planbureau (link).

Miroudot, S. and H. Nordström, 2020, Made in the World? Global Value Chains in the Midst of Rising Protectionism, *Review of Industrial Organization*, vol. 57, no. 2, pp. 195-222 (link).

Rémond-Tiedrez, I. and J. Rueda-Cantuche, 2019, *Full international and global accounts for research in input-output analysis (FIGARO)*, Eurostat.

Santos Silva, J.M.C. and S. Tenreyro, 2006, The log of gravity, *The Review of Economics and statistics*, vol. 88, no. 4, pp. 641-658. (link).

Teulings, R., S. Boeters, D. Freeman, G.H. Van Heuvelen, G. Meijerink and M. van 't Riet, 2023, *How value chains determine tariff costs*, CPB Publication, The Hague: Centraal Planbureau.

Woltjer, P., R. Gouma and M.P. Timmer, 2021, *Long-run World Input-Output Database: Version 1.0 Sources and Methods*, GGDC Research Memorandum 190 (link).