Appendix to "Brexit and the Macroeconomic Impact of Trade Policy Uncertainty" (for online publication only)

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A Data

This section of the appendix provides additional details on data sources and data processing. All source data are contained in the folder `data` in the online supplement. Python scripts referenced below can be found in the folder `scripts`.

A.1 Recent national accounts and trade data

All of the data reported in table 1 and panels (a)–(c) of figure 1 were extracted from Eurostat. They have been seasonally and calendar adjusted. Filtering methods are well-known to give inaccurate results near the end of time series, so I simply compare the data that cover the period after the referendum act was introduced to Parliament to the data prior to the act's introduction. The first column of the table reports the average quarterly growth rates[1] of key macro variables between 2012Q1 and 2015Q2. I choose 2012Q1 as the starting point for the comparison period to eliminate the effects of recovery from the Great Recession; this is the first quarter in which consumption begins to rise after falling during recession. The second column lists average growth rates between 2015Q3 and 2016Q2, the period between the referendum's introduction to Parliament and the actual vote, and the third column lists the growth rates for 2016Q3–2018Q2, the three quarters for which we have data since the vote. The figure simply plots the raw time series.

The two real exchange rate series shown in panel (d) of figure 1 are computed using CPI and nominal exchange rate series from the IMF's International Financial Statistics Database coupled with the raw WIOD data described in the next subsection. First, I split the non-U.K. countries in the WIOD data into two regions: the European Union and the erest of the world. Second, for each country, I compute a bilateral real exchange rate with the United Kingdom using the CPI and nominal exchange rate data from the IFS. All real bilateral real exchange rates are normalized to one in 2015Q2. Third, for each region I compute the average of the bilateral real exchange rates of the constituent countries, weighted by the U.K.'s total trade flows with that

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[1] I report the average values of the investment rate and net exports/GDP instead of growth rates since these variables do not exhibit trend growth.

country in the 2011 WIOD data.

All of these steps are performed in the script `recent-data.py`.

A.2 Input-output matrices

Here I describe the construction of the input-output matrices in Table 3. I begin with the 2011 world input-output matrix from the World Input Output Database (Timmer et al., 2015), which contains 40 countries and 35 industries. I aggregate all countries in the European Union (except for the United Kingdom) into a composite "E.U." country, and the remaining non-U.K. countries into a second "rest of the world" composite. I aggregate all industries into one sector. This yields the matrix in panel (a) of the table. To obtain the balanced matrix in panel (b), I use the RAS method (Bacharach, 1965) to find the most similar matrix in which each country's aggregate trade balance is zero. To apply the method, I add two additional rows for value added, so that each country's value added is in its own row. This allows me to ensure that these value added figures remain unchanged in the procedure. I then impose the restriction in the RAS algorithm that each country's final demand must equal its value added. This implies that net exports must be zero. The balanced matrix is shown in panel (b). Both of these steps are performed in the python script `iomats.py`.

A.3 Exporter facts

In the next two subsections, I describe the processing of the Exporter Dynamics Database and EFIGE data and the calculation of the exporter facts used in the calibration (described in section 3.1.2).

A.3.1 EFIGE Database

The EFIGE dataset (Altomonte and Aquilante, 2012) contains firm-level data for seven European countries on a wide variety of economic performance indicators. Following Piguillem and Rubini (2013), I drop Hungary and Austria due to the small number of observations for these countries, and concentrate on France, Germany, Italy, Spain, and the United Kingdom. I use the following variables:

- `d4`: an indicator of whether a firm is an exporter;
- `d13_1`: the percentage of a firm's exports that go to the 15 core E.U. countries; and
- `d13_2`: the percentage of a firm's exports that go to other E.U. countries.

I compute export participation rates for each country by taking the mean of the variable `d4`. I then report the export participation rate for the United Kingdom and the average export participation rate for non-U.K. countries in the dataset.

For the U.K., I also define a firm as an exporter to the E.U. if `d13_1+d13_2` is positive, and define a firm as an exporter to the rest of the world if 1-`d13_1`-`d13_2` is positive. I then compute the bilateral export participation rates conditional on exporting (the analogue of the measure I compute above for non-U.K. countries using the EDD data) as the means of these variables for the subset of U.K. firms that are exporters (firms with `d4`=1).

These steps are performed in the script `efige_expart_facts.py`.

A.3.2 World Bank Exporter Dynamics Database

The World Bank's Exporter Dynamics Database (Fernandes et al., 2016) contains a wide variety of facts about export participation rates, the distribition of exporter sizes, exit rates, and growth rates in 69 countries that are computed from firm-level panel data. These facts are reported for several levels of aggregation across destinations and sectors. I use the following variables from the country-year-destination level data (the `CYD` dataset):

- `A1`: number of firms that export to the given destination;
- `B2ii`: share of exports for by the top 5 percent of exporters;
- `C2`: exit rate of exporters;
- `A11i`: incumbent growth rate; and
- `A12i`: entrant growth rate.

I also use the total number of exporters across all destinations (variable `A1`) and the average number of destinations served by an exporter (`B4i`) from the country-year data (the `CY` dataset).

I split the source countries in the dataset into two regions. There are 6 E.U. countries in the database: Belgium. Bulgaria, Estonia, Portugal, Spain, and Sweden. I assign the remaining countries into the rest of the world. Similarly, I split destinations into three regions: the U.K., the E.U., and the rest of the world.

To compute bilateral export participation rates (conditional on exporting) I use four steps. First, for each country and year, and destination group (U.K, E.U., or R.W.) I sum the number of exporters for each destination in the group (`A1` in the `CYD` dataset). Second, I divide this sum by the total number of exporters in that country-year (`A1` in the `CY` dataset). Third, for destination regions other than the U.K. (which consists of only one country), I adjust this sum by the average number of destinations served by an exporter (`B4i` from the `CY` dataset) to reflect the fact that many firms export to more than one destination (so that the sum computed in step one could reflect some double counting). These first three steps provide me with an estimate of the propensity of firms in a given source country to export to each region (conditional on being an exporter). Fourth, I compute the averages of these data points for each source region.

To compute the average top 5 share, exit rate, and relative entrant growth rate (the growth rate of entrants minus the growth rate of incumbents), I simply average the relevant variables (`B2ii`, `C2`, `A12i`-`A11i`) in the `CYD` dataset across all source countries, destination countries, and years.

All of these steps are performed in the script `wbedd_expart_facts.py`.

A.4 Tariff and non-tariff barriers

The last two subsections describe the calculation of the post-Brexit trade costs listed in table 4.

A.4.1 Tariffs

To calculate the increases in U.K.-E.U. tariffs for hard Brexit, I use data from two sources:

- W.T.O. data on most-favored-nation tariff rates charged by the European Union on HS6-level products.
- COMTRADE data on HS6-level trade flows between the United Kingdom and the European Union for 2011.

I combine these two data sources to compute trade-flow-weighted average tariffs for each trade flow direction. The average tariff on U.K. imports from the E.U. is weighted by imports, while the average tariff on E.U. imports from the U.K. is weighted by exports. Then, I multiply these averages by the goods (agriculture, mining, and manufacturing) shares of total imports and exports, since there are no tariffs in services trade. These calculations are shown in the first two rows of Table 4, panel (c). These calculations are perfomed in the script `tariffs.py`.

A.4.2 Non-tariff barriers

The data sources for the non-tariff barrier increases are:

- Francois et al. (2013), who estimate the non-tariff barriers in trade between the European Union and the United States for a subset of ISIC Rev. 2 industries, as well as the fraction of these barriers that are policy-reducible.
- WIOD trade flows between the United Kingdom and the European Union at the ISIC Rev. 2 level (the data from A.2 before aggregating across industries).

First, I calculate the policy-reducible non-tariff barriers in E.U.-U.S.A. trade for each industry by multiplying total barriers by their policy-reducibility fractions. Second, I use a similar approach as in A.3.1 to calculating average barriers in U.K.-E.U. trade, here using the WIOD trade flow data as weights. This is complicated slightly by the fact that the Francois et al. (2013) data map closely, but not exactly, to the ISIC Rev. 2 industries. Table A1 lists the concordance that I use between ISIC and Francois et al. (2013) sectors. In several cases, one ISIC sector maps to multiple Francois et al. (2013) sectors (this is noted in the table with "+" signs). In this case, I calculate the non-tariff barrier for the ISIC sector by taking a simple average of the mapped Francois et al. (2013) sectors. In one case, three ISIC sectors maps to one Francois et al. (2013) sector. In this case, I use the same value for all three ISIC sectors. This calculation is performed in the script `ntb.py`.

B Details on calibration and equilibrium solution method

This section of the appendix provides additional details on the calibration procedure and the numerical method used to solve the model.

B.1 Calibration

Before choosing any parameters, I first add scaling factors, $\bar{Y}_i$ and $\bar{Y}_{i,j}$, to the aggregation technologies which I will calibrate so that all steady-state aggregate prices are one:

$$Y_i(Z^t) = \bar{Y}_i \left[\sum_{j \in I} \left(\mu_{i,j}\right)^{\frac{1}{\zeta}} \left(Y_{i,j}(Z^t)\right)^{\frac{\zeta-1}{\zeta}} \right]^{\frac{\zeta}{\zeta-1}}$$

$$Y_{i,j}(Z^t) = \bar{Y}_{i,j} \left[\int_{\nu \in N_{i,j}(Z^t)} y_{i,j}(Z^t, \nu)^{\frac{\theta-1}{\theta}} \, \mathrm{d}\nu \right]^{\frac{\theta}{\theta-1}}$$

This is without loss of generality, but it facilitates the calibration procedure because the entries in the input-output matrix represent both real quantities and nominal expenditures (Kehoe et al., 2018).

B.1.1 Assigned parameter values

First, I assign the following parameter values:

- $\beta = 1/1.02$;
- $\delta = 0.06$;
- $\zeta = 3.25$ (this value, which yields a long-run trade elasticity of 5, was determined through manual experimentation);
- $\gamma = 2$;
- $\varphi = 0.8$;
- $\alpha = 1/3$;
- $\theta = 5$;
- $\lambda = 1$;
- $\chi = 0.7$ (this firm parameter, as well as the next one, can be set directly to target the relevant data, there is no need to formally calibrate it);
- and $\phi = 0.85$.

In addition, I set all trade costs to zero so that Armington shares will absorb both subjective home bias and trade costs as discussed in the main text.

B.1.2 Aggregation technology and household parameters

A number of parameters can be set directly from the input-output data. First, I set the value added shares, η_i, as follows:

$$\eta_i = \frac{1 - \left(\frac{\theta M_i^*}{(\theta-1)Y_i^*}\right)}{1 - \left(\frac{\theta M_i^*}{(\theta-1)Y_i^*}\right)\left(1 - \left(\frac{R_i^*}{\alpha}\right)^{\alpha}\left(\frac{W_i^*}{1-\alpha}\right)^{1-\alpha}\right)}$$

As in the main text, stars indicate steady-state equilibrium values, which are taken directly from the input-output matrix in panel (b) of table 3. Second, I calibrate the Armington share parameters, $\mu_{i,j}$, using marginal-product-pricing conditions:

$$\mu_{i,i} = \frac{1}{\sum_{j\in I}\left(Y_{i,j}^*/Y_{i,i}^*\right)};$$
$$\mu_{i,j} = \mu_{i,i}\left(Y_{i,j}^*/Y_{i,i}^*\right).$$

I normalize $\sum_{j\in I}\mu_{i,j} = 1$. Third, I set the top-level scaling factors, $\bar{Y}_i$:

$$\bar{Y}_i^* = \frac{Y_i^*}{\left[\sum_{j\in I}\left(\mu_{i,j}\right)^{\frac{1}{\zeta}}\left(Y_{i,j}^*\right)^{\frac{\zeta-1}{\zeta}}\right]^{\frac{\zeta}{\zeta-1}}}.$$

Fourth, I set labor endowments equal to steady state employment: $\bar{L}_i = L_i^*$.

B.1.3 Firm parameters

The remaining parameters are calibrated by solving a system of equations. These parameters are:

- productivity dispersion, σ_i, for $i \in I$;
- scaling factors, $\bar{Y}_{i,j}$, for $i, j \in I \times I$;
- marketing efficiency costs, $\psi_{d,i}$, for $i \in I, d \in D_i$;
- customer base depreciation rates, $\omega_{d,i}$, for $i \in I, d \in D_i$;

I solve for values of these parameters that jointly satisfy the following conditions:

- for each country i and destination d, the export participation rate is matches the bilateral export participation rates computed in section 3.1.2;
- for each country i, the share of exports accounted for by the top 5 percent of exporters is 58.4 percent;
- for each country i and destination d, the size of the average growth rate of a new exporter is 13.2 percent higher than the average growth rate of the average incumbent exporter;
- and for each pair i, j, the price of the bilateral aggregate, $Y_{i,j}^*$, is one.

While these parameter values must be solved jointly, each one loosely maps to one of the conditions. The dispersions, σ_i, control the top 5 share. The marketing costs, $\psi_{d,i}$, control export participation rates. The depreciation rates, $\omega_{d,i}$, control the relative growth rates of new entrants. And the scaling factors, $\bar{Y}_{i,j}$, control bilateral aggregate prices.

B.2 Solution method

Typically, DSGE models are solved by linearizing the equilibrium conditions around an invariant, deterministic steady state (higher-order approximations are necessary for analyzing the effects of aggregate uncertainty and making welfare comparisons). The stochastic structure in my model is not amenable to this approach; the process for the aggregate state is non-stationary and there are three long-run steady states, each of which is selected endogenously.[2] Instead, I use a global method that provides an exact, not approximated, solution.

The basic approach is the same as in Kehoe et al. (2018) and Alessandria et al. (2018): assume that the equilibrium converges to a steady state after a finite number T of periods, then solve the resulting finite system of equilibrium variables and equations using the standard Newton-Raphson method. These papers study deterministic models, however. The presence of aggregate uncertainty in my paper complicates the application of this approach but does not prevent it because the number of possible histories is finite.

The computational procedure is further complicated by the need to solve the dynamic program of an exporter. I discretize the firm's state space into a square grid with 300 productivity nodes and 50 market penetration nodes. None of the results are sensitive to the fineness of this grid. For each history Z^t and productivity node a, I use the endogenous grid method to obtain the market penetration policy function of an incumbent exporter and standard 1-dimensional optimization to obtain the policy function of a potential entrant (a firm with zero market penetration at the beginning of the period).

To reduce the size of the solution space, I solve for many of the equilibrium variables analytically as functions of "target" variables which I use in the solver. For example, consumption is implied by gross output, investment, and intermediate inputs through the aggregate market clearing condition (24). The equilibrium variables that are used in the solver are:

- wages, $\{W_i(Z^t)\}_{t=0}^T$;
- bilateral prices, $\{P_{i,j}(Z^t)\}_{t=0}^T$;
- bond prices, $\{Q(Z^t)\}_{t=0}^T$;
- rental rates, $\{R_i(Z^t)\}_{t=0}^T$;
- gross output, $\{Y_i(Z^t)\}_{t=0}^T$;
- and investment, $\{X_i(Z^t)\}_{t=0}^{T-1}$.

The equilibrium equations that are used in the solve are

- numeraire normalization, $P_{uk}(Z^t) = 1$, for $t \leq T$;
- balance of payments for $i = uk, eu$ and $t \leq T$;

[2] As mentioned in the main text, even holding trade costs fixed there is a continuum of possible steady states because I allow for unbalanced trade.

- labor market clearing for $i \in I$ and $t \leq T$;
- capital market clearing for $i \in I$ and $t \leq T$;
- Euler equations for $i \in I$ and $t < T$;
- and market clearing for bilateral trade, $Y_{i,j}(Z^t) = \int y_{i,j}(Z^t, \nu)$, for $i, j \in I \times I$ and $t \leq T$.

The program to solve the model is written in C. It can be found in the folder "quanal/dyn_mkt_pen" in the online supplement. The Alessandria-Choi model is in the folder "quanal/fixed_costs" and the multisector model is in the folder "quanal/multisector." Please note that I have compiled these programs in Linux and linked to BLAS and LAPACK routines in the Intel MKL library. If you do not have acccess to this library, you can use alternative libraries instead (e.g. Atlas, GSL). If you are using Windows and need help, please contact me for assistance.

C Multi-sector model

In this section of the appendix, I describe the multi-sector version of the model briefly mentioned in the main text. I also explain the calibration of the multi-sector model.

Each country in the multi-sector model has two sectors, goods ($s = 1$) and services ($s = 2$). As in Armington, gross output is differentiated by source country and sector but homogeneous across firms within each country-sector pair.[3] International trade is conducted by intermediaries that aggregate purchases of domestic and foreign gross output into artificial composites, which are then sold to domestic households consumption and investment, and to firms for intermediate inputs. Households have the same preferences and solve almost the same maximization problem as in the one-sector model. The only difference is that households choose investment for each sector separately, and sectoral capital stocks follow a law of motion with adjustment costs as in equation (3) in the main text.

C.1 Production and demand system

C.1.1 International trade

In each country i and sector s, competitive distributors intermediate trade in intermediate inputs and final expenditures separately. The intermediate composite, $M_{i,s}(Z^t)$, is an Armington aggregate of sector-s intermediates from all source countries, $M_{i,s,j}(Z^t),\ j \in I$:

$$M_{i,s}(Z^t) = \left\{ \sum_{j \in I} \left(\mu_{i,s,j}\right)^{\frac{1}{\zeta_{i,s}}} \left(M_{i,s,j}(Z^t)\right)^{\frac{\zeta_{i,s}-1}{\zeta_{i,s}}} \right\}^{\frac{\zeta_{i,s}}{\zeta_{i,s}-1}}.$$

[3]The exporter dymamics framework of Alessandria and Choi (2007) used in the one-sector model is not tractable here. The Armington specification is numerically tractable and consistent with theoretical and quantitative findings in the literature regarding the macroeconomic effects of trade frictions. Adding static firm heterogeneity as in Eaton and Kortum (2002) and other "new" trade models would yield similar results (Arkolakis et al., 2012; Eaton et al., 2011).

The final expenditure composite in country i, $F_{i,s}(Z^t)$, is given by

$$F_{i,s}(Z^t) = \left\{ \sum_{j \in I} \left(\theta_{i,s,j}\right)^{\frac{1}{\sigma_{i,s}}} \left(F_{i,s,j}(Z^t)\right)^{\frac{\sigma_{i,s}-1}{\sigma_{i,s}}} \right\}^{\frac{\sigma_{i,s}}{\sigma_{i,s}-1}}.$$

The elasticities of substitution vary across countries, sectors, and uses. Later, I will calibrate them to match WIOD trade flow data and elasticity estimates from Caliendo and Parro (2015).

As in the one-sector model, there are two kinds of trade costs: formal import tariffs and non-tariff iceberg trade costs. Each type of trade cost varies by destination country, sector, source country, use. $\tau^m_{i,s,j}(Z^t)$ and $\tau^f_{i,s,j}(Z^t)$ denote country i's tariffs on intermediate and final imports from country j's s-sector, respectively. All tariff revenues are rebated to households as lump-sum transfers. Similarly, $\xi^m_{i,s,j}(Z^t)$ and $\xi^f_{i,s,j}(Z^t)$ denote country i's non-tariff iceberg costs of intermediate and final imports from country j's s-sector.

C.1.2 Gross output

Gross output of country i's sector s, $Y_{i,s}(z^t)$, is produced by competitive firms using value added, $V_{i,s}(z^t)$, and intermediate inputs of goods and services purchased from distributors, $M^d_{i,s,1}(z^t)$ and $M^d_{i,s,2}(z^t)$, according to a Leontief technology:

$$Y_{i,s}(Z^t) = \min\left\{ \frac{V_{i,s}(Z^t)}{\eta_{i,s,v}}, \frac{M^d_{i,s,2}(Z^t)}{\eta_{i,s,1}}, \frac{M^d_{i,s,2}(Z^t)}{\eta_{i,s,2}} \right\},$$

Value added is produced using capital, $K^d_{i,s}(Z^t)$, and labor, $L^d_{i,s}(Z^t)$, according to the usual Cobb-Douglas function.

$$V_{i,s}(Z^t) = (K^d_{i,s}(Z^t))^{\alpha_{i,s}} (L^d_{i,s}(Z^t))^{1-\alpha_{i,s}}.$$

I use the superscript d to distinguish firms' demand for factors and intermediates from factor supply, which is chosen by households, and intermediate supply, which is chosen by distributors.

C.1.3 Final demand

Each country i's aggregate consumption basket is a CES aggregate of retail goods and services:

$$C_i(Z^t) = \left\{ (\epsilon_{i,1})^{\frac{1}{\rho}} \left(C_{i,1}(Z^t)\right)^{\frac{\rho-1}{\rho}} + (\epsilon_{i,2})^{\frac{1}{\rho}} \left(C_{i,2}(Z^t)\right)^{\frac{\rho-1}{\rho}} \right\}^{\frac{\rho}{\rho-1}}.$$

Following Bems (2008), aggregate investment in each country i is a Cobb-Douglas aggregate of inputs purchased from goods and services retailers:

$$X_i(Z^t) = (X_{i,1}(Z^t))^{\varepsilon_{i,1}} (X_{i,2}(Z^t))^{\varepsilon_{i,2}}$$

C.1.4 Market clearing

The market clearing conditions in the multi-sector model are:

$$
\begin{aligned}
Y_{i,s}(Z^t) &= \sum_{j \in J} \left(M_{i,s,j}(Z^t) + F_{i,s,j}(Z^t) \right), \ \forall i \in I, \ \forall s \in S \\
M_{i,s}(Z^t) &= \sum_{r \in S} M^d_{i,r,s}(Z^t), \forall i \in I, \ \forall s \in S \\
F_{i,s}(Z^t) &= C_{i,s}(Z^t) + X_{i,s}(Z^t), \ \forall i \in I, \ \forall s \in S \\
X_i(Z^t) &= \sum_{s \in S} X^d_{i,s}(Z^t), \ \forall i \\
K_{i,s}(Z^t) &= K^d_{i,s}(Z^t), \ \forall i, s \\
\bar{L}_i(Z^t) &= \sum_{s \in S} L^d_{i,s}(Z^t), \ \forall i \\
0 &= \sum_{i \in I} B_i(Z^t)
\end{aligned}
$$

C.2 Calibration

As in the one-sector model, I first assign elasticities of substitution and other common parameters, then calibrate remaining parameters so that the steady-state replicates an input-output matrix.

C.2.1 Assigned parameters

Assigned parameters, like the discount factor and the capital share, which have the same meaning in the multi-sector model as they do in the one-sector model, are set to the same values as in the main text.

There are several new elasticities, however. I follow Kehoe et al. (2018) and use Atalay (2014)'s estimate of 0.65 for the elasticity of substitution between goods and services in consumption, ρ. To set the Armington elasticities — which are also trade elasticities since this model has no extensive margin — I refer to Caliendo and Parro (2015), who estimate trade elasticities for the same 2-digit ISIC industries that comprise the goods sector in the input-output matrix described below. For each country i, I set the intermediate and final goods trade elasticities, $\zeta_{i,1}$ and $\sigma_{i,1}$, to averages of the Caliendo and Parro (2015) estimates, weighted by these industries shares' in country i's total intermediate goods imports and total final goods imports, respectively. Intermediate goods trade elasticities range from 6.6 to 7.6, while final goods trade elasticities range from 4.4 to 5.3. All countries have higher elasticities for intermediates than for final use. For the services sector, I follow Costinot and Rodríguez-Clare (2014) and set the intermediate and final services trade elasticities, ζ_{i2} and σ_{i2}, all to 5, the average of the Caliendo and Parro (2015) estimates. Note that the aggregate trade elasticities are close to 5 in the multi-sector model.

C.2.2 Parameters calibrated to input-output data

The remaining parameters are calibrated so that the no-Brexit steady state replicates a two-sector version of the input-output matrix constructed from the 2011 WIOD data. The goods sector includes agriculture, mining, and all manufacturing industries (2-digit ISIC codes 37 and lower). The services sector includes all other industries. The two-sector matrix is shown in table A3. With this matrix and the elasticities and other externally-calibrated parameters in hand, we can calibrate the remaining parameters using the model's equilibrium conditions as in the one-sector model.

C.3 Post-Brexit trade costs

To calculate the increases in tariffs and non-tariff barriers after Brexit in the multi-sector model I use the same approach as in the one-sector model, but perform the computations for each sector separately. For tariffs in hard Brexit, the goods-sector tariffs are the figures from A.3.1 prior to scaling by the goods shares of total trade flows; there are no tariffs for the services sector. For non-tariff barriers, I perform the computation separately by sector and use, since the WIOD data that are used as weights distinguish between intermediate and final trade. The results are in table A4.

C.4 Version with import adjustment frictions

The baseline multi-sector model has been calibrated using trade elasticity estimates from Caliendo and Parro (2015), which are in line with other estimates in the literature of trade flows' sensitivity to price changes in the long run. As Ruhl (2008) points out, in the short run trade flows typically respond less to price changes than long-run elasticity estimates would dictate; Heathcote and Perri (2002) estimate an elasticity of 0.9 using HP-filtered data. Recent theoretical work on trade dynamics and endogenous trade elasticities emphasizes fixed costs of importing or exporting as used in the one-sector model (Alessandria and Choi, 2007; Ruhl, 2008; Alessandria et al., 2013, 2018; Ramanarayanan, 2016), source-specific durable goods (Engel and Wang, 2011), destination-specific marketing capital (Drozd and Nosal, 2012), and firm-to-firm relationship stickiness (Lim, 2016). Incorporating these sorts of features into the mult-sector model is not computationally feasible, so I take a similar approach to Engel and Wang (2011) and add convex costs of adjusting import quantities.

In this version of the model, distributors must pay costs to adjust the quantities of inputs they import from other countries. The total adjustment cost paid by sector-s distributors in country i for intermediate trade is

$$\sum_{j \in I \setminus i} \left[\frac{\varphi_m}{2} \left(\frac{M_{i,s,j}(Z^t)}{M_{i,s,j}(Z^{t-1})} - 1 \right)^2 \right].$$

The parameter φ_m governs the size of the adjustment costs, which are paid in units of labor. Decreasing inputs from one foreign country in favor of increasing inputs from another incurs two adjustment costs; substituting inputs from the rest of the world for inputs from the European Union after Brexit is particularly costly. There is a similar adjustment cost for trade in final expenditures. Distributors solve dynamic problems in this version of the model, choosing inputs to maximize the expected present value of dividends.

In contrast to the adjustment-cost model suggested by Krugman (1986) and studied in Drozd and Nosal (2012), in which producers pay costs to adjust export quantities, this model delivers time-varying trade elasticities. In this exercise, I calibrate the adjustment cost parameters φ_m and φ_f so that the average short-term trade elasticity for the United Kingdom, measured over the one-year period 2019–2020 immediately after Brexit implementation, is 1, the standard value in the international business cycle literature.

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Table A1: Concordance between ISIC Rev 2. and Francois et al. (2013) sectors

ISIC code	ISIC sector name	Francois et al. (2013) sector name
AtB	Agriculture, Hunting, Forestry and Fishing	–
C	Mining and Quarrying	–
15t16	Food, Beverages and Tobacco	Food & beverages
17t18	Textiles and Textile Products	Textiles
19	Leather, Leather and Footwear	–
20	Wood and Products of Wood and Cork	Wood & paper products
21t22	Pulp, Paper, Paper , Printing and Publishing	Wood & paper products
23	Coke, Refined Petroleum and Nuclear Fuel	–
24	Chemicals and Chemical Products	Chemicals + Cosmetics + Pharmaceuticals
25	Rubber and Plastics	–
26	Other Non-Metallic Mineral	–
27t28	Basic Metals and Fabricated Metal	Metals
29	Machinery, Nec	Machinery
30t33	Electrical and Optical Equipment	Electronics + OICE + Biotech. + Medical equip.
34t35	Transport Equipment	Aerospace & Space + Automotive
36t37	Manufacturing, Nec; Recycling	–
E	Electricity, Gas and Water Supply	–
F	Construction	Construction
50	Sale, Maint. and Repair of Motor Vehicles	–
51	Wholesale Trade and Commission Trade	–
52	Retail Trade, Except Motor Vehicles	–
H	Hotels and Restaurants	Travel Services
60	Inland Transport	Transport Services
61	Water Transport	Transport Services
62	Air Transport	Transport Services
63	Other Transport Activities	–
64	Post and Telecommunications	Communication Services
J	Financial Intermediation	Financial Services + Insurance Services
70	Real Estate Activities	–
71t74	Renting of M&Eq, Other Business Activities	ICT + Other Business Services
L	Public Admin and Defence	–
M	Education	–
N	Health and Social Work	–
O	Other Community and Personal Services	Personal & Recreational Services
P	Private Households with Employed Persons	–

Table A2: Assigned parameters in multisector model

Parameter	Meaning	Value	Source or target
(a) Trade elasticities			Literature + WIOD
$\zeta_{uk,s}$	UK intermediates	(7.6,5.0)	
$\zeta_{eu,s}$	EU intermediates	(7.5,5.0)	
$\zeta_{rw,s}$	ROW intermediates	(6.6,5.0)	
$\sigma_{uk,s}$	UK final	(4.8,5.0)	
$\sigma_{eu,s}$	EU final	(4.4,5.0)	
$\sigma_{rw,s}$	ROW final	(5.3,5.0)	
(b) Other parameters			
ρ	Consumption elasticity	0.65	Atalay (2014)
β	Discount factor	0.98	2% long-run interest rate
γ	Risk aversion	2.0	Standard
α	capital share	0.33	Standard
δ	Depreciation rate	0.06	Standard
φ_k	Capital adjustment cost convexity	0.76	Steinberg (2018)

Table A3: 2011 world input-output table in multi-sector model

		Intermediate inputs									
		UK		EU		ROW		Final demand			
		Goods	Services	Goods	Services	Goods	Services	UK	EU	ROW	GO
UK	Goods	2.68	2.96	2.12	0.77	1.79	1.11	4.00	1.95	2.25	39.27
	Services	4.61	27.46	0.56	1.83	0.62	1.93	42.41	0.28	0.67	160.73
EU	Goods	1.77	1.41	62.49	29.10	16.11	8.38	3.24	56.30	19.68	396.98
	Services	0.10	0.74	48.01	124.72	5.11	10.13	0.33	224.21	3.84	834.37
ROW	Goods	1.87	1.61	18.16	6.71	474.06	211.32	2.58	14.24	288.49	2,038.10
	Services	0.29	1.64	4.63	8.81	163.50	391.38	0.60	2.48	900.01	2,946.68
VA		19.63	80.37	198.49	417.19	1,019.05	1,473.34	-	-	-	3,208.07
GO		39.27	160.73	396.98	834.37	2,038.10	2,946.68	106.34	598.92	2,429.88	9,551.27

Table A4: Brexit scenarios in multisector model

Exogenous change	Soft Brexit	Hard Brexit
(a) Tariffs on goods trade		
Imports from E.U.	0.00	4.23
Exports to E.U.	0.00	3.29
(b) Non-tariff barriers (imports from E.U.)		
Intermediate goods	1.76	5.23
Intermediate services	0.98	2.94
Final goods	3.08	9.24
Final services	0.38	1.13
(c) Non-tariff barriers (exports to E.U.)		
Intermediate goods	1.49	4.47
Intermediate services	1.44	4.32
Final goods	2.62	7.85
Final services	1.065	3.20