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ARTICLE

UNDERSTANDING THE EFFECTS OF BREXIT ON UK PRODUCTIVITY

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Abstract
In this article, we use a three-country macroeconomic model of trade, in which we allow for the presence of labour market frictions and heterogeneous firms, to analyse the effects of Brexit on UK productivity. We find that, under the Trade and Cooperation Agreement, UK GDP would have been expected to fall by approximately 7.5% in 2021, that is, as soon as the United Kingdom exited the European Union. Our model suggests that UK GDP would then recover, rising back to a long-run level around 4% below where it would have been had Brexit not happened. This fall in GDP is driven by the negative productivity effects of the implied increase in the costs of trading between the United Kingdom and European Union. Specifically, the increase in trading costs will lead to fewer, higher-productivity, UK firms exporting and reduced competition from EU firms in the UK domestic market allows more 'low productivity' firms to remain in the market.

Keywords: Brexit; International trade; heterogeneous firms; productivity

JEL classification: E24; F17; O40

1. Introduction

On 23 June 2016, the UK population voted to leave the European Union in a referendum, an event now known as 'Brexit'. However, it then took a few years of negotiations before the final details of how the separation would occur and what the ensuing trading arrangements would be were finally decided. Indeed, the 'Trade and Cooperation Agreement' (TCA) between the European Union and the United Kingdom was only finally signed in December 2020 and passed into law in the United Kingdom in May 2021. With this agreement, the United Kingdom left both the EU Single Market and the Customs Union. However, this agreement still means that the import and export of goods is tariff and quota free, though goods are now subject to customs checks, while services are now subject to a number of 'non-tariff barriers' such as, for example, rules of origin requirements and regulatory barriers such as the loss of passporting in financial services.

In this article, we analyse the effects of Brexit on UK productivity, and the channels through which these effects operate, by comparing the expected paths of a number of macroeconomic variables under the TCA with a counterfactual in which the United Kingdom remained part of the EU Single Market and Customs Union. We do this using a three-country macroeconomic model of trade based on Ghironi and Melitz (2005), in which we allow for the presence of labour market frictions as modelled by Cacciatore (2014), and heterogeneous firm dynamics in the manner of Hopenhayn (1992a and 1992b).

There is now a voluminous literature attempting to predict and examine the effects of Brexit on the UK economy. This literature has tended to concentrate on the effects of Brexit on trade, foreign direct investment (FDI), and hence GDP and mostly predates the signing of the TCA. Sampson (2017) provides an overview of this pre-TCA literature, outlining the potential possibilities for post-Brexit trading arrangements and discussing their potential impact on both the United Kingdom and European Union. Dhingra *et al.* (2018) find that leaving the EU Single Market leads to higher prices and less variety in the consumption baskets of UK households. Gretton and Vines (2018) used a global macroeconometric model to examine the impact of lower FDI into the United Kingdom as firms can no longer use the United Kingdom as a base for exporting into the European Union.

Ahn *et al.* (2019) make the point that the increased costs of trade and the fall in FDI have stifled competition and reduced opportunities for firms to exploit economies of scale, leading to lower efficiency, limited access to foreign technology and reduced opportunities for innovation. All this implies a fall in the average productivity of UK firms and, so, a fall in UK living standards (Dhingra *et al.*, 2018). Latorre *et al.* (2020) estimated that Brexit lowers the average productivity of UK firms by 2.3% in most manufacturing sectors as less productive firms enter the market due to reduced competition and increased protectionism and a recent survey, Office for Budget Responsibility (2020), showed that the average of the central estimates of the potential productivity impact of Brexit is around 4%. In our paper, we explicitly model the lower competition and reduced economies of scale channels, providing a quantitative analysis of how Brexit has reduced productivity via these channels.

Ebell and Warren (2016) and Hantzsche *et al.* (2018) using the National Institute's Global Econometric Model (NiGEM) to examine the long-run effects of Brexit. In each case, they assumed that Brexit would affect the EU economy through trade, FDIs, productivity and fiscal channels. They find long-run falls in UK GDP of between 3% and 4%. However, given the limitations of NiGEM, they needed to assume the size of the effects on trade, FDI and productivity, whereas in our paper, these are all endogenously determined within the model, given an assumption about the size of trade costs in each scenario.

Bloom *et al.* (2019) used the Bank of England's Decision Maker Panel survey to assess the effects of Brexit uncertainty on investment and productivity. They found that uncertainty led to a gradual decline in investment of 11% in the 3 years following the referendum and a reduction in productivity of UK firms by between 2% and 5% over the same period. Anayi *et al.* (2021) updated these results finding that the effect on firm-level investment had risen to 23% by 2021 but that with the advent of the TCA, uncertainty then fell dramatically, which should help investment to recover moving forward.

Subsequent to the implementation of the TCA, papers have sought to quantify the changes in trade that have resulted from the new barriers to trade, using a variety of methods. Du *et al.* (2023), use a synthetic difference in difference approach to predict a 22.1% fall in exports and 9.5% fall in imports for UK trade with the European Union. In contrast, Freeman *et al.* (2022) use UK–EU and UK-RoW trade ratios and predict a 25% fall in imports but no significant impact on total export volumes. Finally, Kren and Lawless (2024) compare UK–EU, UK-RoW and EU-RoW trade to isolate the impact of Brexit and predict a 16% fall in UK exports to the European Union, and a 24% fall in UK imports from the European Union resulting from the TCA. However, all these studies have focussed on the impact of TCA implementation on trade volumes, without then examining how these changes are likely to have impacted on the economy more widely, which we seek to address.

Overall, as suggested by the Office for Budget Responsibility (2020), there is a consensus that Brexit has resulted in a long run hit to UK productivity as a result of trade becoming more costly. This is supported by the findings of Broadbent *et al.* (2024), who show that the Brexit shock is propagating in the same manner as a news shock to long term productivity growth in the tradeable sector. Although the exact estimates vary depending on estimation techniques and assumptions, the average effect has been estimated at around 4%. In our work, we find that we would expect to have seen a sharp fall in UK labour productivity of approximately 9% as soon as the United Kingdom exited the European Union. After that point, we would see productivity recover to a long-run level around four and a half per cent lower than it would have been absent Brexit.

The rest of the paper is structured as follows. In the following section, we present the model, concentrating on the main building blocks and mechanisms at play rather than presenting all the equations. We then briefly discuss the calibration of the model before going on to generate and discuss our results. A final section concludes.

2. Model

Our basic framework builds on the model of Ghironi and Melitz (2005), where we also allow for the presence of labour market frictions as in Cacciatore (2014) and heterogeneous firm dynamics in the manner of Hopenhayn (1992a and 1992b). We develop a three-country (h, i and j) model with endogenous average firm-level productivity.

2.1. Households

Households are homogeneous and demand goods from both domestic and foreign producers. The representative household in country h supplies $L_{h,t}$ units of labour, to only the firms in country h, at a nominal wage rate $W_{h,t}$; the real wage rate is denoted by $w_{h,t}$. The representative household maximises their expected intertemporal utility from consumption subject to their budget constraint:

$$\text{Maximise} \sum_{t=0}^{\infty} \beta^t \left(\frac{c_{h,t}^{1-\gamma} - 1}{1-\gamma} - \upsilon L_{h,t} \right)$$

Subject to

$$B_{h,t} + \tilde{v}_{h,t} N_{h,H,t} x_{h,t} = (1 + r_{h,t-1}) B_{h,t-1} + \left(\tilde{d}_{h,t} + \tilde{v}_{h,t} \right) N_{h,D,t} x_{h,t-1} + w_{h,t} L_{h,t} + u_b (L_{F,h} - L_{h,t}) - c_{h,t} - T_{h,t} \tag{1}$$

where β is the subjective household discount factor, γ is the inverse of the intertemporal elasticity of substitution and c is the consumption basket, defined over a continuum of goods Ω in every period. $c_{h,t} = \left(\int_{\omega \in \Omega} c_{h,t}(\omega)^{\frac{\theta-1}{\theta}} d\omega \right)^{\frac{\theta}{\theta-1}}$, where $\theta > 1$ is the elasticity of substitution across goods. Total labour force in the economy is denoted by $L_{F,h}$. The real wage is denoted by $w_{h,t}$ and u_b denotes the unemployment benefits, paid for out of a lump-sum tax, $T_{h,t}$. $B_{h,t}$ denotes the consumers end-of-period holdings of bonds, which pay a risk free rate of interest, $r_{h,t}$. We assume that the government runs a balanced budget in every period and so $B_{h,t} = 0 \forall t$. $x_{h,t}$ represents the consumers end-of-period holdings of shares in a mutual fund of domestic firms; $\tilde{v}_{h,t}$ and $\tilde{d}_{h,t}$ are the average value and per-period profits of firms, respectively; $N_{h,D,t}$ is the number of firms at the start of a period and $N_{h,H,t}$ is the number of firms at the end of the period. After the end of every period, an exogenously given proportion of firms δ dies out, thus the number of firms at the start of a period, $N_{h,D,t}$, will be equal to the number of firms operating in the market at the end of the previous period, $N_{h,H,t-1}$, adjusted to reflect the proportion of firms that die out: $N_{h,D,t} = (1-\delta) N_{h,H,t-1}$. The derivations of $\tilde{v}_{h,t}$, $\tilde{d}_{h,t}$, $N_{h,D,t}$ and $N_{h,H,t}$ will be presented in the following section. Additionally, we impose financial autarky: households accumulate risk free domestic bonds and shares in only the firms in their domestic economy.

In each period, only a subset of goods, $\Omega_t \in \Omega$, will be available. Let $p_{h,t}$ (h) denote the country h currency nominal price of a good $\omega \in \Omega_t$. The consumption-based price index in country h is $P_{h,t} = \left(\int_{\omega \in \Omega_t} P_{h,t}(\omega)^{1-\theta} d\omega \right)^{\frac{1}{1-\theta}}$ and the household demand, for each individual good ω, is given by $c_{h,t}(\omega) = \left(\frac{p_{h,t}(\omega)}{P_{h,t}} \right)^{-\theta} c_{h,t}$. The representative households in countries i and j solve a similar problem.

2.2. Firms

There is a continuum of firms in each of the three countries, h, i and j, each producing a different variety of good $\omega \in \Omega$. Firm ω employs $l_t(\omega)$ units of labour to produce output at time t. Their marginal cost in nominal terms will depend on: first, the country specific aggregate technology level Z_t, which evolves according to an AR(1) process with persistence ρ, common to all firms within a country; second, the firm-level productivity z and third, an idiosyncratic job-specific productivity, $a_{z,t}$, for each relationship between a worker and a firm. The firm-level productivity of each firm is drawn by the firm from a distribution $G(z)$ with support on $[z_{\min}, \infty)$, upon market entry. The idiosyncratic job-specific productivity is drawn each period from a distribution with cumulative distribution function $H(a)$ with support (0,1), as in Cacciatore (2014), and the realisation of the job-specific productivity shock does not vary with the firm level productivity, z. Assuming that this job-specific productivity is drawn every period in our model ensures that the Cacciatore (2014) proposition that average match productivity is a fixed proportion of the cut-off productivity for the match holds in the presence of labour market frictions.

To enter the market, and draw a firm-level productivity, the firm must, as in Hopenhayn (1992b) and Melitz (2003), pay a sunk entry cost, f_E, expressed in terms of effective labour units.[1] In the manner of Hopenhayn (1992a) and Melitz (2003) firms also have to pay a per-period fixed cost of production, $f_{h,D}$, as well as per-period costs of entering foreign markets i and j, $f_{h,Xi}$ and $f_{h,Xj}$, respectively, all measured in terms of the consumption good. In addition, exporting firms have to pay a per-unit iceberg cost such that a firm needs to export τ units of their good in order to sell one unit in the destination market. Finally, we assume that all three markets are monopolistically competitive. The firms' problem is to maximise profits subject to their production functions and the three consumer demand curves.

Given that each firm produces a single variety of good, ω, and that the firms' optimal behaviour is determined by their firm-level productivity level z, we move from indexing by ω to indexing by z, such that $c_t(\omega) \equiv c_t(z)$ and $p_t(\omega) \equiv p(z)$ for a firm with a given productivity z. Thus, the total output of a firm with productivity level z is given by:

$$y_{h,t}(z) = zZ_{h,t}\tilde{a}_{h,z,t}l_{h,t}(z) \tag{2}$$

where $\tilde{a}_{h,z,t} \equiv (1 - H(a_{c,h,z,t}))^{-1} \int_{a_{c,h,z,t}}^{\infty} adH(a)$ and $a_{c,h,z,t}$ is an endogenously determined cut-off level of job specific productivity, below which the cost of retaining the job is greater than the cost of termination for the firm, given by the real cost of firing, F.

When employing labour, the process of job creation is subject to matching frictions, in the style of Pissarides (1985) and Pissarides (2001). To post a vacancy, a firm must incur a real cost k, expressed in units of the final consumption basket. The probability that the posted vacancy will result in a match for the firm depends on a constant-returns-to-scale matching function, which converts aggregate vacancies, $V_{h,t}$, and aggregate unemployed workers, $U_{h,t}$, into aggregate matches: $M_{h,t} = \chi U_{h,t}^{\varepsilon} V_{h,t}^{1-\varepsilon}$, with $0 < \varepsilon < 1$, and χ is the matching efficiency, $0 < \chi < 1$. Note that at the time of hiring and firing in period t, aggregate unemployment is equal to the number of workers unemployed at the end of the previous period, plus the number of workers employed by firms that endogenously exit the market, and a fraction of jobs λ_x, which are exogenously separated, at no cost to the firm. The probability of a vacancy posted by a firm resulting in a match is therefore given by $q_{h,t} = \frac{M_{h,t}}{V_{h,t}} = \chi\left(\frac{V_{h,t}}{U_{h,t}}\right)^{-\varepsilon}$, and the probability that an unemployed worker will meet a match is given by $\iota_{h,t} = \frac{M_{h,t}}{U_{h,t}} = \chi\left(\frac{V_{h,t}}{U_{h,t}}\right)^{1-\varepsilon}$. Therefore, for an individual firm, the number of new hires in a period will be equal to $q_{h,t}v_{h,z,t}$, where $v_{h,z,t}$ is the number of vacancies posted by a domestic firm with productivity z at time t.

The timing of hiring and firing for a particular firm is as follows: at the end of the period, each firm draws their idiosyncratic productivity z for the following period. At the beginning of the next period, the exogenous job separation shock hits and a fraction, λ_x, of the firms' workers are separated at no cost. All aggregate shocks then hit, after which the firm decides whether to remain in the market based on their

[1]Effective labour units are calculated as units of labour multiplied by the technology level Z_t.

firm level productivity. If the firm exits the market, all the labour employed by that firm is separated. Once these firms have exited the market, the remaining firms posts vacancies. Once the workers are hired, the idiosyncratic job specific productivity shock hits, and all workers that draw a productivity lower than $a_{c,h,z,t}$ are fired. After these workers have been fired, all remaining workers produce during the period. As in Cacciatore (2014), the law of motion for employment within firms with productivity z is therefore given by:

$$l_{h,t}(z) = (1-\lambda_{h,z,t})\big((1-\lambda_x)l_{h,t-1}(z) + q_{h,t}v_{h,t}(z)\big) \tag{3}$$

where $\lambda_{h,z,t} \equiv H(a_{c,h,z,t})$, is the endogenous separation rate.

A firm with firm-level productivity z in country h maximises the present discounted value of its current and future expected profit streams, $d_{h,t}$, bearing in mind the possibility of it drawing a level of productivity that would cause it to exit the market. Mathematically, it solves the following constrained maximisation problem:

$$\text{Maximise } E_t \sum_{s=t}^{\infty} \beta^{s-t} \left(\frac{c_{h,s}}{c_{h,t}}\right)^{-\gamma} (1-\delta)^{s-t} d_{h,t}(z) =$$

$$\begin{aligned} E_t \sum_{s=t}^{\infty} \beta^{s-t} \left(\frac{c_{h,s}}{c_{h,t}}\right)^{-\gamma} (1-\delta)^{s-t} \Big(& p_{h,D,s}(z) y_{h,D,s}(z) + p_{h,X_i,s}(z) y_{h,X_i,s}(z)\epsilon_i \\ & + p_{h,X_j,s}(z) y_{h,X_j,s}(z)\epsilon_j - \tilde{W}_{h,s} l_{h,s}(z) - f_{h,D} - f_{h,X_i} - f_{h,X_j} - \kappa v_{h,s}(z) \\ & - \lambda_{h,z,s} F\big((1-\lambda_x) l_{h,s-1}(z) + q_{h,s} v_{h,s}(z)\big)\Big) \end{aligned} \tag{4}$$

Subject to

$$y_{h,D,t}(z) + \tau_{h,i,t} y_{h,X_i,t}(z) + \tau_{h,j,t} y_{h,X_j,t}(z) = zZ_{h,t}\tilde{a}_{h,z,t}L_{h,t}(z) \tag{5}$$

$$l_{h,t}(z) = (1-\lambda_{h,z,t})\big((1-\lambda_x)l_{h,t-1}(z) + q_{h,t}v_{h,t}(z)\big) \tag{6}$$

$$y_{h,D,t}(z) = \left(\frac{p_{h,D,t}(z)}{P_{h,t}}\right)^{-\theta} c_{h,t} \tag{7}$$

$$y_{h,X_i,t}(z) = \left(\frac{p_{h,X_i,t}(z)}{P_{i,t}}\right)^{-\theta} c_{i,t} \tag{8}$$

$$y_{h,X_j,t}(z) = \left(\frac{p_{h,X_j,t}(z)}{P_{j,t}}\right)^{-\theta} c_{j,t} \tag{9}$$

where $\tau_{h,i,t}$ and $\tau_{h,j,t}$ are the iceberg costs of exporting from country h to countries i and j, respectively, at time t; for a firm with a given firm-level productivity level z in country h, $p_{h,D,t}(z)$, $p_{h,X_i,t}(z)$ and $p_{h,X_j,t}(z)$ are the prices of domestic goods, exports to country i and exports to country j, denominated in units of the currency of country h, i and j, respectively; $y_{h,D,t}(z)$, $y_{h,X_i,t}(z)$ and $y_{h,X_j,t}(z)$ are the total units of goods sold by the firm in the domestic market and countries i and j, respectively, we assume that supply matches demand: $y_{h,t}(z) = c_{h,t}(z)$; $L_{h,P,t}(z)$ is the amount of labour used in production; $c_{h,t}$, $c_{i,t}$ and $c_{j,t}$ are aggregate consumption in countries h, i and j, respectively; $P_{h,t}$, $P_{i,t}$ and $P_{j,t}$ are the consumption-based price indices of countries h, i and j, respectively; and, ϵ_i and ϵ_j are the nominal exchange rates (units of h currency per unit of i and j currency) between country h and countries i and j, respectively. Finally,

$\widetilde{W}_{h,t} \equiv (1 - H(a_{c,z,t}))^{-1} \int_{a_{c,z,t}}^{\infty} w_{h,z,t}(a) dH(a)$ is the average wage paid by firm z, weighted according to the distribution of job specific productivities. As in Cacciatore (2014), wages are not identical across workers, but they depend on the idiosyncratic job-specific productivity, $a_{z,t}$.

2.2.1. Job creation, job destruction and wage setting

Solving the firm's profit maximisation problem gives us, respectively, the job creation and job destruction conditions:

$$\frac{\kappa}{q_{h,t}} = \left(\varphi_{h,z,t} z Z_{h,t} \tilde{a}_{h,z,t} - \widetilde{w}_{h,z,t} + (1 - \lambda_x) E_t \beta \left(\frac{c_{h,t+1}}{c_{h,t}}\right)^{-\gamma} (1 - \delta) \frac{\kappa}{q_{h,t+1}}\right)(1 - \lambda_{h,z,t}) - F\lambda_{h,z,t} \tag{10}$$

$$\varphi_{h,z,t} z Z_{h,t} a_{c,h,z,t} - w_{h,z,t}(a_{c,h,z,t}) + (1 - \lambda_x) E_t \beta \left(\frac{c_{h,t+1}}{c_{h,t}}\right)^{-\gamma} (1 - \delta) \frac{\kappa}{q_{h,t+1}} = -F \tag{11}$$

where $\varphi_{h,z,t}$ is the Lagrange multiplier on the firm's production function, equation (5), and corresponds to the real marginal cost of the firm. At the optimum, the value to the firm of a job with productivity $a_{c,h,z,t}$ must be equal to zero, implying that the contribution of the match to current and expected future profits is exactly equal to the firm's outside option of firing the worker and paying F.

The wage paid by the firm, to a worker with job specific productivity a, is determined by the following sharing rule:

$$\eta S_{F,z,t}(a) = (1 - \eta) S_{W,z,t}(a) \tag{12}$$

where η is the Nash bargaining power of the worker, $S_{F,z,t}$ is the firm's surplus and $S_{W,z,t}$ is the worker's surplus.

The firm's surplus will be equal to the value of the job to the firm, $\Gamma_{z,t}$(a), plus a saving from not having to pay the firing cost, F. The value of the job to the firm is given by the marginal value product of the match, plus the expected future value of continuation, minus the wage bill:

$$\Gamma_{h,z,t}(a) \equiv \varphi_{h,z,t} z Z_{h,t} a - w_{h,z,t}(a) + (1 - \lambda_x) E_t \beta \left(\frac{c_{h,t+1}}{c_{h,t}}\right)^{-\gamma} (1 - \delta)\left((1 - \lambda_{h,z,t+1})\tilde{\Gamma}_{h,z,t+1} + \lambda_{h,z,t+1} F\right) \tag{13}$$

where $\tilde{\Gamma}_{h,z,t+1}$ is the Lagrange multiplier on the labour law of motion, equation (6), in the firm's maximisation problem.

The worker's surplus meanwhile is given by the current wage, minus the workers outside option, plus the expected future surplus from the match:

$$S_{W,h,z,t} \equiv w_{h,z,t}(a) - \varpi + (1 - \lambda_x) E_t \beta \left(\frac{c_{h,t+1}}{c_{h,t}}\right)^{-\gamma} (1 - \delta)(1 - \lambda_{h,z,t+1}) \tilde{S}_{W,h,z,t+1} \tag{14}$$

where $\tilde{S}_{W,h,z,t}$ is the average worker surplus at the firm with productivity z, $\varpi = \nu c_{h,t}^{\gamma} + u_m + (1 - \lambda_x) E_t \beta \left(\frac{c_{h,t+1}}{c_{h,t}}\right)^{-\gamma} (1 - \delta) \iota_{h,t+1} \tilde{S}_{W,h,t+1}$ and $\tilde{S}_{W,h,t}$ is the average worker surplus at all domestic firms.

Solving for the average wage, as in Cacciatore (2014), it can be shown that all firms set the same cut-off productivity level and pay the same wage, irrespective of their productivity z. It can also be shown that the difference between the wage paid to the average worker and the worker with cut-off productivity is given by $\tilde{w}_{h,z,t} - w_{h,z,t}(a_{c,h,z,t}) = \eta \varphi_{h,z,t} z Z_{h,t}(\tilde{a}_{h,z,t} - a_{c,h,z,t})$. Thus, the worker's outside option is given by:

$$\varpi = \nu c_{h,t}^{\gamma} + u_m + \frac{\eta}{1-\eta}(1-\lambda_x)E_t\beta\left(\frac{c_{h,t+1}}{c_{h,t}}\right)^{-\gamma}(1-\delta)(\kappa\zeta_{h,t+1} + \iota_{h,t+1}F) \tag{15}$$

where $\zeta_{h,t} = \frac{\iota_{h,t}}{q_{h,t}}$ represents the tightness of the labour market. From the expression for the worker's outside option, the final expression for the average wage is obtained:

$$\begin{aligned}\tilde{w}_{h,z,t} = \eta\Bigg(\varphi_{h,t}Z_{h,t}\tilde{a}_{h,z,t} + \kappa(1-\lambda_x)E_t\beta\left(\frac{c_{h,t+1}}{c_{h,t}}\right)^{-\gamma}(1-\delta)\zeta_{t+1} \\ + \left(1 - E_t\beta\left(\frac{c_{h,t+1}}{c_{h,t}}\right)^{-\gamma}(1-\delta)(1-\iota_{h,t+1})\right)F\Bigg) + (1-\eta)\left(\nu c_{h,t}^{\gamma} + u_m\right)\end{aligned} \tag{16}$$

where $\varphi_{h,t} = \frac{\varphi_{h,z,t}}{z_{h,t}}$ is an expression for the average marginal cost.

2.2.2. Firm profits

The firm's profit maximisation problem also implies that firms set their output price as a mark-up over the marginal cost, where the mark-up is given by $\theta/(\theta - 1)$. Given this, the real prices of the firm's goods in each market are as follows: the real price of domestic goods in country h is $\rho_{h,D,t}(z) = \frac{p_{h,D,t}(z)}{P_{h,t}} = \frac{\theta}{\theta-1}\varphi_{h,z,t}$, the real price of goods exported to country i from country h is $\rho_{h,X_i,t}(z) = \frac{p_{h,X_i,t}(z)}{P_{h,t}} = \frac{\tau_{h,i,t}}{Q_{i,t}}\rho_{h,D,t}(z)$, and the real price of goods exported to country j from country h is $\rho_{h,X_j,t}(z) = \frac{p_{h,X_j,t}(z)}{P_{h,t}} = \frac{\tau_{h,j,t}}{Q_{j,t}}\rho_{h,D,t}(z)$, where $Q_{i,t}$ is the real exchange rate between country h and country i, equal to $\epsilon_i\frac{P_{i,t}}{P_{h,t}}$, $Q_{j,t}$ is the real exchange rate between country h and country j, equal to $\epsilon_j\frac{P_{j,t}}{P_{h,t}}$ and $w_{h,t} = \frac{W_{h,t}}{P_{h,t}}$ is the real wage. Equivalent price equations hold for countries i and j.

Total firm profits are given by the sum of profit from domestic sales, $d_{h,D,t}$, and potential profit from exporting, $d_{h,Xi,t}$ and $d_{h,Xj,t}$, to countries i and j, respectively. Given the fixed costs of domestic production and exporting, there will be some firms that do not draw high enough firm-level productivity to make a profit (or break even) in the domestic market, who then exit the market entirely, and some firms that do not export to one or the other of the two foreign markets. Therefore, there are cut-off productivity levels below which a firm will not produce for either the domestic market, $z_{h,D,t} = inf\{z : d_{h,D,t} \geq 0\}$ or for each of the foreign markets, $z_{h,X_i,t} = inf\{z : d_{h,X_i,t} \geq 0\}$ and $z_{h,X_j,t} = inf\{z : d_{h,X_j,t} \geq 0\}$ for exports to countries i and j, respectively.

We assume that the lower bound of the productivity distribution $z_{\min}$ is low enough compared to the domestic cut-off level $z_{h,D,t}$, such that this is above $z_{\min}$. We further assume that the domestic cut-off level, $z_{h,D,t}$, is low enough relative to the export cut-off levels $z_{h,X_i,t}$ and $z_{h,X_j,t}$ such that both $z_{h,X_i,t}$ and $z_{h,X_j,t}$are above $z_{h,D,t}$. These assumptions ensure that: (1) there will be an endogenously determined subset of firms that pay the sunk entry cost f_E, but do not produce for the domestic market and (2) there will be an endogenously determined non-traded sector—the firms with productivities between $z_{h,D,t}$ and the lower of $z_{h,X_i,t}$ and $z_{h,X_j,t}$. The subset of firms that pay the sunk entry cost, but do not draw a productivity above the cut-off level for domestic production immediately exit the market. Therefore, if they want to enter the market again and try to draw a productivity above the cut-off level they must pay the sunk entry cost again. Firm profits are therefore:

$$d_{h,t}(z) = d_{h,D,t}(z) + d_{h,X_i,t}(z) + d_{h,X_j,t}(z) \tag{17}$$

$$d_{h,D,t}(z) = \begin{cases} \frac{1}{\theta}(\rho_{h.D.t}(z))^{1-\theta}c_t - f_{h,D} \, if \, z \geq z_{h,D,t} \\ 0 \, otherwise \end{cases} \tag{18}$$

$$d_{h,X_i,t}(z) = \begin{cases} \frac{Q_{i,t}}{\theta}\left(\rho_{h.X_i.t}(z)\right)^{1-\theta} c_{i,t} - f_{h,X_i} \; if \; z \geq z_{h,,X_i,t} \\ 0 \; otherwise \end{cases} \tag{19}$$

$$d_{h,X_j,t}(z) = \begin{cases} \frac{Q_{j,t}}{\theta}\left(\rho_{h.X_j.t}(z)\right)^{1-\theta} c_{j,t} - f_{h,X_j} \; if \; z \geq z_{h,,X_j,t} \\ 0 \; otherwise \end{cases} \tag{20}$$

Equivalent firm profit equations hold for countries *i* and *j*.

2.2.3. Firm averages

In every period there is a number of firms, $N_{h,D,t}$, that produce for the domestic market, given the cut-off level of domestic production, $z_{h,D,t}$. A number of these firms, given by $N_{h,Xi,t}$ and $N_{h,Xj,t}$, export to countries *i* and *j*, respectively. In a similar manner to Melitz (2003), we define 'average' productivity for all domestic firms, $\tilde{z}_{h,D}$, and for firms that export to countries *i* and *j*, $\tilde{z}_{h,X_i}$ and $\tilde{z}_{h,X_j}$, as:

$$\tilde{z}_{h,D,t} = \left(\frac{1}{1-G(z_{h,D,t})}\int_{z_{h,D,i,t}}^{\infty} z^{\theta-1} dG(z)\right)^{\frac{1}{\theta-1}} \tag{21}$$

$$\tilde{z}_{h,X_i,t} = \left(\frac{1}{1-G(z_{h,X_i,t})}\int_{z_{h,X_i,t}}^{\infty} z^{\theta-1} dG(z)\right)^{\frac{1}{\theta-1}} \tag{22}$$

$$\tilde{z}_{h,X_j,t} = \left(\frac{1}{1-G(z_{h,X_j,t})}\int_{z_{h,X_j,t}}^{\infty} z^{\theta-1} dG(z)\right)^{\frac{1}{\theta-1}} \tag{23}$$

Melitz (2003) shows that these productivity averages contain all the information on the productivity distributions relevant for macroeconomic variables. Thus, our model is isomorphic to a model where $N_{h,D,t}$ firms with productivity $\tilde{z}_{h,D,t}$ produce for the domestic market, and $N_{h,Xi,t}$ and $N_{h,Xj,t}$ firms with productivities $\tilde{z}_{h,X_i,t}$ and $\tilde{z}_{h,X_j,t}$ produce for each of the two export markets. The average price in the domestic market, will be equal to the price of the firm with average productivity, $\tilde{p}_{h,D,t} = p_{h,D,t}(\tilde{z}_{h,D,t})$, and the average price in each of the exporting markets will be equal to the price of the exporting firms with average productivities $\tilde{p}_{h,X_i,t} = p_{h,X_i,t}(\tilde{z}_{h,X_i,t})$ and $\tilde{p}_{h,X_j,t} = p_{h,X_j,t}(\tilde{z}_{h,X_j,t})$. The nominal price index in country *h* reflects the nominal price of both domestic firms and imports from foreign firms. The nominal price index can therefore be written as:

$$P_{h,t} = \left(N_{h,D,t}\tilde{p}_{h,D,t}^{1-\theta} + N_{i,X_h,t}\tilde{p}_{i,X_h,t}^{1-\theta} + N_{j,X_h,t}\tilde{p}_{j,X_h,t}^{1-\theta}\right)^{\frac{1}{1-\theta}} \tag{24}$$

Dividing both sides by $P_{h,t}^{1-\theta}$ we obtain the following real price index:

$$N_{h,D,t}\tilde{p}_{h,D,t}^{1-\theta} + N_{i,X_h,t}\tilde{p}_{i,X_h,t}^{1-\theta} + N_{j,X_h,t}\tilde{p}_{j,X_h,t}^{1-\theta} = 1 \tag{25}$$

Equivalent price index equations hold for countries *i* and *j*.

Average total profits are given by the sum of average profits from domestic sales and average profits from exporting, adjusted to the proportion of firms that export to each market, less total vacancy posting cost and the cost of firing:

$$\tilde{d}_{h,t} = \tilde{d}_{h,D,t} + (1-G(z_{h,X_i,t}))\tilde{d}_{h,X_i,t} + \left(1-G\left(z_{h,X_j,t}\right)\right)\tilde{d}_{h,X_j,t} - \kappa v_t - \frac{\tilde{\lambda}_{h,t}}{1-\tilde{\lambda}_{h,t}} l_{h,t} F \tag{26}$$

This equation can then be written explicitly with the ratios of exporting firms to total domestic firms:

$$\tilde{d}_{h,t} = \tilde{d}_{h,D,t} + \frac{N_{h,X_i,t}}{N_{h,D,t}}\tilde{d}_{h,X_i,t} + \frac{N_{h,X_j,t}}{N_{h,D,t}}\tilde{d}_{h,X_j,t} - \kappa v_t - \frac{\tilde{\lambda}_{h,t}}{1-\tilde{\lambda}_{h,t}} l_{h,t} F \tag{27}$$

Equivalent average total profit equations hold for each of the two foreign countries, *i* and *j*.

2.2.4. Firm value

All producing firms, other than the firm with productivity equal to the cut-off level ($z = z_{h,D,t}$), make positive profits. Thus, the average profit level in country h will be positive ($\tilde{d}_{h,t} > 0$), and the average firm will have a positive value, derived from expected future profits. After the end of a period, an exogenously determined proportion δ of firms in each country will cease to operate. Given that these firms cease to operate after new entrants have entered the market, a proportion δ of the successful new entrants will never operate. Since households own the firms, we can solve the household's problem to calculate the average value of firms in the economy, $\tilde{v}_{h,t}$. Given that the firms are owned entirely by domestic households the value of a firm on entry will be given by the limit of the household share Euler equation: If we assume that there are no bubbles in the economy then $\lim_{j\to\infty}\tilde{\beta}\tilde{v}_{t+j} = 0$, where $\tilde{\beta} = (\beta(1-\delta))^j E_t\left(\frac{c_{h,t+s}}{c_{h,t}}\right)^{-\gamma}$, then the value of a firm will be equal to the discounted present value of its expected profit stream:

$$\tilde{v}_{h,t} = E_t \sum_{s=t+1}^{\infty} (\beta(1-\delta))^{s-1}\left(\frac{c_{h,t+s}}{c_{h,t}}\right)^{-\gamma} \tilde{d}_{h,s} \tag{28}$$

Thus, as long as $\tilde{d}_{h,t}$ is positive, the average firm value in country *h* will also be positive ($\tilde{v}_{h,t} > 0$).

2.2.5. Firm entry and exit

In each period, $N_{h,U,E,t}$ new firms will pay the sunk entry cost to commence production, and then find out their firm-level productivity, *z*. Upon drawing their productivity, some firms will have a productivity less than the expected cut-off level for domestic production in the following period, $E(z_{h,D,t+1})$, thus a proportion of firms that pay the entry cost will not produce, $G(E(z_{h,D,t+1}))$, and will instead exit the market immediately. Firms will choose to enter the market until the average firm value, adjusted by the probability of entering, is equal to the initial entry cost, $f_{h,E}$, expressed in consumption units, which leads to the free entry condition:

$$\tilde{v}_{h,t}(1 - G(E(z_{h,D,t+1}))) = f_{h,E} \tag{29}$$

which, rearranged, is:

$$\tilde{v}_{h,t} = \frac{1}{1 - G(E(z_{h,D,t+1}))} f_{h,E} \tag{30}$$

The number of firms operating at the end of the period, $N_{h,H,t}$, will be equal to the number of firms operating at the start of the period, $N_{h,D,t}$, plus the number of successful new entrants $N_{h,E,t}$. The number of successful new entrants will be equal to the number of firms that pay the entry cost, $N_{h,U,E,t}$, adjusted by the probability of entering the market: $N_{h,E,t} = (1 - G(E(z_{h,D,t+1})))N_{h,U,E,t}$. The number of firms at the end of the period will therefore be given by $N_{h,H,t} = N_{h,D,t} + N_{h,E,t} = N_{h,D,t} + (1 - G(E(z_{h,D,t+1})))N_{h,U,E,t}$.

Given the timing of firm entry and exit we have assumed, the number of firms operating during a period will be given by:

$$N_{h,D,t} = (1-\delta)N_{h,H,t-1} = (1-\delta)(N_{h,D,t-1} + N_{h,E,t-1}) \tag{31}$$

Note that, because the total number of firms can only change endogenously at the end of the period, the average productivity of domestic production during a period, $\tilde{z}_{h,D,t}$, will be predetermined during a period, and will only change in between periods, as a result of the entry and exit of less productive non-trading firms from the domestic market.

2.3. Parameterising productivity

In order to solve the model, we assume that the firm-level productivities, z, follow a Pareto distribution with lower bound $z_{\min}$ and shape parameter k. We assume that $k > \theta - 1$ to ensure that the average of firm size is finite.[2] Thus, we have $G(z) = 1 - (z_{\min}/z)k$.

Average firm-level productivities are then $\tilde{z}_{h,D,t} = \upsilon z_{h,D,t}$, $\tilde{z}_{h,X_i,t} = \upsilon z_{h,X_i,t}$ and $\tilde{z}_{h,X_j,t} = \upsilon z_{h,X_j,t}$, where $\upsilon = \left(\frac{k}{k-(\theta-1)}\right)^{\frac{1}{\theta-1}}$.

The proportion of country h firms that export to each market is given by:

$$\frac{N_{h,X_i,t}}{N_{h,D,t}} = \frac{1-G(z_{h,X_i,t})}{1-G(z_{h,D,t})} \tag{32}$$

$$\frac{N_{h,X_j,t}}{N_{h,D,t}} = \frac{1-G(z_{h,X_j,t})}{1-G(z_{h,D,t})} \tag{33}$$

Using $G(z)$ and average firm-level productivities, these can then be rewritten as:

$$\frac{N_{h,X_i,t}}{N_{h,D,t}} = \frac{\left(\frac{z_{h,min}}{z_{h,X_i,t}}\right)^k}{\left(\frac{z_{h,min}}{z_{h,D,t}}\right)^k} = \tilde{z}^k_{h,D,t}\tilde{z}^{-k}_{h,X_i,t} \tag{34}$$

$$\frac{N_{h,X_j,t}}{N_{h,D,t}} = \frac{\left(\frac{z_{h,min}}{z_{h,X_j,t}}\right)^k}{\left(\frac{z_{h,min}}{z_{h,D,t}}\right)^k} = \tilde{z}^k_{h,D,t}\tilde{z}^{-k}_{h,X_j,t} \tag{35}$$

Equivalent equations for the proportion of firms that export hold for countries i and j.

Given the parameterisation of $G(z_{h,D,t})$, we rewrite the free entry condition, equation (30), as:

$$\tilde{v}_{h,t} = \frac{1}{1-G(E(z_{h,D,t+1}))} f_{h,E} = \left(\frac{E(z_{h,D,t+1})}{z_{h,min}}\right)^k f_{h,E} \tag{36}$$

Equivalent free entry conditions hold for countries i and j.

The country h zero domestic profit cut-off condition $d_{h,D,t}(z_{h,D,t}) = 0$, zero export profit cut-off conditions $d_{h,X_i,t}(z_{h,X_i,t}) = 0$ and $d_{h,X_j,t}(z_{h,X_j,t}) = 0$, and equations (18)–(20) for firm profits, imply that country h average domestic profits and average export profits to each market will satisfy:

[2] According to Axtell (2001), $\theta/(\theta - 1)$ is around 1.06 in the United States.

$$\tilde{d}_{h,D,t} = (\theta - 1)\frac{v^{\theta-1}}{k} f_{h,D} \tag{37}$$

$$\tilde{d}_{h,X_i,t} = (\theta - 1)\frac{v^{\theta-1}}{k} f_{h,X_i} \tag{38}$$

$$\tilde{d}_{h,X_j,t} = (\theta - 1)\frac{v^{\theta-1}}{k} f_{h,X_j} \tag{39}$$

Equivalent zero-profit conditions will hold for countries *i* and *j*.

2.4. Market clearing

Total productive employment will be given by $L_{h,t} = N_{h,D,t}\tilde{l}_{h,t}$ and the total number of posted vacancies will be $V_{h.t} = N_{h,D,t}\tilde{v}_{h,t} + N_{h,E,t}\frac{\tilde{l}_{h,t}}{q_{h,t}}$. Total pre-hiring unemployment is given by:

$$U_{h,t} = L_{F,h} - (1 - \lambda_x)\left(\frac{z_{min}}{z_{h,D,t}}\right)^k \tilde{l}_{h,t-1}(N_{h,D,t-1} + N_{h,E,t-1}) \tag{40}$$

Aggregating the firm's production function, equation (2), across all producing and exporting firms the aggregate production function is obtained:

$$Z_{h,t}\tilde{a}_{h,t}L_{h,t} = \tilde{\rho}_{h,D,t}^{-\theta}\frac{y_{h,C,t}}{\tilde{z}_{h,D,t}}N_{h,D,t} + \tau_{h,i,t}\tilde{\rho}_{h,X_i,t}^{-\theta}\frac{y_{i,C,t}}{\tilde{z}_{h,X_i,t}}N_{h,X_i,t} + \tau_{h,j,t}\tilde{\rho}_{h,X_j,t}^{-\theta}\frac{y_{j,C,t}}{\tilde{z}_{h,X_j,t}}N_{h,X_j,t} \tag{41}$$

where aggregate demand in country *h*, $y_{h,C,t}$, will be given by $y_{h,C,t} = c_{h,t} + N_{h,E,t}f_{h,e} + N_{h,D,t}f_{h,D} + N_{h,X_i,t}f_{h,X_i} + N_{h,X_j,t}f_{h,X_j} + \kappa V_{h.t} + \frac{\tilde{\lambda}_{h,t}}{1-\tilde{\lambda}_{h,t}}L_{h,t}F$. Given that we have assumed no government borrowing, no physical capital and financial autarky, aggregate bond holdings must equal zero at the end of the period, and the aggregate number of shares per company must equal unity. The assumption of financial autarky (value of exports = value of imports) for all countries, also yields the balanced trade equation:

$$Q_{i,t}N_{h,X_i,t}\tilde{\rho}_{h,X_i,t}^{1-\theta}c_{i,t} + Q_{j,t}N_{h,X_j,t}\tilde{\rho}_{h,X_j,t}^{1-\theta}c_{j,t} = N_{i,X_h,t}\tilde{\rho}_{i,X_h,t}^{1-\theta}c_{h,t} + N_{j,X_h,t}\tilde{\rho}_{j,X_h,t}^{1-\theta}c_{h,t} \tag{42}$$

Equivalent conditions for employment, unemployment, vacancies, output and balanced trade will hold for countries *i* and *j*.

3. Calibration

Unlike Ghironi and Melitz (2005), which assume complete symmetry between countries, we allow for asymmetries in country size and barriers to trade and calibrate our model accordingly. Given our model is quarterly, we set the discount factor, β, to 0.99, and the risk aversion parameter, γ, to 2, standard values in quarterly business cycle models. The firm exit rate, δ, is set to 0.0235 to match the 9.4% UK annual firm death rate.[3] Following Bernard *et al.* (2003), θ is set to 3.8[4] and *k* is set to 3.4, satisfying the condition that $k > \theta - 1$.

[3]Firm death rate is obtained from the ONS Business Demography Statistics.

[4]We note that, although the value of θ may appear low (standard macro literature sets $\theta = 6$ to deliver a mark-up over marginal cost of 1.2), the mark-up in this article represents mark-up over average cost, including the entry cost. We have conducted sensitivity analyses on the value of θ and find that values from 1.9 to 4.5 give similar responses to model simulations.

The three countries in the model are the United Kingdom, country h, the European Union, country i and the rest of the world (RoW), country j, where the RoW is defined as all countries in the world that are not members of the European Union except for the United Kingdom. The per unit iceberg costs τ were calculated using data from the World Bank Trade Costs database, and the ONS Pink Book. The World Bank Trade Costs database provides the tariff equivalent rate, x, for trade between pairs of countries, which allows the calculation of the average tariff equivalent rate for 2005–2015 for each country pair. These tariff equivalent rates were then mapped into an iceberg cost for each country pair according to Iceberg Cost = $x/(1 + x)$.

The iceberg costs were calculated individually for UK imports from the European Union, UK imports from the RoW, UK exports to the European Union and UK exports to the RoW as a weighted average of total exports/imports from each country with the total exports and imports from each country obtained from the ONS Pink Book. For example, the iceberg cost for UK exports to the European Union was calculated as the sum of the iceberg cost for UK trade with each European country multiplied by the proportion of UK exports going to each European country. In the baseline—pre-Brexit case—we assumed that the iceberg costs of exporting and importing from the European Union to the RoW were the same as the iceberg costs of exporting and importing from the United Kingdom to the RoW. This seemed a reasonable assumption given that the United Kingdom and the European Union are part of a customs union and share similar geographic characteristics. We calculated the iceberg costs as follows: $_{hi} = 1.316$, $_{hj} = 1.450$, $_{ih} = 1.326$, $_{ij} = 1.450$, $_{jh} = 1.459$ and $_{ji} = 1.459$.[5]

The fixed costs of exporting from the United Kingdom to the European Union and United Kingdom to the RoW are calibrated such that the proportion of UK firms that export to the European Union, and to the RoW match the proportions reported by the ONS Annual Business Survey of Importers and Exporters (approximately 7% and 8%, respectively). The remaining fixed exporting costs are then set in the same proportions as the iceberg costs. As in de Soyres (2016), we normalised the fixed cost of domestic production in the United Kingdom so that no domestic entry threshold lies below the lower bound of the productivity distribution, and set the fixed costs to be identical in all three countries.

We normalise $z_{\min}$ and Z to unity for all three countries as well as normalising the labour force in the United Kingdom to unity.[6] The labour forces in the European Union and the RoW were set such that, in the calibrated model, UK GDP is equal to 1/6 of EU GDP and 1/20 of RoW GDP, in line with 2017 World Bank data. The sunk entry costs are set to 5.2 months of per capita output, as in Cacciatore (2014). The unemployment elasticity of the matching function, ε, is set to 0.4, consistent with Blanchard and Diamond (1990), the bargaining power parameter, η, is set to 0.4, as estimated in Flinn (2006). The unemployment benefit, u_{b}, is set such that the replacement rate, $\frac{u_b}{\tilde{w}}$, matches that reported by the OECD Benefits and Wages statistics for the United Kingdom, European Union and the World, 38%, 69% and 55%, respectively. As in Cacciatore (2014), the firing costs, F, are set to 0.15 times the average wage. The value of λ_{x} is set so that, as in Den Haan *et al.* (2000), exogenous separation accounts for 68% of within firm separations.

The remaining labour market parameters are calibrated as follows: the cost of posting a vacancy, k, the disutility from work, ν, and the matching efficiency, χ, are calibrated to jointly match the steady total job separation rate, the probability of filling a vacancy, and the unemployment rate. The probability of a vacancy posted by a firm resulting in a match, q, is set to 0.9, following Andolfatto (1996). The unemployment rates are set to 4.8%, 7.9% and 5.7% for the UK, EU and RoW, respectively. In addition, the endogenous worker–firm job separation rate set to 1.01% for all three countries. Finally, the job

[5] Although the iceberg costs appear high, particularly for UK–EU trade (given the absence of formal trade barriers) their values reflect not only the cost of formal barriers to trade, but also other costs of exporting, such as language barriers and transport costs.

[6] Changing the entry cost, f_{E}, and the fixed cost of domestic production, f_{D}, while maintaining the same ratios $f_{\mathrm{X}}/f_{\mathrm{E}}$ and $f_{\mathrm{D}}/f_{\mathrm{E}}$ does not have any effect on the firm-level productivity variables, z_{D} and z_{X}, as they are determined by the free entry condition and the zero-profit condition.

specific productivity shock distribution, is calibrated to replicate the volatility of employment relative to GDP, as in Den Haan *et al.* (2000).

4. Effects of Brexit

In the TCA, the United Kingdom has maintained more-or-less tariff-free trade in goods, although the costs of exporting goods to the European Union have increased given the customs checks now necessary since the United Kingdom and European Union no longer form a customs union. When it comes to services, a number of non-tariff barriers such as, for example, rules of origin requirements and regulatory barriers such as the loss of passporting in financial services, now apply. This is reflected in the shock we apply to our model to reflect Brexit. Specifically, we calibrate the shock to non-tariff barriers by setting the fixed costs for UK–EU trade to the equivalent of the fixed costs for UK-Non-EU trade. We then calibrate the variable (iceberg) costs to match the Du *et al.* (2023) estimates of a 22.9% fall in UK exports to the European Union, and a 13.1% fall in UK imports from the European Union resulting from the move to trading under the TCA. We assume that the new barriers to trade are known four quarters prior to their entry into force, reflecting the Brexit 'Transition Period' from January 2020 to January 2021, when the United Kingdom had left the EU, but still traded under their previous trading arrangements. Note that, the effects in our analysis are purely those emerging from changes in trade barriers. We do not interact these with any possible changes to labour markets, productivity and so forth that may have arisen from the COVID-19 pandemic which was occurring simultaneously with the change in trade barriers.

Chart 1 shows the path for UK GDP suggested by our model in response to leaving the European Union under the TCA relative to what would have happened had the United Kingdom remained within the European Union. Interestingly, our results suggest that when the final date of Brexit was announced, there was a slight boost to GDP as firms increased their exports while they still could. Then as the chart shows, under the TCA, UK GDP would have been expected to fall significantly as a result of Brexit. The model suggests a sharp fall of approximately 7.5% as soon as the United Kingdom exited the European Union. After that point, we could have expected GDP to recover somewhat. In the event, UK GDP fell by 10.4% in 2020 relative to 2019, and then grew by 8.7% in 2021 and 4.3% in 2022, but this resulted from the combined effects of COVID and Brexit. Using a model such as ours can help disentangle the effects of the two shocks and enable us to assess the effects of Brexit on its own.

Chart 1 also suggests that the fall in UK GDP is highly persistent with UK GDP remaining around 4–5% lower than it would have been had the country not left the European Union. This number is in line with the long-run impact of Brexit suggested by Hantzsche *et al.* (2018). The fall in UK GDP remains large for two reasons. First, UK manufacturing importers and exporters will continue to face higher

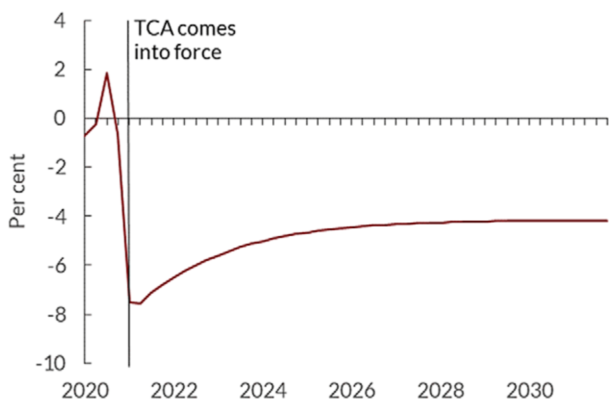

Chart 1. Effect of leaving the European Union under the TCA on UK GDP.

non-tariff barriers, such as customs checks. Second, the TCA does nothing to protect UK importers and exporters of services from and to the European Union, who are facing higher non-tariff barriers and will likely see significant decreases in their profits, which will have knock on effects on the wages and employment of workers within those firms.

Chart 2 shows that Brexit can explain the poor performance of labour productivity and real wages since the pandemic as our model suggests that, other things equal, Brexit would have resulted in large falls in both variables relative to trend. Again, our model suggests that productivity and real wages fell relative to trend immediately the Brexit agreement kicked in. Following the initial fall, we would expect to have seen a recovery, though the model suggests that productivity will remain around 4.5% lower in the long run than it would have been absent Brexit. This is slightly larger than found in the Office for Budget Responsibility (2020).

This poor productivity performance is explained by two main driving forces: decreasing labour demand from UK exporters and reduced competition from abroad on the UK domestic market. As shown in Chart 3, the number of firms in the United Kingdom exporting to the European Union drops dramatically in response to Brexit, while the number exporting to the RoW also falls. In turn, this leads to a fall in demand for labour from exporting firms and, so, to a rise in unemployment (Chart 4), which puts downward pressure on real wages. The fall in real wages will encourage new firms to enter the UK market, acting to somewhat reverse the fall (Chart 2). At the same time, reduced competition from abroad in the UK domestic market, following the increase in barriers to UK imports, allows less

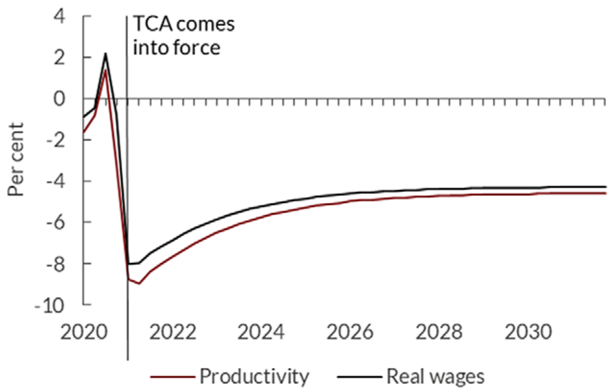

Chart 2. Effect of leaving the European Union under the TCA on UK productivity and real wages.

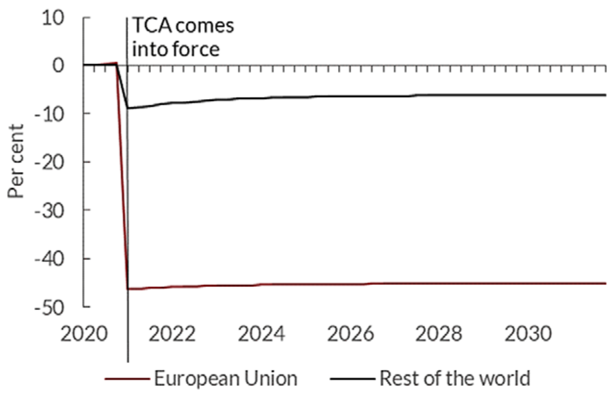

Chart 3. Effect of leaving the European Union under the TCA on the number of UK firms exporting to the European Union and the rest of the world.

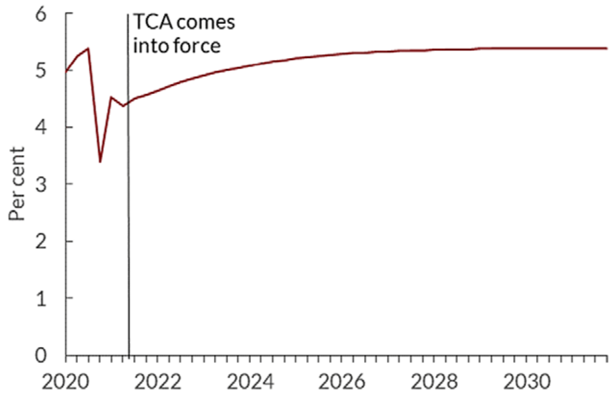

Chart 4. Effect of leaving the European Union under the TCA on the unemployment rate.

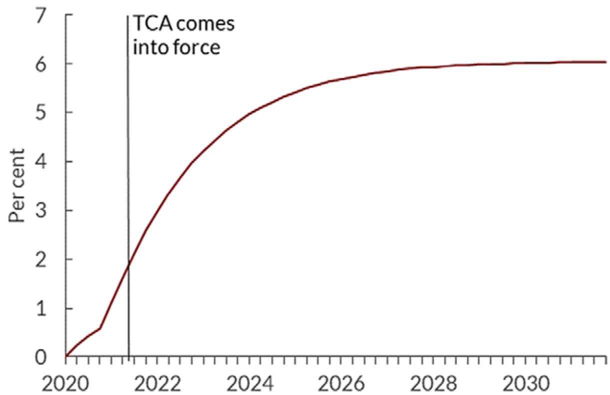

Chart 5. Effect of leaving the European Union under the TCA on the number of UK firms.

productive firms to compete in the UK market, driving down productivity and leading to an overall increase in the number of UK firms (Chart 5).

Perhaps, the most striking result in our analysis is that, according to our model, productivity and GDP fall immediately the United Kingdom leaves the European Union and then recover to their permanently lower level. In contrast, other papers, for example, Kaya *et al.* (2024), find that productivity and GDP drop initially and then continue to fall relative to trend. This may result, however, from how they imposed the Brexit shock in their work. In particular, given the structure of NiGEM, they had to proxy the productivity effects of Brexit by an exogenous technology shock, which they assumed built up over time. We impose only a shock to the costs of trading between the United Kingdom and the European Union. In addition, we assume that the increased trading costs affect UK and EU firms immediately. Other authors have tended to assume that the fall in trade between the United Kingdom and the European Union would build up over time as firms took time to adjust to the new rules and trading arrangement, honouring existing agreements before pulling out of foreign markets.

Finally, one effect that is missing from our analysis is the uncertainty that was generated between the Brexit referendum and the actual date on which the TCA came into force. Kaya *et al.* (2024) suggest that this uncertainty has led to a large decline in investment that, in turn, has driven part of the lower GDP resulting from Brexit. Although we consider this effect to have been important, we omit it from our analysis as recent evidence presented in Anayi *et al.* (2021) suggests the signing of the TCA led to a large reduction in uncertainty relative to the immediate post-referendum period. That said, this omission could explain why our model suggests a slightly smaller GDP impact (around 4%) than theirs (5–6%).

5. Conclusions

In this article, we have used a three-country macroeconomic model of trade, in which we allow for the presence of labour market frictions to analyse the effects of Brexit on UK productivity. We compared the expected paths of a number of macroeconomic variables under the TCA with a counterfactual in which the United Kingdom remained part of the EU Single Market and Customs Union. We found that UK GDP would have been expected to fall by approximately 7.5% as soon as the United Kingdom exited the European Union, before rising back to a long-run level around 4% below where it would have been had the United Kingdom stayed in the European Union. This fall in GDP was driven by the negative productivity effects of the increase in the costs of trading between the United Kingdom and European Union. In particular, we found that the increase in trading costs will lead to fewer UK firms exporting—implying lower productivity through a 'batting average' effect—and reduced competition from abroad on the UK domestic market allowing more 'low productivity' firms to remain in the market.

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