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Abstract

This paper examines the long-term macroeconomic impacts of Brexit on the UK economy employing a dynamic general equilibrium model that incorporates endogenous firm entry, price markups and market competition. By integrating the trade frictions introduced by Brexit, the model explains how increased trade costs have altered firm behaviour, market structure, and broader economic performance. We assess a range of policy responses, from theoretically optimal but practically difficult tax-subsidy schemes, to more realistic measures aimed at reducing firm entry barriers, encouraging private and public investment, and subsidising labour costs. Our findings underscore the critical role of policies that can most directly influence firm creation, investment, and competition in addressing the structural challenges Brexit has introduced.

Keywords: Brexit; Investment; Fiscal and Industrial Policy
JEL Codes: E65, E22, E61

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1 Introduction

This paper examines the long-term macroeconomic consequences of Brexit for the UK economy and explores policy options that could mitigate at least part of the resulting damage. Although the post-Brexit Trade and Cooperation Agreement preserved tariff-free trade with the EU, it introduced non-tariff barriers (NTBs) such as customs checks, rules of origin requirements, regulatory divergence, border delays, and restrictions on services, which have imposed lasting frictions on UK-EU trade.

Our analysis examines how these NTBs impact firm-level decisions and how those effects propagate throughout the broader macroeconomy. One of the central macroeconomic channels we study involves the adverse consequences of these higher trade costs on the number of active firms, price markups and market competition, which, unlike standard models, are endogenous in our model similarly to Ghironi and Melitz (2005), Bilbiie *et al.* (2008, 2012), and Etro and Colciago (2010). We demonstrate that these forces exacerbate the losses from Brexit by eroding competitive forces and productive capacity.[1]

Our framework offers two main contributions. First, it provides a more comprehensive picture of Brexit's economic impact, highlighting how changes in trade policy not only influence firm profitability but also reshape market structure and ultimately households' welfare. It is noteworthy that our model simulations indicate that the trade shocks stemming from Brexit, on their own, are sufficient to produce macroeconomic outcomes consistent with those observed in the data for the post-Brexit period.[2] Second, building on this dynamic general equilibrium (DGE) framework, our analysis aims to identify policies that most effectively promote firm creation, investment, and competition in response to the structural challenges introduced by Brexit.

We evaluate a range of policy responses, from those capable of fully offsetting the Brexit-related costs to others that can partially mitigate them. The former involves a set of theoretically optimal but practically difficult measures: per-unit subsidies to labour, imported intermediate inputs, and capital, plus a lump-sum subsidy to firms, all financed by a lump-sum tax on households. As a more realistic alternative, we therefore assess the effectiveness of policies that: (i) reduce firm entry costs,[3] (ii) increase tax deductions for new investment, (iii) increase public investment spending,

[1] Despite some limited shifts in trade patterns and regulatory alignment following the 2025 Trump tariffs, the substantial trade costs between the UK and the EU, imposed by Brexit, persist.

[2] Note that we calibrate the exogenous Brexit-type trade costs in our model to generate an output loss comparable to that typically associated with Brexit (see Section 5.2). In doing so, we isolate the effects of Brexit itself, abstracting from other contemporaneous shocks such as the COVID-19 pandemic, geopolitical conflicts, and broader economic and political uncertainties.

[3] UK businesses face numerous charges beyond corporation tax and VAT. These include: Employers' National Insurance Contributions, Business Rates, Apprenticeship Levy, Companies House Filing Fees, Licensing and Compliance Fees, and Other Sector-Specific Levies and Operational Taxes. Most of these constitute government revenues and are treated as such in our model.

(iv) subsidise firms' labour costs, and (v) subsidise newly acquired capital.

With rejoining the EU not on the agenda for either major party in the UK, domestic policy must shoulder the burden of the economic response to Brexit. Four key lessons emerge from our analysis: (i) Firm dynamics matter - Brexit's impact extends beyond trade costs by weakening competition and stifling firm creation, (ii) Support firm entry, not just activity - Policies that reduce barriers to starting new businesses outperform broad-based subsidies like those listed above, (iii) Targeted interventions are more effective than blanket spending - Focused support yields greater returns than spending on general public investment, (iv) Fiscal realism is essential - Effective policymaking must align with both inter-temporal budgetary constraints and political feasibility.

There is a substantial and growing body of literature analysing the economic implications of Brexit. Within the strand that employs DGE models, early contributions include Ebell *et al.* (2016), Steinberg (2019) and McGrattan and Waddle (2020), who examined the effects of uncertainty about the trade policy regime and foreign direct investment. More recently, Rubio (2024) focused on the role of macroprudential policy with and without Brexit, while Broadbent *et al* (2024) modelled Brexit as negative news to future productivity in the tradable goods sector. The paper most closely related to ours is Millard *et al.* (2024), who develop a three-country DGE model that incorporates, like our paper, endogenous firm entry and exit. Our approach builds on this framework but differs in two crucial respects. First, we highlight the quantitative significance of novel propagation mechanisms, such as the endogenously determined markups and degree of market competition, triggered by Brexit-induced distortions in the form of trade costs. Second, we explicitly analyse the role of policy interventions in mitigating the adverse macroeconomic consequences of Brexit.[4]

The remainder of the paper is structured as follows: Section 2 presents motivating empirical facts; Section 3 outlines the model; Section 4 details the calibration; Section 5 analyses model predictions and properties; Section 6 examines whether policy can restore the pre-Brexit equilibrium; Section 7 discusses industrial and fiscal policy; and Section 8 concludes.

2 Motivating facts

Since the 2007-2009 global financial crisis, labour productivity growth in the UK has slowed markedly. In the decade before the crisis (1998–2007), productivity growth

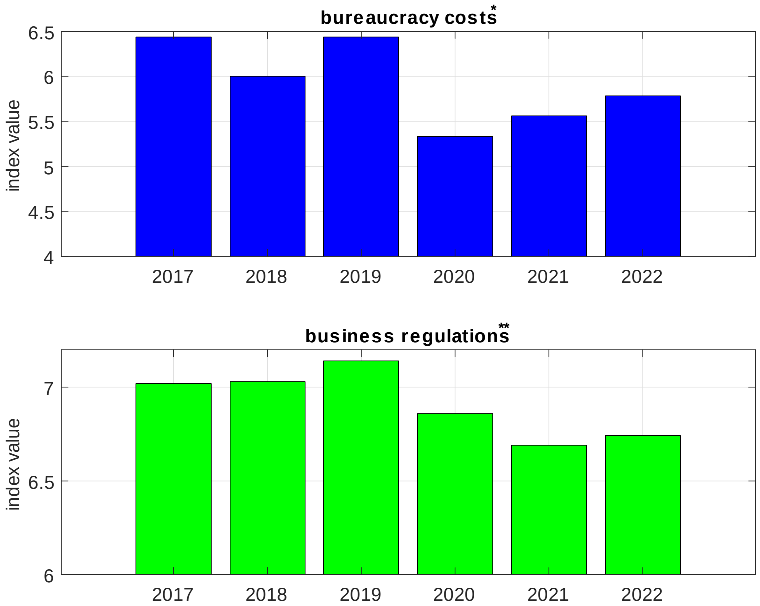
[4] Alongside the DGE-based literature, recent non-technical summaries are provided by Kaya *et al.* (2023, 2024). Econometric analyses of Brexit's economic effects are available in Bloom *et al.* (2019) and Minford and Zhu (2024). Additionally, the broader macroeconomic and productivity impacts of Brexit have been detailed in reports from the Bank of England, the National Institute of Economic and Social Research, the Office for Budget Responsibility, and the Productivity Institute, all of which are referenced throughout this paper.

averaged 1.6% annually. However, from 2008 onwards, it dropped sharply to an average of just 0.2%. Current forecasts remain pessimistic, with GDP growth projected at only 1.4% in 2026 (IMF, 2025).

While Brexit is not the sole cause of the UK's economic slowdown, it has had a significant negative impact.[5] Increased uncertainty, the introduction of border controls, and the imposition of trade barriers have all raised business costs, reduced market competition, and hindered innovation by limiting access to foreign resources and technologies (Ahn *et al.*, 2019). Estimates suggest that these effects have reduced the average productivity of UK firms by between 2.3% (Latorre *et al.*, 2020) and 4% (OBR, 2020).[6]

Other disruptive events have also contributed to the current low-growth environment. The COVID-19 pandemic in 2020-22,[7] subsequent supply chain disruptions, inflationary pressures, and geopolitical instability following Russia's invasion of Ukraine have compounded the challenges facing UK businesses.

Figure 1: Product Market Competition



* A lower value implies higher costs or a less competitive market.

** A lower value implies more regulations or a less competitive market.

Figures 1 and 2 illustrate further factors affecting firms' investment decisions in the post-Brexit period, particularly the effect of increased compliance costs in a more

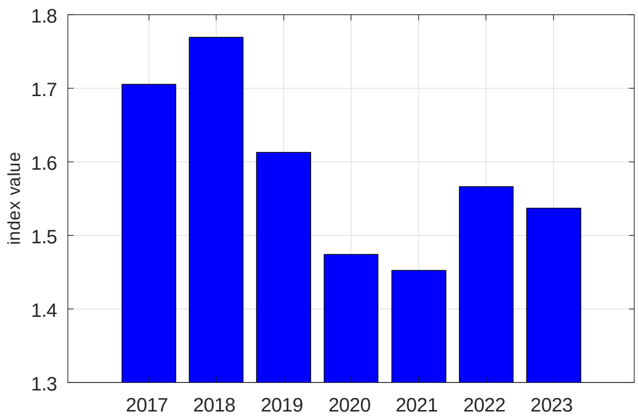
[5] The key dates relating to Brexit in the UK include (i) Referendum: June-July 2016, (ii) Formal Exit (Article 50): 29 March 2017, (iii) Left EU: 31 January 2020 and (iv) Transition Ended / Brexit Completed: 31 December 2020.

[6] The Latorre *et al.* (2020) study refers to the average fall in productivity across sectors. In contrast, the OBR (2020) research refers to the mean fall in potential productivity, which includes the effects on TFP and capital deepening.

[7] In the UK, the first national lockdown was in March 2020, and restrictions were mostly lifted by March 2022.

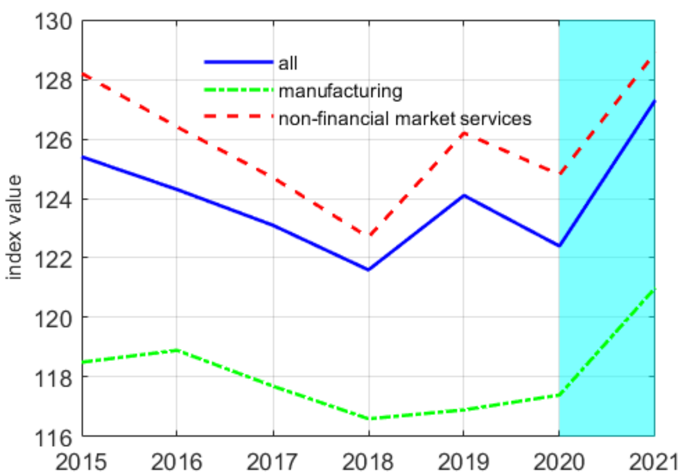
stringent regulatory environment on the competitiveness of the product market.[8] Figure 1 presents indices from the Fraser Institute measuring the effects of bureaucratic costs and business regulation. Declines in these scores post-Brexit indicate rising regulatory burdens that deter new market entrants and force some firms to exit. Similarly, the regulatory quality index in Figure 2 (drawn from the World Bank's Worldwide Governance Indicators) also reflects that poorer regulatory quality has made markets less competitive. Bad regulation creates uncertainty, inefficiency, and unfair advantages, undermining the conditions necessary for healthy market competition.

Figure 2: Regulatory Quality



Furthermore, the decline in the UK's competitiveness, as shown in Figures 1 and 2, is further supported by the post-Brexit rise in average markups illustrated in Figure 3.[9] This upward trend in markups points to a shift toward a less competitive market environment, leading to a reduction in consumer surplus. Figure 3 also high-

Figure 3: Mean Markups



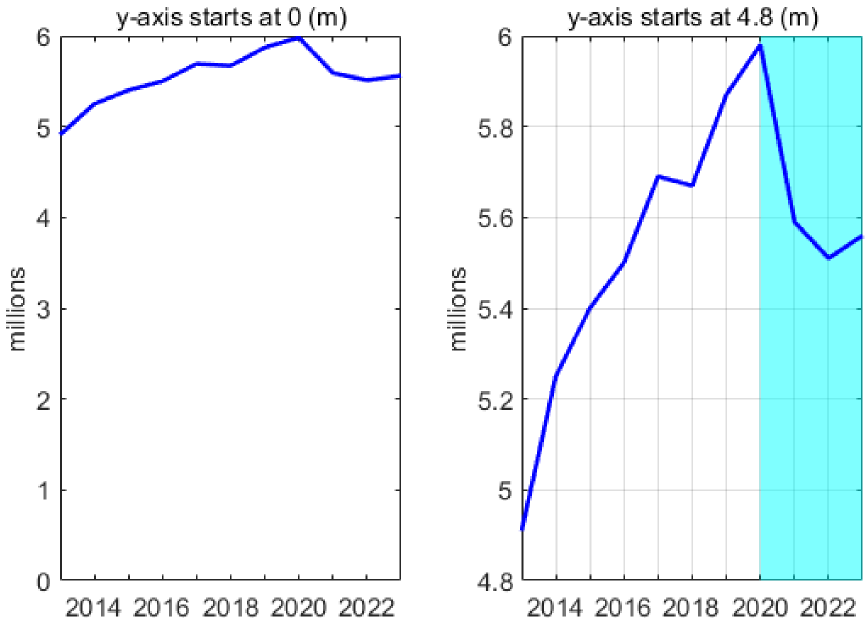
[8]Sources for the data used in Figures 1-4 are reported in Appendix A.

[9]Markups refer to the ratio of a firm's unit output price to its unit cost of intermediate consumption.

lights that this increase in market concentration is broad-based, affecting both the services and manufacturing sectors.

To provide a rough indication of how Brexit may have influenced net firm creation, Figure 4 presents the evolution of the number of private businesses in the UK from 2014 to 2023, based on data from UK.GOV. Subplot one shows the overall trend, while subplot two adjusts the scale to more clearly highlight the sharp decline from the 2020 peak of nearly 6 million businesses to the troughs observed in 2022 and 2023. Specifically, the figures for 2022 and 2023, 5.5 million and 5.55 million firms, respectively, represent declines of 8.3% and 7.5% from the 2020 peak.

Figure 4: Number of Private Businesses (2013-2023)



It is important to note, however, that Figure 4 does not suggest Brexit was the sole driver of this decline. Another major exogenous shock, the COVID-19 pandemic, also triggered a severe economic slowdown, likely exerting significant adverse effects on business operations and firm survival. Thus, the aggregate trends depicted in Figure 4 reflect, among other factors, the combined impact of both Brexit and the pandemic across various sectors of the UK economy.[10]

For instance, industries such as financial services, manufacturing, transport and travel, agri-food and fishing, and consumer-facing sectors experienced elevated firm exits and reduced new firm formation during the Brexit period. Regulatory changes, trade frictions, labour shortages, and diminished investment largely drove these outcomes. In contrast, sectors more directly affected by the pandemic, particularly hos-

[10] For example, according to Anayi *et al.* (2021), the COVID-19 pandemic substantially impacted domestic investment, decreasing it by up to 35% in Q2 2020 and by an average of 25% over the year to Q1 2021. Also, Bunn *et al.* (2021) suggest that UK firms anticipated huge downside risk at the outbreak of the pandemic.

pitality, retail, and leisure, were disproportionately impacted by lockdown measures and shifts in consumer behaviour.

Interestingly, recent research by Bahaj *et al.* (2024) reveals that firm entry in the UK also increased during the pandemic, mainly due to the rapid expansion of the online retail sector, one of the few areas to benefit from COVID-induced changes in demand. Moreover, the pandemic's impact on business activity presents a somewhat paradoxical picture. While one might have anticipated a surge in business closures, this expectation was not borne out in practice. In 2020, corporate bankruptcy filings in most advanced economies, including the UK and other OECD countries, declined by 17% relative to 2019, with even larger reductions compared to earlier years (see Zhang and Djankov, 2021, cepr.org/voxeu/columns/covid-rages-bankruptcy-cases-fall). This decline suggests that initial policy responses, such as fiscal support, loan guarantees, and temporary insolvency relief, were effective in averting a wave of bankruptcies.

Accordingly, while the downward trend in the number of private enterprises from 2020 onward likely reflects the combined effects of Brexit and the pandemic, the sectoral evidence and policy context suggest that Brexit-related uncertainty and structural changes may have played a more decisive role in driving the contraction in firm numbers. That said, this interpretation remains tentative. A more definitive assessment of the relative contributions of Brexit and COVID-19 would require a rigorous econometric analysis, ideally exploiting firm-level panel data and quasi-experimental variation, to disentangle the effects of these overlapping shocks and control for confounding factors.

3 Model

In this section, we develop a dynamic general equilibrium model for an open economy consisting of households, private firms, and the government. To account for imperfect competition in the product market, we build on the widely-used Dixit-Stiglitz model. A key limitation of the baseline Dixit-Stiglitz framework is that it treats markups as exogenous, assuming they are independent of the number of firms, which itself is also fixed exogenously (see, for example, Acemoglu, 2009, Chapter 12.4, for a detailed discussion). To address this limitation and bring the model closer to real-world dynamics, we adopt the approach of Ghironi and Melitz (2007), Bilbiie *et al.* (2008, 2012), and Etro and Colciago (2010), where the number of active firms is endogenously determined through entry and exit. Specifically, we follow the framework of Etro and Colciago (2010), which ensures that, in a Cournot-Nash equilibrium, both markups and market power are endogenously shaped by the number of active firms. This makes markups responsive to economic policies, among other factors. Furthermore, in our model, the government is not limited to the traditional three public spending categories, consumption, investment, and income transfers. Instead, we introduce a broad array of tax and subsidy instruments, including taxes on income, consumption, corporate profits, and a range of potential subsidies. Building on the findings of Ahmet *et al.* (2024) and Portes (2022), who report no significant change in net migration flows between the UK and both EU and non-EU countries following Brexit, as well as Hantzche (2019), who finds only a marginal impact of the UK's net fiscal contributions to the EU on domestic GDP, we exclude both migration and budgetary transfers from our model. In addition, given that the effects of uncertainty have been thoroughly explored in prior research (e.g., Bloom *et al.*, (2019), McGrattan and Waddle (2020), and Broadbent *et al.* (2024)), our analysis shifts focus to policy responses, adopting a deterministic framework, consistent with much of the existing literature on structural reforms. Finally, to concentrate on long-run outcomes, we abstract from nominal rigidities and monetary policy considerations.

3.1 Households

There are $i = 1, 2, ..., N$ identical households, where the population size N is exogenous and constant. Each household i maximizes lifetime utility:

$$\sum_{t=0}^{\infty} \beta^t u\left(\widetilde{c}_{i,t}, l_{i,t}\right), \tag{1}$$

where $\widetilde{c}_{i,t}$ is a composite of private and public consumption, $l_{i,t}$ is work hours and $0 < \beta < 1$ is a time discount factor.

Following Sims and Wolff (2018), Bouakez *et al.* (2023) and Malley and Philippopoulos (2023) the period utility function is:

$$u\left(\widetilde{c}_{i,t}, l_{i,t}\right) = \frac{n}{n-1} \log \widetilde{c}_{i,t} - \mu \frac{l_{i,t}^{1+\frac{1}{\kappa}}}{1+\frac{1}{\kappa}},$$

where $n > 0$ and $\mu \geq 0$ are preference parameters, $\kappa > 0$ is the Frisch elasticity of labour supply, and $\widetilde{c}_{i,t}$ is defined as:

$$\widetilde{c}_{i,t} = \theta_C \left(c_{i,t}\right)^{\frac{n-1}{n}} + (1-\theta_C)(g_t^c)^{\frac{n-1}{n}},$$

where $c_{i,t}$ is i's private consumption, g_t^c denotes per-capita utility-enhancing public goods/services, $0 < \theta_C \leq 1$ is a share parameter, and the preference parameter $n > 0$ is also a measure of the elasticity of substitution between private and public consumption (if $n > 1$, there is substitutability between the consumption goods; if $n < 1$, there is complementarity).

Since there are two final goods, home and foreign, we define the consumption index:

$$c_{i,t} = \frac{\left(c^{H}_{i,t}\right)^{\nu}\left(c^{F}_{i,t}\right)^{1-\nu}}{\nu^{\nu}(1-\nu)^{1-\nu}}, \tag{2}$$

where $c^{H}_{i,t}$ and $c^{F}_{i,t}$ denote each i's domestic and foreign consumption bundles, respectively, and $0 < \nu < 1$ measures the weight given to the domestic relative to the foreign, imported good.

Using Dixit-Stiglitz type aggregators, we define the two bundles, $c^{H}_{i,t}$ and $c^{F}_{i,t}$, as:

$$c^{H}_{i,t} = \left[(N^{h}_{t})^{\theta-1} \sum_{h=1}^{N^{h}_{t}} (c^{H}_{i,h,t})^{\theta} \right]^{\frac{1}{\theta}}, \tag{3}$$

$$c^{F}_{i,t} = \left[(N^{f}_{t})^{\theta-1} \sum_{f=1}^{N^{f}_{t}} (c^{F}_{i,f,t})^{\theta} \right]^{\frac{1}{\theta}}, \tag{4}$$

where $c^{H}_{i,h,t}$ is the amount of domestic variety h consumed by each household i, $c^{F}_{i,f,t}$ is the amount of foreign variety f consumed by each i, where $h = 1, 2, ..., N^{h}_{t}$ is the number of varieties of domestically produced goods (this changes over time as we show below), $f = 1, 2, ..., N^{f}_{t}$ is the number of varieties of imported foreign goods (in a small open economy, this is exogenous, and for notational simplicity, it will be set equal to N^{h}_{t}), $\theta \leq 1$ is a parameter measuring the degree of goods substitutability which is also assumed for simplicity to be the same for domestic and foreign goods. Notice that $(N^{h}_{t})^{\theta-1}$ and $(N^{f}_{t})^{\theta-1}$ are included so that an increase in the number of goods does not directly affect macroeconomic outcomes and thus we avoid scale effects (see, e.g. Blanchard and Giavazzi (2003) and Dimakopoulou *et al.* (2024)).

The period budget constraint of each i is:

$$\begin{gathered}(1+\tau^{c}_{t})\left(\frac{p^{H}_{t}}{p_{t}}c^{H}_{i,t} + \frac{p^{F}_{t}}{p_{t}}c^{F}_{i,t}\right) + \left(b_{i,t} - \frac{p_{t-1}}{p_{t}}b_{i,t-1}\right) + \frac{e_{t}p^{*}_{t}}{p_{t}}\left(f_{i,t} - \frac{p^{*}_{t-1}}{p^{*}_{t}}f_{i,t-1}\right) + \\ +\psi_{i,t} = (1-\tau^{y}_{t})(w_{t}l_{i,t} + \pi_{i,t}) + i^{b}_{t-1}\frac{p_{t-1}}{p_{t}}b_{i,t-1} + i^{*}_{t-1}\frac{p^{*}_{t-1}}{p^{*}_{t}}\frac{e_{t}p^{*}_{t}}{p_{t}}f_{i,t-1} + g^{tr}_{t},\end{gathered} \tag{5}$$

where p_{t} is the consumer price index (CPI) at home, p^{*}_{t} is the CPI abroad, p^{H}_{t} is the price index of the bundle of home goods, p^{F}_{t} is the price index of the bundle of foreign goods expressed in domestic currency (here $p^{F}_{t} = e_{t}p^{H*}_{t}$, where p^{H*}_{t} is the price of the good produced abroad expressed in foreign currency and e_{t} is the nominal exchange rate defined as units of domestic currency per unit of foreign currency), $b_{i,t}$ is the real value of one-period government bonds earning a nominal interest rate i^{b}_{t} in the next period, $f_{i,t}$ is the real value of one-period foreign assets denominated in foreign prices on which the household earns the foreign nominal interest rate i^{*}_{t} in the next period (if $f_{i,t}$ happens to be negative, it denotes foreign private debt), w_{t} is the real wage rate earned by supplying $l_{i,t}$, $\pi_{i,t}$ is the dividend distributed by private firms to each i, $\psi_{i,t}$ is i's transaction cost associated with participation in the foreign capital market (defined below), g^{tr}_{t} is an income transfer from the government to each i, and

$0 \leq \tau_t^c, \tau_t^y < 1$ are tax rates on consumption and income respectively.

We assume that the transaction cost function associated with participation in the foreign asset market is:

$$\psi_{i,t} = \frac{p_t^H}{p_t}\frac{\psi^p}{2}\left(\frac{\frac{e_t p_t^*}{p_t} f_{i,t}}{\frac{p_t^H}{p_t}\overline{y}_t}\right)^2 \overline{y}_t, \tag{6}$$

where, $\psi^p \geq 0$ is a transaction cost parameter associated with the participation in foreign capital markets and $\overline{y}_t$ denotes total gross output divided by the number of households which is taken as given by each individual household.[11]

Each i also faces the following budget constraints:

$$p_t c_{i,t} = p_t^H c_{i,t}^H + p_t^F c_{i,t}^F, \tag{7}$$

where

$$p_t^H c_{i,t}^H = \sum_{h=1}^{N_t^h} p_{h,t}^H c_{i,h,t}^H, \tag{8}$$

$$p_t^F c_{i,t}^F = \sum_{f=1}^{N_t^f} p_{f,t}^F c_{i,f,t}^F, \tag{9}$$

$p_{h,t}^H$ is the price of each variety $h = 1, 2, ...N_t^h$ produced at home, and $p_{f,t}^F$ is the price of each variety $f = 1, 2, ...N_t^f$ produced abroad (expressed in domestic currency).

Each household i chooses $\{c_{i,t}, c_{i,t}^H, c_{i,t}^F, c_{i,h,t}^H, c_{i,f,t}^F, l_{i,t}, b_{i,t}, f_{i,t}\}_{t=0}^{\infty}$ subject to the above. The first-order conditions and the resulting price indexes are presented in Appendix B.

3.2 Private Firms

There are $h = 1, 2, ..., N_t^h$ domestic firms at each t. Each firm h produces a differentiated good of variety h, taking into account the demand for its own product. To produce its output, $y_{h,t}$, each h uses capital, labour and imported intermediate goods, and it also benefits from public infrastructure capital. To this standard Dixit-Stiglitz setup, following, e.g. Ghironi and Melitz (2005), Bilbiie *et al.* (2008, 2012), Etro and Colciago (2010) and Cavallari (2013), we allow for endogenous firm entry and hence for an endogenous determination of the number of active firms or equivalently an endogenous determination of the number of product varieties. Further, by solving the firms' profit maximization problem as in Etro and Colciago (2010), which means that we take into account strategic interactions in a Cournot-Nash equilibrium, we allow the degree of product substitutability to become endogenous depending on the number of active firms rather than to simply be a structural parameter as is the stan-

[11] That is, $\overline{y}_t \equiv \frac{Y_t}{N}$, where Y_t denotes total gross output. As in Leeper *et al.* (2021), the idea is that the transaction cost increases with the overall scale of economic activity. This is not important but helps to have smoother transition paths. Note that in a symmetric equilibrium, $\overline{y}_t \equiv \frac{Y_t}{N} = \frac{N_t^h y_{h,t}}{N} = n_t^h y_{h,t}$, where $n_t^h \equiv \frac{N_t^h}{N}$.

dard Dixit-Stiglitz setup. This endogeneity will imply that the larger the number of active firms and hence the larger the variety of products, the higher the degree of product substitutability, the smaller the price markup and the market power of firms, so that, when more firms enter, the product market moves in the direction of greater competition.

We work in steps. We first derive the demand function for each firm's product. Then, we define the entrants and how the number of active firms evolves through time. In turn, we present the active firms' constraints and objectives and then solve their profit maximisation problem.

We start with the demand for each $h's$ product, $y_{h,t}$. As is shown in Appendix C, this is:

$$y_{h,t} = \left(\frac{p_{h,t}^H}{p_t^H}\right)^{\frac{1}{\theta-1}} \frac{Y_t}{N_t^h} = \left(\frac{p_{h,t}^H}{p_t^H}\right)^{\frac{1}{\theta-1}} \widetilde{y}_t, \tag{10}$$

where $\widetilde{y}_t$ denotes total gross output divided by the number of active firms.[12]

Next, we specify the number of active firms, N_t^h, by working as in the literature mentioned above. That is, instead of assuming that N_t^h is exogenous, we allow for new entrants, N_t^e, whose number at the beginning of each period t is defined as:

$$N_t^e \equiv \Xi_t(N^p - N_{t-1}^h), \tag{11}$$

where N^p is the potential number or pool of firms which is set, for example, equal to the exogenous and constant population size (i.e. $N^p \equiv N$), N_{t-1}^h is the number of active firms at $t-1$, and $0 \leq \Xi_t \leq 1$ is the endogenously determined fraction of inactive firms in the previous period, $(N^p - N_{t-1}^h)$, that become active in the current period.

If we assume, again working as in the above literature, that both incumbents, N_{t-1}^h, and new entrants, $\Xi_t(N^p - N_{t-1}^h)$, are hit by a death shock which occurs with a constant probability, $0 \leq \Omega < 1$, the net number of active firms at t is $N_t^h = (1-\Omega)[N_{t-1}^h + \Xi_t(N^p - N_{t-1}^h)]$, or, equivalently, dividing by their exogenous and constant pool, $N^p \equiv N$:

$$n_t^h = (1-\Omega)[n_{t-1}^h + \Xi_t(n^p - n_{t-1}^h)], \tag{12}$$

where $0 < n_t^h \equiv \frac{N_t^h}{N^p} \equiv \frac{N_t^h}{N} \leq 1$ is the number of active firms as fraction of their potential number and $n^p = \frac{N^p}{N}$ is the number of potential firms as fraction of total population (which here is equal to unity since the potential number of firms is equal to the size of the population).

Before we move on to the other constraints and the objective of active firms, again following the above literature, we need to model the entry decision of the N_t^e firms. Each new entrant pays an entry cost, F_t, which is paid to the government (see

[12] That is, $\widetilde{y}_t \equiv \frac{Y_t}{N_t^h}$. Note that in a symmetric equilibrium, $\widetilde{y}_t \equiv \frac{Y_t}{N_t^h} = \frac{N_t^h y_{h,t}}{N_t^h} = y_{h,t}$.

below). Adopting the convention that a new firm chooses to enter the market and thus pay the entry cost when it is indifferent between doing so or not, we set the usual incentive constraint, $V_{h,t} = F_t$, where $V_{h,t}$ denotes the value of active firm h at t or, in other words, the present discounted value of the firm's profits starting from the current period onwards.[13]

Since entrants pay the entry cost before the death shock is realised and before production takes place, $V_{h,t}$ should satisfy the Bellman-type equation:

$$V_{h,t} = (1-\Omega)\pi_{h,t} + \beta_{h,1}V_{h,t+1}, \tag{13}$$

where $\beta_{h,1}$ is the next period's discount factor adjusted by the death rate (defined below).

We can now turn to the net profit of each active firm h, denoted as $\pi_{h,t}$ (see Appendix C for the derivation):

$$\begin{aligned} \pi_{h,t} &= (1-\tau_t^{\pi})\left(\frac{p_{h,t}^H}{p_t}y_{h,t} - w_t l_{h,t} - \frac{p_t^F}{p_t}m_{h,t}\right) - \\ &- \frac{p_t^H}{p_t}\left[k_{h,t} - (1-\delta)k_{h,t-1}\right] - \frac{p_t^H}{p_t}\frac{\xi^k}{2}\left(\frac{k_{h,t}}{k_{h,t-1}} - 1\right)^2 k_{h,t-1} - \\ &- \frac{p_t^H}{p_t}\left(\frac{\Xi_t(N - N_{t-1}^h)]}{N_t^h}\right)F_t - s^m\frac{p_t^F}{p_t}m_{h,t} - s^x\frac{p_{h,t}^H}{p_t}c_t^{H,*}, \end{aligned} \tag{14}$$

where $y_{h,t}$ is h's output, $l_{h,t}$ is the labour input, $k_{h,t}$ is the capital input used in production in the next period, $m_{h,t}$ is imported goods used in production, $\xi^k \geq 0$ is a parameter measuring standard capital adjustment costs, the first term on the last line is the cost, F_t, paid by new entrants as a fraction of the total number of active firms,[14] and $0 \leq \tau_t^{\pi} < 1$ is the corporate tax rate. Finally, regarding the last two terms on the RHS, the parameters $s^m \geq 0$ and $s^x \geq 0$ capture Brexit-type trade costs associated respectively with firms' imported products used in production and firms' exports to the rest of the world.[15] In the last term in particular, the idea is that if $c_t^{H,*}$ is the quantity demanded by the rest of the world for each firm h's produced output, then a Brexit-type cost associated with trade costs on firm h's exports is $s^x\frac{p_{h,t}^H}{p_t}c_t^{H,*}$.[16]

[13] In addition to the related papers listed above, for firm entry in general and the same condition that ties down the number of firms in particular, see Mas-Colell *et al.* (1995, chapter 12.E).

[14] Thus, $\frac{N_t^e}{N_t^h} = \frac{\Xi_t(N^p - N_{t-1}^h)}{N_t^h} = \Xi_t\left(\frac{1}{n_t^h} - \frac{N_{t-1}^h N^p}{N_t^h N^p}\right) = \Xi_t\left(\frac{1}{n_t^{hi}} - \frac{n_{t-1}^h}{n_t^h}\right) = \Xi_t\left(\frac{1-n_{t-1}^h}{n_t^h}\right)$.

[15] These trade frictions are similar to iceberg costs used in the trade literature, e.g. Krugman (1980) and in the macro literature, e.g. Ghironi and Melitz (2005). As said in the introduction, these have been arguably two of the most significant costs associated with Brexit. In particular, Brexit has permanently reduced the effectiveness of UK trade with the EU by establishing customs checks, rules of origin requirements, and regulatory differences. These obstacles significantly increase costs for both exporters and importers and, as noted in the literature, result in a decline in key macroeconomic aggregates, including GDP, consumption, investment, trade, and competitiveness.

[16] Note that, in a small open economy model, $c_t^{H,*}$, is exogenous and is defined below (see Appendix E). On the other hand, recall that, with monopolistic competition, $p_{h,t}^H$ is an endogenous variable being affected by firm h's decisions. Appendix C provides solution details.

Moving to technology, we assume that the production function of each h is:

$$y_{h,t} = A\left\{x\left[(k_{h,t-1})^{a_1}(m_{h,t})^{a_2}(l_{h,t})^{1-a_1-a_2}\right]^{\sigma} + (1-x)\left(\overline{k}^g_{t-1}\right)^{\sigma}\right\}^{1/\sigma}, \tag{15}$$

where the parameter $0 < x \leq 1$ measures the importance of a Cobb-Douglas composite of the three private inputs relative to per firm public infrastructure capital $\overline{k}^g_{t-1}$,[17] the parameter $\sigma < 1$ shapes the degree of substitutability or complementarity between private inputs and public infrastructure, $1/(1-\sigma)$ (see e.g. Caselli (2005) and Jones (2011)), and $A > 0$ is a standard TFP parameter. Also, $0 < a_1,\ a_2 < 1$ are technology parameters.

Now, we are ready to solve the firm's problem. Each firm h maximizes the discounted sum of dividends distributed to its owners:

$$\sum_{t=0}^{\infty} \beta_{h,t}\pi_{h,t}, \tag{16}$$

where, since capital owners own firms, we will *ex post* postulate that the firm's discount factor, $\beta_{h,t}$, equals the capital owners' marginal rate of substitution between consumption at t and $t+1$ being adjusted by the probability of firms death, namely, $\beta_{h,0} = 1$, $\beta_{h,1} \equiv \frac{\beta(1-\Omega)(1+\tau^c_t)c_{i,t}}{(1+\tau^c_{t+1})c_{i,t+1}}$, etc.

Each active firm h chooses $\{l_{h,t},\ m_{h,t},\ k_{h,t}\}_{t=0}^{\infty}$ to maximize its stream of dividends or net profits, as defined in (16) and (14), subject to the production function in (15) and the inverse demand function in (10). To solve this problem, as said above, we work as Etro and Colciago (2010), meaning that we solve for the Cournot-Nash equilibrium, and thus allow the markup to be shaped by the number of active firms in the sector. Algebraic details and the first-order conditions for the three inputs are provided in Appendix C.

3.3 Government

The period budget constraint of the government written in per capita terms is:

$$\begin{aligned} &\frac{p^H_t}{p_t}(g^c_t + g^i_t) + g^{tr}_t + i^b_{t-1}\frac{p_{t-1}}{p_t}b_{i,t-1} = \left(b_{i,t} - \frac{p_{t-1}}{p_t}b_{i,t-1}\right) + \\ &+\frac{p^H_t}{p_t}\Xi_t(1-n^h_{t-1})F_t + T_t, \end{aligned} \tag{17}$$

where g^i_t is per capita public investment spending and T_t denotes per capita tax revenues:

$$\begin{aligned} T_t \equiv\ &\tau^c_t\left[\frac{p^H_t}{p_t}c^H_{i,t} + \frac{p^F_t}{p_t}c^F_{i,t}\right] + \tau^y_t(w_t l_{i,t} + \pi_{i,t}) + \\ &+\tau^\pi_t n^h_t\left[\frac{p^H_{h,t}}{p_t}y_{h,t} - w_t l_{h,t} - \frac{p^F_t}{p_t}m_{h,t}\right], \end{aligned} \tag{18}$$

[17] Thus, $\overline{k}^g_{t-1} \equiv \frac{K^g_{t-1}}{N^h_t} = \frac{K^g_{t-1}}{N^h_t}\frac{N}{N} = \frac{k^g_{t-1}}{n^h_t}$.

The stock of public capital written in per capita terms evolves over time as:

$$k_t^g = (1 - \delta^g)k_{t-1}^g + g_t^i, \tag{19}$$

where $0 < \delta^g < 1$ is the depreciation rate of public capital and g_t^i is per capita public investment spending. Notice that the entry cost, F_t, paid by new entrants constitutes a revenue for the government, which is consistent with the view that, other things equal, governments can generate revenue through fees associated with permits, licences and other regulatory requirements. Moreover, complex regulations and bureaucratic procedures can create more opportunities for fines in the event of non-compliance.

To bring government spending close to the data, we define $g_t^c = s_t^c n_t^h y_{h,t}$, $g_t^i = s_t^i n_t^h y_{h,t}$ and $g_t^{tr} = \frac{p_t^H}{p_t} s_t^{tr} n_t^h y_{h,t}$ where the policy instruments s_t^c, s_t^i and s_t^{tr} are respectively the GDP shares of government spending on consumption, investment and income transfers.

3.4 Macroeconomic equilibrium system

Market-clearing conditions, including the balance of payments, are presented in Appendix D, while the macroeconomic equilibrium system is presented in detail in Appendix E. This system consists of 23 equations in the paths of $c_{i,t}$, $c_{i,t}^H$, $c_{i,t}^F$, $l_{i,t}$, $b_{i,t}$, $f_{i,t}$, $\pi_{i,t}$, $\pi_{h,t}$, $y_{h,t}$, $l_{h,t}$, $k_{h,t}$, $m_{h,t}$, n_t^h, Ξ_t, V_t, θ_t, i_t^b, T_t, k_t^g, w_t, p_t, p_t^F, p_t^H. This is for given paths of fiscal instruments, $\{\tau_t^c, \tau_t^y, \tau_t^\pi, s_t^c, s_t^i, s_t^{tr}\}$, the entry cost paid by firms, $\{F_t\}$, and the rest-of-the-world variables.[18] Appendix E also defines the resulting value of per capita GDP, which is gross GDP minus the value of imported intermediate goods used in production, and all this is weighted by the population fraction of active firms, which is also endogenous (see equation (E.26)).

4 Calibration

We next outline the calibration of the model's structural and policy parameters, along with the data sources employed. Unless otherwise specified, the data are drawn from official UK institutions, including the Bank of England (BoE), the Office for National Statistics (ONS), and the Office for Budget Responsibility (OBR), and extend up to the year 2019. Appendix A provides additional detail on data sources and the methodologies used. In line with the approach of Ramey (2021) and Malley and Philippopoulos (2023), we use the longest available time series to calibrate the structural parameters, while relying on the most recent pre-pandemic data for the policy parameters. Specifically, we use data from 2019 to avoid the distortions introduced

[18] Notice, as said above, that θ_t, which is a measure of market competition, is among the endogenous variables as in Etro and Colciago (2010).

by the COVID-19 pandemic beginning in 2020.

4.1 Structural parameters

Table 1 lists the model's parameter values not related to exogenous policy. In the final column, we indicate whether the value for the specific parameter was chosen based on the raw data, a data-driven calibration, or other studies in the literature.[19]

Table 1: Structural parameters

Parameter	Description	Value	
A	TFP in firms' production function	1.000	normalised
$1-\alpha_1-\alpha_2$	share of labour in production	0.623	data
α_1	share of private capital in production	0.353	calibrated
α_2	share of imported capital in production	0.024	calibrated
β	time discount factor	0.962	calibrated
δ	depreciation rate of private capital	0.074	data
δ^g	depreciation rate of public capital	0.075	data
κ	Frisch elasticity of labour supply	0.500	literature
μ	preference weight on labour supply	42.30	calibrated
N	UK population (m) in 2019	66.80	data
n	elasticity of substitution: pvt & gvt consumption	0.830	literature
n^p	share of potential number of firms to population	1.000	literature
ν	home goods bias in consumption	0.618	calibrated
ξ^k	capital adjustment cost	0.050	calibrated
ϕ	exponent in the function of exports	1.600	literature
σ	private inputs & public capital substitutability	0.500	literature
r^*	foreign interest rate	0.040	literature
$1-\theta_c$	public consumption share of GDP	0.206	data
θ	substitutability of intermediate goods	0.960	calibrated
$1-x$	contribution of public output to private production	0.040	calibrated
ψ^p	transaction cost parameter in foreign markets	1.0e-5	calibrated
Ω	death rate of active firms	0.028	calibrated

Starting with firms, we normalise the TFP parameter in their production function to unity. The value for the exponent on labour, $(1-\alpha_1-\alpha_2)$, of 0.623 is the average labour income share in the data (ONS). Then, solving equations (E.10) and (E.11) in Appendix E at the steady state and using the average values (from 1997-2019) for the ratios of domestic capital and imported capital goods to GDP (drawn by the ONS), we calibrate the exponent on domestic physical capital, α_1, to 0.353 and the exponent

[19]We wish to report at the outset that our main results are robust to changes in these baseline parameter values, at least within reasonable ranges.

on imported capital α_2 to 0.024. Regarding the parameter, σ, we set it at 0.5 so that the elasticity of substitution between private inputs and public infrastructure capital, $1/(1-\sigma)$, is 2.[20] The parameter x, which measures the importance of private inputs relative to public infrastructure, is calibrated to target a public-to-private capital ratio of roughly 21% (between 1995 and 2019). This calibration implies a value of 0.96 for x. The active firms' death rate, Ω, in equation (12) is calculated using ONS data on the number of businesses closing between 2001 and 2019, which implies a value of 0.028.

Also recall that, in our model, following Etro and Colciago (2010), θ_t is a function that depends on the structural parameter θ, as well as on the endogenous number of firms. Thus, to set the Dixit-Stiglitz parameter, θ (for θ_t see eq. (E.14) in Appendix E), which shapes monopolistic firms' market power and in turn profits, we use the equation for the firm's profit and target a net profit to output ratio of around 14% (which is equal to the average value of the net operating surplus of private sector corporations to GDP between 1995-2019). This implies a value for θ of 0.960, which falls within commonly used ranges. We normalise the potential number of firms to population ratio, n^p, to unity, where the total UK population in 2019 was 66.8 million people.

Moving to households, their time discount factor, β, is calibrated from the steady state Euler equation for bonds (see equation (A.2) in Appendix A) by using a 4% annual interest rate (as in Litsios *et al.* (2020) and DiCecio and Nelson (2007)). The resulting value is $\beta = 0.962$. In the utility function, the weight to labour supply, μ, is set to target households' work time in the data, which is 0.22 and the public consumption share of GDP, $1-\theta_c$, is based on its 2019 value in the data. The Frisch elasticity of labour supply, κ, is generally inelastic in UK studies. For example, the values are 0.43 in Millard *et al.* (2024), 0.372 in Lyu *et al.* (2023), 0.625 in Faccini *et al.* (2013), and 0.43 in Harrison and Omen (2010). Our value of 0.5, reported in Table 1, is roughly the simple average across these studies. Finally, the value for the elasticity of substitution between private and government consumption, n, is derived from the econometric estimate by Bhattarai and Trzeciakiewicz (2017).[21]

The degree of preference for home over foreign goods in total consumption, ν, also known as home bias, is calibrated from the equilibrium expression $\frac{e_t p_t^*}{p_t} = (\frac{p_t^f}{p_t^h})^{2\nu-1}$ (see Appendix E), where $\frac{e_t p_t^*}{p_t}$ is the real exchange rate and $\frac{p_t^f}{p_t^h}$ is the ratio of the price level of the foreign imported good to the price level of the domestically produced good. Using data for the average real effective exchange rate (1.031) from the World Bank and the average ratio of foreign to domestic prices (1.136) over 1997-2019, the resulting value is $\nu = 0.618$.[22]

[20] This is close to the value estimated by An *et al.* (2019) for a world sample of 151 countries, developed and less developed.

[21] Note that we use the mode value of 0.83 reported in Table 2, p. 326.

[22] As a proxy for the ratio of foreign to domestic prices, we use the ratio of foreign to domestic

The annual depreciation rates for private and government capital, denoted by δ and δ^g, are calibrated to 0.074 and 0.075, respectively. These values are based on UK capital stock data from the Office for National Statistics (ONS), covering both private and public assets. Specifically, the depreciation rates are computed as the ratio of current cost depreciation to the net stock of fixed assets at the end of the previous year, averaged over the period from 1995 to 2019.

The transaction cost parameter associated with capital changes in the firm's problem is calibrated to yield an investment loss in terms of output of around 1% (see, e.g., Correia *et al.* (1995) and Kollintzas and Vassilatos (2000)), resulting in a value of $\xi^k = 0.05$.[23] As is known, the transaction cost parameter, ψ^p, associated with participation in foreign asset markets must be positive to "close the model" (see Schmitt-Grohé and Uribe (2003)). Following, e.g. Fernández-Villaverde *et al.* (2011), we set it at the lowest possible value to ensure that the model's dynamic properties are unaffected.

Regarding the country's exports (as defined in equation (E.25) in Appendix E), following the econometric study by Hooper *et al.* (2000) for the UK economy, we set the export elasticity, represented by the parameter ϕ in that equation, at 1.6. The exogenous foreign annual interest rate r_t^* paid for the internationally traded asset is set at 4%.

Finally, note that the values of the Brexit shocks, s^m and s^x, will be calibrated in the next section.

4.2 Policy parameters

We next report in Table 2 the values of policy variables. The value of the UK public debt-to-output ratio, $\frac{b}{y}$, is set to 84.6%, which is equal to its 2019 value (data drawn from OBR). The entry cost parameter, $F = 6.228$, is calibrated to target the ratio of active firms to the total population in 2019. In particular, according to the ONS data, this ratio is 5.9 million divided by 66.8 million, which equals 0.088.

Regarding public spending policy instruments, we set s_t^i and s_t^c, which are, respectively, the GDP shares of government spending on investment and consumption (including intermediate consumption and compensation of public employees), in 2019 (data drawn by ONS), at 0.028 and 0.206.[24] Concerning the effective tax rates, we use data from Eurostat for 2019 (implicit tax rates, European Commission Taxation Trends). Based on these data, we set τ_t^c, τ_t^y and τ_t^π, which are the effective tax rates on consumption, personal income and corporate profits, at 0.152, 0.282, and 0.158,

GDP deflator drawn from the ONS. Regarding the foreign GDP deflator, we have chosen to use the German one based on data from Eurostat.

[23] Our main results are robust to changes in the value of ξ^k.

[24] Note that, with the public debt to GDP ratio as in the data, government transfers, s_t^{tr}, is the residual instrument in the government's budget constraint.

respectively.[25]

Table 2: Policy parameters

Variable	Description	Value	
$\frac{b}{y}$	threshold value of public debt to output	0.846	data
F	entry cost	6.228	calibrated
s^i	public investment to output	0.028	data
s^c	public consumption to output	0.206	data
s_t^{tr}	transfer payments to output	0.155	calibrated
τ^c	effective consumption tax rate	0.152	data
τ^y	effective personal income tax rate	0.282	data
τ^π	effective tax rate on corporate profits	0.158	data

5 Model predictions and properties

Given our focus on the long-run costs of Brexit and the potential policies to mitigate them, the model's ability to capture long-run developments in the UK economy serves as a critical validation test. Accordingly, this section proceeds in four steps. First, we solve for the model's steady state under the assumption that Brexit-related shocks are absent, i.e., we set $s^m = s^x = 0$, to assess the model's baseline predictions against pre-Brexit data. Second, starting from this initial steady state, we introduce the Brexit shocks by permanently switching on s^m and s^x, thereby tracing the macroeconomic impact of Brexit during the transition to a new long-run equilibrium. Third, we decompose this impact to quantify the respective contributions of firm exit and increased markups. Fourth, based on these dynamic responses, we calculate the associated welfare loss stemming from Brexit. Finally, we summarise the key takeaways of the model.

5.1 Initial steady state (pre-Brexit)

Although Section 4 calibrated the model to a range of UK data targets, including the worktime share, the number of active firms per capita, the public-to-private capital ratio, and the shares of profits, debt, public consumption and investment in GDP, many untargeted moments remain. Thus, to evaluate the model's broader ability to replicate the pre-Brexit UK economy (i.e., conditions up to 2019), we solve for the steady state under the assumption $s^m = s^x = 0$ and compare the model's predictions with the corresponding data. Table 3 reports the resulting steady-state

[25] Eurostat provides data for effective (implicit) tax rates for capital income and labour income. To generate the aggregate effective income tax rate, we apply the share of labour tax revenues to total tax revenues (defined as the sum of capital and labour tax revenues) to the effective labour tax rate and the share of capital tax revenues to total tax revenues to the effective capital tax rate. Then, the implied effective income tax rate is the sum of these two components.

values, focusing on key GDP components for which actual data are available. Except for the final row, the 'Data' column reflects historical averages through 2019 for all non-policy variables. In contrast, consistent with the calibration of policy parameters in Table 2, the final row shows the actual value in 2019.

Table 3: Initial, pre-Brexit steady state (GDP shares)

Variable	Description	Solution	Data
$\frac{c}{y}$	consumption	0.619	0.609
$\frac{i}{y}$	investment	0.147	0.143
$\frac{k_p}{y}$	private capital	1.861	1.620
$\frac{k_g}{y}$	public capital	0.350	0.340
$\frac{x}{y}$	exports	0.259	0.272
$\frac{m}{y}$	imports	0.259	0.287
$\frac{pb}{y}$	primary balance	0.026	0.013

Overall, the results indicate that the model aligns closely with the data and successfully reproduces key features of the pre-Brexit UK economy. Notably, it also captures the 2019 primary deficit from the OBR, defined as expenses minus revenues (albeit with a slightly higher magnitude), excluding the revenues associated with the entry costs paid by firms.[26] These findings provide reassurance regarding the model's suitability for analysing the long-run economic consequences of Brexit and evaluating potential policy responses.

5.2 Brexit shocks and transition to the new steady state

We now turn to the macroeconomic effects of imposing positive trade costs, s^m, $s^x > 0$, over time. As defined in eq. (14), these represent iceberg-type costs associated with firms' imports and exports, respectively. To isolate the long-run impact of reduced trade efficiency from the short-run disruptions caused by adverse shocks since 2020, such as those related to TFP, investment, the COVID-19 pandemic, and the war in Ukraine, we introduce permanent increases in both s^x and s^m of approximately 5.25%. This calibration is chosen to generate a 2.5% long-run decline in GDP, consistent with findings from a meta-analysis of nine empirical studies. These studies estimate the permanent output loss for the UK due to Brexit to lie between 2% and 8%, with most estimates concentrated in the 2-3% range.[27] As previously noted, trade frictions of the Brexit type not only reduce firms' profits directly (see Appendix

[26] In the following analysis, incorporating revenues from entry costs into the model yields a primary balance surplus equivalent to 3.88% of GDP. Nevertheless, the model's qualitative results remain unaffected.

[27] See, e.g., HM Treasury Report (2016), Bank of England Report (2018), Hantzche *et al.* (2018) NIESR Report, Springford *et al.* (2016) CER Report, Oxford Economics Report (2016), LSE (2016), HM Treasury Report (2018), ESRC (2017), and Forlett and Clarke (2017) Resolution Foundation Report.

E, Equation (E.9)) but also distort production decisions. Specifically, import costs s^m raise the marginal cost of imported intermediate inputs (see the right-hand side of eq. (E.12)). Additionally, because monopolistically competitive domestic producers internalise the domestic price of exports, export costs s^x increase the marginal cost of all three production inputs: labour, imported intermediates, and physical capital (see the right-hand sides of eq. (E.11)-E.13)).

Figure 5 presents the dynamic responses of the model following the permanent increase in trade costs described above as the economy transitions from the initial pre-Brexit steady state to a new long-run equilibrium, with all variables shown as percentage deviations from their initial steady-state levels.

The results indicate substantial declines in both physical capital and the use of imported intermediate goods. The number of active firms as a share of the total population (n_t^h) decreases, while price markups (defined as $1/\theta_t$) increase, reflecting a decline in market competition. These changes propagate through the economy, leading to broad-based declines in key macroeconomic indicators. Specifically, per capita GDP, consumption, investment and trade volumes all contract, accompanied by a deterioration in the terms of trade.

Figure 5: Permanent trade costs shocks

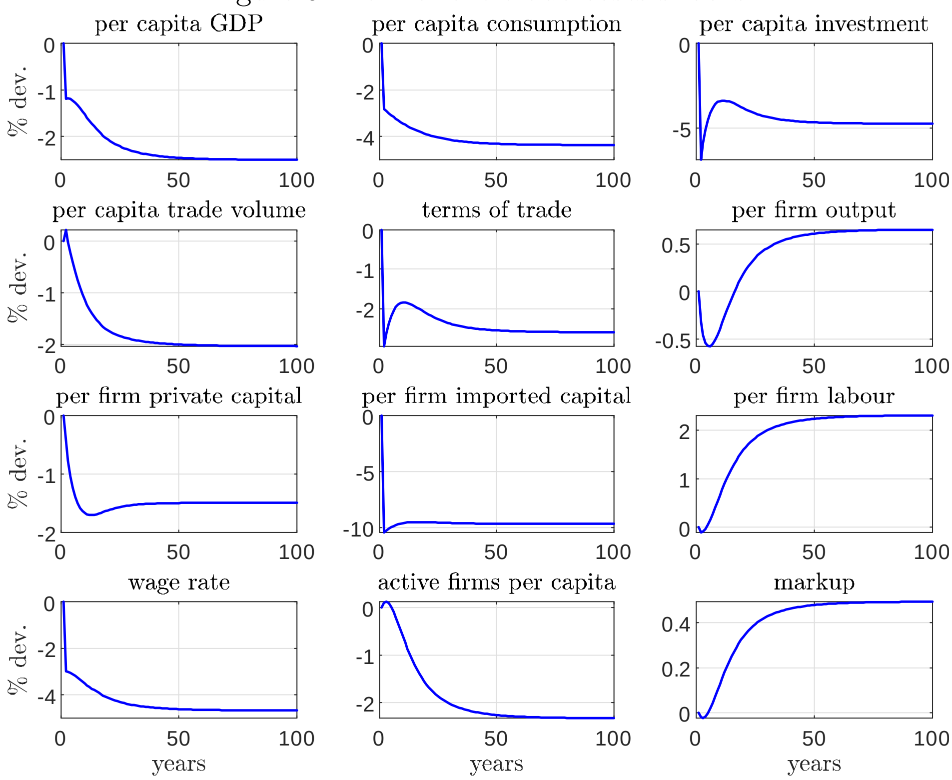
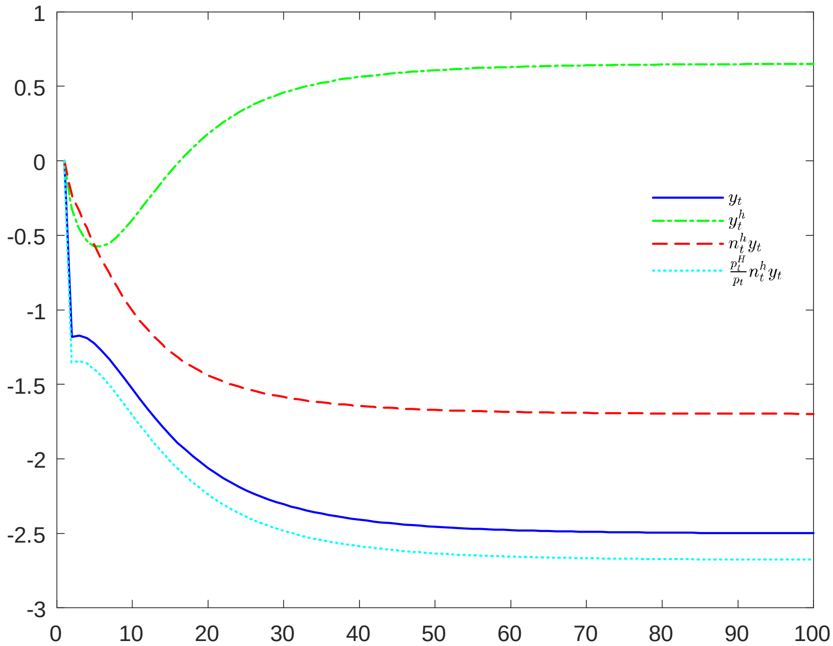


Figure 5 also reveals that, despite a permanent reduction in per-firm private capital and imported intermediates, output per surviving firm increases, driven primarily by a rise in per-firm labour input. This suggests that labour partially substitutes for both types of capital in the production process. However, this firm-level adjustment is insufficient to offset the broader macroeconomic impact: per capita GDP, y_t, ultimately declines by 2.5% in the long run.

Figure 6 helps unpack this outcome by decomposing y_t into gross domestically produced output and the volume of imported intermediate inputs used in production. The figure highlights that the primary driver of the overall decline in per capita GDP is a permanent fall in the endogenous number of active firms, n_t^h. This contraction in firm entry and survival reduces aggregate productive capacity, outweighing the gains in output at the individual firm level. To aid interpretation of Figure 6, recall from Appendix E that per capita GDP is defined as $y_t \equiv n_t^h \left(\frac{p_t^H}{p_t} y_{h,t} - \frac{p_t^F}{p_t} m_{h,t} \right)$ where $n_t^h \frac{p_t^H}{p_t} y_{h,t}$ is gross domestically produced output and $n_t^h \frac{p_t^F}{p_t} m_{h,t}$ is imported goods used as intermediate inputs in production.

Figure 6: Per capita GDP and per firm output



5.3 Exogenous n_t^h and θ_t

To understand how endogenous firm creation and price markups influence the economic losses imposed by Brexit, we reconsider the experiment from the baseline model in Figure 5, but now counterfactually assume that the share of active to potential firms, n_t^h, and the price markup, $1/\theta_t$, are exogenous. Specifically, we fix n_t^h, θ_t, and Ξ_t at their initial steady-state values reported in Table 3. Correspondingly, as detailed in Appendix E, we remove equations (E.14)–(E.17) from the system and exclude the variables n_t^h, θ_t, Ξ_t, and V_t from the set of endogenous variables. This procedure ensures that the initial, departure steady-state values of the baseline and restricted models are identical, enabling a direct comparison of their dynamic responses.

For convenience, the baseline results from Figure 5 are reproduced in Figure 7 alongside the counterfactual outcomes. Apart from per-firm quantities, all adverse macroeconomic effects are noticeably less severe when firms and markups are held fixed. This finding highlights the critical and detrimental role that firm exit and weakened product market competition play in amplifying the economic damage during the post-Brexit adjustment.

Figure 7: Permanent trade costs shocks comparison

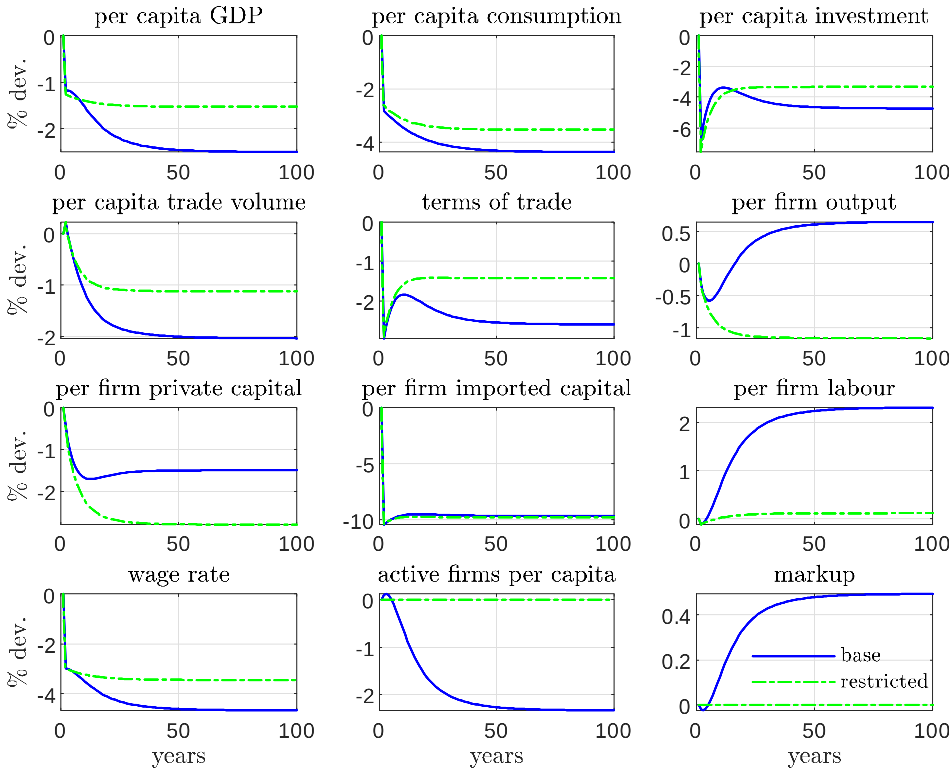


Table 4: Steady state after Brexit

	General Model [1]	Restricted Model [2]	[1] minus [2] [3]
variable	% dev. from ss	% dev. from ss	ppt. diff.
GDP	-2.500	-1.534	-0.967
consumption	-4.369	-3.535	-0.833
investment	-4.749	-3.319	-1.430
trade volume	-2.034	-1.127	-0.907
terms of trade	-2.586	-1.427	-1.159
output per firm	0.6520	-1.1608	1.813
private capital per firm	-1.491	-2.787	1.296
imported capital per firm	-9.689	-9.817	0.128
labour per firm	2.306	0.119	2.187
wage rate	-4.669	-3.434	-1.236
active firms	-2.335	0.000	-2.335
markup	0.493	0.000	0.493

Complementing Figure 7, columns [1] and [2] in Table 4 report the long-run values of all variables under both scenarios. Column [3] presents the differences, which quantify the additional losses attributable to endogenous firm exit and markup increases induced by Brexit-related trade shocks. For instance, relative to the model with exogenous firms and markups, the observed 2.3 percentage point decline in the active firm share and roughly 0.5 percentage point increase in markups generate additional long-run losses of approximately one percentage point in GDP, 0.8 percentage points in consumption, and 1.4 percentage points in investment, among other impacts.

5.4 Welfare loss from Brexit

Table 5 reports the welfare losses associated with the Brexit-related trade shocks, as measured by the compensating consumption supplement, χ, defined in Appendix H. This metric represents the permanent percentage increase in consumption that would be required in every period to make a representative household indifferent between the pre- and post-Brexit equilibria.

The results indicate a decline in lifetime utility equivalent to a permanent consumption loss of approximately 3.10% in the baseline model and 2.69% in the restricted model, where firm entry and markups are held exogenous. These are economically significant welfare costs.

To put these numbers in context, Lucas (1990) famously estimated the welfare gain from transitioning the U.S. economy from its actual tax system to the optimal Ramsey tax regime, a highly ambitious reform, as approximately 4%. Our results, therefore, imply that the long-run welfare costs of Brexit, driven in part by increased trade frictions and the resulting erosion of market competition, are of a comparable order of magnitude. This underscores the substantial and persistent nature of the structural damage induced by Brexit.

Table 5: Lifetime welfare vis-a-vis pre-Brexit (%)

	χ
general model	-3.104
restricted model	-2.694

5.5 Key findings

As shown above, the additional macroeconomic losses observed in the baseline model, relative to the counterfactual with exogenous firm dynamics and markups, can be traced to two interrelated mechanisms: the endogenous reduction in firm entry and survival, and the resulting increase in market power and price markups. These mechanisms, triggered by the permanent trade cost shocks associated with Brexit, interact to reduce competition, diminish productive capacity, and amplify macroeconomic distortions during the transition to the new steady state.

5.5.1 Firm Exit and Reduced Product Variety

As trade costs rise, whether through higher import frictions s^m or export barriers s^x, profitability in the product market declines. In the baseline model, this leads to a contraction in the number of active firms n_t^h, which is determined endogenously based on firm-level profitability and the free-entry condition. A reduced firm count has several adverse implications:

- Lower product variety: Fewer firms imply a reduction in the variety of intermediate and final goods available to consumers and producers, thereby lowering both utility and productive efficiency in the Dixit-Stiglitz framework.
- Decline in capital: With fewer firms in operation, aggregate investment in capital is reduced, dampening long-run per capita GDP.

5.5.2 Weaker Competition and Rising Markups

A key consequence of declining firm numbers is reduced competition in the product market. In the model (see e.g. equation (E.14) in Appendix E), this is captured by an increase in the endogenous measure of market power, $1/\theta_t$, which in turn raises price markups. Higher markups introduce several distortions:

- Allocative inefficiency: Elevated markups drive a wedge between marginal cost and price, distorting resource allocation across firms and sectors.
- Lower real wages and consumption: With firms capturing a larger share of output through higher markups, the labour share of income declines, depressing household consumption.

5.5.3 Amplification Through Feedback Effects

The interaction between firm exit and markup creates a feedback loop that amplifies the macroeconomic damage of trade frictions. As firms exit, competition weakens, allowing markups to rise, which in turn further discourages entry. This self-reinforcing dynamic exacerbates the transition losses and results in a lower long-run per capita output path than would be observed under fixed firm structure and pricing power. These differences highlight the crucial role of endogenous firm dynamics and market structure in shaping the long-term economic implications of Brexit. The losses from trade frictions are not merely static but are endogenously magnified through the erosion of competitive forces and productive capacity.

6 Can policy restore the pre-Brexit allocation?

Given the macroeconomic costs of Brexit outlined above, this section examines a policy mix that can fully offset these effects by replicating the pre-Brexit equilibrium.

As shown earlier, these costs stem from permanent trade shocks, s^m and s^x, which reduce firm profitability and distort input choices by raising the marginal costs of labour, imported intermediate goods, and capital. These distortions ultimately alter the equilibrium allocation of resources, generating what we refer to as the long-run Brexit costs.

To directly address these distortions at the firm level, we introduce a set of targeted input subsidies: a wage subsidy τ_t^w, a subsidy on imported intermediate inputs τ^m, and a subsidy on newly purchased capital τ^k. These appear in the firm's profit function (see equation (F.1) in Appendix F), and accordingly modify its first-order conditions (see equations (F.2)–(F.4)). These subsidies are chosen explicitly to neutralize the distortive effects of the Brexit shocks on firms' input decisions (see equations (F.5)–(F.7)).

In addition, we include a lump-sum transfer $g_{h,t}^s$ to each firm (also defined in equation (F.1)) that, in equilibrium, offsets the direct income effects of the trade shocks and input subsidies, i.e., s_t^m, s_t^x, τ_t^w, τ_t^m and τ_t^k, on profits. To ensure budget neutrality, these firm-level lump-sum transfers are financed by lump-sum taxes levied on households, denoted $T_{i,t}^s$. The algebraic derivations of the new equilibrium conditions under this policy regime are provided in Appendix F.[28]

By construction, this policy mix fully restores the pre-Brexit allocation of resources at all periods t.[29] As a result, the associated welfare gain, as measured by the compensating consumption supplement, is precisely equal in magnitude and opposite in sign to the Brexit-related loss reported in Table 5, amounting to approximately 3.1%.

Table 6 reports the values of the policy instruments required to achieve this replication. The first row of the table displays the three endogenous per-unit input subsidies in columns 1 to 3, and the corresponding lump-sum firm-level subsidy (financed by an equivalent lump-sum household tax) in column 4. Among these instruments, intermediate imports receive the most significant subsidy, approximately 6.6%, followed by labour at roughly 1.3%, and capital at just under 0.25%.

To contextualise the magnitude of these subsidies, the final row of Table 6 reports their values as shares of GDP (see Appendix F, equations (F.15)–(F.19) for the definitions). Except for the wage subsidy, which exceeds 0.5% of GDP, all other subsidy-to-GDP ratios remain below this threshold, indicating that the total fiscal cost of replicating the pre-Brexit equilibrium is relatively modest.

[28] In this case, the net lump-sum transfer received by each household is $g_t^{tr} - n_h g_{h,t}^s$, where g_t^{tr} continues to satisfy the government budget constraint (given the targeted debt-to-GDP ratio), and $g_{h,t}^s$ represents the additional lump-sum tax collected from each household to finance the corresponding firm-level transfers.

[29] See also Barro and Sala-i-Martin (2004, Chapter 6), where, through a suitable combination of input subsidies and lump-sum tax/subsidy instruments, a decentralised market economy with imperfections can be made to replicate the allocation achieved by a social planner.

Table 6: Socially optimal Tax/Subsidy policy

τ^w	τ^m	τ^k	$g^s_{h,t}$
1.336%	6.605%	0.213%	0.364%

$\frac{\text{wage subsidy}}{\text{gdp}}$	$\frac{\text{import subsidy}}{\text{gdp}}$	$\frac{\text{capital subsidy}}{\text{gdp}}$	$\frac{\text{lump-sum subsidy}}{\text{gdp}}$
0.798%	0.152%	0.423%	0.116%

While beneficial as a benchmark, the policy mix described above is highly challenging to implement in practice. As noted by Barro and Sala-i-Martin (2004, p. 300) in a similar normative exercise, although such taxes and subsidies are conceptually straightforward, their execution is far more complex. Specifically, the government must not only subsidise the appropriate inputs but also finance these subsidies through non-distortionary taxation, an inherently difficult task in real-world settings.

Building on the theoretical benchmark, the following section evaluates a set of more pragmatic policy responses that acknowledge political, administrative, and fiscal constraints. Instead of attempting to replicate the pre-Brexit allocation of resources fully, these policies are designed to restore only per capita GDP to its pre-Brexit level, an arguably more attainable objective. Specifically, we examine combinations of commonly used policy instruments, including broad-based subsidies, tax adjustments, and targeted fiscal spending, and assess their macroeconomic and welfare implications. By comparing these second-best alternatives with the optimal but impractical benchmark, we aim to provide policymakers with guidance on how to mitigate the long-term economic costs of Brexit.

7 Industrial and fiscal policy

As discussed above, it is not possible, at least within the context of our model and under realistic policy assumptions, to fully reverse the damage caused by Brexit. We therefore turn to exploring policy interventions that aim to mitigate this damage. Our focus is on measures that, by stimulating private and public investment, can at least restore long-run per capita GDP to its pre-Brexit level, as shown in Table 3. In particular, we consider policies that permanently reduce the fixed cost of firm entry, increase tax allowances for new investment, enhance public investment, and raise per-unit subsidies on labour and capital.[30] Governments worldwide, including those in the UK, have long implemented strategies to encourage private investment to boost their economies' GDP. These often include simplifying regulations, improving

[30] Note that we also examined the possibility of subsidising intermediate imports. However, the incentives provided by this instrument were insufficient to restore GDP to its pre-Brexit value.

infrastructure, and offering financial incentives such as favourable tax treatment and subsidies.

Specifically, the policies we consider include:

1. Reducing the fixed cost of firm entry, F: The calibrated pre-Brexit value of F is 6.23. To restore GDP to its pre-Brexit long-run level, F must be permanently reduced to 5.75, a decrease of approximately 8%. It is essential to note that reducing F is not costless, as it also represents a loss of government revenue (see eq. (17)).

2. Increasing tax deductions for new investment, λ^i: In the pre-Brexit steady-state, $\lambda^i = 0$ (see Appendix G). Restoring GDP requires permanently increasing λ^i to 21.3%.

3. Raising the public investment-to-output ratio, $\frac{g^i}{y}$: The pre-Brexit value of this ratio is 2.8%, based on empirical data. To achieve our GDP target, it must increase to 3.84%.

4. Increasing the subsidy to labour, τ^w: The pre-Brexit steady-state value of τ^w is 0% (see Appendix F). A permanent increase to 6.02% is needed to reach the target GDP.

5. Increasing the subsidy to newly purchased capital, τ^k: Similarly, the pre-Brexit value of τ^k is 0% (see Appendix F). Achieving the target GDP requires a permanent increase to 0.358%.

In summary, for each of these five policy instruments, we calculate the magnitude of change required to raise long-run per capita GDP by 2.5% and return it to its pre-Brexit level, and then examine the resulting macroeconomic dynamics over time. However, none of these policies is a "free lunch". They all imply higher spending or lower revenues, which means that another public financing instrument needs to adjust accordingly to balance the government budget. We will consider two cases: one with the public debt-to-GDP ratio kept constant over time and one with the public debt being free, meaning that a portion of the fiscal cost is in the form of rising public debt over time. As is standard in the literature, we explore the effects of each policy in isolation.

7.1 Results: constant public debt to GDP ratio

We begin by considering a public financing scenario in which the public debt-to-GDP ratio remains constant at its initial level. When implementing the policy changes described in (1) through (5) above, we assume that the government budget constraint is closed via adjustments in lump-sum transfers. In this setting, transfers act as the residual fiscal instrument. Alternatively, we will also consider scenarios in which consumption and income tax rates serve as the residual financing instruments, holding other factors constant.

Table 7: Deviations from baseline post-Brexit steady-state

	g^{tr} financed						
	y %	c %	i %	nx %	n^h %	$\frac{1}{\theta}$ %	$\Delta\frac{g^{tr}}{y}$
$\downarrow F$	2.500	2.198	3.783	2.443	6.144	-1.207	-0.304
$\uparrow \lambda^i$	2.500	1.593	6.416	1.786	1.474	-0.306	-0.661
$\uparrow\frac{g^i}{y}$	2.500	0.765	2.569	1.046	2.258	-0.464	-1.190
$\uparrow\tau^w$	2.500	2.423	2.829	2.486	1.507	-0.312	-3.328
$\uparrow\tau^k$	2.500	1.720	5.859	1.924	2.431	-0.498	-0.745
	τ^c financed						
	y %	c %	i %	nx %	n^h %	$\frac{1}{\theta}$ %	$\Delta\tau^c$
$\downarrow F$	2.355	2.057	3.617	2.297	6.052	-1.190	0.494
$\uparrow \lambda^i$	2.183	1.288	6.044	1.472	1.283	-0.267	1.078
$\uparrow\frac{g^i}{y}$	1.926	0.217	1.920	0.483	1.907	-0.393	1.957
$\uparrow\tau^w$	0.955	0.925	1.080	0.949	0.577	-0.121	5.377
$\uparrow\tau^k$	2.142	1.376	5.442	1.571	2.212	-0.455	1.213
	τ^y financed						
	y %	c %	i %	nx %	n^h %	$\frac{1}{\theta}$ %	$\Delta\tau^y$
$\downarrow F$	2.304	2.008	3.560	2.248	6.021	-1.184	0.414
$\uparrow \lambda^i$	2.071	1.181	5.913	1.362	1.216	-0.253	0.899
$\uparrow\frac{g^i}{y}$	1.722	0.024	1.691	0.284	1.783	-0.368	1.621
$\uparrow\tau^w$	0.434	0.420	0.491	0.431	0.262	-0.055	4.260
$\uparrow\tau^k$	2.016	1.255	5.296	1.447	2.135	-0.439	1.010

The outcomes of these policy experiments are summarised in Table 7 above, which reports the percentage deviations of the new terminal steady state from the baseline post-Brexit steady state (as presented in Section 5) for key macroeconomic indicators. These include per capita GDP y, consumption c, investment i, net exports nx, the share of active firms n^h, and the price markup $\frac{1}{\theta}$, across all five policy interventions. The final column in Table 7 presents the absolute change in the financing instruments, lump-sum transfers, consumption tax rates and income tax rates, relative to their post-Brexit baseline levels.[31] Transfers are reported as a share of GDP to contextualise the scale of fiscal adjustments.[32]

[31] It is important to note that targeting a 2.5% increase in GDP using the two distortionary instruments (τ^w and τ^k) does not change the qualitative welfare rankings reported in Table 7. Furthermore, since our policy analysis focuses on directly or indirectly promoting investment, we do not consider financing policies through increased corporate taxation (τ^π).

[32] For reference, the baseline post-Brexit steady-state values of the residual financing instruments are: $\frac{g^{tr}}{y}$=15.13%, τ^c=15.20% and τ^y=28.17%.

Several significant findings emerge from this analysis:

1. Distortionary financing and macroeconomic gains: When comparing the percentage increases in output, consumption, investment, and net exports across different financing assumptions, gains are consistently lower under distortionary instruments, with the weakest gains emerging under income taxes as the residual instrument, which are more distortionary than consumption taxes.

2. Policy ranking by macroeconomic impact: The firm entry cost reduction (F policy) consistently ranks between first and third in terms of boosting output-related aggregates. In contrast, the public investment policy ($\frac{g^i}{y}$) ranks last or next-to-last for these same aggregates across all financing instruments.

3. Investment effects: The investment allowance (λ^i) and capital subsidy (τ^k) policies yield the strongest increase in investment, regardless of the financing instrument used.

4. Firm dynamics and market power: The F policy is especially effective in increasing the share of active firms, n^h, and lowering the markup, $\frac{1}{\theta}$, outperforming all other policies on these fronts across all financing regimes.

5. Public finance implications: The fiscal cost of reducing the firm entry cost, F, as measured by changes in $\frac{g^{tr}}{y}$, τ^c, and τ^y, is the smallest among all five policies. By contrast, the labour subsidy policy (τ^w) imposes the largest burden on public finances, requiring the most significant fiscal adjustments across all financing instruments.

To assess and compare the welfare implications of the five policy interventions, we present Table 8, which provides a rank ordering based on compensating consumption, χ, as derived in Appendix H. In addition to χ, Table 8 also reports the direct components of household welfare, namely the percentage deviations from the pre-Brexit steady state in: per capita private consumption, c, per capita public consumption, g^c, and labour effort, l_i. This enables a more comprehensive comparison of policy effectiveness, not only in terms of output and investment (as discussed earlier), but also in terms of how each policy affects household utility through its key channels.

Table 8: Welfare gains and drivers

		g^{tr} financed			
rank	policy	χ %	c % dev.	g^c % dev.	l_i %.dev.
1	$\downarrow F$	1.708	2.198	1.333	0.500
2	$\uparrow \tau^k$	0.807	1.720	2.312	0.439
3	$\uparrow \tau^w$	0.786	2.423	2.801	2.643
4	$\uparrow \lambda^i$	0.592	1.593	2.573	0.422
5	$\uparrow \frac{g^i}{y}$	0.091	0.765	2.079	0.615
		τ^c financed			
rank	policy	χ %	c % dev.	g^c % dev.	l_i %.dev.
1	$\downarrow F$	1.641	2.058	1.173	0.349
2	$\uparrow \tau^k$	0.711	1.376	1.914	0.069
3	$\uparrow \lambda^i$	0.518	1.288	2.217	0.094
4	$\uparrow \tau^w$	0.313	0.925	1.069	1.009
5	$\uparrow \frac{g^i}{y}$	-0.094	0.217	1.440	0.021
		τ^y financed			
rank	policy	χ %	c % dev.	g^c % dev.	l_i %.dev.
1	$\downarrow F$	1.752	2.008	1.116	0.296
2	$\uparrow \tau^k$	0.646	1.255	1.774	-0.060
3	$\uparrow \lambda^i$	0.418	1.181	2.092	-0.022
4	$\uparrow \tau^w$	0.147	0.420	0.485	0.458
5	$\uparrow \frac{g^i}{y}$	-0.139	0.024	1.214	-0.190

The first key finding is that the firm entry cost reduction (F policy) delivers the highest welfare across all financing instruments. Its compensating consumption value, $\chi \approx$1.7%, amounts to over half the value obtained in the complete subsidy-based recovery scenario (approximately 3.1%), which fully restored the pre-Brexit allocation of resources.

Interestingly, even though both private, c, and public consumption, g^c, are lowest under income tax financing (τ^y), this case still marginally delivers the highest welfare compared to the lump-sum transfer (g^{tr}) and consumption tax (τ^c) alternatives. This outcome is driven by the fact that the τ^y scenario involves the smallest increase in labour effort, l_i, thereby minimising the disutility associated with work.

Next, the capital subsidy policy (τ^k) consistently ranks second in terms of welfare across all financing schemes. In contrast, the wage subsidy (τ^w) and the tax allowance on new capital investment (λ^i) generally vie for the third and fourth positions, depending on the financing configuration. Finally, public investment ($\frac{g^i}{y}$) ranks last in welfare terms under all financing mechanisms considered.

Thus, among the five policies considered, reducing the fixed cost of firm entry (F policy) emerges as the most effective intervention for mitigating the long-run economic damage of Brexit. It delivers the highest welfare gains across all financing schemes, achieving over half the welfare improvement of a full resource reallocation.

7.2 Results: endogenous public debt to GDP ratio

We now revisit the same policy experiment described above, targeting pre-Brexit per capita GDP, except with a key difference: rather than holding the public debt-to-GDP ratio constant, we allow the end-of-period public debt to adjust endogenously to close the government budget constraint in each period. This modification brings the model closer to the fiscal reality faced by policymakers, where debt levels typically evolve in response to policy decisions and economic conditions. Given our earlier finding that reducing firm entry costs, F (policy 1) yields the most substantial welfare gains relative to the alternative policies (2)–(5), we focus exclusively on this case to economise on space.

It is well established that allowing public debt to be determined endogenously requires a stabilising fiscal feedback mechanism to ensure dynamic stability and determinacy. Specifically, one or more exogenous fiscal instruments must respond to deviations of the debt-to-GDP ratio from its long-run target.[33] Consistent with this approach, we model fiscal adjustment via debt-contingent feedback rules for the three exogenous instruments, government transfer spending, consumption tax rate, and labour income tax rate, as follows:

$$
\begin{aligned}
g_t^{tr} &= (1-\rho)g_t^{tr} + \rho g_{t-1}^{tr} - \gamma^b \left(\frac{b_{i,t}}{y_t} - \frac{b}{y}\right), \\
\tau_t^c &= (1-\rho)\tau^c + \rho \tau_{t-1}^c + \gamma^b \left(\frac{b_{i,t}}{y_t} - \frac{b}{y}\right), \\
\tau_t^y &= (1-\rho)\tau^y + \rho \tau_{t-1}^y + \gamma^b \left(\frac{b_{i,t}}{y_t} - \frac{b}{y}\right),
\end{aligned} \tag{20}
$$

where g^{tr}, τ^c, τ^y and $\frac{b}{y}$ are steady-state values, $0 < \rho < 1$ is a persistence parameter, and $\gamma^b \geq 0$ is a feedback policy coefficient.[34]

Thus, while the end-of-period public debt now closes the budget constraint in each period, fiscal policy also responds endogenously to fluctuations in debt. As in the previous subsection, we consider each fiscal instrument separately to assess their relative performance in stabilising debt and supporting the policy objective.

7.2.1 Macroeconomic outcomes

Figures 8a–8c display the impulse response functions (IRFs) of key macroeconomic variables following a reduction in firm entry costs, F, under different public financing strategies. Specifically, we compare three cases: (i) financing through a combination

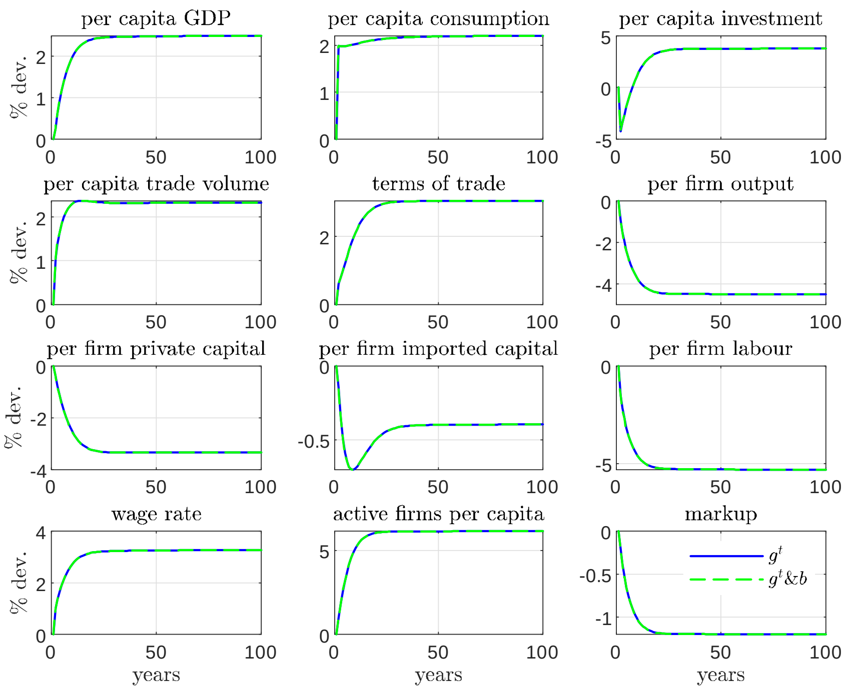
[33] See, e.g. Leeper *et al.* (2010), Sims and Wolff (2018) and Malley and Philippopoulos (2023).

[34] In our numerical solution, we set g^{tr}, τ^c, τ^y and $\frac{b}{y}$ to their calibrated values in Table 2. Moreover, we set $\gamma^b = 0.07$,, the minimum value required to ensure stability across all three fiscal rules, and follow the literature in setting $\rho = 0.85$.

of public debt and lump-sum transfers (Figure 8a); (ii) public debt and consumption taxes (Figure 8b); and (iii) public debt and income taxes (Figure 8c). For each case, we also include the corresponding IRFs under the assumption of a constant public debt-to-GDP ratio, as in the previous subsection, where the same policy change is financed solely by lump-sum transfers, consumption taxes, or income taxes, respectively.

As shown in Figure 8a, there is no difference between using only lump-sum transfers and using a combination of lump-sum transfers and public debt. This outcome is expected: in this class of models, lump-sum transfers and public debt are equivalent instruments in terms of their macroeconomic impact, given the presence of distortionary taxes and other components of public spending that bind the economy's resource constraint.

Figure 8a: F-shock (g^{tr} vs g^{tr} & b financed)



In contrast, Figure 8b reveals that the financing method does matter when consumption taxes are used. Except for consumption, the combination of public debt and debt-contingent consumption taxes generally yields more favourable outcomes in the short to medium term, particularly for per capita GDP, the share of active firms, and markups, compared to using consumption taxes alone. The intuition is straightforward: when a policy instrument is relatively non-distortionary, allowing public debt to absorb some of the short-term fiscal burden can improve macroeconomic performance, even if taxes must eventually be adjusted to restore intertemporal budgetary balance.

Figure 8b: F-shock (τ^c vs τ^c & b financed)

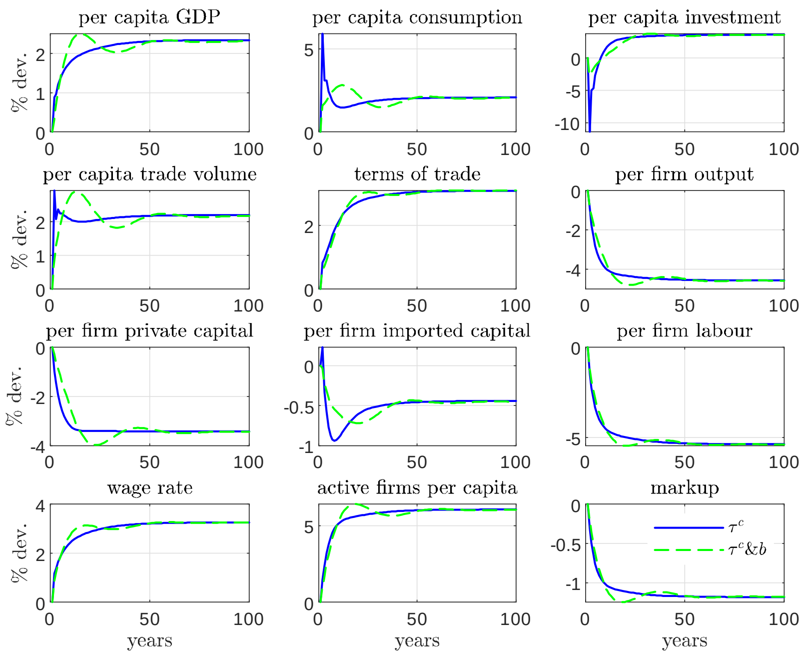


Figure 8c: F-shock (τ^y vs τ^y & b financed)

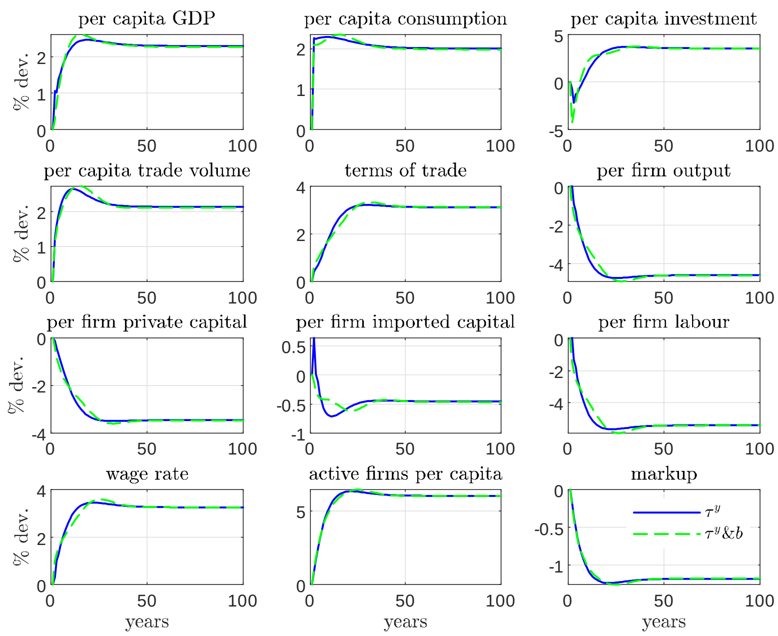
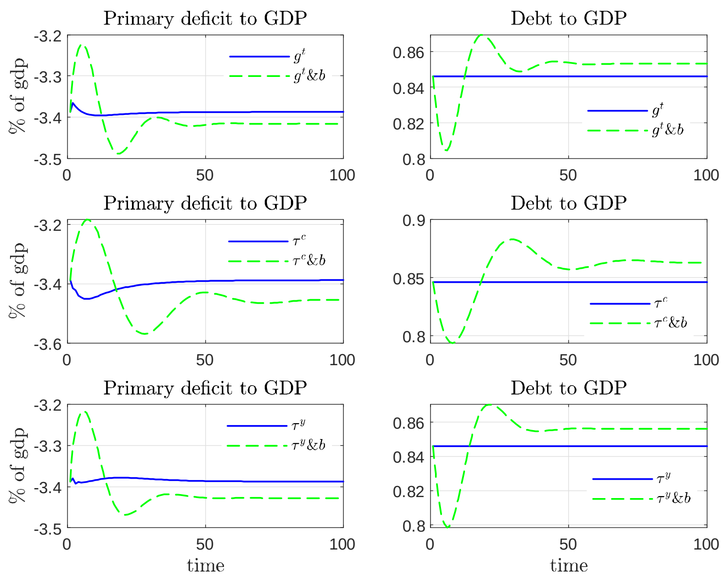


Figure 8c shows some differences between the two financing schemes involving income taxes, but these are relatively minor. In this case, whether the fiscal cost ofreducing F is financed solely by income taxes or by a combination of public debt and debt-contingent income taxes has limited implications for the macroeconomic variables considered.

Finally, Figure 9 presents the dynamic trajectories of the primary deficit-to-GDP and public debt-to-GDP ratios under both financing regimes. In the short term, both ratios improve, driven by the boost in GDP resulting from a reduction in firm entry costs, F. Over time, however, the primary deficit ratio begins to deteriorate gradually, while the debt ratio steadily increases. Eventually, both ratios stabilise, the deficit ratio at a level below its initial steady state, and the debt ratio above it. This divergence highlights the long-run effects of debt financing, particularly the burden of higher interest payments relative to the no-debt-financing scenario.

Figure 9: Debt and Deficits



7.2.2 Lifetime welfare

The compensating consumption supplements reported in Table 9 align closely with the impulse response functions presented in Figures 8a–8c. Specifically, consistent with Figure 8a, the choice between lump-sum transfers alone and a combination of transfers and public debt does not affect welfare outcomes, reflecting the theoretical equivalence of these instruments in this class of models. In contrast, Table 9 confirms that combining public debt with consumption taxes yields slightly higher welfare compared to relying solely on consumption taxes with a constant debt-to-GDP ratio (as in Figure 8b). This highlights the benefit of allowing temporary debt accumulation when the financing instrument is relatively non-distortionary. In contrast, the opposite holds in the case of income taxes, the compensating consumption measure is slightly lower for the joint use of debt and income taxes. The slightly lower compensating consumption measure when income taxes and debt are used jointly likely reflects the compounded distortionary effects and weaker intertemporal smoothing benefits compared to pairing debt with consumption taxes. Nonetheless, the welfare gains within and across financing methods are of a similar order of magnitude.[35]

Table 9: Lifetime welfare from lowering F, $\chi\%$

g^{tr} financed	1.708	g^{tr} & b financed	1.708
τ^c financed	1.641	τ^c & b financed	1.685
τ^y financed	1.752	τ^y & b financed	1.739

7.2.3 Fiscal costs

To further help illustrate the analysis and better understand the fiscal costs associated with lowering the firm entry cost F, we refer to the government budget constraint (GBC) in the terminal steady state (see Appendix E):

$$GBC = \underbrace{\frac{p^H}{p}\left(g^c + g^i\right)}_{G_1} + \underbrace{g^{tr}}_{G_2} + \underbrace{b_i\,(r-1)}_{G_3} - \underbrace{\frac{p^H}{p}\Xi(1-n^h)F}_{T_1} - \\ \underbrace{-\tau^c\left[\frac{p^H}{p}c_i^H + \frac{p^F}{p}c_i^F\right]}_{T_2} - \underbrace{\tau^y\left(wl_i + \pi_i\right)}_{T_3} - \underbrace{\tau^\pi n^h\left[\frac{p_h^H}{p}y_h - wl_h - \frac{p^F}{p}m_h\right]}_{T_4}, \tag{21}$$

where G_1 through G_3 refer to government (i) consumption plus investment spending, (ii) transfer spending and (iii) interest payments on the debt, whereas, T_1 through T_4 refer to tax revenues associated with (i) firm entry costs, (ii) private consumption, (iii) personal (labour and profit) income, and (iv) corporate income or profits. Because the government budget constraint holds in every period, the primary balance is defined as $p_b = \sum_{j=1}^{2} G_j - \sum_{j=1}^{4} T_j$ or, equivalently, $p_b = -G_3$.[36]

To facilitate the analysis of public finances under a reduction in firm entry costs F, Table 10 examines the primary balance and its components as shares of GDP. The first row provides a baseline by reporting the steady-state magnitudes for each element as a percentage of GDP. The subsequent rows present the changes in the primary balance and its components under various financing strategies.

We begin by considering the cases where the fiscal cost of reducing F is financed by adjustments in government transfer spending g^{tr}, consumption taxes τ^c, or income taxes τ^y, while maintaining a constant public debt-to-GDP ratio. In these cases, the steady-state primary balance as a share of GDP remains unchanged, i.e. $\Delta\frac{p_b}{y} = \Delta\frac{-G_3}{y} = \Delta\frac{-b_i(r-1)}{y} = 0$. This result follows analytically, as the assumption of a constant debt-to-GDP ratio implies no change in interest payments relative to

[35]Recall from Table 8 that the relatively higher welfare gains associated with the most distortionary instrument, τ^y, stem from the comparatively larger increase in labour effort, implying a relatively higher gain in utility-enhancing leisure.

[36]Note that expenditures related to tax allowances for new investment and subsidies to labour, imports, and capital are zero in the pre-Brexit steady state. These components are therefore excluded from eq. (21).

GDP. Moreover, both the initial and terminal interest rates are the same value (see Appendix E, Equation E.5, derived from the Euler equation for bonds).

Table 10: Components of the primary balance as a share of GDP

(post-Brexit steady-state ratios multiplied by 100)	$\frac{p_b}{y}$	$\frac{G_1}{y}$	$\frac{G_2}{y}$	$\frac{T_1}{y}$	$\frac{T_2}{y}$	$\frac{T_3}{y}$	$\frac{T_4}{y}$
	-3.388	23.400	15.133	5.937	9.229	20.169	6.585

(changes from post-Brexit steady-state multiplied by 100)	$\Delta\frac{p_b}{y}$	$\Delta\frac{G_1}{y}$	$\Delta\frac{G_2}{y}$	$\Delta\frac{T_1}{y}$	$\Delta\frac{T_2}{y}$	$\Delta\frac{T_3}{y}$	$\Delta\frac{T_4}{y}$
g^{tr} financed	0.000	0.000	-0.304	-0.200	-0.027	0.038	-0.115
τ^c financed	0.000	0.000	0.000	-0.196	0.272	0.038	-0.114
τ^y financed	0.000	0.000	0.000	-0.194	-0.027	0.334	-0.113
g^{tr} & b financed	-0.029	0.000	-0.333	-0.200	-0.027	0.038	-0.115
τ^c & b financed	-0.049	0.000	0.000	-0.195	0.320	0.037	-0.113
τ^y & b financed	-0.040	0.000	0.000	-0.194	-0.027	0.373	-0.113

The numerical results in Table 10 confirm this analytical finding. As expected, the most significant fiscal adjustments occur in the specific spending or revenue categories used to offset the loss in revenues due to the cut in F. For instance, when the public debt ratio is held constant:

- Under g^{tr} financing, public transfers fall from roughly 15.1% to about 14.8% of GDP.
- Under τ^c financing, consumption tax revenues rise from approximately 9.2% to 9.5% of GDP.
- Under τ^y financing, income tax revenues increase from around 20.2% to 20.5% of GDP.

In contrast, when public debt is allowed to vary over time, the fiscal adjustments are larger, reflecting the need to finance not only the initial revenue loss from reducing F but also the resulting increase in interest payments due to higher debt levels. Specifically:

- Public transfers decline from 15.1% to about 14.8% of GDP.
- Consumption tax revenues rise from 9.2% to 9.6% of GDP.
- Income tax revenues increase from 20.2% to 20.5% of GDP.

Furthermore, Table 10 shows that allowing the debt-to-GDP ratio to vary leads to a slight deterioration of the primary balance as a share of GDP across all financing methods. The largest decline occurs in the consumption tax-financed case, followed by the income tax-financed and transfer-financed cases. These worsening deficits are entirely consistent with the higher debt levels and the associated interest obligations discussed earlier.

7.3 Policy outcomes

1. Lowering firm entry costs, F, can strengthen economic performance by encouraging firm creation, enhancing competition, and raising per capita GDP in both the short and long term. However, by reducing government revenue, particularly from entry-related taxes, this policy creates a fiscal shortfall that must be addressed, potentially leading to long-term budgetary pressures.

2. Debt financing can improve outcomes when the tax instrument used to stabilise debt is relatively non-distortionary. For example, funding lower firm entry costs with a mix of debt and consumption taxes yields slightly higher welfare than relying solely on consumption taxes. Debt helps smooth the impact of taxation over time, resulting in higher GDP, more active firms, and lower markups in the short to medium term. Accordingly, the flexible use of public debt can enhance welfare, provided it is managed prudently.

3. While financing lower F through income taxes may yield slightly higher welfare, mainly due to increased leisure, it is generally less effective at stimulating key macroeconomic variables because of its higher distortionary impact. Moreover, combining income taxes with debt offers slightly less additional welfare benefit compared to income tax financing alone.

4. The welfare gains from reducing F are broadly comparable across all financing methods and account for over half of the gains achieved under the optimal policy. Moreover, this reform consistently outperforms all alternative policies in terms of welfare, establishing it as a strongly dominant option.

8 Conclusions

This paper developed a dynamic general equilibrium model to analyse the key macroeconomic effects of Brexit, as observed in the data, and to evaluate policy responses that could mitigate its negative consequences. We focused exclusively on trade shocks to explain these effects, avoiding the need to introduce additional shocks. The model captured a broad set of economic mechanisms beyond the standard impact of rising trade costs on firm decisions. These included a decline in the number of active firms, higher price markups, and reduced market competition, each of which emerged endogenously from the model and aligned closely with empirical patterns.

Using this framework, we quantified the additional economic damage resulting from these endogenous responses. Incorporating them into the analysis resulted in an extra 1% decline in GDP, a 2.3% decrease in the number of active firms, and a 0.5% increase in price markups. The estimated consumption-equivalent welfare cost of Brexit for UK households increased to 3.1%, up from 2.7% when these channels were excluded.

After identifying an optimal tax-subsidy policy that could fully offset the adverse effects of Brexit, we turned to more practical strategies aimed at restoring the pre-Brexit level of per capita GDP. These policies involve trade-offs and do not represent cost-free solutions. Among them, reducing firm entry costs emerged as the most effective, recovering more than half of the welfare loss caused by Brexit across all financing approaches.

Like any study grounded in real-world complexities, our analysis remains partial. The UK's persistent productivity challenges highlight the need for future research that embeds Brexit and related policies within an endogenous growth framework that explicitly models productivity dynamics. We view this as a promising and essential next step.

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Appendix A: Data sources

The data for Figures 1-4 is from the Economic Freedom of the World, World Bank, Office for National Statistics (ONS) and GOV.UK.

Figure 1: efotw.org/economic-freedom/dataset?geozone=world&year=2022&page=dataset&min-year=2&max-year=0&filter=0.

Figure 2: www.worldbank.org/en/publication/worldwide-governance-indicators.

Figure 3: www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/bulletins/trendsinukbusinessdynamismandproductivity/2023.

Figure 4: www.gov.uk/government/statistics/business-population-estimates-2023/business-population-estimates-for-the-uk-and-regions-2023-statistical-release.

The data used for the calibration of the parameter values of the model, unless otherwise stated, are from UK sources, i.e., the Bank of England (BOE), ONS, Office for Budget Responsibility (OBR) and extend to 2019.

[1] The private agents' time discount factor, β, is calibrated from the steady state of the Euler equation for bonds (equation (E.2) in Appendix A). Following the related literature (e.g., Litsios *et al.*, (2020) and DiCecio and Nelson, (2007)), we employ a 4% real interest rate.

[2] The labour supply weight in utility, μ, is calibrated to target households' work time in the data.To arrive at this share, we use ONS data on average actual weekly hours of work for full-time workers, www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/timeseries/ybuy/lms. In particular, the mean value of weekly work hours from 1992-2019 of 37.65 hours or 1807.2 hours per year, as a share of total available hours per year of 8064, is 22%. Note that 1807.2 = (37.65 hours per week) x (4 weeks per month) x (12 months per year), and 8064 = (24 hours per day) x (7 days per week) x (4 weeks per month) x (12 months per year).

[3] For the ratio of foreign to domestic prices, we use, as a proxy, the average ratio of foreign to domestic GDP deflator over the period 1997-2019. The Treasury produces the domestic UK GDP deflator from data provided by the Office for National Statistics (ONS) and the Office for Budget Responsibility (OBR), www.gov.uk/government/statistics/gdp-deflators-at-market-prices-and-money-gdp-march-2024-quarterly-national-accounts. Regarding the foreign GDP deflator, we have chosen to use the German one, using data from the annual National Accounts drawn by Eurostat, www.ec.europa.eu/eurostat/databrowser/view/nama_10_gdp/default/table?lang=en&category=na10.nama10.nama_10_ma.

[4] The average real effective exchange rate over 1980-2019 is from the World Bank, www.databank.worldbank.org/source/world-development-indicators/Series/PX.REX.REER. The real effective exchange rate is a nominal effective exchange rate index adjusted for relative movements in the home country's national price or cost indicators.

[5] The average capital depreciation rates over 1995-2019 on private and public sectors' fixed assets, δ=0.074 and δ^g=0.075, respectively, are calculated using the ONS "Capital stocks and fixed capital consumption" database www.ons.gov.uk/releases/capitalstocksandfixedcapitalconsumptionuk2022. Specifically, our data is drawn from Table 2.1.1 (Net capital stock: by asset and sector, current prices) and Table 3.1.1 (Consumption of fixed capital: by asset and sector, current prices). The same dataset calculates the ratio of the private to public capital stock. To calibrate the respective depreciation rates, we follow the approach by Ramey (2021); the depreciation rates are calculated as the ratio of the current consumption of fixed capital to the stock of the net fixed assets in the previous period.

[6] The ONS derives data (1995-2019) for the ratio of net profits to GDP. Specifically, the net operating surplus of total corporations is the sum of the gross operating surplus of corporations from the financial sector (drawn by www.ons.gov.uk/economy/nationalaccounts/uksectoraccounts/datasets/ukeconomicaccounts and the gross operating surplus of non-financial corporations (drawn by www.ons.gov.uk/economy/national accounts/uksectoraccounts/timeseries/lrwl/prof. Then, we derive the total net operating surplus by subtracting the respective consumption of fixed capital (drawn by ONS "Capital stocks and fixed capital consumption" database, see above). Nominal GDP data are from the OBR www.obr.uk/data.

[7] For the number of closing businesses between 2001-2019, we use data from the ONS, www.ons.gov.uk/businessindustryandtrade/changestobusiness/businessbirthsdeathsandsurvivalrates/datasets/firmlevelbusinessdynamismestimatesfromthelongitudinalbusinessdatabasesummarystatisticsuk.

[8] Data for the average labour income share over 1955-2019 are from the ONS, www.ons.gov.uk/employmentandlabourmarket/peopleinwork/labourproductivity/timeseries/fzln/ucst.

[9] Data for the average private consumption to GDP (1985-2019) and private investment over GDP (1997-2019) are drawn from ONS, www.ons.gov.uk/economy/nationalaccounts/satelliteaccounts/timeseries/abqi/bb and www.ons.gov.uk/economy/grossdomesticproductgdp/datasets/grossfixedcapitalformationbysectorandasset, respectively. For the exports and imports to GDP (1997-2019), data are from ONS, www.ons.gov.uk/economy/nationalaccounts/balanceofpayments/datasets/uktradegoodsandservicespublicationtables.

[10] Data for the public spending items over GDP are from the ONS, `www.ons.gov.uk/economy/governmentpublicsectorandtaxes/publicspending/datasets/esatable2mainaggregatesofgeneralgovernment`. Public debt to GDP data are from the OBR, `www.obr.uk/data`. Data for the effective tax rates are drawn from the European Commission, `op.europa.eu/en/publication-detail/-/publication/d5b94e4e-d4f1-11eb-895a-01aa75ed71a1/language-en`.

Appendix B: Households' problem

The first-order conditions of household i for each domestic and foreign variety, $c_{i,h,t}^{H}$ and $c_{i,f,t}^{F}$, are (here we also use $c_{i,h,t}^{H}=\frac{c_{h,t}^{H}}{N}$ and $c_{i,h,t}^{F}=\frac{c_{f,t}^{F}}{N}$, so that it will be $Nc_{i,t}^{H}=N_t^h c_{h,t}^{H}$, and $Nc_{i,t}^{F}=N_t^f c_{f,t}^{F}$ in a symmetric equilibrium):

$$\frac{N_t^h c_{h,t}^H}{Nc_{i,t}^H}=\left(\frac{p_{h,t}^H}{p_t^H}\right)^{\frac{1}{\theta-1}}, \tag{B.1}$$

$$\frac{N_t^f c_{f,t}^F}{Nc_{i,t}^F}=\left(\frac{p_{f,t}^F}{p_t^F}\right)^{\frac{1}{\theta-1}}, \tag{B.2}$$

which give the demand functions for the products of each domestic firm h and each foreign firm f, respectively.

Moreover, the first-order conditions giving the supply of labor, $l_{i,t}$, the demand for domestic bonds, $b_{i,t}$, and the demand for foreign assets, $f_{i,t}$, are:

$$\mu_2 l_{i,t}^{\frac{1}{\kappa}}=\lambda_{i,t}(1-\tau_t^y)w_t, \tag{B.3}$$

$$\frac{\lambda_{i,t}}{\lambda_{i,t+1}}=\beta(1+i_t^b)\frac{p_t}{p_{t+1}}, \tag{B.4}$$

$$\begin{aligned}&\frac{\lambda_{i,t}}{\lambda_{i,t+1}}\frac{e_t p_t^*}{p_t}+\frac{\lambda_{i,t}}{\lambda_{i,t+1}}\frac{e_t p_t^*}{p_t}\psi^p\left(\frac{\frac{e_t p_t^*}{p_t}f_{i,t}}{\frac{p_t^H}{p_t}n_t^h y_{h,t}}\right)=\\&=\beta\frac{e_{t+1}p_{t+1}^*}{p_{t+1}}(1+i_t^*)\frac{p_t^*}{p_{t+1}^*},\end{aligned} \tag{B.5}$$

where $\lambda_{i,t}$ is the multiplier associated with i's budget constraint:

$$\lambda_{i,t}=\frac{\theta_C\left(c_{i,t}\right)^{\frac{n-1}{n}-1}}{(1+\tau_t^c)\left[\theta_C\left(c_{i,t}\right)^{\frac{n-1}{n}}+(1-\theta_C)(g_t^c)^{\frac{n-1}{n}}\right]}$$

Price equations

The above budget constraints and optimality conditions for the consumption goods also imply the three price indexes:

$$p_t=(p_t^H)^{\nu}(p_t^F)^{1-\nu}, \tag{B.6}$$

$$p_t^H = \left(\frac{1}{N_t^h} \sum_{h=1}^{N_t^h} (p_{h,t}^H)^{\frac{\theta}{\theta-1}} \right)^{\frac{\theta-1}{\theta}}, \tag{B.7}$$

$$p_t^F = \left(\frac{1}{N_t^f} \sum_{f=1}^{N_t^f} (p_{f,t}^F)^{\frac{\theta}{\theta-1}} \right)^{\frac{\theta-1}{\theta}}, \tag{B.8}$$

so that, in a symmetric equilibrium, we will have $p_t^H = p_{h,t}^H$ and $p_t^F = p_{f,t}^F$.

We also assume the law of one price for the imported good so that:

$$p_t^F = e_t p_t^{H*}. \tag{B.9}$$

Appendix C: Firms' problem

Product demand functions

For each active domestic firm $h = 1, 2, ..., N_t^h$, the demand for its product comes from domestic consumption, $c_{h,t}^H = \frac{C_t^H}{N_t^h} = \frac{Nc_{i,t}^H}{N_t^h}$, domestic investment, $i_{h,t} = \frac{I_t}{N_t^h}$, domestic government spending, $g_{h,t} = \frac{G_t}{N_t^h}$, and exports, $c_{h,t}^{H*} = \frac{C_t^{H*}}{N_t^h}$, where C_t^H is total private consumption of domestically produced goods, I_t is total investment spending on domestically produced goods, G_t is total government spending on domestically produced goods and services, and C_t^{H*} is total exports of domestically produced goods. Thus, the aggregate demand for the domestically produced good is $Y_t = C_t^H + I_t + G_t + C_t^{H*}$.

Recall from above that:

$$c_{h,t}^H = \left(\frac{p_{h,t}^H}{p_t^H} \right)^{\frac{1}{\theta-1}} \frac{Nc_{i,t}^H}{N_t^h} = \left(\frac{p_{h,t}^H}{p_t^H} \right)^{\frac{1}{\theta-1}} \frac{C_t^H}{N_t^h}, \tag{C.1}$$

where $Nc_{i,t}^H = N_t^h c_{h,t}^H$.

Using the same functional forms for the other components of demand (namely, private investment, government spending on goods and services, exports, etc.),[37] the demand function for the output of each domestic active firm h is:

$$y_{h,t} = \left(\frac{p_{h,t}^H}{p_t^H} \right)^{\frac{1}{\theta-1}} \frac{Y_t}{N_t^h}, \tag{C.2}$$

where recall that $\frac{Y_t}{N_t^h} \equiv \widetilde{y}_t$ is per active firm total domestically produced output.

Budget constraints

[37] This is common practice in this literature (see e.g. Leeper *et al.* (2021)).

The gross profit of each h denoted as $\pi^g_{h,t}$, is sales, $\frac{p^H_{h,t}}{p_t}y_{h,t}$, minus the wage bill, $w^p_t l_{h,t}$, minus the cost of imported intermediate goods, $m_{h,t}$. Thus,

$$\pi^g_{h,t} \equiv \frac{p^H_{h,t}}{p_t}y_{h,t} - w_t l_{h,t} - \frac{p^F_t}{p_t}m_{h,t}, \tag{C.3}$$

where $y_{h,t}$ is h's output, $l_{h,t}$ is the labour input and $m_{h,t}$ is imported goods used in production.

Gross profit is used for retained earnings, payment of taxes to the government, payment of dividends to shareholders, and the financing of transaction costs associated with changes in the capital stock, entry costs paid by new firms entering the sector, and extra Brexit-type trade costs. Thus, for each active firm h, we have:

$$\begin{aligned} \pi^g_{h,t} &\equiv R_{h,t} + \tau^\pi_t \left(\frac{p^H_{h,t}}{p_t}y_{h,t} - w_t l_{h,t} - \frac{p^F_t}{p_t}m_{h,t}\right) + \pi_{h,t} + \\ &+ \frac{p^H_t}{p_t}\frac{\xi^k}{2}\left(\frac{k_{h,t}}{k_{h,t-1}} - 1\right)^2 k_{h,t-1} + \frac{p^H_t}{p_t}\left(\frac{\Xi_t(N-N^h_{t-1})}{N^h_t}\right)F_t + s^m\frac{p^F_t}{p_t}m_{h,t} + s^x\frac{p^H_{h,t}}{p_t}c^{H,*}_t, \end{aligned} \tag{C.4}$$

where $R_{h,t}$ denotes h's retained earnings, $0 \leq \tau^\pi_t < 1$ a tax rate on gross profits, $\pi_{h,t}$ is the dividend paid to the firm's shareholders, $\xi^k \geq 0$ is a parameter measuring standard capital adjustment costs, while $s^m\frac{p^F_t}{p_t}m_{h,t}$ and $s^x\frac{p^H_{h,t}}{p_t}c^{H,*}_t$ are respectively extra Brexit-type import and export costs. Notice that new entrants also pay the entry cost, F_t, (see the last term on the RHS), which is weighted by the number of new entrants as a share of active firms, $\frac{\Xi_t(N-N^h_{t-1})}{N^h_t}$. Also, notice that we allow for investment spending to be tax deductible since it is a policy announced by both main political parties, which, in effect, works like an investment subsidy.

Purchases of new capital, i.e. investment, are financed by retained earnings only, so that:

$$\frac{p^H_t}{p_t}i_t \equiv \frac{p^H_t}{p_t}\left[k_{h,t} - (1-\delta)k_{h,t-1}\right] \equiv R_{h,t}. \tag{C.5}$$

Combining the above constraints, the firm's net dividend, $\pi_{h,t}$, distributed to its owners is:

$$\begin{aligned} \pi_{h,t} &= (1-\tau^\pi_t)\left(\frac{p^H_{h,t}}{p_t}y_{h,t} - w_t l_{h,t} - \frac{p^F_t}{p_t}m_{h,t}\right) - \\ &- \frac{p^H_t}{p_t}\left[k_{h,t} - (1-\delta)k_{h,t-1}\right] - \frac{p^H_t}{p_t}\frac{\xi^k}{2}\left(\frac{k_{h,t}}{k_{h,t-1}} - 1\right)^2 k_{h,t-1} - \\ &- \frac{p^H_t}{p_t}\left(\frac{\Xi_t(N-N^h_{t-1})}{N^h_t}\right)F_t - s^m\frac{p^F_t}{p_t}m_{h,t} - s^x\frac{p^H_{h,t}}{p_t}c^{H,*}_t, \end{aligned} \tag{C.6}$$

which is equation (14) in the main text.

Firm's optimization problem

Now, we can solve the firm's optimization problem. Each firm h maximizes the discounted sum of dividends distributed to its owners:

$$\sum_{t=0}^{\infty} \beta_{h,t} \pi_{h,t}, \tag{C.7}$$

where, since capital owners own firms, we will *ex post* postulate that the firm's discount factor, $\beta_{h,t}$, equals the capital owners' marginal rate of substitution between consumption at t and $t+1$, namely, $\beta_{h,0} \equiv 1$, $\beta_{h,1} \equiv \frac{\beta(1-\Omega)\lambda_{c,t+1}}{\lambda_{c,t}}$, etc.

Each active firm h chooses $\{l_{h,t},\ m_{h,t},\ k_{h,t}\}_{t=0}^{\infty}$ to maximize its stream of dividends or net profits as defined in (C.7) and (C.6), subject to the demand function for its product in (C.2) above and the production function in equation (15) in the main text. To solve this problem, we work as in Etro and Colciago (2010) by solving for a Cournot-Nash equilibrium, which, as we shall see, allows the markup to be shaped by the number of active firms in the sector.

We start with some preliminaries. Consider first the term $\frac{p_{h,t}^H}{p_t} y_{h,t}$ included in the definition for $\pi_{h,t}$. Since from (C.2) $y_{h,t} = \left(\frac{p_{h,t}^H}{p_t^H}\right)^{\frac{1}{\theta-1}} \frac{Y_t}{N_t^h}$ or equivalently $p_{h,t}^H = p_t^H \left(\frac{y_{h,t}}{Y_t/N_t^h}\right)^{\theta-1}$, we have for sales:

$$\frac{p_{h,t}^H}{p_t} y_{h,t} = \frac{p_t^H \left(\frac{y_{h,t}}{Y_t/N_t^h}\right)^{\theta-1} y_{h,t}}{p_t} = \frac{p_t^H (y_{h,t})^\theta}{p_t (Y_t/N_t^h)^{\theta-1}} \frac{Y_t}{Y_t} = \frac{(y_{h,t})^\theta}{(Y_t)^\theta} \frac{p_t^H Y_t}{(N_t^h)^{1-\theta} p_t}, \tag{C.8}$$

where $p_t^H Y_t$ represents the total expenditure on the domestically produced good and, along with N_t^h and p_t, is taken as given by the individual firm.

Since $Y_t = \left(\frac{1}{(N_t^h)^{1-\theta}} \sum_{h=1}^{N_t^h} (y_{h,t})^\theta\right)^{\frac{1}{\theta}}$, where this is internalized by firm h in a Cournot-Nash type game, differentiation of the above term with respect to $y_{h,t}$, yields:

$$\frac{p_t^H Y_t}{(N_t^h)^{1-\theta} p_t} \left\{ \frac{\theta (y_{h,t})^{\theta-1} \left[\frac{1}{(N_t^h)^{1-\theta}} \sum_{h=1}^{N_t^h} (y_{h,t})^\theta\right] - (y_{h,t})^\theta \theta \frac{(y_{h,t})^{\theta-1}}{(N_t^h)^{1-\theta}}}{\left[\frac{1}{(N_t^h)^{1-\theta}} \sum_{h=1}^{N_t^h} (y_{h,t})^\theta\right]^2} \right\}, \tag{C.9}$$

which, in a symmetric equilibrium, where $\overline{y}_t \equiv \frac{Y_t}{N_t} = \frac{N_t^h y_{h,t}}{N_t} = n_t^h y_{h,t}$, $\widetilde{y}_t \equiv \frac{Y_t}{N_t^h} = \frac{N_t^h y_{h,t}}{N_t^h} = y_{h,t}$ and $p_{h,t}^H = p_t^H$, simplifies to:

$$\begin{aligned} &\frac{p_t^H Y_t}{(N_t^h)^{1-\theta} p_t} \left[\frac{\theta (y_{h,t})^{2\theta-1} (N_t^h)^\theta - \theta (y_{h,t})^{2\theta-1} (N_t^h)^{\theta-1}}{(N_t^h y_{h,t})^{2\theta}}\right] = \\ &= \frac{p_t^H N_t^h y_{h,t}}{(N_t^h)^{1-\theta} p_t} \frac{\theta}{(N_t^h)^\theta y_{h,t}} \left(1 - \frac{1}{N_{h,t}}\right) = \\ &= \frac{p_t^H}{p_t} \theta \left(1 - \frac{1}{N_t^h}\right). \end{aligned} \tag{C.10a}$$

In other words, here, as in Etro and Colciago (2010), the measure of substitutability, and hence market power, is endogenous, in the sense that the higher the number of firms in the sector, the higher is θ_t and hence the more competitive the product market. In particular, the term $\theta\left[1-\frac{1}{N_t^h}\right]$ is the "effective" degree of substitutability or equivalently (its reverse) the price markup (leaving aside parameter definitions, this is similar to equation (15) in Etro and Colciago (2010)).

Consider next the term $s\frac{p_{h,t}^H}{p_t}c_t^{H,*}$ also included in the definition for $\pi_{h,t}$. Working as above, when the firm chooses $y_{h,t}$, this yields in a symmetric equilibrium:

$$s\frac{p_t^H}{p_t}c_t^{H,*}\frac{1}{y_{h,t}}\theta\left(1-\frac{1}{N_t^h}\right). \tag{C.10b}$$

Therefore, using all the above, each active firm's first-order conditions for $l_{h,t}$, $m_{h,t}$ and $k_{h,t}$ are respectively written in a symmetric equilibrium:

$$(1-\tau_t^\pi)w_t+s^x\frac{p_t^H}{p_t}c_t^{H,*}\frac{1}{y_{h,t}}\theta_t\frac{\partial y_{h,t}}{\partial l_{h,t}}=(1-\tau_t^\pi)\theta_t\frac{p_t^H}{p_t}\frac{\partial y_{h,t}}{\partial l_{h,t}}, \tag{C.11}$$

$$(1-\tau_t^\pi)\frac{p_t^F}{p_t}+s^m\frac{p_t^F}{p_t}+s^x\frac{p_t^H}{p_t}c_t^{H,*}\frac{1}{y_{h,t}}\theta_t\frac{\partial y_{h,t}}{\partial m_{h,t}}=(1-\tau_t^\pi)\theta_t\frac{p_t^H}{p_t}\frac{\partial y_{h,t}}{\partial m_{h,t}}, \tag{C.12}$$

$$\begin{aligned}&\frac{p_t^H}{p_t}\left[1+\xi^k\left(\frac{k_{h,t}}{k_{h,t-1}}-1\right)\right]+\beta_{h,1}s^x\frac{p_{t+1}^H}{p_{t+1}}c_{t+1}^{H,*}\frac{1}{y_{h,t+1}}\theta_{t+1}\frac{\partial y_{h,t+1}}{\partial k_{h,t}}=\\&=\beta_{h,1}\frac{p_{t+1}^H}{p_{t+1}}[1-\delta+(1-\tau_{t+1}^\pi)\theta_{t+1}\frac{\partial y_{h,t+1}}{\partial k_{h,t}}-\\&-\frac{\xi^k}{2}\left(\frac{k_{h,t+1}}{k_{h,t}}-1\right)^2+\xi^k\left(\frac{k_{h,t+1}}{k_{h,t}}-1\right)\frac{k_{h,t+1}}{k_{h,t}}],\end{aligned} \tag{C.13}$$

where at all t:

$$\theta_t=\theta\left(1-\frac{1}{N_t^h}\right). \tag{C.14}$$

In the above, we also use the marginal products:

$$\frac{\partial y_{h,t}}{\partial l_{h,t}}=A^\sigma(y_{h,t})^{1-\sigma}x(k_{h,t-1})^{\sigma a_1}(m_{h,t}^f)^{\sigma a_2}(1-a_1-a_2)\left(l_{h,t}\right)^{\sigma(1-a_1-a_2)-1},$$

$$\frac{\partial y_{h,t}}{\partial m_{h,t}}=A^\sigma(y_{h,t})^{1-\sigma}x(k_{h,t-1})^{\sigma a_1}a_2(m_{h,t}^f)^{\sigma a_2-1}\left(l_{h,t}\right)^{\sigma(1-a_1-a_2)},$$

$$\frac{\partial y_{h,t+1}}{\partial k_{h,t}}=A^\sigma(y_{h,t+1})^{1-\sigma}xa_1(k_{h,t})^{\sigma a_1-1}(m_{h,t+1}^f)^{\sigma a_2}\left(l_{h,t+1}\right)^{\sigma(1-a_1-a_2)}.$$

Appendix D: Market-clearing conditions

The market-clearing conditions in the labor, dividend and domestic good markets are respectively:

Labour market:

$$Nl_{i,t}=N_t^h l_{h,t}, \tag{D.1}$$

Dividend market:

$$N\pi_{i,t}=N_t^h\pi_{h,t}, \tag{D.2}$$

National product identity (in real and per capita terms):

$$
\begin{aligned}
& c_{i,t}^{H} + g_t^c + g_t^i + n_t^h \left[k_{h,t} - (1-\delta)k_{h,t-1}\right] + n_t^h c_t^{H,*} + \\
& + n_t^h \tfrac{\xi^k}{2}\left(\tfrac{k_{h,t}}{k_{h,t-1}} - 1\right)^2 k_{h,t-1} + \tfrac{\psi^p}{2}\left(\frac{\frac{e_t p_t^*}{p_t} f_{i,t}}{\frac{p_t^H}{p_t} n_t^h y_{h,t}}\right)^2 n_t^h y_{h,t} = \\
& = n_t^h y_{h,t}.
\end{aligned} \tag{D.3}
$$

where c_t^{H*} denotes each firm's exports to the rest of the world (defined below). This condition defines how the quantity of the domestically produced good is allocated to its various uses. These uses include, in addition to private consumption and public consumption and investment spending on this good, exports to the rest of the world and the resource costs associated with capital adjustment and participation in foreign asset markets. This condition is similar to e.g. Christiano *et al.* (2011, see subsection 2.7.1).[38]

Balance of payments:

Finally, by combining all the above constraints, we get the country's balance of payments (this last budget identity is linearly dependent):

$$
\begin{aligned}
& \tfrac{p_t^F}{p_t} c_{i,t}^F + n_t^h \tfrac{p_t^F}{p_t} m_{h,t} - n_t^h \tfrac{p_t^H}{p_t} c_t^{H,*} + \tfrac{e_t p_t^*}{p_t}\left(f_{i,t} - \tfrac{p_{t-1}^*}{p_t^*} f_{i,t-1}\right) - i_{t-1}^* \tfrac{p_{t-1}^*}{p_t^*} \tfrac{e_t p_t^*}{p_t} f_{i,t-1} + \\
& + s^m n_t^h \tfrac{p_t^F}{p_t} m_{h,t} + s^x n_t^h \tfrac{p_t^H}{p_t} c_t^{H,*} = 0.
\end{aligned} \tag{D.4}
$$

That is, imports plus investment in new foreign assets plus any Brexit-type resource costs are financed by exports plus interest income from foreign assets (see also e.g. Christiano *et al.* (2011, subsection 2.7.2))

Appendix E: Macroeconomic system

In a symmetric equilibrium, the macroeconomic system is summarised by the following equations.

Households

$$
c_{i,t} = \frac{(c_{i,t}^H)^{\nu}(c_{i,t}^F)^{1-\nu}}{\nu^{\nu}(1-\nu)^{1-\nu}}, \tag{E.1}
$$

$$
\begin{aligned}
& (1+\tau_t^c)\left(\tfrac{p_t^H}{p_t} c_{i,t}^H + \tfrac{p_t^F}{p_t} c_{i,t}^F\right) + b_{i,t} + \tfrac{e_t p_t^*}{p_t} f_{i,t} + \psi_{i,t} = \\
& = (1-\tau_t^y)(w_t l_{i,t} + \pi_{i,t}) + (1+i_{t-1}^b)\tfrac{p_{t-1}}{p_t} b_{i,t-1} + \\
& + (1+i_{t-1}^*)\tfrac{p_{t-1}^*}{p_t^*}\tfrac{e_t p_t^*}{p_t} f_{i,t-1} + g_t^{tr},
\end{aligned} \tag{E.2}
$$

[38] Note that here we have again used $y_t = \frac{Y_t}{N} = \frac{N_t^h y_{h,t}}{N} = n_t^h y_{h,t}$, $\widetilde{y}_t = \frac{Y_t}{N_t^h} = \frac{N_t^h y_{h,t}}{N_t^h} = y_{h,t}$ and $p_{h,t}^H = p_t^H$.

$$\frac{c^H_{i,t}}{c^F_{i,t}} = \frac{\nu}{(1-\nu)} \frac{p^F_t}{p^H_t}, \tag{E.3}$$

$$\mu_2 l^{\frac{1}{\kappa}}_{i,t} = \lambda_{i,t}(1-\tau^y_t)w_t, \tag{E.4}$$

$$\frac{\lambda_{i,t}}{\lambda_{i,t+1}} = \beta(1+i^b_t)\frac{p_t}{p_{t+1}}, \tag{E.5}$$

$$\begin{aligned} &\frac{\lambda_{i,t}}{\lambda_{i,t+1}} \frac{e_t p^*_t}{p_t} + \frac{\lambda_{i,t}}{\lambda_{i,t+1}} \frac{e_t p^*_t}{p_t} \psi^p \left(\frac{\frac{e_t p^*_t}{p_t} f_{i,t}}{\frac{p^H_t}{p_t} n^h_t y_{h,t}} \right) = \\ &= \beta \frac{e_{t+1} p^*_{t+1}}{p_{t+1}} (1+i^*_t) \frac{p^*_t}{p^*_{t+1}}, \end{aligned} \tag{E.6}$$

where in the above we use:

$$\lambda_{i,t} = \frac{\theta_C \left(c_{i,t}\right)^{\frac{n-1}{n}-1}}{(1+\tau^c_t)\left[\theta_C \left(c_{i,t}\right)^{\frac{n-1}{n}} + (1-\theta_C)(g^c_t)^{\frac{n-1}{n}}\right]},$$

$$\psi_{i,t} \equiv \frac{p^H_t}{p_t} \frac{\psi^p}{2} \left(\frac{\frac{e_t p^*_t}{p_t} f_{i,t}}{\frac{p^H_t}{p_t} n^h_t y_{h,t}} \right)^2 n^h_t y_{h,t}.$$

Thus, in this block, we have 6 equations associated with the paths of $c_{i,t}$, $c^H_{i,t}$, $c^F_{i,t}$, $l_{i,t}$, $b_{i,t}$, $f_{i,t}$.

Price equations

$$p_t = (p^H_t)^{\nu}(p^F_t)^{1-\nu}, \tag{E.7}$$

$$p^F_t = e_t p^{H*}_t. \tag{E.8}$$

Thus, in this block, we have 2 equations associated with the paths of p_t, p^F_t (see equation (E.23) below for the equation associated with p^H_t).

Firms

$$\begin{aligned} \pi_{h,t} &= (1-\tau^\pi_t)\left(\frac{p^H_t}{p_t} y_{h,t} - w_t l_{h,t} - \frac{p^F_t}{p_t} m_{h,t}\right) - \\ &- \frac{p^H_t}{p_t}\left[k_{h,t} - (1-\delta)k_{h,t-1}\right] - \frac{p^H_t}{p_t}\frac{\xi^k}{2}\left(\frac{k_{h,t}}{k_{h,t-1}} - 1\right)^2 k_{h,t-1} - \\ &- \frac{p^H_t}{p_t}\left(\frac{\Xi_t(1-n^h_{t-1})}{n^h_t}\right) F_t - s^m \frac{p^F_t}{p_t} m_{h,t} - s^x \frac{p^H_t}{p_t} c^{H,*}_t, \end{aligned} \tag{E.9}$$

$$y_{h,t} = A\left\{x\left[(k_{h,t-1})^{a_1}(m_{h,t})^{a_2}\left(l_{h,t}\right)^{1-a_1-a_2}\right]^{\sigma} + (1-x)\left(\frac{k^g_{t-1}}{n^h_t}\right)^{\sigma}\right\}^{1/\sigma}, \tag{E.10}$$

$$(1-\tau^\pi_t)w_t + s^x \frac{p^H_t}{p_t} c^{H,*}_t \frac{1}{y_{h,t}} \theta_t \frac{\partial y_{h,t}}{\partial l_{h,t}} = (1-\tau^\pi_t)\theta_t \frac{p^H_t}{p_t}\frac{\partial y_{h,t}}{\partial l_{h,t}}, \tag{E.11}$$

$$(1-\tau^\pi_t)\frac{p^F_t}{p_t} + s^m \frac{p^F_t}{p_t} + s^x \frac{p^H_t}{p_t} c^{H,*}_t \frac{1}{y_{h,t}} \theta_t \frac{\partial y_{h,t}}{\partial m_{h,t}} = (1-\tau^\pi_t)\theta_t \frac{p^H_t}{p_t}\frac{\partial y_{h,t}}{\partial m_{h,t}}, \tag{E.12}$$

$$\begin{aligned} &\frac{p^H_t}{p_t}\left[1 + \xi^k\left(\frac{k_{h,t}}{k_{h,t-1}} - 1\right)\right] + \beta_{h,1} s^x \frac{p^H_{t+1}}{p_{t+1}} c^{H,*}_{t+1} \frac{1}{y_{h,t+1}} \theta_{t+1} \frac{\partial y_{h,t+1}}{\partial k_{h,t}} = \\ &= \beta_{h,1} \frac{p^H_{t+1}}{p_{t+1}}[1 - \delta + (1-\tau^\pi_{t+1})\theta_{t+1}\frac{\partial y_{h,t+1}}{\partial k_{h,t}} - \\ &- \frac{\xi^k}{2}\left(\frac{k_{h,t+1}}{k_{h,t}} - 1\right)^2 + \xi^k\left(\frac{k_{h,t+1}}{k_{h,t}} - 1\right)\frac{k_{h,t+1}}{k_{h,t}}], \end{aligned} \tag{E.13}$$

$$\theta_t = \theta\left(1 - \frac{1}{N_t^h}\right), \tag{E.14}$$

$$n_t^h = (1-\Omega)[n_{t-1}^h + \Xi_t(1-n_{t-1}^h)], \tag{E.15}$$

$$V_{h,t} = (1-\Omega)\pi_{h,t} + \beta_{h,1}V_{h,t+1}, \tag{E.16}$$

$$V_{h,t} = F_t, \tag{E.17}$$

where in the above we use:

$$\beta_{h,1} \equiv \frac{\beta(1-\Omega)\lambda_{i,t+1}}{\lambda_{i,t}},$$

$$\frac{\partial y_{h,t}}{\partial l_{h,t}} = A^{\sigma}(y_{h,t})^{1-\sigma}x(k_{h,t-1})^{\sigma a_1}(m_{h,t})^{\sigma a_2}(1-a_1-a_2)\left(l_{h,t}\right)^{\sigma(1-a_1-a_2)-1},$$

$$\frac{\partial y_{h,t}}{\partial m_{h,t}} = A^{\sigma}(y_{h,t})^{1-\sigma}x(k_{h,t-1})^{\sigma a_1}a_2(m_{h,t})^{\sigma a_2-1}\left(l_{h,t}\right)^{\sigma(1-a_1-a_2)},$$

$$\frac{\partial y_{h,t+1}}{\partial k_{h,t}} = A^{\sigma}(y_{h,t+1})^{1-\sigma}xa_1(k_{h,t})^{\sigma a_1-1}(m_{h,t+1})^{\sigma a_2}\left(l_{h,t+1}\right)^{\sigma(1-a_1-a_2)}.$$

Thus, in this block, we have 9 equations associated with the paths of $y_{h,t}$, $l_{h,t}$, $k_{h,t}$, $m_{h,t}$, n_t^h, Ξ_t, V_t, $\pi_{h,t}$, θ_t.

Government

$$\frac{p_t^H}{p_t}\left(g_t^c + g_t^i\right) + g_t^{tr} + (1+i_{t-1}^b)\frac{p_{t-1}}{p_t}b_{i,t-1} = b_{i,t} + \frac{p_t^H}{p_t}\Xi_t(1-n_{t-1}^h)F_t + T_t, \tag{E.18}$$

$$\begin{aligned} T_t \equiv \tau_t^c\left[\frac{p_t^H}{p_t}c_{i,t}^H + \frac{p_t^F}{p_t}c_{i,t}^F\right] + \tau_t^y\left(w_t l_{i,t} + \pi_{i,t}\right) + \\ + \tau_t^{\pi}n_t^h\left[\frac{p_t^H}{p_t}y_{h,t} - w_t l_{h,t} - \frac{p_t^F}{p_t}m_{h,t}\right], \end{aligned} \tag{E.19}$$

$$k_t^g = (1-\delta^g)k_{t-1}^g + g_t^i. \tag{E.20}$$

Thus, in this block we have 3 equations associated with the paths of $b_{i,t}$, T_t and k_t^g.

Market-clearing conditions

$$l_{i,t} = n_t^h l_{h,t}, \tag{E.21}$$

$$\pi_{i,t} = n_t^h \pi_{h,t}, \tag{E.22}$$

$$\begin{aligned} & c_{i,t}^H + g_t^c + g_t^i + n_t^h\left[k_{h,t} - (1-\delta)k_{h,t-1}\right] + n_t^h c_t^{H,*} + \\ & + n_t^h\frac{\xi^k}{2}\left(\frac{k_{h,t}}{k_{h,t-1}} - 1\right)^2 k_{h,t-1} + \frac{\psi^p}{2}\left(\frac{\frac{e_t p_t^*}{p_t}f_{i,t}}{\frac{p_t^H}{p_t}n_t^h y_{h,t}}\right)^2 n_t^h y_{h,t} = \\ & = n_t^h y_{h,t}. \end{aligned} \tag{E.23}$$

Thus, in this block, we have 3 equations associated with the paths of $w_t, \pi_{i,t}$ and p_t^H.

Finally, in the above system, we have 23 equations, (E.1)-(E.23), in the paths of 23 variables, $c_{i,t}$, $c_{i,t}^H$, $c_{i,t}^F$, $l_{i,t}$, $b_{i,t}$, $f_{i,t}$, $\pi_{i,t}$, $\pi_{h,t}$, $y_{h,t}$, $l_{h,t}$, $k_{h,t}$, $m_{h,t}$, n_t^h, Ξ_t, V_t, θ_t, T_t, k_t^g, w_t, i_t^b, p_t, p_t^F, p_t^H.

Transformed, final system

Since the model is neoclassical, we solve for relative prices and real asset returns.

We first define the ratio:

$$\frac{p_t^H}{p_t^F} \equiv TT_t, \tag{E.24a}$$

which is the terms of trade in our model in the sense that a decrease in TT_t means a loss in competitiveness (recall that here there is a single domestically produced good which is also exported, so p_t^H is also the price of the exported good).

Then, using the definition in (E.24a) and (E.7)-(E.8) for the two price levels, we have for the two relative prices and the real exchange rate:

$$\frac{p_t^H}{p_t} = (TT_t)^{1-\nu}, \tag{E.24b}$$

$$\frac{p_t^F}{p_t} = (TT_t)^{-\nu}, \tag{E.24c}$$

$$\frac{e_t p_t^*}{p_t} = (TT_t)^{1-2\nu}. \tag{E.24d}$$

Also, in (E.2) and (E.18), we replace $(1+i_{t-1}^b)\frac{p_{t-1}}{p_t}$ with r_{t-1} and, similarly, in (E.5), we replace $(1+i_t^b)\frac{p_t}{p_{t+1}}$ with r_t, where r denotes the gross real sovereign interest rate.

Therefore, omitting (E.7)-(E.8) which have been substituted out, and using $(1+i_{t-1}^b)\frac{p_{t-1}}{p_t} \equiv r_{t-1}$ in (E.2) and (E.18) and $(1+i_t^b)\frac{p_t}{p_{t+1}} \equiv r_t$ in (E.5), we have 25 equations, namely (E.1)-(E.6), (E.9)-(E.23) and (E.24a-d), in the paths of 25 variables, $c_{i,t}$, $c_{i,t}^H$, $c_{i,t}^F$, $l_{i,t}$, $b_{i,t}$, $f_{i,t}$, $\pi_{i,t}$, $\pi_{h,t}$, $y_{h,t}$, $l_{h,t}$, $k_{h,t}$, $m_{h,t}$, n_t^h, Ξ_t, V_t, θ_t, T_t, k_t^g, w_t, r_t, TT_t, $\frac{p_t^H}{p_t^F}$, $\frac{p_t^H}{p_t}$, $\frac{p_t^F}{p_t}$ and $\frac{e_t p_t^*}{p_t}$. This is for given paths of fiscal instruments $\{\tau_t^c, \tau_t^y, \tau_t^\pi, s_t^c, s_t^i, s_t^{tr}\}$, where $g_t^c = s_t^c n_t^h y_{h,t}$, $g_t^i = s_t^i n_t^h y_{h,t}$, $g_t^{tr} = \frac{p_{h,t}^H}{p_t} s_t^{tr} y_{h,t}$, the entry cost F_t, and exports to the rest of the world, $c_t^{H,*}$. The latter and which fiscal instrument is used for public debt stabilisation and boundedness along the transition are defined next. The rest of the exogenous variables (like the foreign real interest rate, etc.) are described in the calibration section in the main text.

Exogenous exports

Similarly to e.g. Christiano *et al.* (2011) and Lorenzoni (2014), we assume that the country's exports (per firm) depend positively on the relative price, $\frac{p_t^F}{p_t^H}$, and on foreign output, y^*, where the latter is exogenously given in a single open economy model.

Thus, in the above system, we use:

$$c_t^{H,*} = \left(\frac{p_t^F}{p_t^H}\right)^{\phi} y^*, \tag{E.25}$$

where $\phi \geq 0$ is a parameter.

Per Capita GDP

Given the above, the standard definition for per capita GDP, denoted as y_t, is the value of the above defined gross domestically produced output in (E.23), $\frac{p_t^H}{p_t} n_t^h y_{h,t}$, minus the value of the imported goods used as intermediate inputs in production, $\frac{p_t^F}{p_t} n_t^h m_{h,t}$, both written in per capita terms:

$$y_t \equiv \frac{p_t^H}{p_t} n_t^h y_{h,t} - \frac{p_t^F}{p_t} n_t^h m_{h,t}. \tag{E.26}$$

Appendix F: Policy interventions to reverse Brexit

Further to the discussion in the main text, in what follows, we formally specify the policy mix that can completely undo the harm caused by Brexit. In particular, each firm's profit changes from eq. (E.9) to (see the four new terms in the last line):

$$\begin{aligned} \pi_{h,t} &= (1-\tau_t^{\pi})\left(\frac{p_t^H}{p_t} y_{h,t} - w_t l_{h,t} - \frac{p_t^F}{p_t} m_{h,t}\right) - \\ &- \frac{p_t^H}{p_t}\left[k_{h,t} - (1-\delta) k_{h,t-1}\right] - \frac{p_t^H}{p_t}\frac{\xi^k}{2}\left(\frac{k_{h,t}}{k_{h,t-1}} - 1\right)^2 k_{h,t-1} - \\ &- \frac{p_t^H}{p_t}\left(\frac{\Xi_t(1-n_{t-1}^h)}{n_t^h}\right) F_t - s^m \frac{p_t^F}{p_t} m_{h,t} - s^x \frac{p_t^H}{p_t} c_t^{H,*} + \\ &+ \tau_t^w w_t l_{h,t} + \tau_t^m \frac{p_t^F}{p_t} m_{h,t} + \tau_t^k \frac{p_t^H}{p_t} k_{h,t} + g_{h,t}^s, \end{aligned} \tag{F.1}$$

where τ_t^w, τ_t^m and τ_t^k are subsidies to labour, imported intermediate goods and end-of-period capital stock respectively, while $g_{h,t}^s$ is a lump-sum subsidy received by each firm h.

Then, the firm's first-order conditions for labour, imported intermediate goods and capital respectively change from eqs. (E.11), (E.12) and (E.13) to:

$$(1-\tau_t^{\pi}) w_t - \tau_t^w w_t + s^x \frac{p_t^H}{p_t} c_t^{H,*} \frac{1}{y_{h,t}} \theta_t \frac{\partial y_{h,t}}{\partial l_{h,t}} = (1-\tau_t^{\pi}) \theta_t \frac{p_t^H}{p_t} \frac{\partial y_{h,t}}{\partial l_{h,t}}, \tag{F.2}$$

$$(1-\tau_t^{\pi}) \frac{p_t^F}{p_t} - \tau_t^m \frac{p_t^F}{p_t} + s^m \frac{p_t^F}{p_t} + s^x \frac{p_t^H}{p_t} c_t^{H,*} \frac{1}{y_{h,t}} \theta_t \frac{\partial y_{h,t}}{\partial m_{h,t}} = (1-\tau_t^{\pi}) \theta_t \frac{p_t^H}{p_t} \frac{\partial y_{h,t}}{\partial m_{h,t}}, \tag{F.3}$$

$$\begin{aligned} &\frac{p_t^H}{p_t}\left[(1-\tau_t^k) + \xi^k\left(\frac{k_{h,t}}{k_{h,t-1}} - 1\right)\right] + \beta_{h,1} s^x \frac{p_{t+1}^H}{p_{t+1}} c_{t+1}^{H,*} \frac{1}{y_{h,t+1}} \theta_{t+1} \frac{\partial y_{h,t+1}}{\partial k_{h,t}} = \\ &= \beta_{h,1} \frac{p_{t+1}^H}{p_{t+1}}\left[1 - \delta + (1-\tau_{t+1}^{\pi}) \theta_{t+1} \frac{\partial y_{h,t+1}}{\partial k_{h,t}} - \right. \\ &\left. - \frac{\xi^k}{2}\left(\frac{k_{h,t+1}}{k_{h,t}} - 1\right)^2 + \xi^k\left(\frac{k_{h,t+1}}{k_{h,t}} - 1\right)\frac{k_{h,t+1}}{k_{h,t}}\right]. \end{aligned} \tag{F.4}$$

To neutralise the impact of Brexit on the demand for labour in eq. (F.2), the demand for imported intermediate goods in eq. (F.3), and the demand for new capital goods in eq. (F.4) requires that τ_t^w, τ_t^m and τ_t^k solve the extra equations, respectively:

$$\tau_t^w w_t = s^x \frac{p_t^H}{p_t} c_t^{H,*} \frac{1}{y_{h,t}} \theta_t \frac{\partial y_{h,t}}{\partial l_{h,t}}. \tag{F.5}$$

$$\tau_t^m \frac{p_t^F}{p_t} = s^m \frac{p_t^F}{p_t} + s^x \frac{p_t^H}{p_t} c_t^{H,*} \frac{1}{y_{h,t}} \theta_t \frac{\partial y_{h,t}}{\partial m_{h,t}}. \tag{F.6}$$

$$\frac{p_t^H}{p_t} \tau_t^k = \beta_{h,1} s^x \frac{p_{t+1}^H}{p_{t+1}} c_{t+1}^{H,*} \frac{1}{y_{h,t+1}} \theta_{t+1} \frac{\partial y_{h,t+1}}{\partial k_{h,t}}. \tag{F.7}$$

We also assume that firms' subsidies, $g_{h,t}^s$, are paid by households, in the form of lump-sum taxes, and this happens through the government budget constraint. That is, each household's budget constraint is now (see the new first term on the LHS) is:

$$\begin{aligned} &T_{i,t}^s + (1+\tau_t^c)\left(\frac{p_t^H}{p_t} c_{i,t}^H + \frac{p_t^F}{p_t} c_{i,t}^F\right) + b_{i,t} + \frac{e_t p_t^*}{p_t} f_{i,t} + \psi_{i,t} = \\ &= (1-\tau_t^y)(w_t l_{i,t} + \pi_{i,t}) + (1+i_{t-1}^b)\frac{p_{t-1}}{p_t} b_{i,t-1} + \\ &+(1+i_{t-1}^*)\frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t} f_{i,t-1} + g_t^{tr}, \end{aligned} \tag{F.8}$$

where $T_{i,t}^s$ denotes the extra lump-sum tax paid by each household i earmarked to finance firms' subsidies.

In other words, aggregating over households and firms, we have:

$$T_{i,t}^s = n_t^h g_{h,t}^s, \tag{F.9}$$

where, to remove any income effects associated with Brexit on the firm's profit in eq. (F.1), the lump-sum subsidy, $g_{h,t}^s$, should satisfy:

$$g_{h,t}^s \equiv s^m \frac{p_t^F}{p_t} m_{h,t} + s^x \frac{p_t^H}{p_t} c_t^{H,*} - \tau_t^w w_t l_{h,t} - \tau_t^m \frac{p_t^F}{p_t} m_{h,t} - \tau_t^k \frac{p_t^H}{p_t} k_{h,t}. \tag{F.10}$$

Given the extra lump-sum tax, $T_{i,t}^s$, the government's per capita tax revenue, T_t, in eq. (E.19) is now (see the new last term on the RHS):

$$\begin{aligned} &T_t \equiv \tau_t^c \left[\frac{p_t^H}{p_t} c_{i,t}^H + \frac{p_t^F}{p_t} c_{i,t}^F\right] + \tau_t^y \left(w_t l_{i,t} + \pi_{i,t}\right) + \\ &+\tau_t^\pi n_t^h \left[\frac{p_t^H}{p_t} y_{h,t} - w_t l_{h,t} - \frac{p_t^F}{p_t} m_{h,t}\right] + T_{i,t}^s. \end{aligned} \tag{F.11}$$

Finally, given eq. (F.10), the balance of payments becomes free of Brexit-effects, namely,

$$\begin{aligned} &\frac{p_t^F}{p_t} c_{i,t}^F + n_t^h \frac{p_t^F}{p_t} m_{h,t} - n_t^h \frac{p_t^H}{p_t} c_t^{H,*} + \frac{e_t p_t^*}{p_t}\left(f_{i,t} - \frac{p_{t-1}^*}{p_t^*} f_{i,t-1}\right) - \\ &-i_{t-1}^* \frac{p_{t-1}^*}{p_t^*}\frac{e_t p_t^*}{p_t} f_{i,t-1} = 0. \end{aligned} \tag{F.12}$$

The above policy mix fully replicates the pre-Brexit solution.

Targeting Pre-Brexit GDP: factor subsidies

Consider now the case in which the government only provides a subsidy to labour or imported intermediate goods or end-of-period capital stock (τ_t^w, τ_t^m and τ_t^k respectively). In each case, these subsidies are chosen to target the level of pre-Brexit GDP per capita and are financed by extra taxes or lower spending.

For instance, when we subsidise labour, $\tau_t^w w_t l_{h,t}$, the firm's profit changes from eq. (E.9) to (see the last term on the RHS):

$$\begin{aligned}
\pi_{h,t} &= (1-\tau_t^\pi)\left(\frac{p_t^H}{p_t}y_{h,t} - w_t l_{h,t} - \frac{p_t^F}{p_t}m_{h,t}\right) - \\
&-\frac{p_t^H}{p_t}\left[k_{h,t}-(1-\delta)k_{h,t-1}\right] - \frac{p_t^H}{p_t}\frac{\xi^k}{2}\left(\frac{k_{h,t}}{k_{h,t-1}}-1\right)^2 k_{h,t-1} - \\
&-\frac{p_t^H}{p_t}\left(\frac{\Xi_t(1-n_{t-1}^h)}{n_t^h}\right)F_t - s^m\frac{p_t^F}{p_t}m_{h,t} - s^x\frac{p_t^H}{p_t}c_t^{H,*} + \\
&+\tau_t^w w_t l_{h,t},
\end{aligned} \tag{F.13}$$

and the firm's first-order condition for labour is given by eq. (F.2).

Also, the government budget constraint changes from eq. (E.18) to (see the first term on the LHS):

$$\begin{aligned}
&n_t^h \tau_t^w w_t l_{h,t} + \frac{p_t^H}{p_t}\left(g_t^c + g_t^i\right) + g_t^{tr} + (1+i_{t-1}^b)\frac{p_{t-1}}{p_t}b_{i,t-1} = \\
&= b_{i,t} + \frac{p_t^H}{p_t}\Xi_t(1-n_{t-1}^h)F_t + T_t,
\end{aligned} \tag{F.14}$$

Finally, the balance of payments remains as in (D.4).

When we subsidise imported intermediate goods, we replace $\tau_t^w w_t l_{h,t}$ with $\tau_t^m \frac{p_t^F}{p_t} m_{h,t}$ in eqs. (F.13) and (F.14) and use the firm's FOC for imports, given by eq. (F.3).

When we subsidise capital, we replace $\tau_t^w w_t l_{h,t}$ with $\tau_t^k \frac{p_t^H}{p_t} k_{h,t}$ in eqs. (F.13) and (F.14) and use the firm's FOC for capital, given by eq. (F.4).

Subsidy to GDP ratios

The values reported in Table 6 of the main text are calculated as follows:

$$\frac{\text{wage subsidy}}{\text{GDP}} = \frac{n^h(\tau^w w l_h)}{y}, \tag{F.15}$$

$$\frac{\text{import subsidy}}{\text{GDP}} = \frac{n^h(\tau^m TT^{-\nu} m_h)}{y}, \tag{F.16}$$

$$\frac{\text{capital subsidy}}{\text{GDP}} = \frac{n^h(\tau^k TT^{(1-\nu)} k_h)}{y}, \tag{F.17}$$

$$\frac{\text{lump-sum subsidy}}{\text{GDP}} = \frac{n^h g_{h,t}^s}{y}. \tag{F.18}$$

Appendix G: Tax deductions

Assume now that, a fraction of firms' expenses on new investment is deducted from their taxable income. In particular, say that now each firm's tax deductible income includes $\lambda_t^i i_{h,t}$ where $0 \leq \lambda_t^i \leq 1$, is a fiscal policy instrument. That is, now the firm's taxable income is $\frac{p_t^H}{p_t} y_{h,t} - w_t l_{h,t} - \frac{p_t^F}{p_t} m_{h,t} - \frac{p_t^H}{p_t} \lambda_t^i i_{h,t}$.

This implies the following changes in the final system presented in Appendix E:

$$\begin{aligned} \pi_{h,t} = (1-\tau_t^\pi)\left(\frac{p_t^H}{p_t} y_{h,t} - w_t l_{h,t} - \frac{p_t^F}{p_t} m_{h,t}\right) - \\ -(1-\tau_t^\pi \lambda_t^i)\frac{p_t^H}{p_t}\left[k_{h,t} - (1-\delta)k_{h,t-1}\right] - \frac{p_t^H}{p_t}\frac{\xi^k}{2}\left(\frac{k_{h,t}}{k_{h,t-1}} - 1\right)^2 k_{h,t-1} - \\ -\frac{p_t^H}{p_t}\left(\frac{\Xi_t(1-n_{t-1}^h)}{n_t^h}\right) F_t - s^m \frac{p_t^F}{p_t} m_{h,t} - s^x \frac{p_t^H}{p_t} c_t^{H,*}, \end{aligned} \tag{G.1}$$

$$\begin{aligned} \frac{p_t^H}{p_t}\left[(1-\tau_t^\pi \lambda_t^i) + \xi^k\left(\frac{k_{h,t}}{k_{h,t-1}} - 1\right)\right] + \beta_{h,1} s^x \frac{p_{t+1}^H}{p_{t+1}} c_{t+1}^{H,*} \frac{1}{y_{h,t+1}} \times \\ \times \theta_{t+1}\frac{\partial y_{h,t+1}}{\partial k_{h,t}} = \beta_{h,1}\frac{p_{t+1}^H}{p_{t+1}}[(1-\delta)(1-\tau_{t+1}^\pi \lambda_{t+1}^i) + (1-\tau_{t+1}^\pi) \times \\ \times \theta_{t+1}\frac{\partial y_{h,t+1}}{\partial k_{h,t}} - \frac{\xi^k}{2}\left(\frac{k_{h,t+1}}{k_{h,t}} - 1\right)^2 + \xi^k\left(\frac{k_{h,t+1}}{k_{h,t}} - 1\right)\frac{k_{h,t+1}}{k_{h,t}}], \end{aligned} \tag{G.2}$$

$$\begin{aligned} T_t \equiv \tau_t^c\left[\frac{p_t^H}{p_t} c_{i,t}^H + \frac{p_t^F}{p_t} c_{i,t}^F\right] + \tau_t^y\left(w_t l_{i,t} + \pi_{i,t}\right) + \\ +\tau_t^\pi n_t^h\left[\frac{p_t^H}{p_t} y_{h,t} - w_t l_{h,t} - \frac{p_t^F}{p_t} m_{h,t}\right] - \tau_t^\pi \lambda_t^i n_t^h \frac{p_t^H}{p_t} i_{h,t}. \end{aligned} \tag{G.3}$$

Appendix H: Welfare

Recall from eq. (1) that lifetime discounted utility is:

$$\sum_{t=0}^{\infty} \beta^t u\left(\widetilde{c}_{i,t}, l_{i,t}\right),$$

where:

$$u\left(\widetilde{c}_{i,t}, l_{i,t}\right) = \frac{n}{n-1}\log \widetilde{c}_{i,t} - \mu \frac{l_{i,t}^{1+\frac{1}{\kappa}}}{1+\frac{1}{\kappa}},$$

$$\widetilde{c}_{i,t} = \theta_C \left(c_{i,t}\right)^{\frac{n-1}{n}} + (1-\theta_C)(g_t^c)^{\frac{n-1}{n}},$$

To calculate social welfare denoted as, W_t, we work as in, e.g. Schmitt-Grohé and Uribe (2007), Sims and Wolff (2018) and Malley and Philippopoulos (2023), by adding the following recursive specification of welfare to our equilibrium conditions:

$$W_t = u\left(\widetilde{c}_t, l_{h,t}\right) + \beta W_{t+1}, \tag{H.1}$$

so that starting at $t = 0$, $W_0 = \sum_{t=0}^{T} \beta^t u\left(\widetilde{c}_{i,t}, l_{i,t}\right)$ is the present discounted value (PDV) of household's lifetime utilities.

For our quantitative analysis, we define the pre-Brexit welfare as the PDV of lifetime utilities had we stayed forever in the pre-Brexit steady-state (ss) meaning the model's steady state solution without the Brexit-type shocks, which is denoted as $W_{ss} = \frac{u\left(\widetilde{c}_{ss}, l_{h,ss}\right)}{1-\beta}$.

In contrast, to assess the welfare accruing from Brexit starting in period 1, we calculate the path of $\{W_t\}_{t=0}^{\infty}$ and use its value at $t = 1$, W_1, to measure the discounted life-time utility with the Brexit-type shocks. Then, working as in the related literature, we define a permanent and constant (private and public) consumption subsidy, χ, provided, say, at the pre-Brexit regime that solves the equation:

$$W_1 = \frac{\frac{n}{n-1}\log\left[\theta_C\{(1+\chi)c_{ss}\}^{\frac{n-1}{n}} + (1-\theta_C)\{(1+\chi)g_{ss}^c\}^{\frac{n-1}{n}}\right] - \mu\frac{l_{i,ss}^{1+\frac{1}{\kappa}}}{1+\frac{1}{\kappa}}}{1-\beta} = \\ = \frac{\log(1+\chi)+u_{ss}}{1-\beta} = \frac{\log(1+\chi)}{1-\beta} + W_{ss}. \tag{H.2}$$

Solving $(H.2)$ for χ gives:

$$\chi = \left(e^{(1-\beta)(W_1 - W_{ss})} - 1\right) \times 100. \tag{H.3}$$

In other words, χ is the subsidy that should be given to the household pre-Brexit to make it as well off as during Brexit. A negative value of χ implies a welfare loss from Brexit, and vice versa if χ is positive.