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ABSTRACT

Using simulations from a multicountry neoclassical growth model, we analyze several post-Brexit scenarios. First, the United Kingdom unilaterally imposes tighter restrictions on FDI from other EU nations. Second, the European Union retaliates and imposes the same restrictions on UK FDI. Finally, the United Kingdom reduces restrictions on other major foreign investors during the post-Brexit transition. Model predictions depend crucially on the policy response of multinationals' investment in technology capital, accumulated know-how from investments in R&D, brands, and organizations used simultaneously in their domestic and foreign operations. A final section compares our predictions to those found by gravity analysis.

Keywords: Brexit, Foreign investment, FDI, United Kingdom, European Union
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1. Introduction

In June of 2016, voters in the United Kingdom decided to leave the European Union, a decision popularly known as *Brexit*. The dissolution meant that multinational firms of the United Kingdom and European Union would no longer enjoy free movement of capital across each other's borders, as their subsidiaries would be subject to more stringent regulations and higher production costs.[1] In this paper, we estimate the impact of higher capital restrictions on foreign investment, production, and welfare—in the United Kingdom, European Union, and other nations that hosted EU investment and invested in the European Union prior to the referendum.

To conduct our analysis, we extend the multicountry dynamic general equilibrium model in McGrattan and Prescott (2010) and Holmes, McGrattan, and Prescott (2015). The main feature of their models is technology capital, which is accumulated know-how from investments in R&D, brands, and organizations that can be used simultaneously by multinational firms in their domestic and foreign operations. This capital implies an essential role for foreign direct investment (FDI) since multinationals have more locations in which to use it when countries become more open. In our environment, a country that erects barriers to inward FDI suffers welfare losses because foreign innovation is effectively blocked and costly domestic investment in technology capital is required to supplant the foreign investment. The increased technology capital, since it can be used simultaneously in foreign subsidiaries, benefits nations that remain open. If two countries (or unions) simultaneously erect barriers on each other's FDI, there are offsetting forces—blocked innovation and higher domestic investment—with consequences that are difficult to predict, especially given that other nations will respond to these policy changes in a global general equilibrium setting.

Here, the main extension of Holmes, McGrattan, and Prescott (2015) that we introduce is the explicit modeling of all bilateral costs on FDI, which then enables us to study the partial dissolution of an economic union. For our main simulation, we assume that UK investments in the European

[1] For evidence of restrictive policies, see Kalinova, Palerm, and Thomsen (2010), who discuss indices of the OECD Investment Division that measure FDI restrictiveness of member countries, specifically regulatory restrictions such as foreign equity limits, screening and approval, restrictions on key personnel, and operational regulations.

Union face the same restrictions as either Norway or Switzerland following the Brexit and that EU investments in the United Kingdom are treated reciprocally. To provide intuition, we analyze these policy changes in steps: first assuming that the United Kingdom tightens restrictions on EU FDI unilaterally and then assuming that both economies restrict the movement of capital across each other's borders. If the United Kingdom acts alone and tightens restrictions on EU FDI, EU firms have fewer incentives to invest in technology capital. Lower investment by EU firms has a negative impact on the United Kingdom. With less technology capital coming from abroad, UK firms must increase investment in their own R&D and other intangibles, which is costly. UK consumption falls and hours of work rise, implying a welfare loss for UK citizens. If EU nations remain open to UK outward FDI, their citizens enjoy a modest gain from the increased UK investment since it is deployed in subsidiaries throughout Europe.

If EU nations respond in kind by tightening restrictions on FDI from the United Kingdom, then the welfare of UK citizens is not necessarily lower in the post-Brexit period. In response to higher costs on their FDI, UK multinationals lower their investments in technology capital and begin to disinvest in their EU subsidiaries. Since the European Union is much larger in population and productive capacity than the United Kingdom, UK firms have more subsidiaries affected by the policy change and thefore greater disincentives to invest. With FDI restrictions equally tight in both economies, we predict investment in technology capital to fall in the United Kingdom and to rise in the remaining EU nations. Thus, while the United Kingdom faces higher costs on its outward FDI, it benefits from the E.U.'s increased investment in intangible capital, which is deployed in UK subsidiaries. How this affects welfare depends not only on the relative sizes of the United Kingdom and European Union but also on pre-Brexit FDI stocks of foreign investors such as the United States and Japan.

To make quantitative predictions, we parameterize the model using cross-country data in the period prior to the Brexit referendum. The parameters are chosen to ensure that populations, corporate tax rates, real GDPs, and bilateral FDI flows are the same in the model and data.

In the first experiment, we assume that EU FDI into the United Kingdom faces higher costs, equivalent to a lowering of TFP of 5 percent, which is in line with costs for Norway. In this case, we find an average increase in UK investment in technology capital of 16 percent over the first decade following the policy change, with the predicted rise closer to 45 percent by 2050. Higher investment in technology capital leads to higher FDI outflows—by roughly 45 percent in 2050—since multinationals can use it simultaneously at home and abroad, as well as lower inflows—by roughly 33 percent in 2050. UK consumption is lower by 2.6 percent throughout the transition, and hours of work rise, eventually reaching 2.5 percent above pre-Brexit levels. As a result, UK welfare is lower by 3.6 percent. Meanwhile, EU consumption is unchanged, but EU hours of work fall slightly because the EU firms lower investment and production in response to increased UK investment. This implies a modest welfare gain of 0.2 percent for EU citizens.

In the second experiment, we increase costs of EU FDI into the United Kingdom and the costs of UK FDI into the European Union and raise restrictions on EU FDI. In this case, the United Kingdom dramatically reduces its investment in technology capital: 65 percent over the first decade and eventually 88 percent relative to pre-Brexit levels. Since the technology capital of UK firms is significantly lower, their domestic and foreign production falls. Inward FDI to the United Kingdom rises because all other nations respond to the Brexit by increasing investment in technology capital and, in turn, increasing production in their UK subsidiaries. The loss of income in the United Kingdom from domestic production is made up by an increase in income from international lending. In other words, we predict that after Brexit, the United Kingdom finances production by non-UK multinationals. As a result, UK consumption falls by only 2 percent even though the predicted fall in UK business output is greater than 10 percent in the long run. With the fall in production, leisure rises sufficiently to imply a small but positive welfare gain of 0.3 percent for UK citizens.

We predict that the EU countries are significantly worse off if they respond in kind to the U.K.'s policy. The model predicts a large stock of UK technology capital in the pre-Brexit period because innovation is concentrated in countries with high total factor productivity (TFP) and the freedom to move capital across borders. This arrangement was beneficial for EU countries that could take advantage of better technologies without making the investments themselves. With significant disinvestment by U.K. firms after Brexit, EU countries must increase their own investments in technology capital, and do so by roughly 26 percent in the first decade and eventually by 43 percent. Other expenditures fall and business output is down modestly, about 0.4 percent in the long run. Consumption falls by more, roughly 1.4 percent, and leisure falls somewhat. As a result, we find welfare losses on the order of 1.6 percent for those remaining in the European Union.

We run additional experiments in which there are higher costs of FDI flows between the United Kingdom and the European Union, but lower costs on FDI inflows to the United Kingdom from other nations. We include these experiments to demonstrate that UK citizens could in fact be made better off by negotiating new deals with non-European nations. We start by assuming that during the Brexit, the United Kingdom simultaneously lowers restrictions on US foreign direct investment. In this case, production in the United Kingdom falls by less and the welfare of UK citizens rises significantly more. A greater presence of US multinationals raises the level of technology capital used in local production. We repeat the exercise, assuming the United Kingdom loosens restrictions on more and more economies. The final simulation has all foreign inflows treated symmetrically, in line with EU direct investment. In this case, the welfare of UK citizens is higher by almost 5 percent per year, and business output is lower than pre-Brexit levels by about 3 percent.

Most of the related work that estimates the impact of Brexit on FDI flows has been empirical, based either on the synthetic counterfactuals method or on gravity regressions. Campos and Coricelli (2015) use the synthetic counterfactuals method, comparing actual UK FDI inflows to that of a synthetic United Kingdom whose data is a weighted sum of data from control countries—in this case, the United States, Canada, and New Zealand—that did not enter the European Union. They estimate inflows would be 25 to 30 percent lower if the United Kingdom had not entered the union.[2] Dhingra et al. (2016) summarize recent work that analyzes the overall impact of EU membership on FDI stocks and flows. Most closely related to our paper is the work of Bruno et al. (2016), who estimate gravity regressions with bilateral FDI inflows in 34 OECD countries as the dependent variable and use source and host country characteristics, including EU membership, as independent variables. They find that EU membership has a positive effect—averaging 28 percent across regression specifications—on FDI inflows. Reversing this, Bruno et al. (2016) predict that leaving the union would result in a decline of 22 percent (or $-0.28/1.28$), which is close to the estimate of Campos and Coricelli (2015).

These results are in stark contrast to the main finding in our baseline model with both the United Kingdom and the European Union erecting barriers to each other's FDI. Our model predicts that inward FDI in the United Kingdom would rise—not fall—because other nations increase investment and outward FDI in response to Brexit policies. To better understand the gravity results, we conduct the same analysis as Bruno et al. (2016) with model-generated data. As in Bruno et al. (2016), our gravity analysis predicts that inward FDI is higher for EU members than nonmembers, controlling for GDP, population, and fixed effects. Thus, from the gravity analysis, we would conclude that inward FDI should fall in the United Kingdom following the Brexit, whereas the model-generated data show an increase. To understand the result, we compare the paths of inward FDI for the European Union and the United States—two similar-sized economies. The European Union receives more inward FDI than the United States, leading to a positive coefficient for EU membership in the gravity regression. Thus, we rationalize the gravity analyses but highlight the difficulty in interpreting the estimated coefficient on EU membership.

Other related work considers the impact of higher trade costs following the Brexit. Here, we focus on FDI and global capital flows and, to keep things tractable, work with a one-good model, estimating changes in *net* rather than *gross* exports. We can, however, compare estimates

[2] See Campos, Coricelli, and Moretti (2014) for details of the method and results for all EU members. See Pain and Young (2004) and Barrell and Pain (1997) for other work estimating the impact of EU membership on FDI flows and macroeconomic aggregates.

of predicted changes in UK production due to increased trade costs with predicted changes due to increased costs of FDI. Steinberg (2017) analyzes the impact of higher trade costs following Brexit in a dynamic model and estimates that UK output will be lower in the long run. He predicts declines in output ranging from 0.4 to 1.1 percent lower than the pre-Brexit levels. In our baseline simulation with the UK and EU both raising costs, we find larger effects with output falling by roughly 2 percent relative to trend in the first decade of the transition and eventually falling by more than 10 percent. Arkolakis et al. (2017), who analyze a static economy with costs on both trade and FDI, also find larger effects from raising costs on FDI than on trade. However, the mechanism underlying our results, which depends critically on how the Brexit impacts global investments in technology capital, is different than that of Arkolakis et al. (2017), who model innovation as the creation of differentiated goods in single-product firms, with labor being the only factor of production.

In Section 2, we describe the model, and in Section 3, we discuss how we parameterize the model using pre-Brexit data from national and international accounts. In Section 4, we report results for the Brexit simulations, and in Section 5 we check the sensitivity of the main results. In Section 6, we compare our predictions to those found by gravity analyses. Section 7 concludes.

2. Model

The environment we use builds on McGrattan and Prescott (2010) and Holmes, McGrattan, and Prescott (2015). There are I economic unions, which are groups of countries, states, or provinces that impose few to no restrictions on cross-border direct investments of multinational firms. Each economic union is characterized by its productive capacity, its TFP, and its degree of openness to direct investments from outside the union. More specifically, economic union i at time t has a total number of locations, N_{it}, where domestic or foreign firms can operate, a level of TFP, A_{it}, and a degree of openness to investments from firms in j, $\sigma_{it}^{j} \in [0, 1]$, where $\sigma_{it}^{i} = 1$. These characteristics are taken as given by multinational firms when making their production decisions.[3] In this section, we describe the technologies available to these firms and the preferences of households that are the shareholders.

2.1. Firm Problem

Firms choose labor and capital in all locations. Some of the capital is tangible (e.g., structures and equipment), and some is intangible (e.g., R&D, brands, organizations). Some intangible capital is location-specific (e.g., local customer or client lists), and some is nonrivalrous and can be used in all locations (e.g., R&D). We denote the location-specific inputs of labor, tangible capital, and intangible capital used by firms from j operating in economic union i by L_i^j, $K_{T,i}^j$, and $K_{I,i}^j$, respectively. We denote the nonrivalrous intangible capital of j used in i by M_i^j and refer to it as *technology capital* to distinguish it from the location-specific stocks.

As in Holmes, McGrattan, and Prescott (2015), we assume that firms choose how intensively they deploy their technology capital in certain foreign economies that allow firms market access only in exchange for the transfer of technology capital. Holmes, McGrattan, and Prescott (2015) refer to this as a *quid pro quo* arrangement.[4] We denote the fraction of technology capital deployed in economic union i by firms in j by q_i^j—which we refer to as the *intensity level*. In this case, the total effective stock of technology capital is $q_i^j M_i^j$, with $q_i^j \in [0, 1]$ and $q_i^i = 1$.[5] We include the quid pro quo trade-off here because the United Kingdom and other EU nations invest in countries that insist on joint ventures for high-tech foreign firms with the hope of increasing their chance of fulfilling the goal of having more indigenous innovation.

In each period t, total output produced by multinationals from j in economic union i is given

3 Another interpretation of the σ_{it}^j parameters is that they represent frictions between pairs of countries due to differences in language and geographic distance. See, for example, Keller and Yeaple (2013), Ramondo and Rodriguez-Clare (2013), and Ramondo (2014). These frictions can impact the pre-Brexit levels of openness, but not the post-Brexit transition.

4 As we show later, this modeling choice partly endogenizes the degrees of openness to foreign investment, parameterized otherwise by σ_i^j.

5 In the absence of a quid pro quo arrangement, multinationals would use all of their technology capital in all possible locations, and we would not need to index M^j with an i.

by

$$Y_{it}^{j}=A_{it}\sigma_{it}^{j}\left(q_{it}^{j}M_{it}^{j}N_{it}\right)^{\phi}\left(\left(K_{T,it}^{j}\right)^{\alpha_T}\left(K_{I,it}^{j}\right)^{\alpha_I}\left(L_{it}^{j}\right)^{1-\alpha_T-\alpha_I}\right)^{1-\phi}. \tag{2.1}$$

Factor inputs are chosen to maximize the present value of after-tax worldwide dividends, $(1-\tau_{dt})\sum_t p_t D_t^j$, where τ_{dt} is the tax rate on shareholder dividends, p_t is the Arrow-Debreu price, and D_t^j is the total dividend payment. The total dividend payment is the sum of payments across economic unions hosting the FDI, namely,

$$\begin{aligned} D_t^j = \sum_i \Big\{ & (1-\tau_{p,it})\left(Y_{it}^j - W_{it}L_{it}^j - \delta_T K_{T,it}^j - X_{I,it}^j - \chi_i^j X_{M,t}^j\right) \\ & - K_{T,i,t+1}^j + K_{T,it}^j \Big\} + \tau_s\left(\bar{X}_{M,t}^j/\mu_t^j\right) X_{M,t}^j \end{aligned} \tag{2.2}$$

with $\chi_j^j = 1$ and $\chi_i^j = 0$ if $i \neq j$. The dividend from economic union i is computed as the after-tax accounting profit less retained earnings plus any subsidies to investment in R&D and other intangibles. The tax rate on profits in i is given by $\tau_{p,i}$ and is assessed on taxable income equal to output Y_i^j less payments to labor L_i^j at rate W_i, depreciation of tangible capital $K_{T,i}^j$ at rate δ_T, new investment in intangible capital $X_{I,i}^j$ that is location-specific, and investment at home in new technology capital X_M^j. When computing taxable profits, investments in tangible capital are treated as capital expenditures, implying that the firm subtracts only the depreciation allowance, whereas investments in the two intangible capitals are treated as expenses and are therefore fully subtracted. This differential tax treatment implies that retained earnings recorded by the accountants are net investment in *tangible* capital, which is given by $K_{T,i,t+1}^j - K_{T,it}^j$ between period t and $t+1$. The last term in (2.2) is a subsidy for R&D and other intangibles, which is a function of aggregate investment in technology capital in j, $\bar{X}_{M,t}^j$, as a share of all technology capital employed in j, μ_t^j (defined below). We use the following functional form:

$$\tau_s(x) = \nu_0 \exp(-\nu_1 x)$$

and interpret this as a subsidy that governments make to ensure that aggregate R&D is not too low.

The capital accumulation equations for the location-specific stocks are given by

$$K^j_{T,i,t+1} = (1-\delta_T)\, K^j_{T,it} + X^j_{T,it} - \varphi\left(X^j_{T,it}/K^j_{T,it}\right) K^j_{T,it} \tag{2.3}$$

$$K^j_{I,i,t+1} = (1-\delta_I)\, K^j_{I,it} + X^j_{I,it} - \varphi\left(X^j_{I,it}/K^j_{I,it}\right) K^j_{I,it}, \tag{2.4}$$

where $X^j_{T,i}$ and $X^j_{I,i}$ are new investments, δ_T and δ_I are depreciation rates for the tangible and intangible stocks, respectively, and φ is a function governing the cost of adjusting investment. In our analysis later, we use the following functional form:

$$\varphi\left(X/K\right) = \frac{\varphi_0}{2}\left(X/K - \delta - \gamma_Y\right)^{\varphi_1},$$

where δ is the depreciation rate of the relevant investment series and γ_Y is trend growth in the global output. In the absence of any quid pro quo policy, the accumulation equation for technology capital is assumed to have the same form as the accumulation equations in (2.3)-(2.4). If there are quid pro quo transfers, however, then some of the technology capital is transferred to local firms in the economy hosting the FDI. In this case, the next period technology capital is given by

$$M^j_{i,t+1} = (1-\delta_M)\left(1 - h^j_{it}\left(q^j_{it}\right)\right) M^j_{it} + X^j_{M,t} - \varphi\left(X^j_{M,t}/\mu^j_t\right)\mu^j_t, \tag{2.5}$$

where $h^j_{it}(q^j_{it}) \in [0,1]$ is the share transferred, say through forced joint ventures, when foreign firms choose intensity level q^j_{it}.[6] The function $h^j_{it}(\cdot)$ is assumed to be weakly increasing in the intensity choice q^j_{it}; the more technology capital brought in, the greater the required transfer.

In economic unions that engage in quid pro quo, there are two types of firms operating domestically: those that innovate and those that appropriate. The problem of the former is given above. The problem of the latter is different in several respects. First, the technology capital that appropriators accumulate is from the quid pro quo arrangement, not from their own investment. Thus, the technology capital appropriated from foreigners, which we denote by $\tilde{M}_i$, accumulates as follows:

$$\tilde{M}_{i,t+1} = (1-\delta_M)\,\tilde{M}_{it} + \sum\nolimits_j (1-\delta_M)\, h^j_{it}\left(q^j_{it}\right) M^j_{it}. \tag{2.6}$$

[6] If there are no quid pro quo arrangements, we do not need to index M with the destination i, as companies would deploy all of their capital in all possible locations. In economies that use quid pro quo, some technology is transferred and we need to keep track of the remaining stocks, which differ by FDI host.

Holmes, McGrattan, and Prescott (2015) find evidence from Chinese patent data that property rights being exchanged in quid pro quo arrangements apply in the domestic market, not outside. Thus, we assume that appropriators can only use the $\tilde{M}_i$ domestically. Their domestic output is given by

$$\tilde{Y}_{it} = A_{it} \left(\tilde{M}_{it} N_{it}\right)^{\phi} \left(\left(\tilde{K}_{T,it}\right)^{\alpha_T} \left(\tilde{K}_{I,it}\right)^{\alpha_I} \left(\tilde{L}_{it}\right)^{1-\alpha_T-\alpha_I}\right)^{1-\phi}. \tag{2.7}$$

Given that production for appropriators is limited to domestic locations, parameters governing the level of intensity and the degree of openness are set equal to 1. Like multinationals, appropriators choose location-specific inputs to maximize the present after-tax discounted stream of dividends, which we denote by $\tilde{D}_{it}$. These dividends are paid to domestic households.

Now that we have introduced both types of firms, we can be more specific about the total technology capital available to multinationals incorporated in economy j. This total is given by

$$\mu_t^j = M_{jt}^j + \tilde{M}_{jt} + \sum_{\ell \neq j} \left(\sigma_{jt}^{\ell}\right)^{\frac{1}{\phi}} q_{jt}^{\ell} M_{jt}^{\ell}.$$

The first term on the right-hand side is the technology capital of multinationals incorporated in j. The second term is the technology capital of appropriators in j. The third term is the available technology capital of foreign multinationals operating in j, which is a function of the degrees of openness and the intensity levels.

We turn next to a description of the household problem.

2.2. Household Problem

Households choose sequences of consumption C_{it}, labor L_{it}, and assets B_{it+1} to solve the following problem:

$$\max \sum_t \beta^t \left[\log\left(C_{it}/N_{it}\right) + \psi \log\left(1 - L_{it}/N_{it}\right)\right] N_{it} \tag{2.8}$$

subject to

$$\sum_t p_t \left[C_{it} + B_{i,t+1} - B_{it}\right] \leq \sum_t p_t [(1-\tau_{l,it}) W_{it} L_{it} + (1-\tau_{dt}) \left(D_t^i + \tilde{D}_{it}\right) + r_{bt} B_{it} + \kappa_{it}], \tag{2.9}$$

where τ_{li} and τ_d are tax rates on labor and dividends, r_b is the after-tax return on international borrowing and lending, N_{it} is the population in economic union i, and κ_{it} is exogenously determined income, which includes both government transfers and nonbusiness net income.[7] Note that an implicit assumption being made is that N_i is both the count of production locations and the size of the population. We are assuming that a union's productive capacity scales with the population.

2.3. Market Clearing

The worldwide resource constraint is

$$\sum_i \left\{ C_{it} + \sum_j \left(X^j_{T,it} + X^j_{I,it} \right) + X^i_{M,t} + \tilde{X}_{T,it} + \tilde{X}_{I,it} + \bar{X}_{nb,it} \right\}$$
$$= \sum_{i,j} Y^j_{it} + \sum_i \left(\tilde{Y}_{it} + \bar{Y}_{nb,it} \right), \tag{2.10}$$

which is the market-clearing condition for the goods market that includes nonbusiness output $\bar{Y}_{nb,it}$ and nonbusiness investment $\bar{X}_{nb,it}$. Recall that these are components of nonbusiness net income for households, which is included in κ_{it} in (2.9).

Market clearing in asset markets occurs if $\sum_i B_{it} = 0$, and market clearing in labor markets occurs if

$$L_{it} = \sum_j L^j_{it} + \tilde{L}_{it} + \bar{L}_{nb,it}, \quad i = 1, \ldots, I,$$

where L^j_{it} is the labor input for multinationals from j operating in i, $\tilde{L}_{it}$ is the labor input of appropriators in i, and $\bar{L}_{nb,it}$ is the time devoted to nonbusiness work.

2.4. Accounting Measures

When simulating the model, we compare our theoretical predictions to empirical analogues in the national and international accounts. The most commonly used accounting measures are gross domestic product (GDP), gross national product (GNP), and components of the current account,

[7] Nonbusiness net income is included so that we can match accounts of the model to accounts in the data. In our application, we want to distinguish value added and investment from business and nonbusiness sectors. We also include nonbusiness labor as part of the total labor input, and this too is exogenously set. Public consumption is included with C_i.

namely, net exports and net factor incomes. In the model, we compute GDP and net factor incomes (NFI) as follows:

$$\text{GDP}_{it} = C_{it} + \sum_j X^j_{T,it} + \tilde{X}_{T,it} + \bar{X}_{nb,it} + NX_{it} \tag{2.11}$$

$$\text{NFI}_{it} = \sum_{l \neq i} \left(K^i_{T,l,t+1} - K^i_{T,lt} + D^i_{lt}\right) - \sum_{l \neq i} \left(K^l_{T,i,t+1} - K^l_{T,it} + D^l_{it}\right) + r_{bt} B_{it}, \tag{2.12}$$

where GNP is the sum of GDP and NFI, NX_{it} is net exports of goods and services by economy i, and NFI_{it} is equal to profits from direct investment abroad (first sum) less profits from direct investment by foreigners producing in i (second sum) plus foreign net interest. Although some categories of intangible investments have recently been included in measures of GDP for some countries, most is still excluded. In light of this, we use the old concept of GDP and assume full expensing of intangible investments.[8]

3. Model Parameters

In this section, we parameterize the model using data from national and international accounts prior to the June 2016 referendum in the United Kingdom. The analysis includes all nations that are major investors in the United Kingdom and European Union.[9] Parameters are chosen to replicate key statistics, and the model is then used to simulate alternative Brexit scenarios.

Table 1 displays parameters that are assumed to be the same for all economies. We use common parameters for household preferences (β, ψ), trend growth in TFP $(1+\gamma_A)^t$, trend growth in population $(1+\gamma_N)^t$, income shares $(\phi, \alpha_T, \alpha_I)$, nonbusiness activities ($\bar{L}_{nb}$, $\bar{X}_{nb}$/GDP, $\bar{Y}_{nb}$/GDP), depreciation rates (δ_M, δ_T, δ_I), tax rates on individual incomes (τ_l, τ_d), R&D subsidies (ν_0, ν_1), and adjustment costs (φ_0, φ_1). Specifically, we use estimates from Holmes, McGrattan, and Prescott's (2015) study of global capital flows, which are reported in Table 1.

[8] We do sensitivity analysis to ensure that this assumption does not affect our results.

[9] More specifically, we include the United Kingdom, all other European Union countries, the United States, Canada, Norway, Switzerland, Australia, New Zealand, South Africa, Japan, Korea, China, Hong Kong, and India. China and Hong Kong are treated as an economic union, and all FDI flows between them are netted.

We assume, as in Holmes, McGrattan, and Prescott (2015), that quid pro quo policies are only used by some countries and only vis-à-vis some inward FDI. In the application here, we assume that these policies are only used in China and India, which impose joint ventures on high-tech companies from developed nations doing significant R&D. The functional form for a quid pro quo policy for hosts i that impose it is given by

$$h_i^j(q) = \min\{\bar{h} q \exp(-\eta(1-q)), 1\}, \tag{3.1}$$

where i indexes either China or India and j indexes either the United Kingdom, other EU countries, the United States, or Japan. For all other i, j, $h_i^j(q) = 0$. Note that the function in (3.1) is weakly increasing in q, and the functional form is motivated by the fact that we need some curvature (that is, $\eta > 0$) in order for an interior equilibrium to exist. In our simulations, we set $\bar{h} = 700$ and $\eta = 10$, which are taken from Holmes, McGrattan, and Prescott (2015). These settings imply a sharp increase in costs when q exceeds 0.3.

Table 2 reports parameters that differ across economies. The first set shown in Table 2A includes levels of TFP, populations, and corporate income tax rates. TFP and population for the United Kingdom are normalized to 100, and estimates for all other economies are set relative to theirs. The second set shown in Table 2B includes all bilateral degrees of openness σ_i^j, $i, j = 1, \ldots, I$. The rows in Table 2B represent the recipients of FDI, and the columns represent the originators of FDI. In the pre-Brexit period, we impose that $\sigma_j^i = 1$ for bilateral flows between the United Kingdom and the European Union since the investment can flow freely within the union. The remaining bilateral degrees of openness and the levels of TFPs are set so as to exactly replicate all bilateral FDI flows (relative to GDP) and real GDPs per capita (relative to a common long-run growth trend).[10] (See the appendix for data sources.)

[10] To parameterize the degrees of openness, we use actual FDI flows rather than indices of FDI restrictiveness such as that computed by the OECD (2010). The indices have no theoretical counterpart and cannot accurately measure the overall restrictiveness of the regulatory regime.

4. Post-Brexit

In this section, we use the parameterized model to run three sets of numerical experiments. First, we lower only the degree of openness for EU FDI in the United Kingdom, namely, the parameters σ_{it}^{j} with i indexing the host, which in this case is the United Kingdom, and j indexing the source, which in this case is the European Union (or, equivalently, element (2,1) of the matrix in Table 2B). The time series we feed in is shown in Figure 1 and is assumed to be known by all nations starting in 2016. The actual changes occur two years after the referendum, and the openness parameter ultimately falls to 0.95. The latter estimate represents the pre-Brexit degree of openness in the European Union to FDI from Norway.

In the second experiment, we lower the degree of openness for UK FDI in the European Union and simultaneously for EU FDI in the United Kingdom. In this case, two of the σ_{it}^{j} parameters are lowered, and we use the same time series as shown in Figure 1. Finally, we assume as before that there is a lowering of the openness parameters between the United Kingdom and the European Union, and, in addition, we assume that the United Kingdom unilaterally loosens restrictions on FDI from other nations. We start with only the United States. Then we additionally add Japan, then China, then all other countries. For each simulation, we report key statistics related to expenditures, the labor market, the current account, and welfare.

4.1. Costs of EU FDI Increased

In Table 3A, we report results in the case in which the United Kingdom tightens restrictions on inward FDI from EU nations and does so unilaterally. For expenditures and labor market variables, we compute the percentage changes relative to the pre-Brexit levels. For current account variables, which could be close to zero or negative, we first divide the values by GNP and then take absolute differences between the post- and pre-Brexit ratios. Two predictions are reported: the average over the first decade and the change once the economy has converged to a new balanced growth path. The latter is shown in parentheses.

First consider the changes in expenditures. Higher costs on EU subsidiaries in the United Kingdom have the largest impact on investment in technology capital since this type of capital can be used nonrivalrously in multiple locations. If costs are higher on EU FDI, EU firms are at a relative disadvantage in creating new R&D and brands and therefore respond by lowering their investment in X_M. If less technology capital is coming into the United Kingdom, the UK firms respond by increasing their own investments in technology capital. In this case, we predict an average decline in EU technology capital investments of 19 percent relative to pre-Brexit levels over the first decade and 45 percent in the long run. For UK firms, we see roughly the reverse: an average increase of 16 percent over the first decade and 45 percent in the long run.

The increase in UK investment in R&D, brands, and other intangibles is beneficial to the European Union since much of this capital can be deployed costlessly in subsidiaries throughout Europe. In fact, the trade-off between higher costs of outward FDI and higher benefits from UK investment is roughly offsetting, and EU consumption is unchanged. With the drop in their own investment, EU output and hours of work are slightly lower. For the United Kingdom, on the other hand, an increase in investment means lower consumption and higher output and hours of work. UK consumption falls 2.6 percent, and hours of work by the end of the transition are higher by 2.5 percent, leaving UK citizens worse off under a unilateral policy change.

The effects of the policy change are also reflected in net factor incomes. Higher restrictions on EU FDI imply a relative disadvantage to EU multinationals and, therefore, lower their outward FDI. Net factor incomes from corporate profits (NFI_{prof}) relative to GNP eventually fall for EU firms by about 3 percent and rise for UK firms by about 16 percent, with the difference attributed to the European Union being much larger than the United Kingdom. Overall, EU net factor incomes change little because EU nations respond to higher FDI costs by increasing lending to non-EU producers that have a relative advantage. This lending shows up in higher net foreign interest payments that roughly offset the fall in net foreign profits. For the United Kingdom, the policy has the opposite effect, and therefore net foreign profits are higher and net foreign interest payments are lower after the change.

For other countries, the main effect of the policy change is the response of investment in technology capital since all countries are affected by costs on capital flow movements. Lower investment by EU firms affects all nations with inward FDI from the European Union. However, general equilibrium effects are important. For example, although the United Kingdom increases its investment, the UK economy is relatively small. Therefore, higher costs on EU firms can lead large countries, such as the United States, to increase their own investment in R&D, brands, and other capital. In this simulation, we predict that the United States increases its investment by roughly 6 percent. Small and relatively open countries such as Canada can take advantage of the US response since they are hosts to large US FDI stocks.

4.2. Costs of UK and EU FDI Increased

Next, we analyze a Brexit scenario with the European Union responding in kind to the UK policy of tighter regulations on inward FDI. For this simulation, the degree of openness parameters in elements (2,1) and (1,2) of the matrix in Table 2B are both lowered as shown in Figure 1. We find that the economic impact of these policy changes depends crucially on the relative sizes and TFPs of the investing nations and their pre-Brexit FDI stocks.[11]

In Table 3B, we report results of these policy changes. UK expenditures on all types of investments fall after 2016, with investments in new technology capital falling the most dramatically. On the new balanced growth path, investment in technology capital, X_M, of UK multinationals is down 88 percent. In the pre-Brexit period, the model predicts that a significant amount of investment in R&D and other intangibles is done in the United Kingdom because it has a much higher level of TFP than the other countries in the union. (See Table 2A.) Given the nonrivalrous

[11] Kierzenkowski et al. (2016) argue that "lower FDI inflows would seem unavoidable" if access to the EU single market is restricted. Here, the impact on FDI inflows is not unambiguously negative.

nature of technology capital, UK multinational firms could costlessly use this capital in many locations within the union prior to the Brexit. When costs of producing in the European Union rise after Brexit, the United Kingdom reduces direct investment in the other EU locations and instead increases financing of production of non-UK multinationals. In effect, the UK foreign investment shifts from FDI to portfolio investment. Production at home and abroad falls, and, in the new balanced growth path, UK net factor income is no longer in the form of profits but rather net interest. Overall, the current account relative to GNP is higher not because of net factor incomes but because net exports as a share of GNP rise. Domestic absorption in the United Kingdom falls significantly because of lower investment spending.

In the second two rows of Table 3B, we report predictions for the European Union. With less UK technology capital, the remaining EU countries must accumulate more of their own. The fact that they face higher costs in their UK subsidiaries has little impact on their investment decisions since the United Kingdom is a much smaller economy (and therefore has fewer productive locations). The results show a shift by the European Union from investing in location-specific capital to investing in technology capital, which continues throughout the transition. Evidence of this shift can also be seen in the current account changes. In contrast to the United Kingdom, the current account share of GNP falls, the net exports share of GNP falls, and EU countries do less financing of other production and more outward FDI. Overall, the impacts are significantly smaller as the European Union is much bigger in size—in both population and production locations. Business output falls by only 0.4 percent by the end of the transition. Consumption also falls by less, roughly 1.4 percent, but labor rises modestly, even with domestic wages falling somewhat.

Figure 2 shows the timing of FDI flows between the United Kingdom and the European Union as a share of the host economy's GNP.[12] Prior to the referendum of 2016, we estimate a ratio for the EU investment in the United Kingdom relative to UK GNP to be close to 1.7 percent. We estimate a ratio of UK investment in the European Union relative to EU GNP to be slightly over 1.4 percent.

[12] As we noted earlier, we use the old concept of GNP that excludes intangible investment. If we add back all intangible investments, the differences in the ratios reported are less than 0.15 percentage point.

We should note that although the EU investment ratio is higher than the UK investment ratio, UK GNP is much lower than EU GNP, implying that the United Kingdom does a considerable amount of outward FDI given its size. Following the referendum, we find that the U.K.'s direct investment in the European Union as a share of EU GNP falls dramatically and is in fact negative during most of the transition and roughly zero by 2050. A negative FDI share means that retained earnings from the EU subsidiaries are falling, in this case to zero, as UK firms shut them down. Meanwhile, EU firms retain less in the initial decades, but as they accumulate technology capital, they eventually bring investment levels in their UK subsidiaries back to pre-Brexit levels as a share of UK GNP. If we include all inward flows, both series in Figure 2 would be higher by roughly 1.5 percentage points, implying a greater role for inward FDI in the United Kingdom after Brexit.

As costs on foreign producers rise in the United Kingdom and European Union, total business outputs in these two economies fall. In Figure 3, we display the time series for business outputs relative to trend for these economies along with an aggregate of all other nations. Thus, prior to the referendum in 2016, all estimates are zero. Then, there is an adjustment period before costs on FDI actually rise. During that period, business outputs in the United Kingdom and European Union rise modestly given there is significant technology capital still in place. By 2050, UK output is below trend by almost 10 percent, EU output is below by roughly 1 percent, and all other output is up by 0.4 percent. Production shifts from the United Kingdom and the European Union to other economies, most notably to Australia, New Zealand, South Africa, and Japan early on, and then later to Norway, Switzerland, the United States, and Canada. When aggregated, the business output of non-UK and non-EU firms is initially below the pre-Brexit level but eventually rises to above that level.

For non-U.K economies, the main similarity in the results is the response of technology capital investments (X_M). All but one non-UK country has higher investment in the long run because, after Brexit, they have a comparative advantage to innovate. As a result, non-UK countries do more outward FDI and have higher net factor incomes from profits abroad. Exactly how much more depends on their pre-Brexit FDI stocks, which in turn is a function of their relative sizes, TFPs, and degrees of openness. For example, Switzerland has a large stock of technology capital because it is relatively closed to inward FDI, whereas other countries are relatively more open to its outward FDI. In the post-Brexit period, with UK firms disinvesting, Swiss firms take advantage of their position as a major foreign investor and increase their technology capital stock even further.

4.3. Costs of Inward FDI from non-EU Countries Decreased

Next, we estimate the impact of looser restrictions on FDI into the United Kingdom from other nations, with the timing the same as the Brexit timing shown in Figure 1. In the post-Brexit scenario, these other nations are treated symmetrically with the nations in the European Union.

In Table 4, we show statistics for the United Kingdom aggregates. The first two columns are results from Table 3, which we repeat for easier comparison. In column 3, we report results in the case that restrictions are loosened on FDI from the United States to the United Kingdom. Reading across the first row of Table 2B, we see that the pre-Brexit degree of openness for these flows is 0.91 (which is element (1,5) in the matrix). We assume that during the transition, this parameter rises to 0.95, using the same timing as in Figure 1. In other words, as FDI restrictions are tightening between the United Kingdom and the European Union, they are loosening on US FDI into the United Kingdom. Notice that with this additional policy change, FDI inflows to the United Kingdom rise by more than 30 percent, on average in the first decade and eventually on the new balanced growth path. As in the baseline case (column 2), there is a collapse in outward FDI flows. However, UK consumption is unchanged from the pre-Brexit level, even though domestic activity falls. Net foreign profits fall and net foreign interest payments rise. In this scenario, the United Kingdom benefits significantly from increased US technology investment and earns interest income by financing the production of foreigners.

The last three columns of Table 4 relate to experiments with the United Kingdom sequentially loosening restrictions on Japan, China, and then all other nations listed in Table 2A, with the final experiment such that all inward FDI is treated equally (and the degree of openness is equal to 0.95). In each case, the US restrictions have already been loosened. As further restrictions are loosened, we find higher FDI inflows, higher consumption, and less domestic production. Quantitatively, opening more to the United States has the largest impact on UK aggregates since it has the largest stock of technology capital.

As we will see next, the more open policies translate into positive welfare gains for the United Kingdom.

4.4. Welfare Gains and Losses

Table 5 shows the welfare gains and losses for the six policy experiments described above. Welfare is calculated as the consumption equivalent needed to be indifferent between the new policies (that is, lower σ's) and no change. A positive value indicates a gain relative to the pre-Brexit baseline.

With the UK unilaterally changing policy, we predict a significant welfare loss to UK citizens, on the order of 3.6 percent. In this case, EU citizens have a modest gain because of a modest increase in leisure. If both the United Kingdom and the European Union tighten regulations on each other's FDI, we see the reverse: a gain for UK citizens and a loss for EU citizens. This is shown in column 2 of Table 5. Although consumption in the United Kingdom falls, there is a large increase in hours of leisure and thus a small gain. EU citizens are worse off because they consume less and work more. Similarly for most other nations, the welfare impact depends crucially on whether or not the UK acts alone because the relative advantages for countries doing outward FDI are different under the two Brexit scenarios. Furthermore, the interconnectedness of investment and production is clear from the fact that the welfare losses and gains in many of the non-EU countries are large, in the range of -0.86 to 0.69.

Restricting inward FDI flows from EU nations while simultaneously loosening flows from the United States implies a significantly higher welfare gain for UK citizens, roughly 2.3 percent, and a greater loss of 1.7 percent for EU citizens. (See Table 5, column 3.) How other nations fare depends on whether they are relatively open or closed to US FDI. Those that are relatively open to US FDI gain because the United States does more investment in technology capital when costs are lowered on its outward FDI to the United Kingdom. However, general equilibrium effects imply wage changes as production patterns shift, and this can lead to a negative impact on welfare. In all of the countries that have lower welfare relative to the baseline (in the second column), wages are lower during the transition.

The last three columns of Table 5 relate to experiments with the United Kingdom sequentially loosening restrictions on Japan, China, and then all other nations listed in Table 2A. If the United Kingdom loosens restrictions on both the United States and Japan, UK welfare is predicted to be 3.4 percent higher than the pre-Brexit baseline, and EU welfare is predicted to be roughly 1.8 percent lower. (See Table 5, column 4.) Here, again, how other nations fare is dependent on their bilateral relationships with the United States and Japan. The last two experiments assume that FDI from China—and then all other nations—faces the same restrictions as the European Union, the United States, and Japan. In the case of China, the results change only modestly since China has a relative small stock of technology capital. But the final experiment—with all inward FDI to the United Kingdom treated symmetrically—shows a welfare gain of close to 5 percent for the United Kingdom and a welfare loss of 1.7 percent for the European Union. In this case, the remaining EU countries are worse off because they restricted free access to UK technology.

5. Sensitivity

To assess the importance of our choices of the magnitude and timing of our baseline experiment, we run several alternative policy simulations and report key statistics for the United Kingdom in Table 6.[13]

The first alternative assumes the same timing for the decline in the degree of openness as

[13] All other results can be found by running codes available on our website.

in Figure 1, but the magnitude in the post-Brexit period is lower at 0.97 instead of 0.95 in the baseline case. In the second alternative, we again allow the timing of the initial policy change to be the same as in the baseline, but in this case we reduce the degree of openness between the European Union and the United Kingdom to match that of Norway relative to the European Union ($\sigma = 0.95$) and then slowly transition to matching the openness of Switzerland relative to the European Union ($\sigma = 0.97$). The degree of openness is reduced to 0.95 within the first 5 years of the transition but then takes 20 years to rebound to 0.97. In the third alternative, we delay the Brexit by 2 years relative to the baseline case. Finally, in the fourth alternative, we assume the restrictions are tightened at a slower pace, with the decline in σ taking roughly 2 additional years.

In all experiments, we find similar qualitative results. Quantitatively, we find an increase in FDI inflows of 7.5 to 19.8 percent in the first decade and around 25 percent in all cases on the new balanced growth path. In no case do we find a decrease in inward FDI on the transition, which is in stark contrast to gravity analyses.

6. Comparison to Gravity Analysis

To compare our results with much of the existing literature, we now turn to a gravity analysis, using model-generated data to estimate the following equation:

$$\ln(1 + FDI_{o,d,t}) = \alpha_0 + \alpha_1 X_{o,t} + \alpha_2 X_{d,t} + \eta_{o,d} + T_t + u_{o,d,t},$$

where $X_{o,t}$ and $X_{d,t}$ are vectors of origin- and destination-specific indicators, respectively, which include a dummy that equals one if the country is a member of the European Union, the log of GDP, and the log of the country's population.[14] We also include in the regression a vector of country-pair dummies, $\eta_{o,d}$, and a vector of year dummies, T_t. Population for the country of origin (sender) is excluded because it is collinear with the country-pair fixed effect once we control for population for the destination country, since the ratio of country populations in the model does not

[14] In particular, we base our analysis on Bruno et al. (2016), who follow Anderson and Van Wincoop (2003). In McGrattan and Waddle (2017), we replicate the findings of Bruno et al. (2016).

vary over time. The country-pair dummies control for the usual gravity variables, such as distance, common border, and common language, as these characteristics vary across country-pairs but not across time. The time dummies are included in order to control for macroeconomic conditions that may affect FDI flows but are common to all countries, such as the global financial crisis.

We modify the model-generated data in three ways. First, we scale up all variables by $100,000$ to make them comparable with the OECD data, which are measured in millions of dollars. Second, as indicated above, we add 1 to our scaled observations of FDI, following Bruno et al. (2016). Lastly, we drop the negative observations of FDI, again following Bruno et al. (2016). About 2.5 percent of observations are negative in our baseline case, so we don't lose a substantial number of observations by doing this. However, this assumption is not innocuous, and we will explore its impact below.[15] We analyze 130 years' worth of model-generated data: 30 years before the Brexit vote and 100 after. In the baseline case, represented in the first column of Table 7A, the United Kingdom leaves the European Union two periods after the referendum is held, and the degree of openness between the European Union and the United Kingdom decreases to 0.95 over the course of 5 years. The remaining experiments assume variations on the policy implementations, as in our sensitivity analysis.

As can be seen in the first column of Table 7A, when we simulate data for 30 years pre-Brexit and 100 years post-Brexit for the baseline experiment, when openness drops to $\sigma = 0.95$, EU membership is associated with higher inward FDI. A coefficient of 1.31 means that inward FDI is, on average, 131 percent higher for EU members than nonmembers, controlling for GDP and population as well as fixed effects. Using this coefficient, we can calculate the expected drop in inward FDI into the United Kingdom following its exit from the union. If being a part of the union is associated with a 131 percent rise in inward FDI, leaving it would be associated with a 56 percent ($= 1.31/(1 + 1.31)$) drop in inward FDI. However, the model's simulated time series features an *increase* in inward FDI to the United Kingdom following its exit from the union, not a decrease. As

[15] We also report how this assumption affects our estimation results for the data. See McGrattan and Waddle (2017).

shown in Table 3B for the baseline case, FDI is higher by 16.9 percent in the first decade relative to pre-Brexit levels and by 25.5 percent on the new balanced growth path. Moreover, aggregate inward FDI into the European Union drops dramatically following the Brexit. In the first decade, EU inward FDI falls 79.9 percent and then rebounds to an overall reduction of 38 percent relative to pre-Brexit levels.

In order to understand what may seem like a counterintuitive result of a positive coefficient on our variable of interest (EU membership) when our model predicts increasing inward FDI for the United Kingdom and declining inward FDI for the European Union following the Brexit, it is useful to compare what happens with Europe's closest counterpart in the model: the United States. Because the regression is controlling for country size and wealth, comparing the time series for the European Union with that of the only country with comparable population and GDP will help us to understand the coefficient. If we plot total inward FDI for the European Union and the United States following Brexit—with negative values excluded in order to be consistent with the regressions—we find a dramatic decline for the European Union, but the inward FDI remains higher than that of the United States throughout the transition. Therefore, one would expect the coefficient on membership to be positive, since for two countries with similar-sized economies and populations, the European Union receives more inward FDI than its counterpart, the United States. We find a similar pattern in the other experiments of Table 7A. What is different is the relative magnitudes of inward FDI for the European Union and the United States.

In the other experiments of Table 7A, the difference between the European Union and the United States follows a similar pattern, although relative magnitudes change. When the degree of openness between the European Union and United Kingdom is closest to its pre-Brexit value (for example, when $\sigma = 0.97$ rather than 0.95 as in the baseline), then the difference between the amount of inward FDI into the European Union and the United States is smallest. This is reflected in a smaller coefficient estimate for EU membership, meaning that the extra benefit in terms of inward FDI for EU members versus nonmembers of a similar size is smaller under this specification than under the baseline. An intermediate case has a steep drop in the openness parameter to $\sigma = 0.95$—which is interpreted as the regulatory environment that Norway faces—and a recovery to $\sigma = 0.97$—which is interpreted as the regulatory environment that Switzerland faces. A delay in the start of Brexit is comparable to the $\sigma = 0.97$ case, and a slower phaseout is comparable to our baseline case. However, in all cases, the model predicts an increase in inward FDI to the United Kingdom, not a decrease.

As we noted above, dropping negative FDI values is not innocuous for our results. In Table 7B, we report the results from estimating the same equation, but now we replace the negative observations with zeros, that is, $\ln(1+FDI) = \ln(1)$. When we include these modified observations, the estimated impact of EU membership is lower. In the model-generated data, the negative observations are FDI outflows from the United Kingdom to the partner countries. For example, in the baseline case, the European Union experiences negative FDI inflows from the United Kingdom for 37 years after the referendum. Dropping these negative observations artificially inflates the positive impact on inward FDI of being an EU member. The interpretation of the coefficient estimates here is the same: being a member of the European Union increases inward FDI by 55 percent on average, controlling for origin and destination characteristics. This would indicate that, all else equal, when the United Kingdom exits the union, we would expect to see a decline in inward FDI of roughly 35 percent. Instead, the model predicts an increase in inward FDI into the United Kingdom throughout the transition. Again, this coefficient can be explained by the fact that the European Union is the net recipient of more inward FDI than its closest counterpart, the United States, after controlling for GDP and population.

In summary, the gravity analysis highlights the difficulty in interpreting the estimated coefficient on EU membership as the net benefit received from joining the union (or the net cost paid for leaving it), as well as the importance of the treatment of negative FDI values in the estimation of the gravity equation.[16]

[16] In the appendix, we explore an additional option for dealing with negative observations of inward FDI, which further highlights this point.

7. Conclusion

In this paper, we estimated the impact of tightening regulations on foreign producers following the UK referendum to leave the European Union. We showed that the impact on investment, production, and welfare depends importantly on whether the United Kingdom acts unilaterally to block EU FDI or jointly with EU nations to erect cross-border barriers on each other's FDI. Economies that remain open enjoy the benefit of new ideas and knowledge of others, without undertaking costly investments themselves. If the United Kingdom unilaterally tightens regulations, UK firms must invest on their own, and UK citizens are worse off because they enjoy less consumption and less leisure. Although its outward FDI faces higher costs, the European Union benefits from increased investment by UK firms in R&D and other intangible capital.

If the European Union also tightens regulations on UK FDI, then the relative sizes and TFPs of the two economies, along with other investing nations, will determine global investment and production patterns in the post-Brexit period. Given the United Kingdom is relatively small, if the UK and EU firms face the same regulations, we predict that the optimal response of UK firms is to lower investments in R&D and other intangibles and to disinvest in their EU subsidiaries. In this scenario, the United Kingdom would increase international lending, financing the production of others, both domestically and abroad, which would imply greater inward FDI and greater benefits to UK citizens. Reducing current restrictions on other major investors, such as the United States and Japan, would lead to even further increases in UK inward FDI and potentially significant gains in welfare.

A. Data Sources

In this appendix, we report on our data sources. All of our data and computer codes are available at our website, www.econ.umn.edu/≃erm.

The main series used for our analysis are aggregate populations, gross domestic products, FDI flows, and average corporate tax rates. The source of the population and GDP data is the World Bank's World Development Indicators (WDI) database. The specific series that we use are total population (SP.POP.TOTL), GDP in current U.S. dollars (NY.GDP.MKTP.CD), and GDP at purchasing power parity in constant 2011 international dollars (NY.GDP.MKTP.PP.KD). For each of these variables, when constructing a composite series for a group of countries, such as the European Union or China and Hong Kong, we simply add populations and GDPs across countries to arrive at the total for the economic union.

The main source for bilateral foreign direct investment flows is the Organisation for Economic Co-operation and Development (OECD) FDI statistics. These flows are reported to the OECD by the member countries for each of their partner countries. The data for inward FDI flows to China from its partners come from the *China Statistical Yearbook*. These data are available from 1990 to 2013. Outward FDI data by host country are available from the *China Commerce Yearbook* for years 2003–2013. When constructing FDI statistics for the European Union members and for China and Hong Kong, we subtract any FDI flows between member countries.

The source of data on corporate tax rates are estimates from the accounting firm KPMG International (1993-2016). In order to construct tax rates for our composite countries, a simple average is taken across prevailing tax rates in the countries being aggregated.

For computation of the initial steady state, an average of each of the data series was taken across three years: 2010 through 2012. We chose a start date of 2010 to avoid the trough of the Great Recession and an end year of 2012 because that was the last year in which all of the data series were available.

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Table 1

Model Parameters Common across Economies

Parameter	Expression	Value
Preferences		
Discount factor	β	.98
Leisure weight	ψ	1.32
Growth rates (%)		
Population	γ_N	1.0
Technology	γ_A	1.2
Income shares (%)		
Technology capital	ϕ	7.0
Tangible capital	$(1-\phi)\alpha_T$	21.4
Plant-specific intangible capital	$(1-\phi)\alpha_I$	6.5
Labor	$(1-\phi)(1-\alpha_T-\alpha_I)$	65.1
Nonbusiness sector (%)		
Fraction of time at work	$\bar{L}_{nb}$	6
Investment share	$\bar{X}_{nb}/\text{GDP}$	15
Value-added share	$\bar{Y}_{nb}/\text{GDP}$	31
Depreciation rates (%)		
Technology capital	δ_M	8.0
Tangible capital	δ_T	6.0
Plant-specific intangible capital	δ_I	0
Tax rates (%)		
Labor wedge	τ_l	34
Dividends	τ_d	28
R&D subsidy parameters		
Slope	ν_0	0.5
Curvature	ν_1	150
Adjustment cost parameters		
Slope	φ_0	1
Curvature	φ_1	2

Note.—Parameters are taken from Holmes, McGrattan, and Prescott's (2015) analysis of the US current account. See Holmes, McGrattan, and Prescott (2014) for a sensitivity analysis with respect to these parameter choices.

Table 2A

Exogenous Inputs: TFPs, Populations, Profit tax rates

Economy	TFP	Population	Tax Rate
United Kingdom (UK)	100	100	26
European Union (EU)	83	698	23
Norway (NO)	175	8	28
Switzerland (CH)	163	13	21
United States (US)	117	493	40
Canada (CA)	117	54	28
Australia (AU)	115	35	30
New Zealand (NZ)	117	7	29
South Africa (ZA)	53	82	35
Japan (JP)	100	202	40
Korea (KR)	96	79	23
China (CN)	37	2136	21
India (IN)	21	1972	33

Table 2B

Exogenous Inputs: Bilateral Degrees of Openness

In\Out	UK	EU	NO	CH	US	CA	AU	NZ	ZA	JP	KR	CN	IN
UK	1	1	.85	.58	.91	.88	.60	.74	.65	.81	.75	.89	.91
EU	1	1	.95	.97	.90	.93	.61	.73	.66	.79	.82	.87	.79
NO	.68	.75	1	.68	.48	.73	.61	.49	.50	.54	.49	.64	.61
CH	.37	.42	.40	1	.74	.40	.39	.42	.42	.73	.41	.47	.50
US	.88	.92	.91	.94	1	.91	.97	.85	.78	.86	.84	.78	.86
CA	.77	.54	.52	.50	.79	1	.51	.55	.55	.72	.54	.61	.65
AU	.81	.74	.55	.78	.79	.83	1	.81	.58	.82	.67	.81	.71
NZ	.62	.45	.53	.54	.44	.61	.85	1	.45	.58	.48	.50	.54
ZA	.78	.49	.48	.68	.62	.48	.47	.50	1	.65	.52	.55	.60
JP	.72	.47	.60	.78	.46	.61	.68	.48	.47	1	.70	.70	.62
KR	.68	.71	.68	.68	.68	.68	.69	.51	.52	.75	1	.70	.75
CN	.78	.89	.66	.75	.82	.74	.79	.82	.68	.93	.84	1	.73
IN	1	1	.64	.88	.93	.59	.90	.62	.63	.98	.84	.76	1

Table 3A. Changes in Global Aggregates, Relative to Pre-Brexit Levels[a]

(UK Tightens Restrictions on EU FDI Unilaterally)

	FDI flows		Expenditures[b]					Labor Market		Current Account			
	In	Out	Y	C	X_T	X_I	X_M	L	W	CA	NX	NFI_{prof}	NFI_{int}
United Kingdom	-58.1	38.8	0.2	-2.6	-2.0	-5.0	15.7	2.1	-1.9	-2.2	-0.6	-0.4	-1.3
	(-33.4)	(45.2)	(0.7)	(-2.6)	(0.7)	(0.7)	(44.8)	(2.5)	(-1.8)	(-4.0)	(-5.9)	(15.8)	(-13.9)
European Union	25.3	-74.5	-0.2	0.0	-0.5	-1.0	-18.8	-0.1	0.0	1.4	0.6	0.4	0.5
	(27.2)	(-52.4)	(-0.8)	(0.0)	(-0.8)	(-0.8)	(-44.6)	(-0.6)	(-0.2)	(1.1)	(1.1)	(-3.1)	(3.2)
Norway	-25.0	16.1	0.2	-0.2	0.6	1.4	5.5	0.3	-0.1	-0.7	-0.2	-0.2	-0.2
	(-26.3)	(14.9)	(0.2)	(-0.2)	(0.2)	(0.2)	(13.6)	(0.3)	(-0.1)	(-0.5)	(-0.8)	(2.1)	(-1.8)
Switzerland	3.1	4.5	-0.1	0.2	0.2	0.8	1.1	-0.2	0.1	-0.8	-0.6	0.0	-0.2
	(2.0)	(3.2)	(0.5)	(0.2)	(0.5)	(0.5)	(2.5)	(0.3)	(0.2)	(-0.4)	(-0.3)	(0.9)	(-1.1)
United States	-12.1	17.5	0.0	0.1	0.4	1.0	3.3	0.0	0.1	-0.5	-0.3	-0.1	-0.1
	(-11.0)	(9.1)	(0.2)	(0.0)	(0.2)	(0.2)	(5.8)	(0.2)	(0.1)	(-0.2)	(-0.2)	(0.6)	(-0.5)
Canada	9.3	3.6	-0.2	0.3	0.1	0.5	0.0	-0.3	0.2	-0.4	-0.4	0.0	-0.1
	(11.0)	(-1.1)	(0.2)	(0.2)	(0.2)	(0.2)	(-2.4)	(0.0)	(0.2)	(0.0)	(0.2)	(-0.4)	(0.2)
Australia	2.4	-8.1	-0.3	0.4	-0.3	-0.3	-3.2	-0.5	0.2	-0.4	-0.4	0.1	0.0
	(3.8)	(-10.1)	(0.4)	(0.3)	(0.4)	(0.4)	(-9.6)	(0.1)	(0.4)	(-0.3)	(0.4)	(-0.6)	(-0.1)
New Zealand	-1.1	1.3	0.0	0.0	0.3	0.9	0.5	0.0	0.0	-0.1	-0.1	0.0	0.0
	(-1.9)	(0.2)	(0.0)	(0.0)	(-0.1)	(0.0)	(0.8)	(0.0)	(0.0)	(0.1)	(-0.1)	(0.1)	(0.1)
South Africa	27.1	-13.9	-0.3	0.3	-0.2	-0.3	-5.7	-0.4	0.2	0.0	-0.2	0.1	0.1
	(34.3)	(-19.2)	(0.0)	(0.3)	(0.0)	(0.0)	(-18.9)	(-0.2)	(0.2)	(0.2)	(0.5)	(-1.3)	(1.0)
Japan	18.0	1.5	0.0	0.1	0.3	0.8	0.2	0.0	0.0	-0.2	-0.1	0.0	0.0
	(21.3)	(-0.8)	(0.0)	(0.0)	(0.0)	(-0.1)	(-0.6)	(-0.1)	(0.0)	(0.1)	(0.0)	(-0.1)	(0.2)
Korea	-3.6	2.5	0.0	0.0	0.3	0.8	0.6	0.0	0.0	-0.2	-0.1	0.0	0.0
	(-3.9)	(0.8)	(0.0)	(0.0)	(0.0)	(0.0)	(0.7)	(0.0)	(0.0)	(0.1)	(-0.1)	(0.1)	(0.0)
China	-10.5	14.6	-0.1	0.1	-0.1	-0.2	2.3	-0.1	0.0	-0.2	-0.1	0.0	0.0
	(-10.0)	(5.8)	(0.0)	(0.0)	(0.0)	(0.1)	(2.7)	(0.0)	(0.0)	(-0.1)	(0.0)	(0.1)	(-0.1)
India	-0.2	18.1	-0.1	0.1	-0.2	-0.6	2.7	-0.1	0.0	-0.1	-0.1	0.0	0.0
	(0.2)	(6.6)	(0.1)	(0.0)	(0.1)	(0.1)	(3.0)	(0.1)	(0.1)	(-0.1)	(0.0)	(0.0)	(-0.2)

[a] Values for expenditures and labor market variables are percentage changes, and values for the current account are absolute changes after dividing the series by GNP. Averages over the first decade (years 2016-2025) are displayed first, and changes relative to the eventual balanced growth path are displayed below in parentheses.

[b] Results are reported only for business output and investments.

Table 3B. Changes in Global Aggregates, Relative to Pre-Brexit Levels[a]
(UK and EU Tighten Restrictions on Each Other's FDI)

	FDI flows		Expenditures[b]					Labor Market		Current Account			
	In	Out	Y	C	X_T	X_I	X_M	L	W	CA	NX	NFI_{prof}	NFI_{int}
United Kingdom	16.9	-196.8	-1.9	-2.0	-8.1	-18.6	-64.5	0.1	-2.0	16.9	11.5	-0.5	5.9
	(25.5)	(-92.4)	(-10.4)	(-2.1)	(-10.4)	(-10.4)	(-87.8)	(-6.4)	(-4.3)	(8.8)	(7.9)	(-24.0)	(24.9)
European Union	-79.9	20.2	-1.0	-1.3	-3.4	-8.0	25.8	0.2	-1.2	-1.2	-0.1	-0.6	-0.5
	(-38.4)	(26.2)	(-0.4)	(-1.4)	(-0.4)	(-0.4)	(43.1)	(0.7)	(-1.1)	(-1.6)	(-1.0)	(3.3)	(-3.9)
Norway	7.9	45.3	-0.1	0.9	1.4	4.1	8.9	-0.7	0.6	-2.6	-1.9	0.0	-0.7
	(12.2)	(9.4)	(1.1)	(0.8)	(1.1)	(1.1)	(3.0)	(0.2)	(0.9)	(-0.3)	(0.0)	(0.2)	(-0.5)
Switzerland	-9.0	57.1	0.1	1.0	2.6	7.0	15.8	-0.6	0.8	-7.0	-5.4	0.8	-2.4
	(-7.0)	(25.3)	(3.2)	(0.9)	(3.2)	(3.2)	(20.2)	(1.7)	(1.5)	(-2.7)	(-2.4)	(7.4)	(-7.7)
United States	-7.3	59.8	0.0	0.6	1.3	3.6	8.3	-0.5	0.5	-1.9	-1.4	-0.1	-0.5
	(-1.3)	(22.5)	(1.0)	(0.5)	(1.0)	(1.0)	(8.1)	(0.3)	(0.6)	(-0.5)	(-0.1)	(0.7)	(-1.0)
Canada	-25.4	48.4	0.1	0.4	1.6	4.2	11.4	-0.2	0.4	-2.5	-1.6	-0.2	-0.8
	(-16.9)	(20.1)	(0.9)	(0.3)	(0.9)	(0.9)	(13.6)	(0.4)	(0.5)	(-0.7)	(-0.6)	(1.9)	(-2.0)
Australia	-1.8	1.8	0.5	-0.5	1.2	2.6	3.3	0.8	-0.2	0.5	0.5	0.0	0.0
	(-3.3)	(-2.2)	(-1.0)	(-0.6)	(-1.0)	(-1.0)	(1.3)	(-0.3)	(-0.7)	(0.8)	(-0.4)	(0.2)	(1.0)
New Zealand	-10.4	10.7	0.3	0.1	1.3	3.5	3.7	0.2	0.1	-0.5	-0.3	0.0	-0.2
	(-9.1)	(3.7)	(-0.1)	(0.0)	(-0.1)	(-0.1)	(4.2)	(-0.1)	(-0.1)	(0.2)	(-0.2)	(0.4)	(0.0)
South Africa	-109.1	45.0	0.3	-0.5	0.4	0.5	22.7	0.6	-0.3	-1.2	-0.3	-0.4	-0.5
	(-71.5)	(33.3)	(0.3)	(-0.6)	(0.3)	(0.3)	(38.6)	(0.6)	(-0.3)	(-1.0)	(-0.9)	(2.7)	(-2.8)
Japan	-53.9	12.5	0.3	0.2	1.5	3.8	2.4	0.1	0.2	-0.6	-0.4	0.0	-0.2
	(-33.1)	(2.6)	(0.0)	(0.1)	(0.0)	(0.0)	(1.2)	(-0.1)	(0.0)	(0.2)	(-0.2)	(0.1)	(0.2)
Korea	4.5	12.9	0.2	0.2	1.4	3.7	1.8	0.0	0.2	-0.5	-0.4	0.0	-0.2
	(3.6)	(0.7)	(-0.1)	(0.1)	(-0.1)	(-0.1)	(-0.4)	(-0.1)	(0.0)	(0.3)	(-0.1)	(-0.1)	(0.5)
China	21.2	62.1	0.0	0.1	0.1	-0.5	10.5	-0.1	0.1	-0.3	-0.2	0.0	-0.1
	(10.1)	(28.7)	(0.3)	(0.0)	(0.3)	(0.3)	(14.2)	(0.2)	(0.1)	(0.0)	(0.0)	(0.0)	(0.0)
India	-12.0	39.9	-0.1	-0.3	-0.5	-1.8	8.0	0.1	-0.2	0.2	0.3	0.0	0.0
	(-6.4)	(20.6)	(-0.5)	(-0.4)	(-0.5)	(-0.5)	(10.7)	(-0.1)	(-0.4)	(0.2)	(-0.2)	(0.2)	(0.2)

[a] Values for expenditures and labor market variables are percentage changes, and values for the current account are absolute changes after dividing the series by GNP. Averages over the first decade (years 2016-2025) are displayed first, and changes relative to the eventual balanced growth path are displayed below in parentheses.

[b] Results are reported only for business output and investments.

Table 4

Changes in UK Aggregates Relative to Pre-Brexit Levels, Alternative Policies[a]

	Less open to FDI		Sequentially, UK is more open to:[b]			
Statistic	UK Only	UK & EU	US	Japan	China	All others
FDI inflows	-58.1	16.9	33.6	37.9	41.4	39.5
	(-33.4)	(25.5)	(31.1)	(34.3)	(35.3)	(38.8)
FDI outflows	38.8	-196.8	-195.1	-193.1	-192.5	-190.5
	(45.2)	(-92.4)	(-91.4)	(-90.6)	(-90.3)	(-89.6)
Consumption	-2.6	-2.0	0.0	1.2	1.6	2.7
	(-2.6)	(-2.1)	(0.1)	(1.3)	(1.7)	(2.9)
Business output	0.2	-1.9	-2.9	-3.7	-3.9	-5.0
	(0.7)	(-10.4)	(-7.2)	(-5.4)	(-4.8)	(-2.7)
Business investment	5.6	-34.7	-34.7	-35.1	-34.9	-36.1
	(20.5)	(-45.1)	(-42.6)	(-41.0)	(-40.5)	(-38.7)
Labor input	2.1	0.1	-2.2	-3.6	-4.0	-5.7
	(2.5)	(-6.4)	(-5.5)	(-5.0)	(-4.8)	(-4.1)
Wage rate	-1.9	-2.0	-0.7	-0.1	0.2	0.7
	(-1.8)	(-4.3)	(-1.8)	(-0.4)	(0.0)	(1.4)
Net foreign profits	-0.4	-0.5	-0.2	-0.1	0.0	0.1
	(15.8)	(-24.0)	(-24.1)	(-24.1)	(-24.1)	(-24.1)
Net foreign interest	-1.3	5.9	5.7	5.5	5.5	5.3
	(-13.9)	(24.9)	(23.1)	(21.9)	(21.6)	(19.9)

[a] See Table 3 notes.

Table 5

Welfare Gains and Losses, Alternative Policies[a]

	Less open to FDI		Sequentially, UK is more open to:[b]			
Economy	UK Only	UK & EU	US	Japan	China	All others
United Kingdom	-3.61	0.25	2.30	3.40	3.78	4.84
European Union	0.23	-1.59	-1.72	-1.78	-1.79	-1.74
Norway	-0.36	0.69	0.55	0.55	0.55	0.89
Switzerland	0.06	0.23	0.30	0.31	0.30	-0.03
United States	-0.04	0.39	0.55	0.50	0.47	0.45
Canada	0.23	0.12	0.17	0.17	0.16	0.41
Australia	0.38	-0.61	-0.58	-0.47	-0.39	-0.15
New Zealand	-0.02	-0.10	-0.21	-0.21	-0.22	0.43
South Africa	0.38	-0.86	-0.85	-0.84	-0.84	-0.44
Japan	0.02	0.01	-0.03	0.48	0.45	0.40
Korea	-0.01	0.05	0.03	0.04	0.04	0.44
China	0.01	-0.05	0.01	0.03	0.08	-0.12
India	0.03	-0.37	-0.28	-0.24	-0.28	-0.52

[a] The gains are percentage increases in the paths of consumption necessary for households to be indifferent between the new policy and no change. A positive (negative) value indicates a gain (loss) with Brexit.

[b] All policy experiments assume that the United Kingdom and the European Union are less open to each other's FDI as in column 2.

Table 6

Changes in UK Aggregates Relative to Pre-Brexit Levels[a]

(Alternative Policy Implementations[b])

Statistic	Baseline	$\sigma = 0.97$	$\sigma = 0.95 \Rightarrow 0.97$	Delayed	Slow Phaseout
FDI inflows	16.9	16.7	7.5	19.8	18.2
	(25.5)	(24.9)	(25.5)	(25.3)	(25.7)
FDI outflows	-196.8	-150.9	-185.9	-187.1	-188.3
	(-92.4)	(-83.9)	(-84.1)	(-92.4)	(-92.4)
Consumption	-2.0	-0.7	-0.9	-1.9	-2.1
	(-2.1)	(-0.8)	(-1.0)	(-2.1)	(-2.2)
Business output	-1.9	-2.0	-3.3	-0.8	-1.2
	(-10.4)	(-7.8)	(-7.4)	(-10.5)	(-10.2)
Business investment	-34.7	-27.2	-34.7	-31.9	-33.5
	(-45.1)	(-39.7)	(-39.6)	(-45.2)	(-45.0)
Labor input	0.1	-0.9	-1.8	0.8	0.6
	(-6.4)	(-5.3)	(-4.9)	(-6.5)	(-6.2)
Wage rate	-2.0	-1.0	-1.6	-1.6	-1.9
	(-4.3)	(-2.6)	(-2.6)	(-4.2)	(-4.3)
Net foreign profits	-0.5	-0.1	-0.3	-0.1	-1.0
	(-24.0)	(-22.1)	(-22.2)	(-24.0)	(-24.1)
Net foreign interest	5.9	4.6	5.5	5.6	5.6
	(24.9)	(21.9)	(20.9)	(25.2)	(24.4)

[a] See Table 3 notes.

[b] The baseline implementation corresponds to Figure 1. The $\sigma = 0.97$ case uses the same timing as the baseline but looser FDI restrictions. The $\sigma = 0.95 \Rightarrow 0.97$ case assumes the first 5 years are as in the baseline and then σ recovers to 0.97 in the subsequent 20 years. The delayed case assumes a 2-year delay in implementation. The slow phaseout case assumes the Brexit occurs at the same time as the baseline but takes 2 years longer to reach $\sigma = 0.95$.

Table 7A. Gravity Regressions, Alternate Policy Implementations[a]
(Negative Values Dropped)

Independent Variable	Baseline	$\sigma = 0.97$	$\sigma = 0.95 \Rightarrow 0.97$	Delayed	Slow Phaseout
EU member (recipient)	***1.31	*0.50	***1.00	*0.36	***1.33
	(0.13)	(0.27)	(0.15)	(0.21)	(0.13)
EU member (sender)	**0.32	-0.21	-0.01	-0.30	**0.35
	(0.13)	(0.27)	(0.15)	(0.21)	(0.14)
ln GDP (recipient)	-2.09	1.67	-3.91	1.07	-1.77
	(1.32)	(2.84)	(1.45)	(2.02)	(1.33)
ln GDP (sender)	-0.82	0.35	*-2.59	-0.25	-0.50
	(1.32)	(2.84)	(1.45)	(2.02)	(1.33)
ln population (recipient)	***1.32	***-0.14	***1.36	***-0.14	***1.32
	(0.03)	(0.05)	(0.03)	(0.05)	(0.03)
Country-pair fixed effect	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes
Observations	20,065	20,208	20,187	20,069	20,070

[a] Values with ***, **, and * are significant at the 1, 5, and 10 percent levels, respectively. Standard errors are reported in parentheses. All regressions include country-pair and year fixed effects.

Table 7B. Gravity Regressions, Alternate Policy Implementations[a]

(Negative Values Replaced with Zeros)

Independent Variable	Baseline	$\sigma = 0.97$	$\sigma = 0.95 \Rightarrow 0.97$	Delayed	Slow Phaseout
EU member (recipient)	***0.55	0.20	***0.93	***0.48	***0.41
	(0.14)	(0.17)	(0.14)	(0.14)	(0.14)
EU member (sender)	**-0.24	***-0.68	-0.01	-0.30	***-0.38
	(0.14)	(0.17)	(0.15)	(0.14)	(0.14)
ln GDP (recipient)	***-22.62	***-21.15	***-11.17	***-24.60	***-24.45
	(1.29)	(1.76)	(1.42)	(1.28)	(1.29)
ln GDP (sender)	***-22.49	***-19.93	***-9.94	***-23.48	***-23.33
	(1.29)	(1.76)	(1.42)	(1.28)	(1.29)
ln population (recipient)	***1.19	***1.27	***1.28	***1.19	***1.19
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Country-pair fixed effect	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes
Observations	20,436	20,436	20,436	20,436	20,436

[a] Values with ***, **, and * are significant at the 1, 5, and 10 percent levels, respectively. Standard errors are reported in parentheses. All regressions include country-pair and year fixed effects.

Figure 1. Degree of Openness, UK to EU and EU to UK
(1=Fully open, 0=Fully closed)

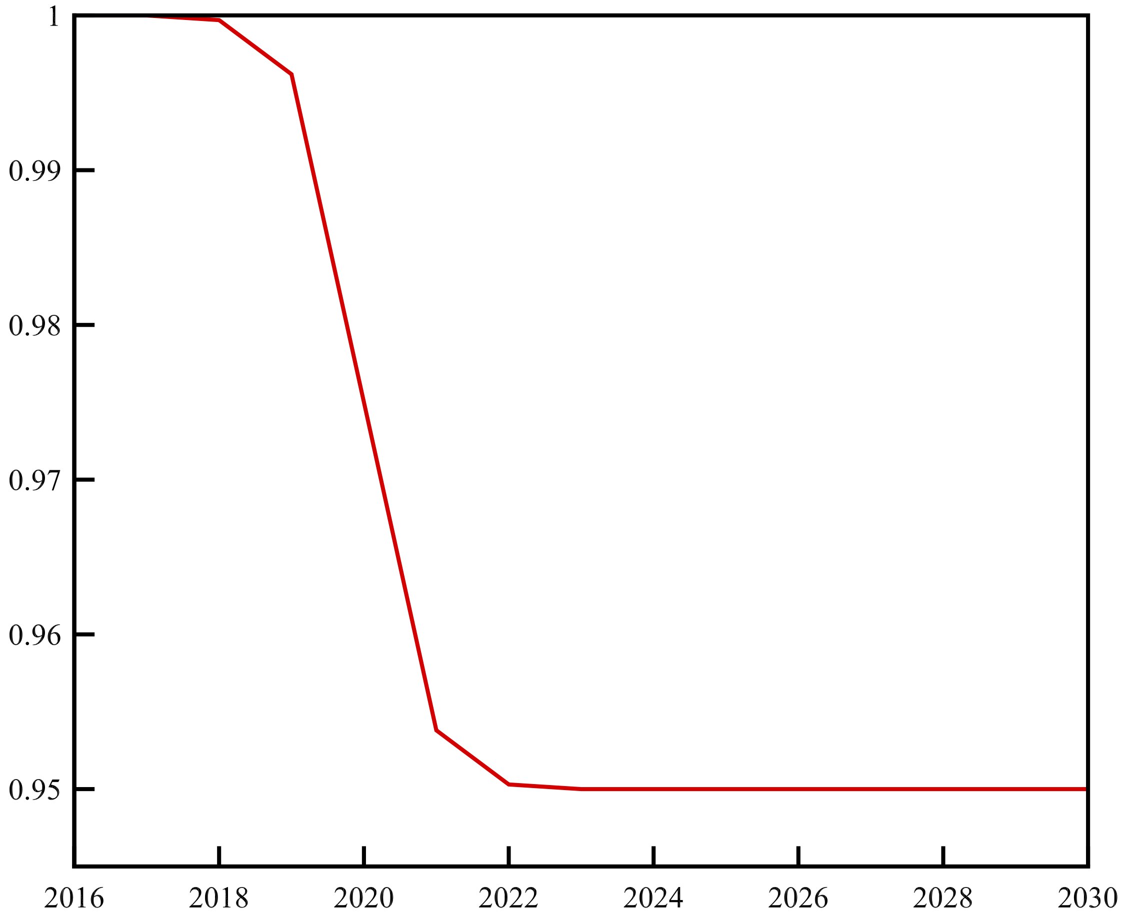

Figure 2. FDI Flows between UK and EU

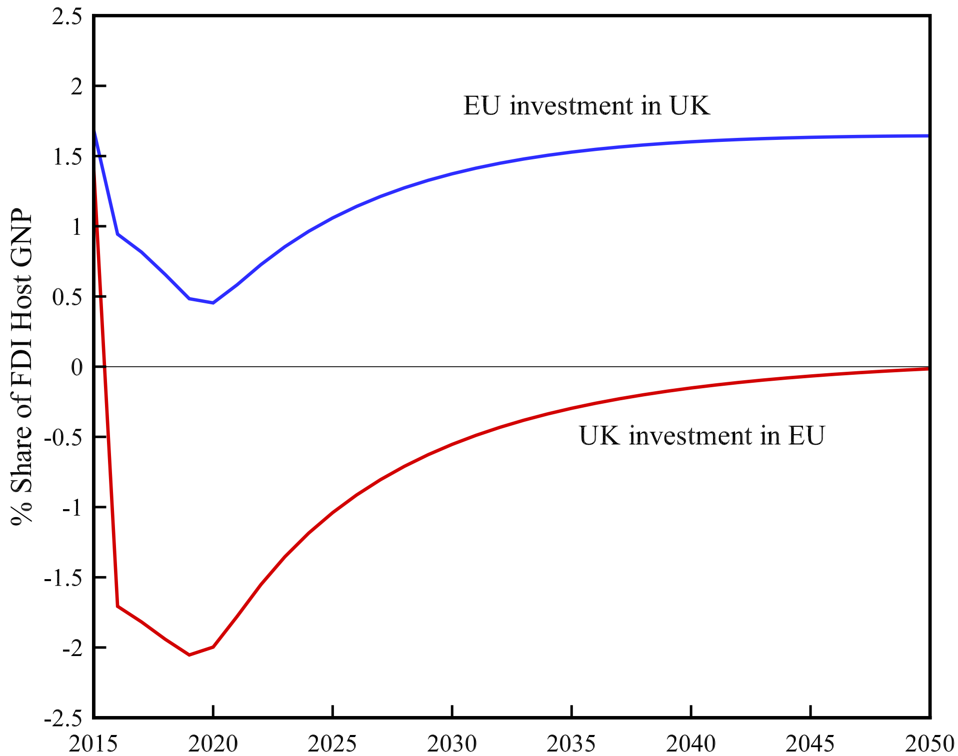

Figure 3. Business Outputs of UK, EU, and All Other Economies