American Economic Journal: Macroeconomics 2020, 12(1): 76–103
https://doi.org/10.1257/mac.20170399

The Impact of Brexit on Foreign Investment and Production[†]

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Using simulations from a multi-country neoclassical growth model, we analyze several post-Brexit scenarios. First, the United Kingdom unilaterally imposes tighter restrictions on FDI and trade from other EU nations. Second, the European Uunion retaliates and imposes the same restrictions on the United Kingdom. Finally, the United Kingdom reduces restrictions on other nations 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. (*JEL* D25, F13, F15, F23, G31, O32)

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 trade costs would rise and 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 trade costs and 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 multi-country dynamic general equilibrium model of McGrattan and Prescott (2009, 2010) by introducing trade frictions and allowing for bilateral costs on FDI, which then enables us to study the partial dissolution of an economic union. The main feature of the framework is technology capital, which is the accumulated know-how from investments in R&D, brands, and organizations that can be used simultaneously by multinational firms in their

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[†] Go to https://doi.org/10.1257/mac.20170399 to visit the article page for additional materials and author disclosure statement(s) or to comment in the online discussion forum.

[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.

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 of the country that is becoming more closed benefits nations that remain open since the capital can be used simultaneously in foreign subsidiaries. If two countries (or unions) simultaneously erect barriers on each other's FDI, offsetting forces—namely, blocked innovation and higher domestic investment—have consequences that are difficult to predict without a framework like ours, especially given that other nations will respond to these policy changes in a global general equilibrium setting. If costs on imported goods are simultaneously increased, then the losses are even greater because consumers want the foreign varieties, but the producers cannot costlessly shift to producing domestically and shipping the goods.

In our baseline Brexit scenario, we assume that the United Kingdom and the remaining countries in the European Union impose tighter restrictions on both FDI and trade from each other. To provide intuition for these results, we first analyze each policy change independently. To analyze the impact of changes in FDI policy, we first assume that the United Kingdom tightens restrictions on EU capital unilaterally, and then we assume 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.

The next step is to consider the impact of rising trade costs alone, assuming no change in FDI policy. We start by assuming a unilateral move by the United Kingdom to restrict EU goods and then a retaliation by the EU countries. With higher trade costs, multinationals shift from less exporting to FDI, but the impacts on innovation of multinational parents are much smaller than in the cases with higher FDI costs. We run additional experiments in which there are higher costs on trade and investment 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 compare the welfare of UK citizens in the baseline scenario to an alternative scenario in which the United Kingdom has negotiated new trade and investment deals with non-European nations.

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, bilateral FDI flows, and bilateral trade flows are the same in the model and data. In the baseline scenario, we assume that trade costs and FDI costs both rise by 5 percentage points, starting in 2019 and fully phased in by 2022. In the case of FDI costs, this cost increase is equivalent to lowering TFP by 5 percent. Given that negotiations are ongoing and there is uncertainty about the specific policies that will be enacted, we also experiment with the timing and magnitude of the cost increases. Since we work with a dynamic model, we can compare predictions for responses immediately following the referendum to the long-run outcomes. Given that the accumulation or decumulation of technology capital plays a central role in the model, the long run in our model is roughly 50 years after the referendum. Furthermore, between the referendum and the actual policy implementation, firms and households take advantage of existing capital inputs that can be used in production before costs on current account flows rise. Thus, the UK and EU economies can appear counterintuitively strong despite the Brexit.

In the baseline scenario, with the United Kingdom and European Union mutually raising both trade and FDI costs by 5 percentage points, we find welfare losses of 1.4 and 2.3 percent for UK and EU citizens, respectively. If we only raise trade costs, with no restrictions on FDI, the losses are much smaller, roughly 0.2 and 0.02 percent for UK and EU citizens, respectively. The main reason for the difference is that higher trade costs lead consumers to substitute between UK and EU varieties and lead producers to substitute between exports and FDI, but have little impact on innovation by multinational parents. Innovation is driven by investment in technology capital, which depends critically on the relative degrees of openness of countries to FDI. If the United Kingdom acts alone and tightens restrictions on EU FDI, EU firms have fewer incentives to invest in technology capital and lower their investment by an average of roughly 5 percent over the first decade and by more than 6 percent in the long run, regardless of the changes in trade policy. Given that technology capital is used in all locations around the world, the impact on production and welfare is large. If the European Union retaliates and raises restrictions on UK FDI, we find a dramatic reduction in UK technology capital investment—eventually by 30 percent in the baseline scenario—and a 12 percent increase in EU technology capital investment. Since the European Union is much larger in population and productive capacity than the United Kingdom, UK firms have more subsidiaries that are affected by the policy change and therefore have less incentive to invest. This turns out to be important for EU welfare since the United Kingdom was a significant investor in the pre-Brexit period.

If the United Kingdom lowers trade and FDI costs on other nations, we find welfare gains rather than losses. We first consider a lowering of costs on the United States and Canada by 5 percentage points on both trade and FDI. In this case, we predict a welfare gain for the United Kingdom of 0.7 percent, much higher than the 1.4 percent loss in the baseline, with little change for the European Union. The United Kingdom effectively replaces a lower TFP investment and trading partner with a higher TFP partner. If the United Kingdom lowers costs on all non-EU partners, again by 5 percentage points, then the UK welfare gain is 1.3 percent. In both scenarios, the lowering of FDI costs is key to higher welfare because innovation increases significantly in the other regions. All nations gain except the European Union.

Most of the related work that estimates the impact of Brexit on current account 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 are 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 that 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), which estimates gravity regressions with bilateral FDI inflows in 34 OECD countries as the dependent variable and uses source and host country characteristics, including EU membership, as independent variables. Bruno et al. (2016) 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). In the baseline scenario, 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.

Other related work uses quantitative theory to estimate the impact of Brexit. Steinberg (2019) 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 United Kingdom and European Union both raising costs on each other's trade and FDI, we find larger effects, with output falling by roughly 1 percent relative to trend in the first decade of the transition, and eventually falling by more than 3 percent. Arkolakis et al. (2017), which analyzes a static economy with costs on both trade and FDI, finds larger effects from raising costs on FDI than on trade, which is consistent with our findings.[3] However, the mechanism underlying our results, which depends critically on how the Brexit affects global investments in technology capital, is different from that of Arkolakis et al. (2017), which models innovation as the creation of differentiated goods in single-product firms, with labor being the only factor of production.[4] Furthermore, our analysis is relevant for the aggregate economy, whereas Arkolakis et al. (2017) only analyze the manufacturing sector.

In Section I, we describe the model, and in Section II, we discuss how we parameterize the model using pre-Brexit data from national and international accounts. In Section III, we report results for the Brexit simulations, and in Section IV we check the sensitivity of the main results. Section V concludes.

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

[3] In recent work, Anderson, Larch, and Yotov (2017) use a dynamic model in the spirit of McGrattan and Prescott (2009, 2010) to study the interaction between FDI and trade, but do not analyze Brexit.

[4] See also Antràs and Yeaple (2014) for a survey of theories of multinational firms in international trade. In contrast to our theory, the theories that they review assume capital is immobile across countries and are, therefore, not suitable for analyzing FDI flows.

I. Model

There are I economic unions, which are groups of countries, states, or provinces that impose few to no restrictions on cross-border shipments or direct investments of multinational firms. Each economic union is characterized by its productive capacity, its TFP, its policy governing traded goods, and its policy governing investments by foreigners, and these characteristics are taken as given by multinational firms when making their production and foreign investment decisions. Multinational firms in each union invest in technology capital, which can be used for production at home or abroad. If produced at home, the firms incur trade costs when shipping goods to foreign customers. If produced abroad, subsidiaries of these firms face regulatory and production costs. More specifically, each economic union i at time t has a total number of locations, N_{it}, where domestic or foreign firms can operate and a level of TFP, A_{it}. Foreign multinationals are associated with a particular proprietary technology, which we index by ω, and their production decisions depend on trade costs for shipments to union i, denoted by $\zeta_{it}(\omega)$, and union i's degree of openness to the firm's investments, denoted by $\sigma_{it}(\omega)$.[5] In this section, we describe the technologies available to these firms and the preferences of households that are the shareholders.

A. *Firm Problem*

Following McGrattan and Prescott (2009), we start by describing technologies for domestic and foreign plants and then derive aggregate production functions at the company level and the economy-wide level. Given these aggregate production functions, we can specify the main problem of a multinational firm that maximizes worldwide dividends.

A firm with technology ω chooses labor and capital in all locations around the world. 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 non-rivalrous and can be used in all locations (e.g., R&D). To simplify the exposition, suppose that the location-specific capital and labor inputs can be combined into a composite input z. Suppose also that the firm has made investments in R&D and has a "blueprint," which when combined with the other inputs z, produces output

$$y = A_i z^{1-\phi} \tag{1}$$

at one location in i.[6] Assuming the blueprint can be used non-rivalrously, the firm can use it to produce at other locations in i with additional factor inputs. If the economic union is totally open to foreign affiliates (incorporated outside the union), then (1)

[5] Another interpretation of the $\sigma_{it}(\omega)$ parameters is that they are not policy parameters but rather represent differences in union characteristics, such as language, that inhibit foreign investment. See, for example, Keller and Yeaple (2013) and Ramondo (2014). These differences can affect the pre-Brexit levels of openness, but not the post-Brexit transition.

[6] This does not rule out multi-plant firms that deploy more than one blueprint in a location.

summarizes the plant-level technology regardless of where the firm's parent company is located.

If economic union i is not fully open, then output produced in i with technology capital developed abroad, say, in economic union j, is given by

$$y = \sigma_i(\omega) A_i z^{1-\phi}, \tag{2}$$

with $\sigma_i(\omega) \in [0,1]$ and $\omega \in \Omega_j$, where Ω_j is defined to be the set of technologies developed in j. If $\sigma_i(\omega) = 1$, then foreign and domestic firms are treated symmetrically by the government in i, just as in (1). If $\sigma_i(\omega) = 0$, then i is totally closed to the use of the foreign technology ω. It may also be the case that there are greater regulatory costs or restrictions on foreign firms than domestic firms, without a complete ban on their inward FDI, which would imply an intermediate value for $\sigma_i(\omega) \in (0,1)$.[7]

Since there are diminishing returns to the composite input z at the plant level, firms maximize total output by proportionally allocating plant-specific inputs across production locations and blueprints. Let N_i be the total number of production locations in i. These locations correspond to markets, and markets are a measure of people.[8] Let $M(\omega)$ be the total stock of *technology capital* for firm ω, that is, the total stock of blueprints and other know-how embodied within the firm. If this firm is operating in i with $Z_i(\omega)$ units of the composite input, then it will optimally allocate an even share of the $Z_i(\omega)$ to the total $M(\omega) N_i$ production possibilities. In this case, total output produced in i by this firm will be given by

$$Y_i(\omega) = \sigma_i(\omega) A_i \big(M(\omega) N_i\big)^{\phi} Z_i(\omega)^{1-\phi}, \tag{3}$$

where, again, $\sigma_i(\omega) = 1$ if $\omega \in \Omega_i$.[9] Here, the composite input $Z_i(\omega)$ is composed of location-specific inputs of labor, $L_i(\omega)$, tangible capital, $K_{T,i}(\omega)$, and intangible capital $K_{I,i}(\omega)$.

It is worth noting that the mathematical computation underlying the production technologies is similar to that in a standard love-of-variety model with constant returns to scale in production, constant elasticity of substitution preferences, and monopolistic competition in the goods market. In the love-of-variety model, setting the elasticity of substitution between varieties equal to $1/\phi$ implies the same decreasing returns at the plant level as in (1). In the aggregate, there are scale effects in both models: gains to openness in the love-of-variety model are due to expanding

[7] Later, we analyze aggregate capital flows and estimate the degree of openness for all FDI coming from a country or union, but the analysis can just as easily be applied to industry-level restrictions, such as those possibly warranted by national security concerns.

[8] In our quantitative work, we assume N_i is proportional to the size of the population.

[9] McGrattan and Prescott (2009) derive the aggregate production function, which is the maximal output that can be produced in a country with technology level A_i, a measure of locations N_i, and openness measures $\{\sigma_i(\omega)\}$. They show that the function is $F(Z_i, \{M(\omega)\}_\omega) = A_i N_i^{\phi} \big(\sum_\omega \sigma_i(\omega)^{1/\phi} M(\omega)\big)^{\phi} Z_i^{1-\phi}$, which displays constant returns to scale. Despite this fact, the total output of a set of open economies with $\sigma_i(\omega) > 0$ is greater than the total output of a set of closed economies. Thus, it is as if there were increasing returns, when in fact there are none.

product varieties, whereas our gains are due to expanding the set of locations where non-rival technology capital can be deployed.

Next, consider the problem of multinationals in our environment. They choose factor inputs to maximize the present value of after-tax worldwide dividends, given by $(1-\tau_{dt})\sum_t p_t D_t(\omega)$, where τ_{dt} is the tax rate on shareholder dividends, p_t is the Arrow-Debreu price, and $D_t(\omega)$ is the total dividend payment. The total dividend payment is the sum of payments across economic unions hosting the FDI, namely, $D_t(\omega) = \sum_i D_{it}(\omega)$, where

$$(4)\quad D_{it}(\omega) = (1-\tau_{p,it})\Big(P_{it}(\omega)\big[Y_{it}(\omega) - \delta_T K_{T,it}(\omega) - X_{I,it}(\omega) - \chi_i(\omega)X_{Mt}(\omega)\big] - W_{it}L_{it}(\omega)\Big) - P_{it}(\omega)\big[K_{T,i,t+1}(\omega) - K_{T,it}(\omega)\big].$$

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 sales $P_i(\omega)\,Y_i(\omega)$ less payments to labor $L_i(\omega)$ at rate W_i, depreciation of tangible capital $K_{T,i}(\omega)$ at rate δ_T, new investment in intangible capital $X_{I,i}(\omega)$ that is location-specific, and investment at home in new technology capital $X_M(\omega)$. Here, we assume that technologies are developed and investments fully expensed in the country where the firm is incorporated. Thus, we set $\chi_i(\omega) = 1$ if $\omega \in \Omega_i$ and 0 otherwise, where Ω_i is defined to be the set of technologies developed in economic union i. 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 types of intangible capital are treated as expenses and 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 $K_{T,i,t+1}(\omega) - K_{T,it}(\omega)$ between period t and $t+1$.

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

$$(5)\quad K_{T,i,t+1}(\omega) = (1-\delta_T)\,K_{T,it}(\omega) + X_{T,it}(\omega) - \varphi\big(X_{T,it}(\omega), K_{T,it}(\omega)\big),$$

$$(6)\quad K_{I,i,t+1}(\omega) = (1-\delta_I)\,K_{I,it}(\omega) + X_{I,it}(\omega) - \varphi\big(X_{I,it}(\omega), K_{I,it}(\omega)\big),$$

$$(7)\quad M_{t+1}(\omega) = (1-\delta_M)\,M_t(\omega) + X_{Mt}(\omega) - \varphi\big(X_{Mt}(\omega), M_t(\omega)\big),$$

where $X_{T,it}(\omega)$, $X_{I,it}(\omega)$, and $X_{Mt}(\omega)$ are new investments; δ_T, δ_I, δ_M are depreciation rates for the location-specific tangible and intangible stocks and the technology capital, respectively; and φ is a function governing the cost of adjusting investment. In our analysis later, we use the following functional form:

$$\varphi(X,K) = \frac{\varphi_0}{2}\left(X/K - \delta - \gamma_Y\right)^{\varphi_1} K, \tag{8}$$

where δ is the depreciation rate of the relevant investment series and γ_Y is trend growth in the global output.

We turn next to a description of the household problem.

B. *Household Problem*

Households in economic union i choose sequences of consumption $C_{it}(\omega)$ for all varieties of goods ω, labor supply L_{it}, shares in companies $S_{i,t+1}(\omega)$ indexed by ω, and bonds $B_{i,t+1}$ to solve the following problem:

$$\max \sum_t \beta^t \left[\log\left(C_{it}/N_{it}\right) + \psi \log\left(1 - L_{it}/N_{it}\right)\right] N_{it} \tag{9}$$

subject to

$$\sum_t p_t \left[\sum_\omega \left(P_{it}(\omega)\, C_{it}(\omega) + V_t(\omega)\left(S_{i,t+1}(\omega) - S_{it}(\omega)\right)\right) + B_{i,t+1} - B_{it}\right]$$

$$\leq \sum_t p_t \left[\left(1 - \tau_{l,it}\right) W_{it} L_{it} + \left(1 - \tau_{dt}\right) \sum_\omega D_t(\omega)\, S_{it}(\omega) + r_{bt} B_{it} + \kappa_{it}\right],$$

where

$$C_{it} = \left(\sum_\omega C_{it}(\omega)^{\frac{\rho-1}{\rho}}\right)^{\frac{\rho}{\rho-1}} \tag{10}$$

with $\rho > 0$. Here, 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.[10] As we noted earlier, 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 an economic union's productive capacity scales with the population.

Goods purchased from a foreign multinational can be either bought locally from one of the affiliates in i or bought from the parent company and shipped. We denote

[10] 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.

by $C_{it}^F(\omega)$ the goods purchased from affiliates, where F indicates it is included with FDI statistics, and we denote by $C_{it}^T(\omega)$ the goods purchased abroad, where T indicates it is included with trade statistics. We assume that these goods are not perfect substitutes, but are nearly so, with

$$(11) \qquad C_{it}(\omega) = \left(C_{it}^F(\omega)^{\frac{\varrho-1}{\varrho}} + C_{it}^T(\omega)^{\frac{\varrho-1}{\varrho}}\right)^{\frac{\varrho}{\varrho-1}}, \quad \omega \notin \Omega_i$$

and $\varrho \gg \rho$, where recall that Ω_i are technologies that have been developed in i. Prices for foreign goods bought locally reflect costs to affiliates when operating in i. These costs show up as lower output in (3) per unit of composite input because of regulatory costs on foreign direct investment modeled as $\sigma_i(\omega) < 1$. Prices for shipped goods include an additional cost given by $\zeta_i(\omega) P_j(\omega)$, $\omega \in \Omega_j$, if shipped from j to i. Here, we assume that it is not cheaper to ship goods from an affiliate operating in a third country.[11]

C. *Market Clearing*

For each technology ω, we require that the following resource constraints hold:

$$(12) \qquad Y_{jt}(\omega) = C_{jt}^F(\omega) + X_{T,jt}(\omega) + X_{I,jt}(\omega), \quad j \neq i,$$

$$(13) \qquad Y_{it}(\omega) = C_{it}(\omega) + \sum_{j \neq i}\left(1 + \zeta_{jt}(\omega)\right) C_{jt}^T(\omega) + X_{T,it}(\omega) + X_{I,it}(\omega) + X_{Mt}(\omega) + \bar{X}_{nb,it} - \bar{Y}_{nb,it},$$

where i is home for the multinational firm with this technology, that is, $\omega \in \Omega_i$, and j are the economic unions that host the firm's foreign affiliates.

The market-clearing price for the bundle of goods consumed in i, C_{it}, is given by

$$(14) \qquad P_{it} = \left(\sum_{\omega} P_{it}(\omega)^{1-\rho}\right)^{\frac{1}{1-\rho}}.$$

For goods with technology developed abroad, say in union j, the price in i is

$$(15) \qquad P_{it}(\omega) = \left(P_{it}^F(\omega)^{1-\varrho} + P_{it}^T(\omega)^{1-\varrho}\right)^{\frac{1}{1-\varrho}},$$

where $P_{it}^F(\omega)$ is the producer price in i and $P_{it}^T(\omega)$ is the producer price in j plus the trade cost, that is, $P_{it}^T(\omega) = P_{jt}(\omega)\left(1 + \zeta_{it}(\omega)\right)$.

[11] In our quantitative investigation, we treat geographically close countries, such as Canada and the United States, as one region given proximity facilitates intra-firm trade between parents and affiliates.

In addition to goods market clearing, we require asset markets to clear, with $\sum_i B_{it} = 0$ and $\sum_i S_{it}(\omega) = 1$ for all periods and all firms ω. Finally, we require that labor markets clear in all economic unions, that is,

$$L_{it} = \sum_{\omega} L_{it}(\omega) + \bar{L}_{nb,it}, \tag{16}$$

with the total labor supplied by households L_{it} equal to the total demanded labor by firms $L_{it}(\omega)$ and nonbusiness entities $\bar{L}_{nb,it}$.

D. *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, namely, exports, imports, net factor receipts, and net factor payments.

In the model, we compute nominal GDP as follows:

$$GDP_{it} = \sum_{\omega} P_{it}(\omega)\big(Y_{it}(\omega) - X_{I,it}(\omega) - \chi_i(\omega)\,X_{Mt}(\omega)\big) - P_{nb,it}\bar{X}_{nb,it}, \tag{17}$$

where $P_{nb,it}$ is the price index for nonbusiness goods, which is assumed later to be an index of prices for technologies developed in i. Notice here that we have subtracted the intangible investments, which are expensed by firms. Although some categories of intangible investments have recently been included in measures of GDP for some countries, most categories are still excluded. In light of this, we use the old concept of GDP and assume full expensing of intangible investments.[12]

To compute nominal GNP, we need net factor receipts (NFR) from foreigners and net factor payments (NFP) to foreigners, which are recorded in the international accounts of i as

$$\begin{aligned} NFR_{it} = {} & \sum_{j \neq i} \sum_{\omega \in \Omega_i} \big(D_{jt}(\omega) + P_{jt}(\omega)\big[K_{T,j,t+1}(\omega) - K_{T,jt}(\omega)\big]\big) \\ & + \sum_{j \neq i} \sum_{\omega \in \Omega_j} S_{it}(\omega)\,D_t(\omega) + \max(r_{bt}B_{it}, 0), \end{aligned} \tag{18}$$

$$\begin{aligned} NFP_{it} = {} & \sum_{j \neq i} \sum_{\omega \in \Omega_j} \big(D_{it}(\omega) + P_{it}(\omega)\big[K_{T,i,t+1}(\omega) - K_{T,it}(\omega)\big]\big) \\ & + \sum_{j \neq i} \sum_{\omega \in \Omega_i} S_{jt}(\omega)\,D_t(\omega) + \max(-r_{bt}B_{it}, 0). \end{aligned} \tag{19}$$

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

In both expressions, the first sums are direct investment income from multinational profits—dividends plus retained earnings. The second sums are portfolio income from equity holdings of households. Finally, the third terms are payments of net interest, which flow in if positive or out if negative. GNP is the sum of GDP and net factor incomes (NFR less NFP).

The current account in the international accounts is computed as the sum of net factor income and the trade balance (exports less imports). Nominal exports (EX) and imports (IM) for i are given by

$$EX_{it} = \sum_{j \neq i} \sum_{\omega \in \Omega_i} P_{it}(\omega)\left(1 + \zeta_{jt}(\omega)\right) C_{jt}^{T}(\omega), \tag{20}$$

$$IM_{it} = \sum_{j \neq i} \sum_{\omega \notin \Omega_i} P_{jt}(\omega)\left(1 + \zeta_{it}(\omega)\right) C_{it}^{T}(\omega). \tag{21}$$

In equilibrium, the net of these values is also equal to GDP less consumption and tangible investment, which is consistent with the national accounts measure of net exports.

Later, we work with real variables. We deflate all nominal variables with the chain-weighted output deflator for one country (which, in our quantitative analysis, is the United States).

II. 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.[13] 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, ρ, ϱ), trend growth in TFP $\left(1+\gamma_A\right)^t$, trend growth in population $\left(1+\gamma_N\right)^t$, 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), and adjustment costs (φ_0, φ_1). For all but the elasticities ρ and ϱ, we use estimates from McGrattan and Prescott's (2010) study, which are reported in Table 1. For the substitution parameters that govern the trade elasticities, we set $\rho = 10$ and $\varrho = 100$. The literature has a wide range of trade elasticities (ρ), from low estimates of 1 to 2 to match quarterly international business cycle fluctuations to high estimates of 10 to 15 to match growth following a trade liberalization.[14] Given we are studying Brexit, we used a relatively high estimate, but later we do sensitivity analysis and rerun our experiments with $\rho = 5$

[13] More specifically, we include the United Kingdom, all other European Union countries, Norway, and Switzerland as a non-EU European region, the United States and Canada as one region, and Japan, Korea, and China as one region. All trade and FDI flows between countries in a region are netted.

[14] See Ruhl (2008) and Simonovska and Waugh (2014) for discussions of the wide range of estimates.

Table 1—Model Parameters Common across Economies

Parameter	Expression	Value
Preferences		
Discount factor	β	0.98
Leisure weight	ψ	1.32
Growth rates (percent)		
Population	γ_N	1.0
Technology	γ_A	1.2
Income shares (percent)		
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 (percent)		
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 (percent)		
Technology capital	δ_M	8.0
Tangible capital	δ_T	6.0
Plant-specific intangible capital	δ_I	0
Tax rates (percent)		
Labor wedge	τ_l	34
Dividends	τ_d	28
Trade elasticities		
Armington	ρ	10
Produced at home versus abroad	ϱ	100
Adjustment cost parameters		
Slope	φ_0	1
Curvature	φ_1	2

Notes: Parameters are taken from McGrattan and Prescott's (2010) analysis of the US current account, with the exception of trade elasticities and adjustment costs. See the main text for more details.

and $\rho = 15$. We chose a very high value for ϱ since this is the parameter governing substitution between goods sold by the parent and the good sold by an affiliate.

Table 2 reports parameters that differ across economies. The first set shown in panel A of Table 2 includes levels of TFP, populations, and corporate profit tax rates. TFP and population for the United Kingdom are normalized to 100, and estimates for all other economies are set relative to the United Kingdom's economy. The second set of parameters shown in Table 2, panel B, includes all bilateral degrees of openness in the pre-Brexit period, namely, $\sigma_{i0}(\omega)$. To keep the analysis tractable and focused on aggregate capital flows, we assume that $\sigma_{i0}(\omega)$ is the same for all $\omega \in \Omega_j$, for all i,j with $j \neq i$, which means that all multinationals from j face the same restrictions on their foreign investments in i.[15] The rows in Table 2, panel B, represent the recipients of FDI, and the columns represent the originators of FDI. The third set

[15] The analysis can easily be extended if bilateral flows are available at a more disaggregated level.

Table 2—Exogenous Inputs

Panel A. TFPs, populations, profit tax rates

Economy	TFP	Population	Percent tax rate
United Kingdom	100	100	26
European Union	83	698	23
Non-EU Europe	128	20	25
United States–Canada	119	547	34
Asia	40	2,418	28

Panel B. Degrees of openness $(\sigma_i(\omega))$

Technology ω from: Invested in i:	United Kingdom	European Union	Non-EU Europe	US–Canada	Asia
United Kingdom	1	1	0.51	0.88	0.73
European Union	1	1	0.90	0.87	0.72
Non-EU Europe	0.40	0.73	1	0.64	0.57
United States–Canada	0.77	0.84	0.81	1	0.71
Asia	0.59	0.64	0.64	0.60	1

Panel C. Trade costs $(\zeta_i(\omega))$

Technology ω from: Shipped to i:	United Kingdom	European Union	Non-EU Europe	US–Canada	Asia
United Kingdom	0	0	0.00	0.14	0.02
European Union	0	0	0.00	0.14	0.00
Non-EU Europe	0.75	0.49	0	0.75	0.51
United States–Canada	0.12	0.08	0.00	0	0.00
Asia	0.53	0.42	0.12	0.52	0

Notes: The European Union includes all EU countries other than the United Kingdom, non-EU Europe includes Norway and Switzerland, and Asia includes Japan, Korea, and China. All FDI and trade flows between multi-country economies are netted. TFP and population are normalized to 100 for the United Kingdom with other estimates relative to theirs.

of parameters that differ for each region are shown in Table 2, panel C, namely, the trade costs. Again, the rows are recipients and the columns are originators. In the pre-Brexit period, we impose that $\sigma_{i0}(\omega) = 1$ and $\zeta_{i0}(\omega) = 0$ for bilateral flows between the United Kingdom and the European Union, since goods and investments can flow freely within the union.

The remaining bilateral degrees of openness, trade costs, and the levels of TFPs are set so as to exactly replicate all bilateral FDI flows (relative to GDP), all bilateral trade flows (relative to GDP), and real GDPs per capita (relative to a common long-run growth trend).[16]

III. Post-Brexit

In this section, we use the parameterized model to analyze several post-Brexit scenarios. In our baseline scenario, both the United Kingdom and the European Union raise costs on each other's foreign investment and trade, effectively dissolving the economic union. To fully understand the forces at work, we start by analyzing a unilateral move by the United Kingdom to raise costs on EU foreign investment, with no change in trade costs. We contrast these results with the case in

[16] To parameterize the degrees of openness, we use actual FDI flows rather than indices of FDI restrictiveness such as those computed by the OECD (1990–2016). The indices have no theoretical counterpart and cannot accurately measure the overall restrictiveness of the regulatory regime. See the Appendix for data sources.

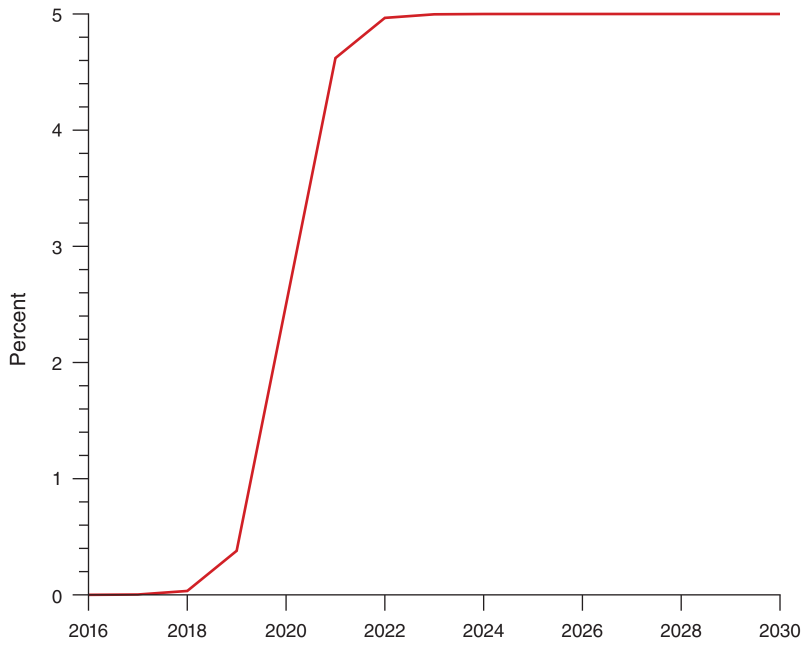

Figure 1. Timing and Magnitude of Cost Increases during Transition

which the European Union retaliates and imposes the same restrictions on the UK investment. We repeat the exercise with free movement in FDI but higher trade costs, with restrictions first imposed by the United Kingdom and then simultaneously by the European Union. For comparable cost increases, we find much larger welfare losses from increased costs of FDI than for increased trade costs because innovation is affected to a greater degree. We then compare the results to the baseline scenario with higher costs on both FDI and trade, first assuming that the United Kingdom acts alone and then assuming that the European Union retaliates. In this baseline case, the welfare of EU citizens is hardly affected if the United Kingdom acts alone but suffers considerably if the EU retaliates. The final scenarios consider a lowering of costs for trade and investment into the United Kingdom from nations outside of the European Union. In these scenarios, greater openness to outside nations yields large welfare gains for the United Kingdom.

The timing of cost changes for the numerical experiments is shown in Figure 1. The actual changes occur two years after the referendum of 2016 and are fully phased in by 2022. In the case of higher trade costs, this is the time series for $\zeta_{it}(\omega)$, with i indexing the recipient and ω indexing the source. For example, if the United Kingdom acts alone to restrict trade from countries in the European Union, we feed in the cost increases shown in Figure 1, with the cost starting at 0 (as in element $(2,1)$ of the matrix in panel C of Table 2) and rising eventually to 5 percent. In the case of higher costs on FDI, we use the time series in Figure 1 for $1-\sigma_{it}(\omega)$. For example, when the United Kingdom and European Union allow for freely mobile investment, $\sigma_{it}(\omega)$ is equal to 1. By 2022, the degree of openness—for whichever country is restricting

FDI—is equal to 0.95. In the final section, we vary the timing and magnitude of the cost changes and discuss the sensitivity of the results to parameter assumptions.

A. *Costs of FDI Increased*

In Table 3, we analyze one aspect of the post-Brexit transition: rising costs on FDI. For these simulations, the degree of openness parameters in elements $(2, 1)$ and then $(1, 2)$ of the matrix in Table 2, panel B, are lowered to 0.95. The first five rows of Table 3, panels A and B, show results if the United Kingdom tightens restrictions on inward FDI from EU nations and does so unilaterally. The last five rows in both panels show results if both the United Kingdom and the European Union tighten restrictions on each other. The first 11 columns are percentage changes in current account flows, national account expenditures, and labor market variables relative to the pre-Brexit levels. 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. Welfare, listed in the last column of panel B, is calculated as the consumption equivalent needed to be indifferent between the new policies (that is, higher FDI costs) and no change. A positive value indicates a gain relative to the pre-Brexit baseline.

First consider the scenario of the United Kingdom acting alone to increase costs on inward FDI from other nations in the European Union. Following the announcement, there is a significant decline in UK inward FDI flows, roughly 43 percent on average in the first decade. The transition period is around 50 years, and the eventual decline in inward FDI to the United Kingdom is 16 percent. Over the transition, UK trade flows rise significantly as firms circumvent the increased FDI costs. The other effects of the cost increase are best understood if we consider what happens to innovation by EU and UK multinationals. Higher costs on EU subsidiaries in the United Kingdom affect investment in technology capital since this type of capital can be used non-rivalrously 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.[17] In this case, we predict an average decline in EU technology capital investments of 5 percent relative to pre-Brexit levels over the first decade and 6.4 percent in the long run. For UK firms, we see the reverse pattern, with an average increase of 2.8 percent over the first decade and 3.7 percent in the long run. Although investment in UK technology capital rises, other domestic expenditures fall by roughly 1.6 percent in the long run, and UK welfare is lower by roughly 1.9 percent.

[17] McGrattan and Prescott (2009) work through simple examples to show how country characteristics like TFP, population, and the degree of openness affect predictions about where production takes place and which firms innovate. Because technology capital is non-rivalrous, there is an advantage to size—arising either from higher TFP or from more productive locations—even if countries are not open to FDI. Countries that are open to FDI can exploit foreign technology capital by permitting direct investment, and therefore the model predicts that more innovation is done by those that are relatively less open, all else equal.

TABLE 3—CHANGES IN RESPONSE TO HIGHER FDI COSTS, RELATIVE TO PRE-BREXIT LEVELS

Panel A. FDI and trade flows

	FDI flows		Trade flows	
	In	Out	In	Out
United Kingdom tightens restrictions on EU FDI unilaterally				
United Kingdom	−42.7	1.8	−2.8	6.2
	(−16.2)	(1.5)	(15.5)	(32.2)
European Union	1.6	−33.1	0.8	0.4
	(1.2)	(−13.7)	(6.6)	(5.6)
Non-EU Europe	−1.9	0.7	0.6	−0.4
	(−1.4)	(0.4)	(−0.6)	(−1.4)
United States–Canada	−1.3	5.1	0.6	−1.1
	(−1.1)	(2.1)	(−1.1)	(−1.5)
Asia	−1.3	3.7	0.5	−0.8
	(−0.8)	(1.5)	(−0.9)	(−0.8)
United Kingdom and European Union tighten FDI restrictions on each other				
United Kingdom	−37.7	−80.4	−0.9	45.4
	(−11.6)	(−34.5)	(33.7)	(123.3)
European Union	−35.4	−20.7	0.8	2.7
	(−15.3)	(−4.6)	(34.3)	(16.9)
Non-EU Europe	−0.5	22.2	3.6	−3.6
	(0.9)	(9.3)	(2.0)	(−1.2)
United States–Canada	−0.1	33.9	4.0	−6.6
	(−0.1)	(13.4)	(−4.4)	(−5.7)
Asia	2.9	16.7	1.3	−2.7
	(1.1)	(6.2)	(1.0)	(1.2)

Panel B. Expenditures, labor market, and welfare

	Expenditures					Labor market		Welfare
	Y	C	X_T	X_I	X_M	L	W	Δ
United Kingdom tightens restrictions on EU FDI unilaterally								
United Kingdom	−0.2	−1.7	−2.0	−4.7	2.8	1.1	−1.3	−1.87
	(−1.6)	(−1.7)	(−1.6)	(−1.6)	(3.7)	(0.1)	(−1.7)	
European Union	−0.1	0.1	0.1	0.5	−5.0	−0.1	0.0	0.01
	(0.0)	(0.0)	(0.0)	(0.0)	(−6.4)	(0.1)	(0.0)	
Non-EU Europe	0.0	0.1	0.1	0.5	0.3	−0.1	0.1	−0.08
	(0.1)	(0.1)	(0.1)	(0.1)	(0.4)	(0.0)	(0.1)	
United States–Canada	0.0	0.0	0.1	0.2	0.6	0.0	0.0	−0.01
	(0.0)	(0.0)	(0.0)	(0.0)	(0.8)	(0.0)	(0.0)	
Asia	0.0	0.1	0.0	0.2	0.1	0.0	0.0	0.00
	(0.0)	(0.0)	(0.0)	(0.0)	(0.1)	(0.0)	(0.0)	
United Kingdom and European Union tighten FDI restrictions on each other								
United Kingdom	−1.9	−0.7	−3.3	−3.9	−24.6	−0.9	−1.0	−0.30
	(−3.5)	(−0.8)	(−3.5)	(−3.5)	(−28.3)	(−2.2)	(−1.5)	
European Union	−0.7	−1.5	−1.4	−0.3	11.8	0.6	−1.3	−2.36
	(−1.3)	(−1.5)	(−1.3)	(−1.3)	(15.9)	(0.1)	(−1.4)	
Non-EU Europe	0.3	0.4	0.8	1.4	6.0	−0.1	0.4	0.30
	(1.1)	(0.4)	(1.1)	(1.1)	(6.8)	(0.4)	(0.6)	
United States–Canada	−0.1	0.2	0.3	0.9	3.4	−0.2	0.1	0.17
	(0.4)	(0.2)	(0.4)	(0.4)	(3.7)	(0.1)	(0.2)	
Asia	0.0	0.1	0.2	0.6	0.5	−0.1	0.1	0.04
	(0.1)	(0.1)	(0.1)	(0.1)	(0.5)	(−0.1)	(0.1)	

Notes: Values reported are percentage changes relative to the pre-Brexit baseline in response to an increase in costs that follows the path shown in Figure 1. 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. Changes in output and investments are reported only for businesses.

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 production and welfare are hardly affected. Essentially, the European Union lowers investment in technology capital and increases net exports. The European Union also benefits from increased investment in the technology capital of other nations, which also rises in response to the EU disinvestment. More technology capital means more outward FDI from these nations, especially the United States, Canada, and Asia, benefiting all FDI recipients. We find that the quantitative impact of these policy changes depends crucially on the relative sizes and TFPs of the investing nations and their pre-Brexit FDI stocks.

Next, consider the scenario in which both the United Kingdom and the European Union raise costs on foreign affiliates with the same magnitude and timing as in the unilateral case. The results are shown in the last five rows of Table 3, panels A and B. Not surprisingly, FDI flows between them fall throughout the transition and trade flows increase. UK expenditures of all types fall, 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 28 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 2, panel A.) Given the non-rivalrous 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 its financing of production of non-UK multinationals. In effect, the UK foreign investment shifts from FDI to portfolio investment.

With less UK technology capital, the remaining EU countries must accumulate more of their own, and investment in technology capital rises by close to 12 percent over the first decade and ultimately by 16 percent. This investment benefits all nations with EU subsidiaries, including the United Kingdom. We also see that other nations respond with an increase in technology capital investment, which again has a positive impact on all FDI recipients. As a result, production and outward FDI flows rise in all other regions. In terms of welfare, the United Kingdom is worse off by -0.3 percent, but the welfare losses are attenuated by increased global innovation. In this case, the European Union is much worse off, with welfare down 2.4 percent, because of lost capital from the United Kingdom.

B. *Costs of Trade Increased*

In Table 4, we analyze a second aspect of the post-Brexit transition—rising trade costs. To isolate the impact of these costs, we assume no change in FDI costs. As before, we first consider a unilateral move by the United Kingdom, and then we assume that the European Union retaliates.

Consider first the results shown in the first five rows of Table 4, panels A and B, for a unilateral policy change. With higher costs on EU goods shipped to the United

TABLE 4—CHANGES IN RESPONSE TO HIGHER TRADE COSTS, RELATIVE TO PRE-BREXIT LEVELS

Panel A. FDI and trade flows

	FDI flows		Trade flows	
	In	Out	In	Out
United Kingdom tightens restrictions on EU trade unilaterally				
United Kingdom	27.5	1.6	−4.9	−24.4
	(9.3)	(0.0)	(−19.7)	(−47.6)
European Union	1.4	15.1	−7.8	−3.2
	(0.2)	(5.5)	(−14.1)	(−9.5)
Non-EU Europe	−2.3	−0.5	0.5	1.8
	(−0.5)	(−0.2)	(1.6)	(3.3)
United States–Canada	−1.9	−0.7	2.2	2.2
	(−0.5)	(−0.2)	(4.7)	(4.8)
Asia	0.5	−1.0	0.6	0.8
	(0.3)	(−0.3)	(1.3)	(1.3)
United Kingdom and European Union tighten trade restrictions on each other				
United Kingdom	30.2	3.1	−7.4	−31.6
	(10.1)	(0.6)	(−23.5)	(−58.0)
European Union	2.3	16.2	−9.5	−4.3
	(0.5)	(5.8)	(−16.5)	(−11.0)
Non-EU Europe	−2.2	−0.5	0.4	1.7
	(−0.5)	(−0.2)	(1.5)	(3.1)
United States–Canada	−2.1	−0.9	2.7	2.7
	(−0.6)	(−0.3)	(5.0)	(5.2)
Asia	−0.7	−1.2	0.8	1.0
	(0.0)	(−0.4)	(1.5)	(1.5)

Panel B. Expenditures, labor market, and welfare

	Expenditures					Labor market		Welfare
	Y	C	X_T	X_I	X_M	L	W	Δ
United Kingdom tightens restrictions on EU trade unilaterally								
United Kingdom	1.0	1.6	3.2	7.5	−0.7	−0.5	1.5	−0.19
	(1.6)	(1.6)	(1.6)	(1.6)	(−1.1)	(0.0)	(1.6)	
European Union	−0.1	−0.3	−0.5	−1.2	0.8	0.1	−0.2	−0.04
	(−0.3)	(−0.3)	(−0.3)	(−0.3)	(1.2)	(0.0)	(−0.3)	
Non-EU Europe	−0.1	−0.1	−0.2	−0.5	−0.2	0.0	−0.1	0.07
	(−0.1)	(−0.1)	(−0.1)	(−0.1)	(−0.1)	(0.0)	(−0.1)	
United States–Canada	0.0	0.0	0.0	−0.1	0.1	0.0	0.0	0.02
	(0.0)	(0.0)	(0.0)	(0.0)	(0.1)	(0.0)	(0.0)	
Asia	0.0	0.0	0.0	−0.1	−0.1	0.0	0.0	0.01
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	
United Kingdom and European Union tighten trade restrictions on each other								
United Kingdom	0.8	1.5	2.8	6.8	−0.3	−0.5	1.3	−0.24
	(1.5)	(1.5)	(1.5)	(1.5)	(−0.8)	(0.0)	(1.5)	
European Union	−0.1	−0.2	−0.4	−1.0	0.6	0.1	−0.2	−0.02
	(−0.2)	(−0.2)	(−0.2)	(−0.2)	(1.0)	(0.0)	(−0.2)	
Non-EU Europe	−0.1	−0.1	−0.2	−0.5	−0.2	0.0	−0.1	0.07
	(−0.1)	(−0.1)	(−0.1)	(−0.1)	(−0.1)	(0.0)	(−0.1)	
United States–Canada	0.0	0.0	0.0	−0.1	0.1	0.0	0.0	0.02
	(0.0)	(0.0)	(0.0)	(0.0)	(0.1)	(0.0)	(0.0)	
Asia	0.0	0.0	0.0	−0.1	0.0	0.0	0.0	0.01
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	

Note: See notes at the end of Table 3.

Kingdom, EU exports and UK imports both fall. In the long run, with trade costs higher by 5 percent, EU exports are lower by 10 percent and UK imports are lower by 20 percent. With substitution across goods, trade flows increase in other regions and FDI flows increase between the United Kingdom and European Union. Because of higher trade costs, prices of goods and total expenditures rise, but quantities consumed and welfare both fall. The welfare loss in this case is only 0.19 percent, which is much smaller than in the case with unilaterally higher FDI costs. (See Table 3.) There is also a modest loss of welfare for the European Union and modest gains for other regions.

If the European Union retaliates and raises trade costs on goods shipped from the United Kingdom, the results are quantitatively similar to the case with only the United Kingdom changing policy. The reason is that, in the pre-Brexit period, the United Kingdom relied heavily on both EU trade and FDI, whereas the European Union relied little on UK trade and more heavily on UK FDI. Thus, raising barriers against trade from the United Kingdom does not change outcomes very much.

C. *Costs of FDI and Trade Increased*

We turn now to our baseline scenario with costs of both FDI and trade increased in the post-Brexit transition. The results for this case are shown in Table 5, again with a unilateral UK policy change and with both the United Kingdom and European Union putting restrictions on each other's multinationals. To make results comparable, we have assumed the same timing and magnitudes for cost changes as before. (See Figure 1.)

If the United Kingdom acts alone, we predict lower inward FDI and imports due to the increased costs, a modest impact on business output, and a 2.4 percent decline in welfare. Other regions, including the European Union, respond by making current account adjustments but do not see much impact on welfare. Because FDI costs are higher, the main effect on expenditures is higher investment in technology capital in the United Kingdom and less in the European Union.

In the baseline scenario shown in the last five rows of Table 5, panels A and B, with the United Kingdom and the European Union putting up barriers against each other, we predict that both lose. Welfare in the United Kingdom falls 1.4 percent, and welfare in the European Union falls 2.3 percent.[18] Since multinationals face both FDI and trade cost increases, the impact on FDI inflows is not unambiguously negative. Here, it helps to compare the results of Table 3 with only FDI policy changed and Table 5 with both FDI and trade policy changed. In the latter case, we find an *increase* in inward FDI of 7.4 percent in the first decade and 3.7 percent in the long run, which is in contrast to the prediction of Kierzenkowski et al. (2016), who argue that "lower FDI inflows would seem unavoidable" if access to the EU single market is restricted. What matters for the result is the relative cost of producing abroad

[18] Arkolakis et al. (2017) run a similar Brexit experiment in a static model without capital calibrated to manufacturing data and find real expenditure losses—their measure of the change in welfare—equal to −1.6 percent for the United Kingdom. In contrast to our results, losses for the remaining EU countries are much smaller. However, since the share of manufacturing value added of GDP is only 9 percent in the United Kingdom, it is not known how large these losses would be if their analysis were extended to include all production.

TABLE 5—CHANGES IN RESPONSE TO HIGHER FDI AND TRADE COSTS, RELATIVE TO PRE-BREXIT LEVELS

Panel A. FDI and trade flows

	FDI flows		Trade flows	
	In	Out	In	Out
United Kingdom tightens restrictions on European Union FDI and trade unilaterally				
United Kingdom	−16.3	4.2	−9.2	−18.2
	(−8.3)	(2.2)	(−5.7)	(−21.3)
European Union	3.4	−20.7	−6.9	−3.0
	(1.7)	(−10.0)	(−8.2)	(−4.0)
Non-EU Europe	−4.5	0.3	1.2	1.4
	(−2.1)	(0.3)	(0.9)	(1.7)
United States–Canada	−3.2	5.6	2.8	0.8
	(−1.6)	(2.4)	(2.6)	(2.2)
Asia	−1.4	3.1	1.1	−0.1
	(−0.7)	(1.3)	(0.4)	(0.5)
United Kingdom and European Union tighten FDI and trade restrictions on each other				
United Kingdom	7.4	−69.2	−18.3	4.0
	(3.7)	(−29.9)	(−16.5)	(−9.1)
European Union	−27.3	−0.6	−10.0	−5.6
	(−12.0)	(1.8)	(−1.9)	(−5.4)
Non-EU Europe	−2.6	22.2	4.0	−2.4
	(0.2)	(9.4)	(3.1)	(0.8)
United States–Canada	−4.8	33.4	7.8	−1.8
	(−1.6)	(13.5)	(4.4)	(3.1)
Asia	−4.9	15.4	2.5	−0.9
	(−1.5)	(5.8)	(4.0)	(4.3)

Panel B. Expenditures, labor market, and welfare

	Expenditures					Labor market		Welfare
	Y	C	X_T	X_I	X_M	L	W	Δ
United Kingdom tightens restrictions on European Union FDI and trade unilaterally								
United Kingdom	0.9	−0.4	1.2	3.0	2.4	1.0	−0.1	−2.41
	(−0.3)	(−0.4)	(−0.3)	(−0.3)	(3.2)	(0.1)	(−0.4)	
European Union	−0.2	−0.2	−0.4	−0.7	−4.9	−0.1	−0.2	−0.02
	(−0.3)	(−0.2)	(−0.3)	(−0.3)	(−6.2)	(−0.1)	(−0.2)	
Non-EU Europe	−0.1	0.0	−0.1	0.0	0.1	−0.1	0.0	−0.03
	(0.0)	(0.0)	(0.0)	(0.0)	(0.3)	(0.0)	(0.0)	
United States–Canada	0.0	0.0	0.0	0.1	0.8	0.0	0.0	0.00
	(0.1)	(0.0)	(0.1)	(0.1)	(1.0)	(0.0)	(0.0)	
Asia	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.01
	(0.0)	(0.0)	(0.0)	(0.0)	(0.1)	(0.0)	0.0)	
United Kingdom and European Union tighten FDI and trade restrictions on each other								
United Kingdom	−1.0	−0.5	−2.0	−2.1	−23.9	−0.4	−0.6	−1.40
	(−3.2)	(−0.5)	(−3.2)	(−3.2)	(−26.9)	(−2.1)	(−1.2)	
European Union	−0.7	−1.3	−1.1	0.5	10.8	0.4	−1.1	−2.32
	(−1.0)	(−1.2)	(−1.0)	(−1.0)	(14.3)	(0.1)	(−1.2)	
Non-EU Europe	0.3	0.4	0.6	0.9	6.0	−0.1	0.3	0.33
	(1.1)	(0.4)	(1.1)	(1.1)	(6.9)	(0.4)	(0.6)	
United States–Canada	−0.1	0.2	0.2	0.5	3.7	−0.2	0.1	0.19
	(0.4)	(0.2)	(0.4)	(0.4)	(4.0)	(0.1)	(0.3)	
Asia	0.0	0.1	0.2	0.5	0.5	−0.1	0.1	0.05
	(0.2)	(0.2)	(0.2)	(0.2)	(0.6)	(0.0)	(0.2)	

Note: See notes at the end of Table 3.

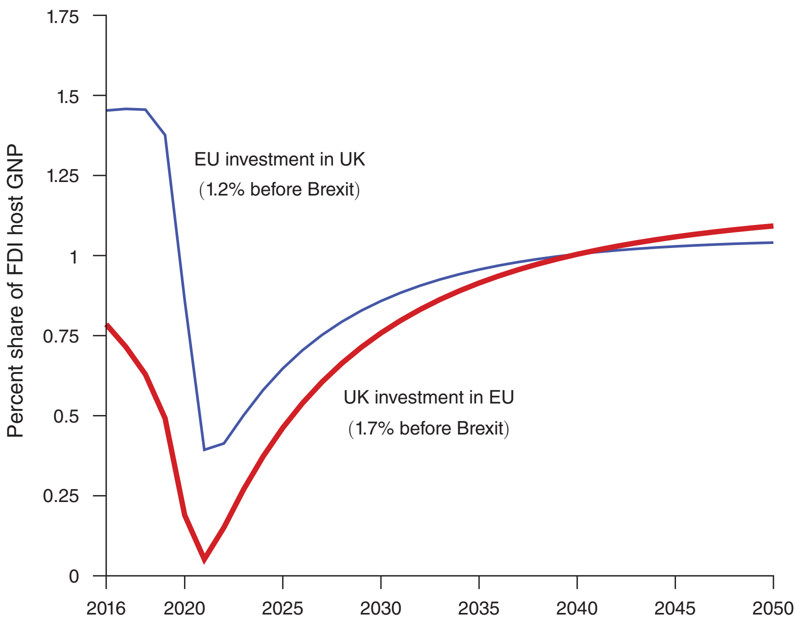

Figure 2. FDI Flows between United Kingdom and European Union

versus shipping abroad. A more predictable outcome, especially when companies are investing heavily in technology capital, is a decline in *outward* FDI, especially for the United Kingdom, which is the smaller country. With its technology capital blocked, the UK multinationals innovate less and produce less abroad.

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.[19] Prior to the referendum of 2016, we estimate a ratio for the EU investment in the United Kingdom relative to UK GNP to be about 1.2 percent. We estimate a ratio of UK investment in the European Union relative to EU GNP to be about 1.7 percent. These pre-Brexit estimates are noted in the figure. Following the referendum, we find that UK direct investment in the European Union as a share of EU GNP falls nearly to zero and reaches 1.2 percent by 2050. Meanwhile, EU investment rises before the policy changes, and then falls significantly, before eventually bringing investment levels close to pre-Brexit levels as a share of UK GNP.

As trade and investment costs 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 and trade 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

[19] 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 points.

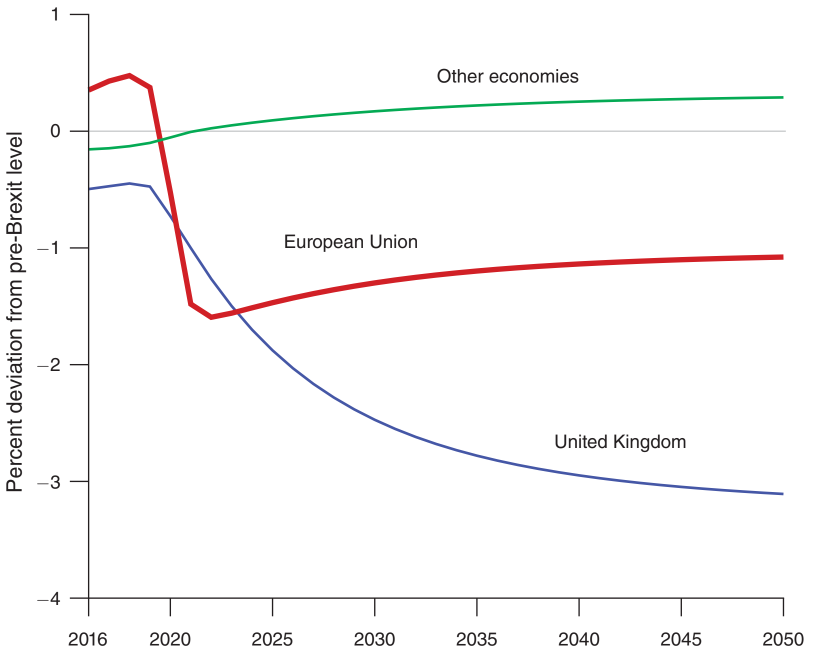

Figure 3. Business Outputs of United Kingdom, European Union, and All Other Economies

below trend by roughly 3 percent and EU output is below by roughly 1 percent. When aggregated, the business output of non-UK and non-EU firms is initially below the pre-Brexit level, but eventually rises by roughly 0.3 percent above that level.

D. *Costs of Non-EU FDI and Trade into UK Decreased*

Next, we estimate the impact of looser restrictions on FDI and trade into the United Kingdom from other nations, with the timing the same as the Brexit timing shown in Figure 1. We start by assuming that the United Kingdom lowers costs only on flows from the United States and Canada and then repeat the exercise for all nations. In both experiments, the FDI and trade costs are lowered eventually by 5 percentage points relative to the pre-Brexit level.

The results of these experiments are shown in Table 6. The first five rows of panels A and B show the economic impact of lower costs on US and Canadian multinationals that export to and operate in the United Kingdom. These estimates can be directly compared to the baseline scenario shown in the last five rows of Table 5, panels A and B. Not surprisingly, we find larger FDI inflows and more imports because of the lower costs. Lower FDI costs incentivize US and Canadian multinationals to invest more in technology capital and thus do more outward FDI, with the increase at close to 50 percent higher than the pre-Brexit level. This increase has a large effect on UK welfare, which is now higher by 0.72 percent. Effectively, the United Kingdom is replacing its old partner, which has a relatively low level of TFP, with a new partner that has a higher level of TFP. The change does little to affect the EU outcomes since we assume they do not open up more to the United States

Table 6—Changes in Response to Lower FDI and Trade Costs into the United Kingdom from Other Nations in the Baseline Scenario, Relative to Pre-Brexit Levels

Panel A. FDI and trade flows

	FDI flows		Trade flows	
	In	Out	In	Out
United Kingdom lowers restrictions on United States				
United Kingdom	26.3	−71.1	−11.3	10.9
	(13.8)	(−30.9)	(−18.2)	(−7.1)
European Union	−26.7	−10.1	−12.2	−5.5
	(−11.7)	(−2.3)	(−3.6)	(−6.3)
Non-EU Europe	−2.3	22.1	3.6	−2.8
	(0.3)	(9.5)	(2.8)	(0.0)
United States–Canada	−8.9	49.2	12.2	2.1
	(−3.4)	(21.3)	(7.3)	(4.2)
Asia	−5.1	12.1	1.8	−0.7
	(−1.6)	(4.5)	(3.8)	(3.9)
United Kingdom lowers restrictions on all but European Union				
United Kingdom	32.9	−71.3	−9.5	11.1
	(17.1)	(−31.0)	(−20.1)	(−10.2)
European Union	−26.7	−12.3	−12.4	−5.4
	(−11.8)	(−3.2)	(−3.6)	(−6.3)
Non-EU Europe	−2.3	22.6	3.6	−2.7
	(0.3)	(9.8)	(2.4)	(−1.0)
United States–Canada	−9.0	47.8	12.1	2.1
	(−3.5)	(20.7)	(7.5)	(4.4)
Asia	−5.5	30.2	2.0	0.1
	(−1.7)	(12.8)	(3.2)	(2.7)

Panel B. Expenditures, labor market, and welfare

	Expenditures					Labor market		Welfare
	Y	C	X_T	X_I	X_M	L	W	Δ
United Kingdom lowers restrictions on United States								
United Kingdom	−1.9	0.3	−2.8	−4.3	−25.9	−1.6	−0.3	0.72
	(−2.3)	(0.5)	(−2.2)	(−2.2)	(−29.3)	(−2.1)	(−0.2)	
European Union	−0.8	−1.5	−1.3	0.2	9.0	0.5	−1.3	−2.39
	(−1.2)	(−1.3)	(−1.2)	(−1.2)	(12.3)	(0.0)	(−1.3)	
Non-EU Europe	0.1	0.2	0.4	0.7	5.9	0.0	0.2	0.33
	(1.0)	(0.4)	(1.0)	(1.0)	(7.0)	(0.4)	(0.5)	
United States–Canada	0.0	0.1	0.3	0.6	5.6	−0.1	0.1	0.25
	(0.6)	(0.3)	(0.6)	(0.6)	(6.5)	(0.1)	(0.4)	
Asia	−0.1	−0.1	0.0	0.3	0.3	−0.1	−0.1	0.04
	(0.1)	(0.1)	(0.1)	(0.1)	(0.4)	(−0.1)	(0.1)	
United Kingdom lowers restrictions on all but European Union								
United Kingdom	−2.1	0.7	−2.8	−4.1	−26.4	−2.0	−0.1	1.27
	(−1.8)	(0.8)	(−1.8)	(−1.8)	(−29.9)	(−2.1)	(0.1)	
European Union	−0.8	−1.5	−1.3	0.2	8.6	0.5	−1.3	−2.41
	(−1.2)	(−1.3)	(−1.2)	(−1.2)	(12.0)	(0.0)	(−1.3)	
Non-EU Europe	0.2	0.2	0.4	0.6	6.0	0.0	0.2	0.32
	(1.0)	(0.4)	(1.0)	(1.0)	(7.2)	(0.4)	(0.5)	
United States–Canada	0.0	0.1	0.3	0.6	5.5	−0.1	0.1	0.24
	(0.6)	(0.3)	(0.6)	(0.6)	(6.3)	(0.1)	(0.4)	
Asia	−0.1	−0.1	0.0	0.2	0.7	0.0	−0.1	0.07
	(0.1)	(0.1)	(0.1)	(0.1)	(0.9)	(−0.1)	(0.1)	

Notes: See Table 5, panel B for a comparison to the baseline scenario. See notes at the end of Table 3 for further details.

or Canada. The last five rows of Table 6, panels A and B, show results if costs are lowered for all nations. In this case, there is a further boost to UK welfare, which is now higher by 1.27 percent relative to the pre-Brexit regime. Clearly, this alternative scenario, which has been discussed by the UK government as part of the Brexit plan, is preferable to the baseline scenario for UK citizens. In either case, however, citizens in the rest of the European Union are worse off.

IV. Sensitivity

To assess the importance of the policy experiments and parameters, we rerun the baseline numerical experiment shown in the last five rows of Table 5, panels A and B, and report key statistics for the United Kingdom in Table 7.[20]

In the first three alternatives, we change the timing and magnitude of the policy changes shown in Figure 1. In the first case, the start of cost increases is delayed by two years relative to the baseline case. In the second, we assume the restrictions are tightened at a slower pace, with the decline in costs taking roughly two additional years. In the third, we assume that the eventual costs are different by 10 percentage points, a doubling of the baseline case. Delays and slower phase-ins affect the averages over the first decade, but not by much. The doubling of costs has a near-doubling effect on investment in technology capital and welfare, but less so on the current account and production.

In the remaining alternatives listed in rows 5 to 10 of Table 7, we change the model parameters. First, we broaden the notion of trade by including both goods and services trade when calibrating the trade costs. Since services trade is still relatively small, this does not change our results very much. Second, we change the Armington elasticity ρ, first lowering it to $\rho = 5$ (row 6) and then increasing it to $\rho = 15$ (row 7), to cover the wide range of estimates in the literature. Changes in this variable affect imports and inward FDI in predictable ways: when the elasticity is high, inflows are more sensitive to changes in policy as consumers are more likely to respond to higher-priced foreign goods by substituting more toward domestically produced goods. Likewise, more sensitivity to trade costs implies that the multinational is more likely to produce its good in the foreign country rather than ship it. Therefore, in the higher elasticity case, we see that inward FDI increases by even more than in the baseline case. If we lower the elasticity of substitution between foreign goods produced by affiliates and those produced by parents to $\varrho = 10$, we find much greater welfare losses for the United Kingdom when costs of foreign goods, whether produced in the United Kingdom or abroad, rise. In this case, which is summarized in row 8, the pre-Brexit UK consumption has a much lower domestic share, and thus the negative impact of higher costs on foreign goods during the post-Brexit period is greater.

We also reran the numerical experiments with lower technology capital shares. The case with $\phi = 0.01$ is reported in row 9 of Table 7. If we compare these results to the baseline case in row 1, we see that the changes in predicted FDI inflows are of opposite signs. This is to be expected as ϕ approaches zero, since companies invest little in

[20] We have also conducted experiments in the more general model of Holmes, McGrattan, and Prescott (2015).

Table 7—Changes in UK Aggregates Relative to Pre-Brexit Levels (Alternative Policies and Parameters)

	Inward FDI	Imports	Business output	Technology investment	Welfare
Baseline	7.4	−18.3	−1.0	−23.9	−1.40
	(3.7)	(−16.5)	(−3.2)	(−26.9)	
Delay Brexit	13.4	−13.5	−0.7	−21.4	−1.33
	(3.7)	(−16.3)	(−3.2)	(−26.9)	
Slower phase-in	10.5	−16.2	−0.9	−22.6	−1.37
	(3.7)	(−16.4)	(−3.2)	(−26.9)	
Double costs	7.5	−31.7	−1.6	−44.8	−2.94
	(5.8)	(−26.4)	(−6.2)	(−48.0)	
Broaden scope	6.8	−16.4	−0.9	−24.0	−1.38
	(3.6)	(−14.7)	(−3.2)	(−26.9)	
Decrease elasticity	−2.1	−10.3	−0.6	−13.6	−1.69
	(−2.5)	(−2.8)	(−1.7)	(−13.1)	
Increase elasticity	14.7	−24.1	−1.2	−31.6	−1.14
	(9.6)	(−27.2)	(−4.6)	(−38.8)	
Set elasticities equal	24.3	−11.1	−2.4	−24.6	−3.04
	(8.6)	(−15.5)	(−5.0)	(−26.9)	
Lower capital share	−10.4	−14.2	−1.5	−25.0	−1.58
	(−17.9)	(7.1)	(0.2)	(−28.5)	
No adjustment costs	12.9	−23.3	−1.3	−33.1	−1.23
	(3.6)	(−16.0)	(−3.4)	(−27.0)	

Notes: See notes at the end of Table 3. The baseline implementation corresponds to the last five rows of Table 5, panels A and B. The "delay Brexit" assumes a two-year delay in implementation. The "slow phase-in" assumes the Brexit occurs at the same time as the baseline but takes two years longer to be phased in. The "double costs" assumes that long-run costs rise to 10 percentage points. The "broaden scope" uses trade data on services as well as goods to parameterize the model. The "decrease elasticity" uses an Armington elasticity of $\rho = 5$. The "increase elasticity" uses an Armington elasticity of $\rho = 15$. The "set elasticities equal" uses $\varrho = \rho = 10$. The "lower capital share" uses $\phi = 0.01$. The "no adjustment costs" turns off all costs of adjusting capital.

R&D and other intangibles, and thus have less of an incentive to engage in FDI than in the baseline case, especially with regulatory costs rising. On the new balanced growth path, we find a smaller change in UK output and little reallocation of global production, since technology capital investment is a critical determinant of who produces and where. Finally, although not shown in the table, we find that further opening up to non-EU countries (as in the experiments shown in Table 6) does not lead to positive welfare gains for the United Kingdom, as we found in the baseline. The positive gains in the $\phi = 0.07$ case are derived from significant increases in intangible investment and greater outward FDI by non-EU nations in the post-Brexit period.

In the last row of Table 7, we rerun the numerical experiment without adjustment costs. As expected, there are larger initial responses because investment adjusts immediately after the policy announcement. In fact, some equilibrium investments fall below negative, which is why they were included in the baseline parameterization. Even so, the outcomes are not significantly different from the baseline.

V. Conclusion

In this paper, we estimate the impact of tightening regulations on trade and FDI of foreign multinationals following the UK referendum to leave the European Union.

We show that the impact on investment, production, and welfare depends importantly on whether the United Kingdom acts unilaterally to block EU flows or jointly with EU nations to erect cross-border barriers on each other. 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 will be significantly worse off. Although its exports and outward FDI face 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 trade and FDI from the United Kingdom, then the relative sizes and TFPs of the two economies, along with those of other investing nations, will determine global investment and production patterns in the post-Brexit period. Given that the United Kingdom is relatively small, if the UK and EU firms face the same stricter 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. We predict that the optimal response of UK citizens will be to increase international lending by financing the production of non-UK multinationals, both domestically and abroad. In this scenario, we estimate significant welfare losses for both the United Kingdom and other EU nations. However, we estimate significant welfare gains for UK citizens if their government were to simultaneously reduce current restrictions on major investors outside of the European Union.

Data Appendix

In this Appendix, we report our data sources. All data and computer codes can be found at www.econ.umn.edu/∼erm.

The main series used for our analysis are populations, GDPs, FDI flows, trade flows, and average corporate tax rates. The source for populations and GDPs is the World Bank's World Development Indicators (WDI) database (1960–2016). The specific series that we use are total population (SP.POP.TOTL), GDP in current US 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 composite countries, such as the European Union or the United States plus Canada, we simply add populations and GDPs across countries to arrive at the total for the composite country.

The main source for bilateral foreign direct investment flows is the FDI statistics from the Organisation for Economic Co-operation and Development (OECD). 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* (1990–2016). These data are available from 1990 to 2013. Data on outward FDI by host country are available from the *China Commerce Yearbook* (2003–2016) for the years 2003–2013. When constructing total FDI statistics for composite country groups, we subtract any FDI cross-flows between the member countries of these groups.

We use two sources for bilateral trade flows: the United Nations Comtrade database and the World Input-Output Database (Timmer et al. 2015). In the main calibration, we use the Comtrade data, which include trade in goods only. We gather data on total imports (flow = 6) and total exports (flow = 5) between countries, where trade is reported using the ISIC revision 3 nomenclature. In our sensitivity analysis, we use data from the World Input-Output Database, which is available from 1995 to 2012 and includes trade in goods and services. The annual tables provided by the World Input-Output Database report the amount of a good produced by Country A in a given industry and used by Country B, by category or industry of end use. In order to construct total bilateral flows of exports from Country A to Country B, we sum across all industries of production by Country A and all categories of use by Country B. In both cases, we aggregate the data into the five composite country-groups. Similar to our construction of bilateral FDI flows, we construct all composite country-group flows by summing all imports (exports) into (out of) the countries within the composite country and subtracting any within-country-group flows from the total. Additionally, we use the bilateral trade data to construct total imports (exports) from the other countries in the model.

Data on corporate tax rates are from 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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