SFB 823

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Nr. 27/2021

Discussion Paper

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September 26, 2021

Abstract: The paper presents empirical evidence on the international effects of US fiscal policy from structural vector autoregressions identified through external instruments in a panel setting for the G7 countries. An exogenous increase in US government spending is estimated to produce sizeable positive responses of output and consumption in the rest of the G7 countries, both about half as large as their domestic US counterparts, while strongly depreciating the US terms of trade and lowering short-run real interest rates. Moreover, fiscal shocks are estimated to have a strongly positive impact on hourly labor productivity in the private sector. We solve a two-country New Keynesian model in closed form and show that a low cost elasticity of varying technology utilization can simultaneously explain the positive productivity, consumption and international spillover effects as well as the real depreciation resulting from expansionary US government spending shocks.

JEL: E32, F41, F44.

Keywords: International transmission of fiscal shocks, government spending, labor productivity, terms of trade, proxy-vector autoregressions.

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We thank Francesco Furlanetto, Robert Kollmann, Jesper Lindé, Marco Lippi, Anna Rogantini Picco, Karl Walentin, Roland Winkler, and Francesco Zanetti for helpful comments and suggestions. The opinions expressed in this article are the sole responsibility of the authors and should not be interpreted as reflecting the views of Sveriges Riksbank.

1 Introduction

Since the Great Recession has triggered a deep and prolonged global economic downturn, debates about internationally-coordinated fiscal policy actions are high on the agenda of policy discussions. At the London summit in 2009, G-20 leaders committed to a 'concerted fiscal expansion that will, by the end of [2010], amount to $5 trillion...' (G-20, 2009). Recently, commentators frequently ask for a globally coordinated fiscal stimulus to foster the recovery after the Covid 19 pandemic abates and the Great Lockdown ends.[1] The conventional wisdom underlying these recommendations is that government spending increases are thought to have sizable and positive international spillover effects. However, most theoretical models predict cross-country fiscal spillovers to be small and even ambiguous in sign (Cwik and Wieland 2011, Corsetti et al. 2010, Devereux and Yu 2019), lending weak support, if any, to the apparently shared belief in policy circles.

This paper makes two contributions. First, we estimate the cross-country effects of US government spending shocks identified by external instrumental variables in empirical proxy-vector-autoregressive (VAR) models using a panel of the G7 countries. We highlight an often overlooked but in our view important dimension consisting in an endogenous positive response of hourly labor productivity to fiscal expansions. Second, we derive closed form solutions of a two-country New Keynesian business cycle model that allows for government spending shocks to endogenously affect productivity. We analyze the conditions under which the productivity channel of fiscal policy brings the theoretical model predictions in line with the empirical evidence.

Empirically, we use proxy-VARs (Stock and Watson, 2012, 2018, Mertens and Ravn, 2013) to identify US government spending shocks. Following Hall (2009), Barro and Redlick (2011) and Miyamoto et al. (2019), we use the growth in US real military spending as an external instrument that is arguably correlated with US fiscal spending shocks, but not with other shocks originating either in the US or in the panel of G7 countries other than the US (called the G6 countries henceforth). However, we demonstrate that the results are very similar if we use an alternative instrumental variable, namely the forecast error based on survey expectations concerning government spending, as also used in Ramey (2011) and Auerbach and Gorodnichenko (2012). The fact that the results show little change when using the two different instrumental variables lends credibility to the proxy-VAR approach. This is particularly useful as previous literature (surveyed below) based on other identification schemes has provided partly contradictory results.

We find that a positive shock to US government spending robustly increases real consumption and output both domestically and in the G6 countries. The foreign responses are around half as strong as the domestic ones, which points towards sizeable positive spillovers of US fiscal policy, thus corroborating the common policy narrative. The terms of trade

[1] See, e.g., https://blogs.imf.org/2020/04/15/fiscal-policies-to-contain-the-damage-from-covid-19/ and https://voxeu.org/article/stronger-together-policy-mix-strikes-back.

and the real exchange rate strongly and persistently depreciate (from the point of view of the US), while short-run real interest rates decline. Although these results are in line with parts of the earlier literature, they appear hard to reconcile with many open economy macro models which predict that higher government spending pushes up prices, real interest rates, and leads to a terms of trade and real exchange rate appreciation.

Most importantly, however, we emphasize a less studied empirical result that we argue is key to understanding the international transmission effects of fiscal policy. In particular, we find that hourly labor productivity in the private sector strongly and immediately increases in response to an exogenous rise in government spending. This result, too, is counterintuitive from the point of view of many standard models, where a demand increase from higher government spending would be expected to raise output through higher labor input, but to decrease output per hour due to diminishing returns. While, relatedly, several authors have found real wage increases following fiscal spending surges (Gali et al. 2007, Bilbiie et al. 2008), the leading explanation is that the business cycle upswing engendered by higher government spending endogenously lowers price-marginal cost markups allowing wages to rise (Ravn et al., 2012). However, this does not explain the strong increase in hourly output that we observe. Further, while it is possible, in principle, that parts of government spending are productive and thus shift up the aggregate economy's production function, this would most likely be the case for spending on public capital like infrastructure. We consider this explanation unlikely, since effects of public capital would likely build up slowly over time, but we find that the positive productivity response to higher fiscal spending is immediate and roughly has the same time profile as the response of output.

Theoretically, we show that the empirical result of consumption increases at home and abroad coupled with a domestic real depreciation and higher productivity can be explained in a simple New Keynesian open economy model with an endogenous productivity channel through variable technology utilization. In particular, we adapt the closed-economy setting in Jorgensen and Ravn (2021) to a two-country framework and model firms as choosing the intensity with which the existing stock of technological knowledge can be used to a variable extent by firms if they incur a convex adoption cost. As we demonstrate below, for purposes of short-run business cycle analysis this can alternatively be interpreted as a model with labor effort that can be varied subject to resource costs. This allows us to model an economy where marginal costs do not respond strongly positively to increasing output following demand shocks, provided the cost elasticity of varying productivity is small. Flat marginal costs have also been considered in Auerbach et al. (2021) resulting from fixed capacity, or in Michaillat and Saez (2015) arising from search frictions. The model we adopt here has the benefit of being particularly simple, allowing to set up a simplified and highly tractable two-country model that admits analytical solutions in closed form for the main results.

In particular, we show that when the elasticity of the function that describes the firms' costs of changing productivity through endogenous technology adoption is small enough, a domestic increase in government spending is followed by a productivity increase of empirically plausible size, a domestic terms of trade depreciation and consumption and output increases along with declining real interest rates, much as we find empirically. Further, we show that for plausible parameters as frequently used in the open economy business cycle literature, the spillover of a domestic fiscal expansion on foreign output and consumption is positive, as found in the data. In particular, in addition to the analytical results from a highly stylized model, we show numerical responses of an enlarged model with a richer set of transmission channels, and demonstrate that, conditional on a low cost elasticity of technology utilization, generally positive international spillovers from fiscal policy result. The size of international output spillover is decreasing in the price elasticity of demand for foreign goods, and increasing in the importance of imported goods as intermediate inputs in production.

This paper is related to various strands of literature. Methodologically, several studies rely on external instruments to identify the dynamic effects of fiscal policy (e.g., Mertens and Ravn, 2013, Ramey and Zubairy 2018, Miyamoto et al. 2019). In contrast to other empirical identification approaches, this procedure has the advantage that neither controversial parameter restrictions, nor a priori knowledge of the signs of impulse responses are required. In contrast to most existing studies, we use the proxy-VAR methodology to estimate the international dimension of US fiscal policy.

Our paper contributes to a large literature on the open economy effects of fiscal policy. Many studies have analyzed the real exchange rate response to an expansionary fiscal spending shock, using various identification methods. Yet, to date, the empirical evidence appears mixed, with some studies finding that an increase in government spending leads to a real depreciation (e.g., Corsetti et al. 2012, Ravn et al. 2012, Monacelli and Perotti 2010), but others pointing to the opposite result of a real appreciation (Auerbach and Gorodnichenko 2016, Benetrix and Lane 2013, Ferrara et al. 2020). Our proxy-VAR evidence strongly and robustly favors a terms of trade and real exchange rate depreciation following an exogenous increase in government spending.

A number of empirical studies investigate the cross-country spillovers of expansionary fiscal interventions (e.g, Auerbach and Gorodnichenko 2013, Faccini et al. 2016, Corsetti and Müller 2013). Our estimates in favor of positive international spillovers are broadly consistent with their findings. Some papers examine fiscal spillovers within theoretical models and show how international repercussions are affected by relevant factors like openness, trade elasticities, or how the fiscal stimulus is financed (e.g., Cacciatore and Traum 2020, Corsetti et al. 2010, Devereux and Yu 2019). In contrast to these studies, we highlight the role of the endogenous productivity channel to bring the theoretical predictions closer to the empirical estimates.

Finally, our study relates to the recent literature on incorporating an endogenous productivity mechanism into business cycle models. Jordà et al. (2020) provide historical international evidence for long-run effects of monetary policy and propose a model with endogenous TFP to reconcile the empirical findings. Bianchi et al. (2019) construct and estimate an endogenous growth model to better understand the relationship between business cycle fluctuations and long-term growth. Relatedly, Anzoategui et al. (2019) develop a model with an endogenous total factor productivity channel, due to costly development and adoption of technologies, to examine how demand shocks affect productivity fluctuations. Concerning the relationship between the fiscal transmission mechanism and endogenous productivity, two contributions have shown that such a channel helps rationalizing empirical patterns in closed-economy contexts (Jorgensen and Ravn 2021, D'Alessandro et al. 2019). D'Alessandro et al. (2019) extend a standard New Keynesian model to allow for skill accumulation through past work experience to account for the observed increase in total factor productivity following an expansionary government spending shock. Jorgensen and Ravn (2021) demonstrate that variable technology utilization can enable an otherwise standard New Keynesian model to account for their empirical finding of a decline in inflation following higher government spending. While these papers study closed-economy environments, we argue that endogenous productivity is central for understanding the empirically observed open-economy dynamics.

We proceed as follows. Section 2 outlines the econometric method and specification and presents estimation results. In section 3, we outline a stylized two-country model with an endogenous productivity channel. Section 4 derives closed-form solutions for the main model predictions about the effects of domestic fiscal shocks and discusses the international transmission mechanism. In section 5, we demonstrate that the intuition from the simplified analytical model carries over to a richer model with endogenous persistence. Section 6 concludes.

2 Empirical effects of US government spending shocks

2.1 Econometric method

This section presents the proxy-VAR model used to estimate interdependence between the US and the $N = 6$ other G7 countries (i.e. Canada, France, Germany, Italy, Japan, and the UK, labelled G6 henceforth). Similarly to Klein and Linnemann (2020), we estimate a series of two-country proxy-VARs each comprising variables from the US and one out of the other G6 countries, and constrain the parameters governing impulse responses to be the same for all country pairs. The reduced form model is

$$y_{it} = c_i + Az_{it-1} + u_{it}, \quad i = 1, \dots, N,$$

where y_{it} is a vector of K variables pertaining to the US and the i-th G6 country, $z_{it-1} = (y'_{it-1}, \dots, y'_{it-p})'$ collects $p \geq 1$ lags, c_i is a vector of country-specific constants, u_{it} a reduced form disturbance vector, and A a $K \times pK$ matrix of lag parameters. Letting T be the sample size and defining

$$\underset{(K\times T-p)}{Y_i} = (y_{i,p+1},\ldots,y_{i,T}), \qquad \underset{(K\times N(T-p))}{Y} = (Y_i,\ldots,Y_N),$$

$$\underset{(pK\times T-p)}{Z_i} = (z_{i,0},\ldots,z_{i,T-1}), \qquad \underset{(pK\times N(T-p))}{Z} = (Z_i,\ldots,Z_N), \qquad X = \left(\left(I_N \otimes \mathbf{1}_{T-p}'\right)', Z'\right)',$$

where I_N is the N-dimensional identity matrix and $\mathbf{1}_{T-p}$ is a column vector of ones of length $T-p$, we get least squares estimates as

$$(\widehat{c}_1,\ldots,\widehat{c}_N,\widehat{A}) = YX'\left(XX'\right)^{-1},$$

and the reduced form residual matrix is $\widehat{U} = (Y - \widehat{A}X)'$, where each column contains the time series of residuals for one of the K equations, with the N country-specific residual time series vertically stacked.

The corresponding structural model is

$$B^{-1}y_{it} = B^{-1}c_i + B^{-1}Az_{it-1} + e_{it}, \qquad i = 1,\ldots,N,$$

where B is the matrix of the impact effects of structural shocks and $e_{it} = B^{-1}u_{it}$ is the vector of structural, economically interpretable shocks assumed to be serially and mutually uncorrelated. Suppose that (for expositional ease and without loss of generality) the US government spending shock is the first element in e_{it}, say $e_{it}^{(1)}$, such that we need to identify the first column of B, say B_1. Following Stock and Watson (2012, 2018) and Mertens and Ravn (2013), suppose that a proxy-instrument z_t is available that is correlated with the US government spending shock but with no other shock, such that

$$E\left(z_t e_{it}^{(1)}\right) = a \neq 0 \;\text{ and }\; E\left(z_t e_{it}^{(k)}\right) = 0 \quad \text{for } k = 2,...,K,\; i = 1,...,N, \tag{1}$$

where $e_{it}^{(k)}$ denotes the k-th element in e_{it}. Since $u_{it} = Be_{it}$, (1) ensures $E(z_t u_{it}) = BE(z_t e_{it}) = B_1 a$ and thus

$$\frac{B_1^{(k)}}{B_1^{(1)}} = \frac{E\left(z_t u_{it}^{(k)}\right)}{E\left(z_t u_{it}^{(1)}\right)},$$

where $u_{it}^{(k)}$ and $B_1^{(k)}$ are the k-th element in u_{it} and B_1, respectively. Thus, the elements of B_1 relatively to the first one can be estimated by instrumental variable regressions of the k-th column of $\widehat{U}$ on its first column, using $(\mathbf{1}_N \otimes z_t)$ as the instrument (where $\mathbf{1}_N$ is an $N \times 1$ vector of ones). Normalizing $B_1^{(1)} = 1$ then identifies B_1 by imposing the unit effect normalization (Stock and Watson, 2018) that the first shock has an impact effect of one on the first variable. Following the advice of Stock and Watson (2018), we apply this normalization inside the bootstrap loop, i.e. for each repetition of the resampling procedure used to construct confidence bands. Specifically, we use the moving blocks bootstrap that has recently been recommended by Jentsch and Lunsford (2019) for proxy-VARs in order to appropriately take into account the uncertainty about the relation between the structural shocks and the instruments and thus to obtain consistent confidence bands. We follow Jentsch and Lunsford (2019) and use as block length $\kappa T^{1/4}$ rounded to the next integer, where $\kappa = 5.03$ and T is the sample size, which for our baseline specification results in a block length of 18. The confidence bands reported below are based on 10,000 bootstrap repetitions.

2.2 Data and specification

For our main specification, we include a set of US and G6 variables intended to shed light on the international transmission mechanism of US government spending shocks. The core variable set contains as US variables the log of real per capita government spending, log real per capita GDP, the government budget deficit as a fraction of GDP, log real per capita private consumption, a short-run real interest rate measured as the difference between the Federal Funds Rate and the annualized growth rate of the GDP deflator, and the log of hourly labor productivity in the non-farm business sector. For the G6 countries, we include the logs of real GDP and real private consumption, as well as the log of the terms of trade. Note that since quarterly population data is unavailable for the G6, we cannot construct per capita variables. However, our results are robust to either using the US variables as aggregates instead of per capita values, too, or to using per capita values for the G6 with population data linearly interpolated from annual values. The terms of trade are constructed as the nominal exchange rate (the price of a unit of foreign currency in US dollars) times the G6 countries' price index of exports over the US export price index. Henceforth, we take the US as the domestic economy and thus label an increase (decrease) in the terms of trade a real depreciation (appreciation). Appendix A1.1 gives a detailed description of the data sources and definitions.

We estimate the model on quarterly G7 data over the period 1983Q1 to 2019Q4, using a VAR specification with two lags and allowing for a constant. The choice of two lags is recommended by the Akaike information criterion, whereas the Schwarz and the Hannan-Quinn information criteria recommend the use of one lag. However, the results do not change much quantitatively, and all qualitative conclusions remain unaltered, if we alternatively use one or four lags. We follow Corsetti et al. (2012) and choose 1983Q1 as the starting date to exclude the turbulent pre-Volcker period from the sample. A substantial body of work (e.g. Boivin and Giannoni 2006) has suggested that the transmission mechanism of U.S. monetary policy may have materially changed following the end of the Volcker disinflation. Several other studies also detect a change in the fiscal transmission mechanism at the beginning of the 1980s (e.g., Bilbiie et al. 2008, Perotti 2005). Thus, the sample choice has the advantage that we focus on a period in which the monetary-fiscal policy framework was relatively stable.

As an instrument for exogenous changes in government spending we use the growth rate of military spending per head of population. Hall (2009), Barro and Redlick (2011), and Miyamoto (2019), amongst others, also use military spending data to identify exogenous government spending shocks. Changes in military spending are often large and regularly respond to foreign policy developments, suggesting that these changes are exogenous in the sense that they are less likely to be driven by domestic cyclical forces. In particular, military spending does not respond in an endogenous way to the state of the business cycle, the monetary policy stance or financial conditions of the private sector. Moreover, military spending is closely associated with the wasteful spending assumed in many macroeconomic models implying that our empirical findings can be used to test predictions of competing theoretical models.[2] Furthermore, as we show below, the results are very similar if we use the forecast error in government spending based on the Survey of Professional Forecasters as an alternative instrument for government spending shocks. We also show that the results are robust to including the defense news series provided provided by Ramey (2011) and Ramey and Zubairy (2018) as a check for anticipation effects. It is important to note that both instruments appear strong, with the military spending instrument used for the main specification delivering a first stage F-statistic of 595.26. This suggests that instrument weakness is unlikely to be a concern for our analysis.

2.3 Empirical results

Figure 1 shows impulse responses for the identified US government spending shock. Here and henceforth, the lightly shaded areas indicate bootstrapped 90% confidence bands, the darker shaded areas indicate 68% confidence bands, and the unit of the horizontal axis is a quarter. To interpret the scale of the responses, note that we normalize the shock size to a fiscal spending increase of one percent of government spending. As can be seen from the figure, the estimated shock triggers a strong and persistent response of government spending which slowly converges back to its initial level. The increase in government spending is followed by a significant and persistent increase in the fiscal deficit, which implies that spending increases are mainly financed through higher government debt in the short run. US real GDP rises significantly in the first few periods after the shock, before it moves back to its initial pre-shock level and then somewhat undershoots at the end of the forecast horizon. US real private consumption increases significantly, and the response closely mimics the output response, highlighting the important role of consumption dynamics for understanding the aggregate output effects. The short-run real interest rate responds negatively to government spending shocks (when disentangling the real interest rate response into to the nominal interest rate and the inflation response, we find that both variables fall in the first periods of the forecast horizon).

Most importantly for the subsequent analysis, hourly labor productivity significantly and persistently increases after a fiscal spending shock. On impact, the increase in labor productivity is of a similar size as the one of real GDP, and the response is highly significant for the whole forecast horizon. Note that the measure of productivity used for Figure 1

[2] Our main findings change only marginally when the proxy is constructed as the change in military spending relative to lagged GDP as proposed by Barro and Redlick (2011).

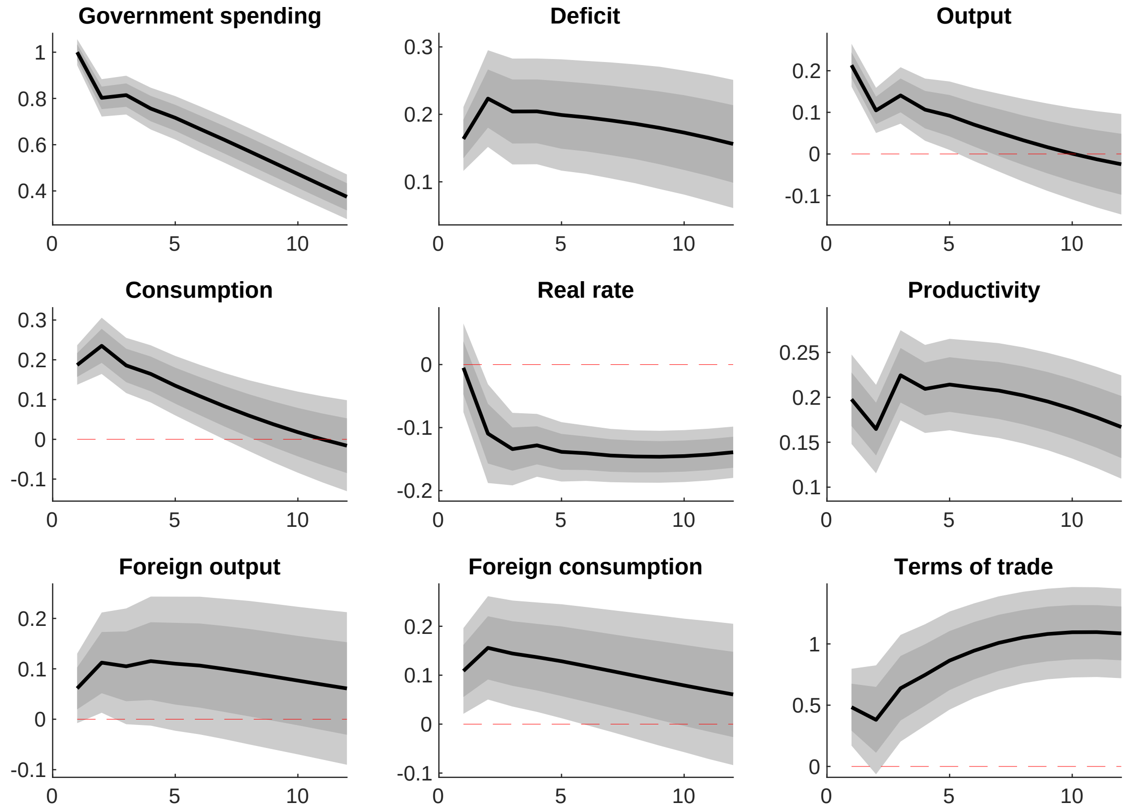

Figure 1: Baseline results.

Notes: Solid lines show point estimates. Shaded areas indicate 68% and 90% bootstrapped confidence intervals.

pertains to the non-farm business sector and thus reflects output per hour in the private economy. However, the results are very similar if we replace it by aggregate real GDP over total hours worked. Further, as we show in Section 2.4, productivity reacts very similarly if we alternatively identify government spending shocks through forecast errors, include various measures to control for anticipation effects, and replace labor productivity by total factor productivity. The positive productivity response to the fiscal spending shock will be a central argument in our theoretical account of the international transmission mechanism of fiscal policy described below.

Turning to the international transmission of the government spending shock, we find that the terms of trade strongly and persistently depreciate, with the maximum response reached about three years after the shock materialized. As will be shown below, this estimated terms of trade response is very similar to the depreciation we get when replacing the terms of trade with the consumption based real exchange rate. The US government spending shock is also associated with strongly positive estimated spillovers to the G6 countries. Foreign output significantly increases and the maximum response is about half as strong as the GDP response in the US. Moreover, also foreign consumption increases significantly with a hump-shaped adjustment pattern. The foreign consumption response closely mimics the domestic one, with a crowding-in on impact about half the size of the US consumption increase.

Compared to the previous literature, some of the results are in line with earlier findings, while others are more controversial. Positive domestic output and consumption effects of fiscal spending increases are found in many studies. From a theoretical point of view, a positive private consumption response to an exogenous increase in public consumption has received much attention in the literature, since it appears difficult to rationalize through many models of the real business cycle or the New Keynesian variety. In these models, a government spending increase through higher future taxation induces a negative wealth effect such that households would be expected to increase savings and reduce consumption expenditures. However, as is well known, models with limited asset market participation, countercyclical markups, consumption-leisure complementarity or different forms of interactions between fiscal and monetary policies can overturn these effects such that households consume more in response to a fiscal spending increase (Forni et al., 2009; Gali et al., 2007; Leeper et al., 2017). Relatedly, the aggregate demand increase through a fiscal shock would usually be expected to raise inflation and thus, provided the central bank's interest rate policy is active, a real interest rate increase, while we find a real interest rate decrease, in line with earlier studies (Mountford and Uhlig 2009, D'Alessandro et al. 2019).

Evidence of positive and sizeable international spillovers of US fiscal policy is also presented by Cacciatore and Traum (2020), Corsetti and Müller (2013) and Faccini et al. (2016). The terms of trade (or real exchange rate) response following a government demand shock appears less settled in the existing literature, with some studies providing evidence in favor of an appreciation (Auerbach and Gorodnichenko 2016, Benetrix and Lane 2013, Ferrara et al. 2020), while others find a depreciation as we do (Corsetti et al. 2012, Ravn et al. 2012, Monacelli and Perotti 2010). In theory, the direction and magnitude of fiscal spillovers is ambiguous. As shown by Devereux and Yu (2019), fiscal spillovers depend sensitively on many structural factors like the trade elasticity and the degree of openness. The terms of trade would be expected to appreciate following higher government spending in many models, since higher demand would theoretically be expected to raise interest rates and thus an exchange rate decline. In models with international risk sharing, a real exchange rate appreciation would be the counterpart to a consumption decline in response to higher fiscal spending. Both results are at odds with the empirical findings.

The literature has proposed two modeling strategies to reproduce the finding of a domestic consumption crowding-in coupled with a terms of trade or real exchange rate depreciation. First, in the model of Ravn et al. (2012), the presence of deep habits renders goods demand more elastic upon an expansionary government demand shock, such that the price-marginal cost markup declines, increasing real wages and private consumption, which ultimately depreciates the real exchange rate. Second, Corsetti et al. (2012) base their explanation on the empirical finding that higher current government spending is regularly associated with future lower spending. These future spending reversals, if expected by private agents, would tend to lower the current long-term real interest rate and thus stimulate current private consumption and lead to a real depreciation. Importantly, both model extensions do not account for the sizeable productivity change triggered by the fiscal expansion that motivates our theoretical analysis. Furthermore, in their models an increase in government spending raises inflation and the real policy interest rate, which is not supported by our empirical evidence.[3] Below, we will present a model with endogenously varying productivity in which a fall in the real interest rate following the fiscal shock can be an endogenous outcome.[4]

The positive estimated labor productivity response is also puzzling from the point of view of standard business cycle models, since the labor supply increase induced by the negative wealth effect of the financing of higher fiscal spending would usually be associated with a decrease in labor productivity due to diminishing marginal returns, or a flat response if there are constant returns to labor in the short run. However, the empirical finding of a positive productivity response is in line with recent evidence by D'Alessandro et al. (2019) and Jorgensen and Ravn (2021). These authors interpret the result in a closed economy context as evidence for learning-by-doing or endogenous technology adoption. In the theoretical model below, we take a similar view and show that the empirical results reported here can be rationalized in a model where highly variable technology utilization allows for endogenously increasing productivity, leading to a positive reaction of goods supply to a fiscal demand shock that simultaneously raises consumption and output at home and abroad, while lowering real interest rates and depreciating the terms of trade.

2.4 Robustness

In this section, we show that our main empirical findings are robust to various modifications of the baseline model. In particular, we demonstrate that our results change little if we add controls for fiscal foresight or use an alternative instrument for exogenous government spending shocks, measure productivity by total factor productivity, and that the real depreciation results holds for the real exchange rate in a similar way as for the terms of trade.

Fiscal foresight. A potential obstacle for estimating the effects of fiscal shocks is the so-called fiscal foresight problem. It arises when private agents not only react to actual fiscal policy changes, but to breaking news about impending future policy plans. In this case, the econometrician cannot recover the true unexpected fiscal shock, because due to an implementation lag the agents' and the econometricians' information sets are misaligned (Leeper et al. 2013). We conduct two different modifications of our baseline model to properly address this issue. We include as additional endogenous variable either real-time professional forecasts for government spending or Ramey and Zubairy's (2018) defense spending

[3]The deep-habits model by Ravn et al. (2012) predicts a strong fall in the price-marginal cost markup in response to the government spending shock. However, this channel is challenged by empirical evidence by Nekarda and Ramey (2020) showing that higher government spending leads to an increase in the markup.

[4]While in the model by Corsetti et al. (2012), the real policy interest rate can fall in the medium run, the impact effect on inflation and the policy rate is unambiguously positive.

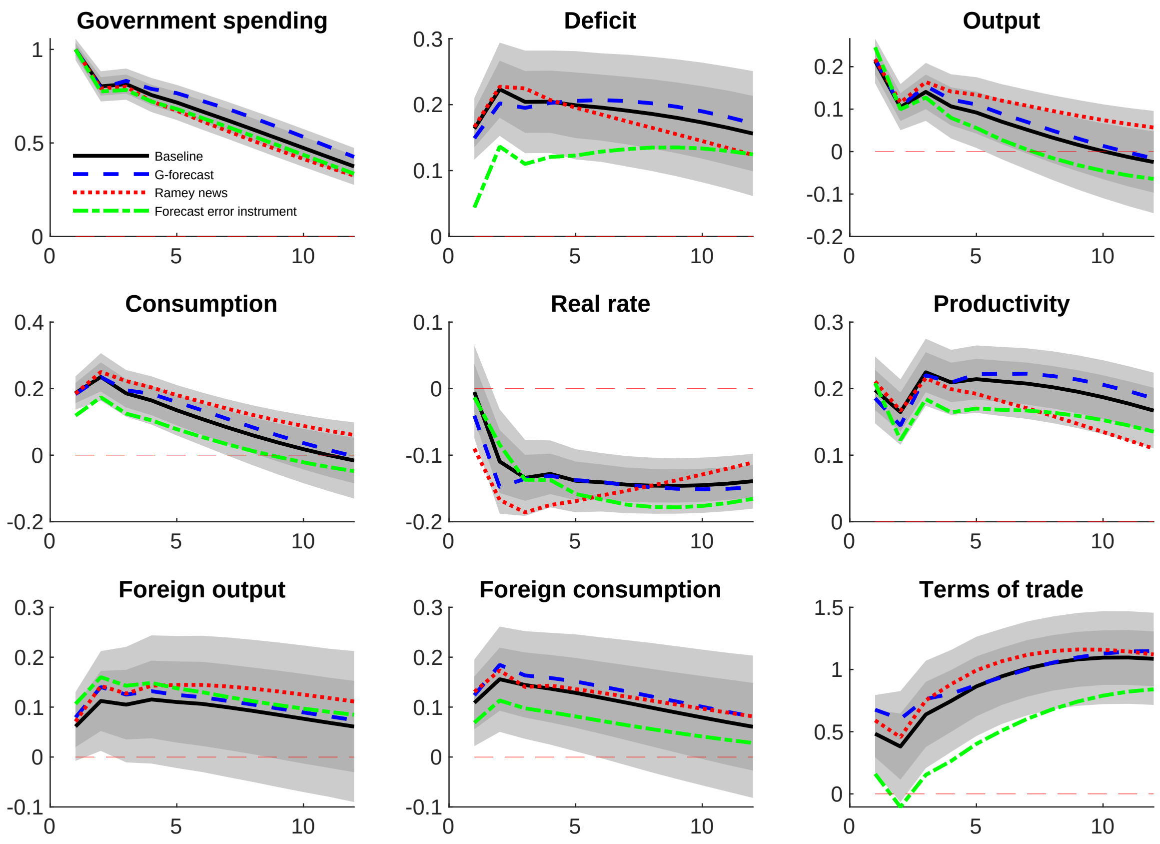

Figure 2: Robustness.

Notes: Solid lines show point estimates. Shaded areas indicate 68% and 90% bootstrapped confidence intervals of our baseline model.

news variable. Real-time professional forecasts for government spending is a spliced series of government spending forecasts provided by the Greenbook and the Survey of Professional Forecasters. We extend the series provided by Auerbach and Gorodnichenko (2012) which covers the period 1966-2008 to include the remaining sample years. The defense news variable is a measure of anticipated government spending equal to the present discounted value of expected future spending as recovered from newspaper sources.[5]

Figure 2 shows the result of the respective estimations, where solid lines and shaded areas show the point estimates of the responses and their confidence bands from our baseline specification presented in Figure 1. The remaining lines correspond to point estimates of the responses from the respective modified models. We see that changes in the results relatively to the baseline model are quantitatively minor. When controlling for anticipation by either including defense spending news or government spending forecasts, the point estimates are almost indistinguishable from our baseline. Importantly, we still find that a US government spending shock significantly increases labor productivity, crowds in private consumption expenditures, lowers the real interest rate, and depreciates the terms of trade coupled with sizeable positive international spillovers. Overall, these findings indicate that our main

[5]Because the defense spending news series is just available until 2015Q4, the results reported are based on a VAR estimation on this shorter sample.

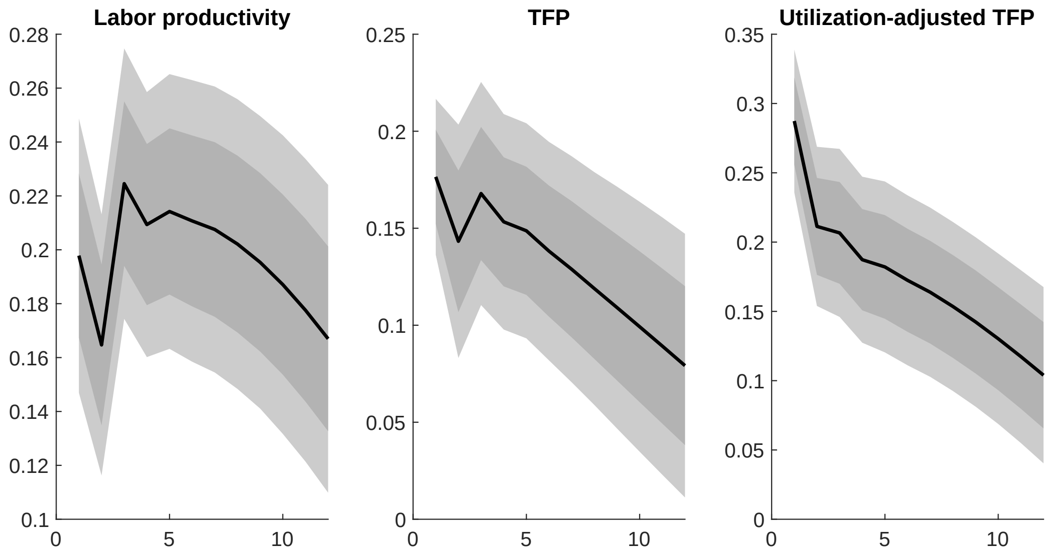

Figure 3: Alternative productivity measures.

Notes: Solid lines show point estimates. Shaded areas indicate 68% and 90% bootstrapped confidence intervals of our baseline model.

result is robust when taken potential anticipation effects into consideration.

Alternative instrument. As an additional check, we use an alternative instrument to trace out exogenous government spending shocks. We rely on the government spending forecast error to instrument exogenous changes in government spending. This approach was also applied by Ramey (2011) and Auerbach and Gorodnichenko (2012). The underlying idea is that the forecast error captures only those changes in government spending that are not related to aggregate news and thus unanticipated by private agents. Importantly, the forecast error instrument delivers a strong first-stage result with an F-statistic of 364.47. The dashed-dotted lines in Figure 2 show the estimates of this exercise. Again, the impulse responses are very similar to the responses of our baseline model. The main empirical picture is still present when relying on this alternative instrument. Thus, our empirical findings do not rest solely on the military spending instrument used in our baseline estimate.

Productivity measure. The empirical positive productivity response to a government spending shock does not depend on the specific empirical measure of productivity. As Figure 3 shows, when we replace the simple labor productivity measure (output per hour) in the baseline model by either total factor productivity (TFP) or TFP adjusted for capacity utilization (the latter measures both obtained from Fernald, 2014), the responses are similar. All of the factor productivity measures significantly increase in a fiscal expansion. The impact effect is strongest for the adjusted TFP series, whereas labor productivity and (unadjusted) TFP share a similar response pattern. Notably, the respective responses are significantly different from zero for all periods of the forecast horizon. Thus, the finding of a fiscal spending induced productivity gain is not affected by the specific concept of measuring productivity.

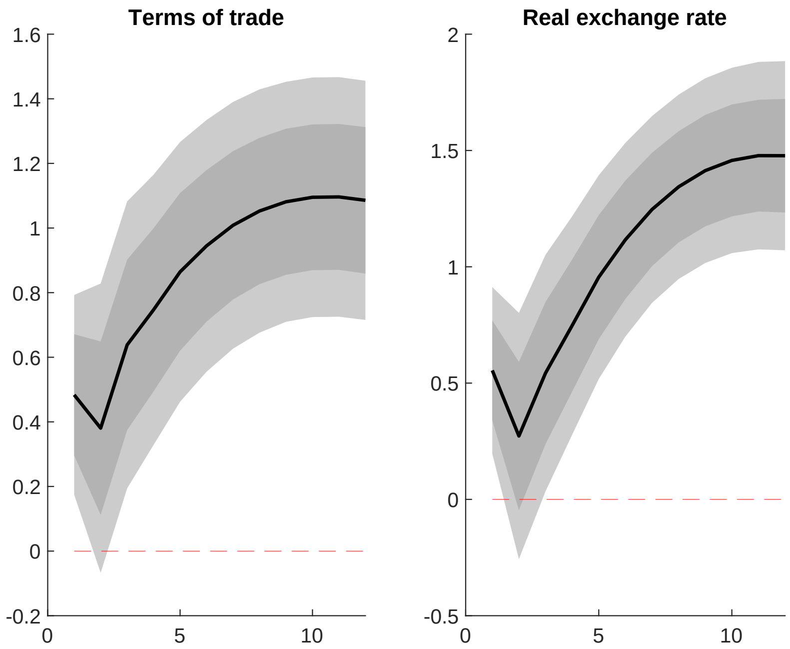

Figure 4: Relative prices.

Notes: Solid lines show point estimates. Shaded areas indicate 68% and 90% bootstrapped confidence intervals of our baseline model.

Real exchange rate. In our baseline specification, we used the terms of trade to study how US fiscal policy shapes international prices. Another important measure in the open-economy literature is the real exchange rate, defined as the nominal exchange rate time relative consumer price levels. Ex-ante, because of potentially divergent price patterns in traded and non-traded prices it is not clear whether the terms of trade and the real exchange rate respond similar to the fiscal policy change. To investigate this issue, we replace the terms of trade in our baseline model by the real exchange rate which is measured as the log of the ratio of the bilateral nominal exchange rate (the price of a G6 currency unit in US dollars) times the foreign country's CPI over the US CPI. Thus, as before an increase in the series is a real depreciation of the US dollar with respect to the foreign country.

As Figure 4 indicates, we find very similar responses for the terms of trade and the real exchange rate. The fiscal spending shock also leads to a sizeable depreciation of the real exchange rate which is estimated to be significant for most periods considered. Our evidence of a persistent terms of trade and real exchange rate depreciation following an expansionary government spending shock supports previous evidence presented by Enders et al. (2011) but stands in contrast to the divergent response pattern detected by Cacciatore and Traum (2020).

Further checks. Additionally, in Appendix A1.2 we present the results of further robustness analyses, which show that the main findings also hold up when varying the lag length, using a shadow policy interest rate to construct the real interest rate during the zero lower bound episode, measuring foreign real variables in per capita terms, or leaving out the turbulent Great Recession period by shortening the sample. Moreover, we demonstrate that our results are robust to using an aggregate of the G6 countries, instead of including the countries individually in a panel setup, to measure foreign output, consumption and the terms of trade. Finally, we test for the possibility of internationally correlated shocks which might violate our identifying assumptions. In particular, we estimate the foreign government spending response to our identified US public spending shock. It turns out, that foreign government spending is not significantly affected, with a flat response suggesting that correlated shocks are unlikely to be of concern.

3 A stylized New Keynesian two-country model

In this section, we present a stylized New Keynesian two-country model. The model is deliberately kept simple to allow for a closed form derivations of the central results (we will numerically analyze a richer and more complicated model in section 5 below). The world consists of two equal sized countries called home (H) and foreign (F). Foreign variables are denoted with '∗'. For brevity, since the model is largely symmetric across countries, we only show the equilibrium conditions pertaining to the home economy, while the full set of equilibrium conditions is given in detail in Appendix A1.3. Unless otherwise stated, all parameters characterizing foreign agents are the same as in home.

3.1 Households

All variables are understood as per capita values unless otherwise stated. Domestic households maximize

$$E_0 \sum_{t=0}^{\infty} \beta^t \ln C_t - \frac{\chi}{1+\phi} N_t^{1+\phi}, \quad \beta \in (0,1), \chi, \phi > 0,$$

where C is consumption, N is labor supply, and E_0 is conditional expectation as of time 0. Foreign households have the same utility function, and households in both countries have access to a complete set of internationally traded contingent claims, as well as to riskless local government bonds. Optimal choices thus imply

$$W_t = \chi N_t^{\phi} C_t, \tag{2}$$

$$C_t^{-1} = \beta E_t C_{t+1}^{-1} \frac{R_t}{\pi_{t+1}}, \tag{3}$$

where π_t is the home inflation rate $\pi_t = P_t/P_{t-1}$ with P_t the domestic consumption price index (CPI), W_t is the domestic consumption-based real wage, and R_t is the nominal gross return on government bonds. Since foreign households are similar, perfect international asset markets entail the risk sharing condition

$$\omega Q_t C_t^{-1} = C_t^{*-1}, \tag{4}$$

where C_t^* is foreign consumption, $\omega > 0$ is a constant depending on the initial asset distribution, and $Q_t = X_t P_t^*/P_t$ is the real exchange rate, with X_t being the price of a unit of foreign currency in terms of the home currency, and P_t^* the foreign CPI.

3.2 Goods demand

Total per capita consumption C_t consists of consumption of home goods C_{Ht} and foreign goods C_{Ft}, with the aggregator

$$C_t = \left[(1-\gamma)^{1/\eta} C_{Ht}^{\frac{\eta-1}{\eta}} + \gamma^{1/\eta} C_{Ft}^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}, \tag{5}$$

where $\gamma \in (0,1)$ denotes the steady state share of imported foreign-produced goods, and $\eta > 0$ is the substitution elasticity between both goods (also referred to as trade elasticity henceforth). Unless otherwise stated, for the most part we confine the analysis to the realistic case $\gamma < 1/2$ indicating home bias. The associated price level is

$$P_t = \left[(1-\gamma) P_{Ht}^{1-\eta} + \gamma P_{Ft}^{1-\eta}\right]^{\frac{1}{1-\eta}}, \tag{6}$$

where P_H (P_F) denotes the price level of home- (foreign-) produced goods in domestic currency. A similar demand structure in the foreign country gives rise to foreign demands C_H^* (C_F^*) for home- (foreign-) produced consumption goods, where we assume that foreigners' steady state share of foreign-produced goods is γ^* (foreign's import share is $1-\gamma^*$). For later use, we define the terms of trade S_t as

$$S_t = \frac{P_{Ft}}{P_{Ht}}, \tag{7}$$

and refer to an increase (decrease) in S_t as a terms of trade depreciation (appreciation).

Home and foreign consumption goods consist of individual varieties C_{Hi} and C_{Fi} indexed on the unit interval $i \in [0,1]$ according to

$$C_{Ht} = \left(\int_0^1 C_{Hit}^{\frac{\theta-1}{\theta}} di\right)^{\frac{\theta}{\theta-1}}, \quad C_{Ft} = \left(\int_0^1 C_{Fit}^{\frac{\theta-1}{\theta}} di\right)^{\frac{\theta}{\theta-1}}, \tag{8}$$

where $\theta > 1$ is the substitution elasticity between individual varieties, and the associated price levels are $P_{Ht} = \left(\int_0^1 P_{Hit}^{1-\theta} di\right)^{\frac{1}{1-\theta}}$ and $P_{Ft} = \left(\int_0^1 P_{Fit}^{1-\theta} di\right)^{\frac{1}{1-\theta}}$, where P_{Hi} (P_{Fi}) is the i-th individual home- (foreign-) produced variety's price in domestic currency. Foreign demand aggregators are similar.

Governments in both countries demand the same goods as consumers aggregated in the same way, and thus have the same demand functions. The law of one price holds on the level of varieties, $P_{Hit} = X_t P_{Hit}^*$, $P_{Fit} = X_t P_{Fit}^*$, and thus on the level of price indices, $P_{Ht} = X_t P_{Ht}^*$, $P_{Ft} = X_t P_{Ft}^*$, where P_{Hit}^* (P_{Fit}^*) is the foreign currency price of the i-th home- (foreign-) produced good, and P_{Ht}^* (P_{Ft}^*) the corresponding price index. Consequently, total demand Y_{Hi} for a home variety is

$$Y_{Hit} = \left(\frac{P_{Hit}}{P_{Ht}}\right)^{-\theta} (C_{Ht} + C_{Ht}^* + G_{Ht} + G_{Ht}^*), \tag{9}$$

where G_H and G_F (G_H^* and G_F^*) are the home- and foreign-produced goods bought by the home (foreign) government, while demand for a foreign variety is $Y_{Fit} = \left(\frac{P_{Fit}}{P_{Ft}}\right)^{-\theta} (C_{Ft} + C_{Ft}^*$

$+G_{Ft} + G^*_{Ft})$.

3.3 Firms

In each country, there is a measure one of monopolistically competitive firms indexed on $i \in [0,1]$, each producing a particular variety of the output good subject to Rotemberg (1982) style quadratic price adjustment costs. The i-th domestic firm's production function is $Y_{Hit} = (Z_{Hit}N_{it})^{\alpha}\left(U^k_{Hit}K_{it}\right)^{1-\alpha}$ with $\alpha \in (0,1)$ where N_{it} is the labor input hired by firm i, K_{it} is the capital stock, U^k_{Hit} its utilization rate, and Z_{Hit} is firm i's use of the level of technological knowledge. The latter is, following Bianchi et al. (2019), composed of the aggregate stock of knowledge capital Z_{Ht}, and the firm - specific usage of existing technological knowledge U_{Hit} according to $Z_{Hit} = U_{Hit}Z_{Ht}$. Adopting the technological stock of knowledge for productive use is costly, such that firms have resource costs $h(U_{Hit})$ when making use of it in production. We assume that $h(U_{Hit})$ is positive, and has positive first and second derivatives. This specification is a short-hand way to capture costs of technology adoption such as the retraining of employees and the reorganization of the production process (see e.g. Anzoategui et al. 2019 for a more detailed modelling of costly technology adoption).

Since our focus is on the short run, we do not model the accumulation of capital and the stock of technological knowledge.[6] In the interest of analytical tractability, we keep the aggregate technology level constant at $Z_{Ht} = Z_H$, and set $\alpha = 1$, such that firm i's production function reads[7]

$$Y_{Hit} = Z_H U_{Hit} N_{it}. \tag{10}$$

This formulation is similar to the one in Jorgensen and Ravn (2021), who use it as a reduced form way to incorporate endogenous technology adoption in a closed economy model. The central property is that firm-level productivity, or TFP, $Z_H U_{Hit}$ is an endogenous variable that can be chosen by firms who are willing to incur the resource costs of adoption. Note that in the simplified production function (10), TFP changes are observationally equivalent to changes in the degree of utilization of labor. An alternative interpretation would thus be one of time-varying labor effort as e.g. in Bils and Cho (1994), with the only difference that we model the costs of varying effort as direct resource costs to firms instead of a wage premium to compensate for the disutility of effort. In the remainder, we follow Jorgensen and Ravn (2021) and refer to U_{Hit} as technology utilization. However, as the analysis below will show, irrespective of the precise interpretation the feature that productivity is an endogenous variable is of central importance for the international transmission of fiscal shocks and the terms of trade.

Firms maximize the present discounted value of real profits on behalf of household-

[6] Bianchi et al. (2019) present a full model of the accumulation of knowledge capital through R&D investment subject to adjustment costs, resulting in endogenous growth. However, they show that the latter plays virtually no role at business cycle frequencies.

[7] We have verified through numerical simulation that the resuls reported below are robust to assuming decreasing returns to labor and capital accumulation subject to adjustment costs.

owners subject to quadratic price adjustment costs,

$$\sum_{t=0}^{\infty} E_0 \beta^t \frac{C_{t+1}^{-1}}{C_t^{-1}} \left[\frac{P_{Hit}}{P_{Ht}} Y_{Hit} - W_t \frac{P_t}{P_{Ht}} N_{it} - \frac{\zeta}{2} \left(\frac{P_{Hit}}{P_{Hit-1}} - 1 \right)^2 - h(U_{Hit}) \right],$$

where $\zeta > 0$ measures the size of price adjustment costs, subject to (9) and (10).

In a symmetric equilibrium, all firms choose the same price, labor input and technology utilization, such that (letting Φ_t be the multiplier on the demand constraint) the symmetric optimality conditions read

$$W_t \left(P_t / P_{Ht} \right) = \left(1 - \Phi_t \right) Y_{Ht} / N_t, \tag{11}$$

$$Y_{Ht} \left(1 - \Phi_t \theta \right) = \zeta \left(\pi_{Ht} - 1 \right) \pi_{Ht} - \beta \zeta E_t \left(C_{t+1}^{-1} / C_t^{-1} \right) \left(\pi_{Ht+1} - 1 \right) \pi_{Ht+1}, \tag{12}$$

$$\left(1 - \Phi_t \right) Y_{Ht} / U_{Ht} = h'(U_{Ht}), \tag{13}$$

where $\pi_{Ht} = P_{Ht}/P_{Ht-1}$, together with the symmetric production constraint $Y_{Ht} = Z_H U_{Ht} N_t$. Foreign firms are similar.

3.4 Fiscal and monetary policy

In each country, a central bank follows a simple Taylor - type rule to choose the nominal interest rate R (R^*) in response to domestic producer price inflation, with

$$R_t = \frac{1}{\beta} \pi_{Ht}^{\xi}, \quad R_t^* = \frac{1}{\beta} \pi_{Ft}^{*\xi},$$

where $\xi > 1$ is a reaction coefficient satisfying the Taylor principle, and in a steady state with price stability the interest rates in both countries are $1/\beta$. Government expenditure is financed through lump-sum taxes on domestic residents. Home government spending evolves as

$$G_t = (1 - \rho) G + \rho G_{t-1} + \varepsilon_t,$$

where $G_t = \left[(1-\gamma)^{1/\eta} G_{Ht}^{\frac{\eta-1}{\eta}} + \gamma^{1/\eta} G_{Ft}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}$, the constant G is its steady state value, ε_t is a serially uncorrelated mean zero random shock, and $\rho \in (0, 1)$. Government spending G_t^* in the foreign country is assumed to be constant.

3.5 Log-linear approximation

We log-linearize the model at a steady state where all prices are equal to one by choice of units, and where $U_H = U_F = 1$. Lower case letters denote log-deviations of a variable from its constant steady state value, i.e. for any variable Z_t we use $z_t = \ln(Z_t/Z)$, where Z is a constant steady state value (and φ_t is lower case for Φ_t). We assume that trade is balanced in the steady state, impose that the steady state share of own-produced goods is the same in each country by constricting $\gamma = 1 - \gamma^* < 1/2$, and that both countries have the same steady state government spending to output ratio $\omega_g := G/Y_H = G^*/Y_F \in (0, 1)$.

The Euler equation (3) can by using the CPI formula (6) and the definitions of the terms of trade (7) and of domestic producer price inflation $\pi_{Ht} = P_{Ht}/P_{Ht-1}$ be written as

$$c_t = E_t c_{t+1} - r_t + E_t \pi_{Ht+1} + \gamma E_t (s_{t+1} - s_t),$$

and its foreign counterpart reads $c_t^* = E_t c_{t+1}^* - r_t^* + E_t \pi_{Ft+1}^* - \gamma E_t (s_{t+1} - s_t)$. From the risk sharing condition (4) together with (6) and (7) we get relative consumption as a function of the terms of trade,

$$c_t - c_t^* = (1 - 2\gamma) s_t. \tag{14}$$

With balanced trade in the steady state and equal government shares, the market clearing constraints (9) with foreign government spending constant ($g_t^* = 0$) can by using the demand functions for the different goods be written as

$$y_{Ht} = (1-\gamma)(1-\omega_g) c_t + \gamma (1-\omega_g) c_t^* + (1-\gamma)\omega_g g_t + 2\eta\gamma (1-\gamma) s_t, \tag{15}$$

$$y_{Ft} = \gamma (1-\omega_g) c_t + (1-\gamma)(1-\omega_g) c_t^* + \gamma\omega_g g_t - 2\eta\gamma (1-\gamma) s_t. \tag{16}$$

On the supply side, if the slopes of the Phillips curves are the same in both countries, which we achieve by normalizing steady state output levels to $Y_H = Y_F = 1$ (through choice of the scaling constants) we get by log-linearizing (12)

$$\pi_{Ht} = \beta E_t \pi_{Ht+1} - \frac{1}{\zeta}\varphi_t, \tag{17}$$

as well as its foreign counterpart $\pi_{Ft}^* = \beta E_t \pi_{Ft+1}^* - \frac{1}{\zeta}\varphi_t^*$, together with the labor market clearing condition (from (2) and (11))

$$(\phi + 1) n_t + c_t + \gamma s_t = -\frac{1}{\theta - 1}\varphi_t + y_{Ht},$$

which in foreign reads $(\phi + 1) n_t^* + c_t^* - \gamma s_t = -\frac{1}{\theta-1}\varphi_t^* + y_{Ft}$.

In the optimality condition (13), we denote as $x := h''/h' > 0$ the steady elasticity of the costs of changing technology utilization. The parameter x will be central to the discussion below, since it determines the variability of productivity in response to shocks, and thus the reaction of goods supply to government demand changes. In log-linearized terms, the optimal choice for utilization satisfies

$$-\frac{1}{\theta - 1}\varphi_t + y_{Ht} = (1 + x) u_{Ht}, \tag{18}$$

and analogously $-\frac{1}{\theta-1}\varphi_t^* + y_{Ft} = (1+x) u_{Ft}$ in foreign, where $y_{Ht} = u_{Ht} + n_t$ and $y_{Ft} = u_{Ft} + n_t^*$ from the production contraint (10) and its foreign counterpart. The Taylor rules finally are $r_t = \xi\pi_{Ht}$ and $r_t^* = \xi\pi_{Ft}^*$, and exogenous government spending follows $g_t = \rho g_{t-1} + \varepsilon_t$. The complete set of log-linearly approximated equilibrium conditions is given in Appendix A1.4.

As in Devereux and Yu (2019), denote relative variables with R and world aggregate variables with W superscripts, such that $c_t^R = c_t - c_t^*$, $c_t^W = c_t + c_t^*$, $\pi_t^R = \pi_{Ht} - \pi_{Ft}^*$ and $\pi_t^W = \pi_{Ht} + \pi_{Ft}^*$. Then (as shown in detail in Appendix A1.5) the log-linearly approximated equilibrium conditions can be summarized through the joint interaction between relative and aggregate consumption and inflation with the terms of trade s_t and exogenous government spending g_t, as

$$s_t = E_t s_{t+1} - \xi \pi_t^R + E_t \pi_{t+1}^R, \tag{19}$$

$$\pi_t^R = \beta E_t \pi_{t+1}^R + \Psi_1^R s_t + \Psi_2^R g_t, \tag{20}$$

and

$$c_t^W = E_t c_{t+1}^W - \xi \pi_t^W + E_t \pi_{t+1}^W, \tag{21}$$

$$\pi_t^W = \beta E_t \pi_{t+1}^W + \Psi_1^W c_t^W + \Psi_2^W g_t, \tag{22}$$

where the composite coefficients are

$$\Psi_1^R = \Delta \left[(\phi x - 1)\, \Xi + x + 1 \right], \tag{23}$$

$$\Psi_2^R = \Delta\, (\phi x - 1)\, (1 - 2\gamma) \omega_g, \tag{24}$$

$$\Psi_1^W = \Delta \left(\phi x\, (1 - \omega_g) + \omega_g + x \right), \tag{25}$$

$$\Psi_2^W = \Delta\, (\phi x - 1)\, \omega_g, \tag{26}$$

with $\Xi = (1-2\gamma)^2 (1-\omega_g) + 4\eta\gamma(1-\gamma) > 0$ and $\Delta = \frac{\theta-1}{\zeta} \frac{1}{\phi+x+2} > 0$.

Crucially, the signs of the composite parameters $\Psi_{1,2}^{\{R,W\}}$ depend on the expression $\phi x - 1$ that relates the cost of changing technology utilization x to the curvature of the utility function that determines the Frisch elasticity of labor supply $1/\phi$. In particular, $\Psi_2^{\{R,W\}}$ (the direct partial effect of government spending on relative and world inflation in the Phillips curves 20 and 22) has the same sign as $\phi x - 1$, while Ψ_1^R (the partial effect of the terms of trade on relative inflation) is ambiguous in sign and Ψ_1^W (the partial effect of world consumption on world inflation) is unambiguously positive.

The intuition for the main effect can already be conjectured from this representation. Suppose, first, that the cost of changing technology utilization is relatively high, such that the cost elasticity x is larger than the Frisch elasticity of labor supply, $x > 1/\phi$. In this case, an increase in home government spending is likely (as a partial effect) to raise relative and world aggregate inflation ($\Psi_2^{\{R,W\}} > 0$). The relative increase in home inflation and consequently interest rates would then tend to appreciate the terms of trade and thus depress consumption. The result of a combined consumption decline and terms of trade appreciation would be clearly at odds with our empirical results, which show the opposite tendency.

Alternatively, suppose that the cost of changing technology utilization is low in the sense of $x < 1/\phi$. In this case, $\Psi_2^{\{R,W\}} < 0$ and the direct partial effect of an increase in government spending on relative inflation is negative. A fiscal expansion would thus likely trigger a decline in home interest rates and a terms of trade depreciation, leading to a domestic consumption expansion, and possibly also a positive transmission of the home shock to the foreign country. The intuition is that in this case a temporary demand increase due to government spending can be met with a large expansion of goods supply which at the same time does not lead to a large cost increase, since $x < 1/\phi$ means that adjusting productivity is less costly than changing labor input. This production flexibility leads to the demand shock actually lowering relative inflation and increasing the terms of trade and consumption.

However, the partial effects mentioned above are of course only suggestive of the full general equilibrium effects. Therefore, in the next section, we derive closed form solutions for the responses of the model variables to a fiscal spending shock.

4 Closed form solution

The model has no endogenous persistence, such that the impulse responses follow the dynamics of the exogenous autoregressive process for g_t. It thus suffices to pin down the impact effects of a fiscal shock, since the dynamics of the responses after the impact period are governed by a geometric decline at rate ρ. A richer model with endogenous persistence is numerically analyzed in the section 5.

4.1 Main result

We first state several results for the impact responses, and discuss the economics of the transmission mechanism further below.

Proposition 1 *(Model solution) Let*

$$\Lambda^R = \Psi_2^R \left[\Gamma + \Psi_1^R (\xi - \rho)\right]^{-1} \tag{27}$$

and

$$\Lambda^W = \Psi_2^W \left[\Gamma + \Psi_1^W (\xi - \rho)\right]^{-1} \tag{28}$$

with $\Psi_{1,2}^{\{R,W\}}$ *as defined in (23) to (26) and* $\Gamma = (1-\beta\rho)(1-\rho) > 0$*. The following holds with respect to a shock to* g_t*:*

1. *The impact effect on the terms of trade is*

$$\partial s_t / \partial g_t = -(\xi - \rho)\Lambda^R$$

2. *The impact effects on home variables are*

$$\begin{aligned}
\partial c_t / \partial g_t &= -0.5(\xi - \rho)\left[(1-2\gamma)\Lambda^R + \Lambda^W\right] \\
\partial y_{Ht} / \partial g_t &= -0.5\Xi(\xi - \rho)\Lambda^R - 0.5(1-\omega_g)(\xi - \rho)\Lambda^W + (1-\gamma)\omega_g \\
\partial \pi_{Ht} / \partial g_t &= 0.5(1-\rho)\Lambda^R + 0.5(1-\rho)\Lambda^W \\
\partial u_{Ht} / \partial g_t &= -\frac{0.5}{1+x}\left[(\Xi(\xi - \rho) - \epsilon)\Lambda^R + ((1-\omega_g)(\xi - \rho) - \epsilon)\Lambda^W\right] + \frac{1-\gamma}{1+x}\omega_g
\end{aligned}$$

where $\epsilon = \zeta\Gamma/(\theta - 1) > 0$.

3. *The impact effects on foreign variables are*

$$\begin{aligned}
\partial c_t^*/\partial g_t &= 0.5\left(\xi-\rho\right)\left[(1-2\gamma)\Lambda^R-\Lambda^W\right] \\
\partial y_{Ft}/\partial g_t &= 0.5\Xi\left(\xi-\rho\right)\Lambda^R-0.5\left(1-\omega_g\right)\left(\xi-\rho\right)\Lambda^W+\gamma\omega_g \\
\partial \pi_{Ft}^*/\partial g_t &= -0.5(1-\rho)\Lambda^R+0.5(1-\rho)\Lambda^W \\
\partial u_{Ft}/\partial g_t &= \frac{0.5}{1+x}\left[\left(\Xi\left(\xi-\rho\right)-\epsilon\right)\Lambda^R-\left(\left(1-\omega_g\right)\left(\xi-\rho\right)-\epsilon\right)\Lambda^W\right]+\frac{\gamma}{1+x}\omega_g
\end{aligned}$$

Proof.

1. *Equations (19) and (20) can be solved by undetermined coefficients for* $\pi_t^R=(1-\rho)\Lambda^R g_t$ *and* $s_t=-\left(\xi-\rho\right)\Lambda^R g_t$*, whence part 1. follows.*

2. *Equations (21) and (22) can similarly be solved for* $\pi_t^W=(1-\rho)\Lambda^W g_t$ *and* $c_t^W=-\left(\xi-\rho\right)\Lambda^W g_t$*. The claim concerning* π_{Ht} *follows from the identity* $\pi_{Ht}=0.5\pi_t^R+0.5\pi_t^W$ *together with the result from part 1. The claim concerning* c_t *follows by noting that* $c_t^R=(1-2\gamma)s_t$ *from (14) and from the identity* $c_t=0.5c_t^R+0.5c_t^W$ *together with the result from part 1. The claim concerning* y_{Ht} *follows from noting that by (15) and (16) with (14) relative output is* $y_t^R=\Xi s_t+(1-2\gamma)\omega_g g_t$*, world output is* $y_t^W=\left(1-\omega_g\right)c_t^W+\omega_g g_t$ *and from the identity* $y_{Ht}=0.5y_t^R+0.5y_t^W$ *together with the result from part 1. Concerning* u_{Ht}*, from the Phillips curve (17) we have* $\partial\varphi_t/\partial g_t=-\zeta\left(1-\beta\rho\right)\partial\pi_{Ht}/\partial g_t$*, which when used in the optimality condition for utilization (18) together with the result for* y_{Ht} *proves the claim.*

3. *The claims concerning* c_t^**,* y_{Ft} *and* π_{Ft}^* *follow from the results in parts 1. and 2. together with the identities* $c_t^*=c_t^W-c_t$*,* $y_{Ft}=y_t^W-y_{Ht}$ *and* $\pi_{Ft}^*=\pi_t^W-\pi_{Ht}$*. Concerning* u_{Ft}*, from the foreign Phillips curve* $\pi_{Ft}^*=\beta E_t\pi_{Ft+1}^*-\frac{1}{\zeta}\varphi_t^*$ *it is true that* $\partial\varphi_t^*/\partial g_t=-\zeta\left(1-\beta\rho\right)\partial\pi_{Ft}^*/\partial g_t$*, which used in the optimality condition for foreign utilization* $-\frac{1}{\theta-1}\varphi_t^*+y_{Ft}=(1+x)u_{Ft}$ *together with the previous results proves the claim.*

■

Note that in general the impact multipliers can have either sign, since the composite parameters Λ^R and Λ^W can be either positive or negative depending, among other parameters, on the cost elasticity of technology utilization x. To clarify the implications of the model, we will thus proceed with an assumption concerning the parameter constellation under which clear-cut results can be obtained.

Assumption A1: $\Gamma+\Psi_1^R\left(\xi-\rho\right)=\Gamma+\Delta\left(\xi-\rho\right)\left[\left(\phi x-1\right)\Xi+x+1\right]>0$.

Note that this is an assumption on the denominator of Λ^R. The only component that can be negative in this denominator is $\phi x-1$, which is multiplied by Ξ, the effect of the terms of trade on relative output. Since Ξ depends positively on the trade elasticity η, assumption A1 can be understood as a statement that the trade elasticity should not be 'too large'. Below, when we discuss numerical solutions based on calibrated parameter values, we find that A1 is satisfied for plausible constellations of parameters as frequently used in the literature. The results discussed next follow from the fact that the composite parameter Λ^W has the same sign as $\phi x-1$ in general, and the same is true for Λ^R if assumption A1 holds.

Proposition 2 *(Signs of impact effects)*

1. Suppose $\phi x - 1 > 0$. Then

$$\partial s_t/\partial g_t < 0, \quad \partial c_t/\partial g_t < 0, \; \partial \pi_{Ht}/\partial g_t > 0$$

2. Suppose $\phi x - 1 < 0$ and assumption A1 holds. Then

$$\partial s_t/\partial g_t > 0, \quad \partial c_t/\partial g_t > 0, \; \partial y_{Ht}/\partial g_t > 0, \quad \partial \pi_{Ht}/\partial g_t < 0$$

Proof.

1. *The proof follows from proposition 1 by noting that for $\phi x - 1 > 0$ both Λ^R and Λ^W as defined in (27) and (28) are positive since their components (23) to (26) are all positive.*
2. *The proof follows from proposition 1 by noting that for $\phi x - 1 < 0$ it is the case that $\Lambda^W < 0$ and, if assumption A1 holds, $\Lambda^R < 0$ since the expressions in (26) and (24) are negative.*

■

Proposition 2 states the core result. Clear analytical results are available for the domestic shock effects, while the international transmission effects are ambiguous in general and can have any sign, in principle, depending on parameters. We therefore analyze the international transmission effects separately for plausible parameter choices in the next section.

Concerning the domestic shock effects, the first part of proposition 2 states that if the cost elasticity x is large in the sense of $\phi x - 1 > 0$, then an increase in home government spending will produce a terms of trade appreciation while home consumption declines and inflation increases. The effects on home output and technology utilization are ambiguous in principle, but would likely be positive for plausible parameter choices. Note that the case $\phi x - 1 > 0$ also includes the corresponding model variant with exogenous productivity, which can be seen as the limit for $x \to \infty$. Thus, if the cost elasticity of changing technology utilization x is large in the sense $\phi x - 1 > 0$, the model implications are largely counterfactual when compared to the empirical results shown above. While the model can (for suitable parameters) be compatible with rising home and foreign output, the prediction for the case of $\phi x - 1 > 0$ of declining home consumption and a real home appreciation are precisely the opposite of what we find empirically.

This is reversed for the case $\phi x - 1 < 0$, as stated in the second part of proposition 2, provided the sufficient condition stated in assumption A1 holds. If adopting more productive technologies is relatively cheap, in the sense that the cost elasticity x is low enough to fulfill $\phi x - 1 < 0$, an increase in home government spending will depreciate the terms of trade and raise domestic consumption and output, while inflation and thus interest rates decline domestically. Thus, for $\phi x - 1 < 0$ the predictions of the model with respect to the home variables are qualitatively in line with the empirical evidence.

The intuition for the central result stated in proposition 2 is straightforward. An increase in the demand for domestic goods through higher government spending exerts upward pressure on goods prices, and will for large x result in higher interest rates. This is compatible with a real appreciation of the terms of trade, which from the risk sharing condition associated with international capital markets coincides with a decrease in domestic consumption. If, however, x is low enough such that varying technology utilization is relatively cheap, the reverse outcome obtains. Note that, from Proposition 1, the effect of government spending on u_H is ambiguous in principle. However, in the case $\phi x - 1 < 0$ productivity is likely to rise for plausible parameter values since the parameter $\epsilon = \zeta\Gamma/(\theta - 1)$ appearing in the response of u_H depends on $\Gamma = (1 - \beta\rho)(1 - \rho)$ which is likely to be small for a discount factor close to one and a realistic degree of shock persistence. Assuming this, for low x the higher goods demand from fiscal spending will lead to an endogenous increase in productivity and thus in goods supply, which lowers prices and interest rates, produces a real depreciation and allows for an increase in domestic consumption, much as found in the empirical evidence.

4.2 Transmission effects

The international transmission effects of domestic fiscal shocks on the foreign economy are ambiguous in general, since they depend on the strength of the expenditure switching effects of changes in the terms of trade (as can be seen from Λ^R entering with the opposite sign as Λ^W in the expressions for the foreign economy effects in proposition 1). However, for the special case where no home bias exists, i.e. for $\gamma = 0.5$, clear results are available, as stated in the following corollary to proposition 2.

Corollary 3 *(International transmission without home bias) If $\gamma = 0.5$, the terms of trade are constant and the effects of domestic fiscal shocks on home and foreign variables are equal. If there is a positive shock to g_t:*

1. $\phi x - 1 < 0$ *is necessary and sufficient for foreign consumption to rise and inflation to decline.*

2. $\phi x - 1 < 0$ *is sufficient for foreign output to rise.*

3. $\phi x - 1 < 0$ *and* $(1 - \omega_g)(\xi - \rho) - \epsilon > 0$ *is jointly sufficient for foreign technology utilization to rise.*

   Proof. *The proof follows from proposition 1 for $\gamma = 0.5 \Rightarrow \Lambda^R = 0$.* ■

In this special case of no home bias, the terms of trade (and the real exchange rate) are constant and purchasing power parity (PPP) obtains. This entails the lack of any expenditure switching effects, such that relative (home to foreign) variables are constant. As a consequence, a positive effect of domestic fiscal policy on home and foreign consumption results for low cost elasticities in the sense of $\phi x - 1 < 0$.

However, the case of $\gamma = 0.5$ is both special and unrealistic, since empirically home bias appears to exist as import shares in consumption are typically well below 50 percent, which is compatible with the terms of trade responding strongly to domestic fiscal shocks as shown in the empirical part of the paper. In the more realistic case of $\gamma < 0.5$, changes in the terms of trade will partly counteract the positive transmission effects that would obtain under purchasing power parity. The international transmission with endogenously varying terms of trade depends on too many parameters such that the analytical results do not yield unambiguous results for the relevant parameter range. We will therefore analyze the international transmission effects numerically in the remainder of this section.

Figure 5 illustrates the transmission mechanism by showing the impact responses to fiscal shocks for several parameter constellations. The computations shown in the figure are based on a discount factor $\beta = 0.99$, shock persistence $\rho = 0.9$, a Taylor rule coefficient implying an active monetary policy $\xi = 2.4$, price stickiness parameter $\zeta = 24.12$, price elasticity $\theta = 10$, and a government share of $\omega_g = 0.2$. The parameter values chosen here merely serve as example values to illustrate the logic of the model, while the justification for their choice is given below in Section 5. For the inverse labor supply elasticity, we choose $\phi = 1$. To demonstrate how the model works when PPP does not hold, we choose a steady state import share of $\gamma = 0.27$ (a choice explained in Section 5) to allow for a realistic degree of home bias.

Figure 5 shows the impact responses to a positive one percent government spending shock as functions of the cost elasticity x on the horizontal axis, for trade elasticities labelled low ($\eta = 0.5$, solid lines) or high ($\eta = 1.5$, dashed lines). These trade elasticities roughly span the range of values that are routinely used in the literature. The figure shows that for low x, a positive home government shock produces a terms of trade depreciation along with an increase in home output, consumption, and productivity. The impact responses of foreign output and consumption mostly have the same positive signs as their domestic counterparts, with the exception that foreign output may respond negatively for extremely low x. For values of x that lead to a home depreciation, the effect is quantitatively stronger for a low trade elasticity.

The intuition for the transmission mechanism illustrated in the figure is straightforward. The domestic expansion of government spending triggers an increase in home labor supply due to the negative wealth effect of implied higher taxation. This generally raises home output, and makes domestic firms choose a more productive technology such that productivity rises, while the effect on other variables depends on x. Specifically, for high values of x (around $x > 1$ for the chosen parameters), home consumption declines. The reason is that higher government demand raises domestic producer prices and thus, given active interest rate policy, the domestic real interest rate, which leads to a terms of trade appreciation. By the risk sharing property of financial markets, home consumption needs to decline in this case.

For low values of x, the preceding effects are overturned since higher domestic labor input goes along with a stronger increase in technology utilization, which is relatively cheap to vary if x is low. As a result, output and productivity expand more strongly, such that a larger increase in goods supply overcompensates the government induced demand increase,

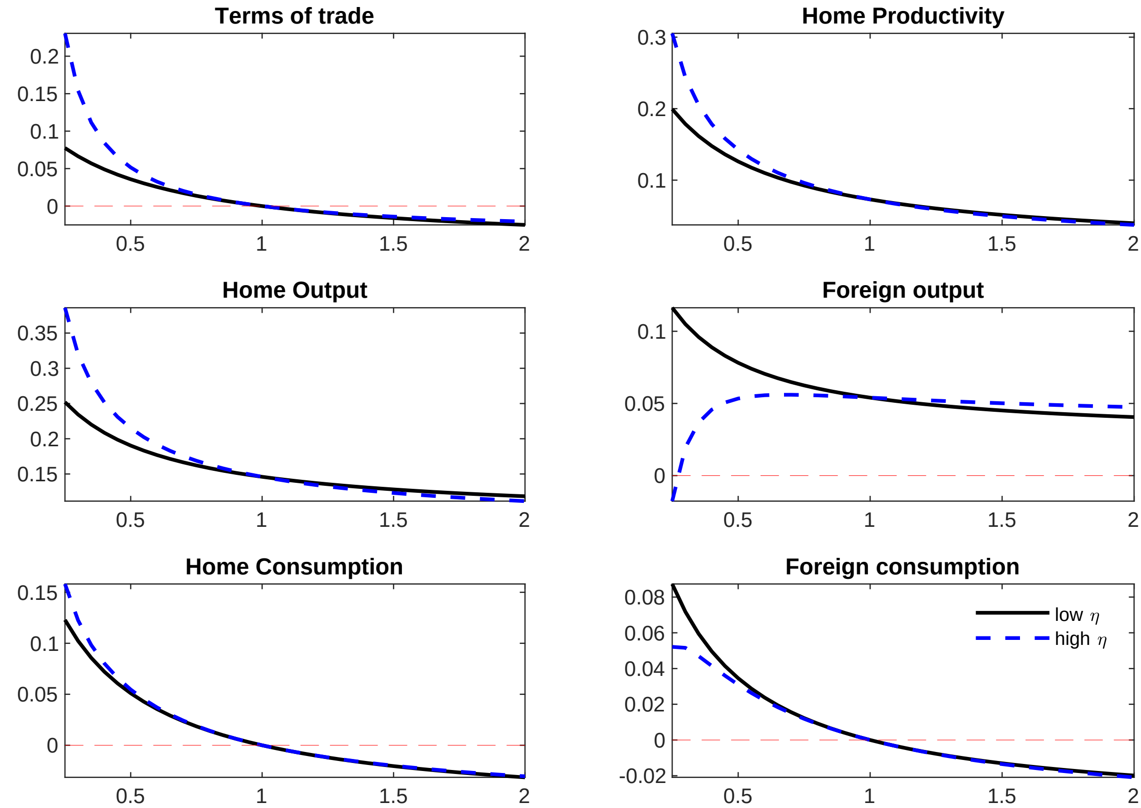

Figure 5: Impact responses in stylized model.

and thus lowers inflation and domestic real interest rates. This leads to a depreciation of the terms of trade, allowing domestic consumption to increase. The domestic effects are larger for a higher trade elasticity, since more elastic foreign demand leads to stronger expenditure switching towards home goods that have become relatively cheaper through the domestic depreciation.

Conversely, the transmission of the shock to the foreign economy is decreasing in the trade elasticity for values of x that imply a home depreciation, due to the adverse effect of an increase in the home terms of trade on foreign price competitiveness. Foreign consumption increases as long as the terms of trade increase due to the positive wealth effect of a home depreciation on foreign consumers. The foreign consumption increase is, however, less strong than the domestic one, such that relative home consumption rises. Concerning foreign output, for very low values of the cost elasticity x the expenditure switching towards home goods due to the domestic depreciation can be so strong that foreign production could decline, though only if a high trade elasticity diverts a large amount of expenditure away from foreign goods, while for more moderate values of x, or lower trade elasticities, the increased demand for foreign goods due to higher foreign consumption in the presence of home bias dominates to make foreign output increase.

To sum up, for moderately low technology utilization cost elasticities, the signs of the model's impact responses are in line with the empirical findings reported above, implying that a positive government spending shock induces a positive international transmission, increasing consumption both at home and less strongly in foreign, and an increase in the terms of trade. The key to these results is the endogenous positive productivity response that allows an expansion of goods supply. Conversely, for high cost elasticities, the model implies a domestic appreciation and a domestic and foreign consumption decrease, at odds with empirical findings.

5 Impulse responses in an enlarged model

The results discussed above were based on a stylized model that has been kept deliberately simple in order to allow for analytical results. In particular, we used the assumptions that household utility is logarithmic in consumption and additively separable in leisure, and that there are constant returns to labor. While useful to keep the model tractable, these assumptions are admittedly special, which raises the question if the results generalize to a richer model. In this section, we numerically analyze the fiscal tranmission mechanism in an enlarged model that incorporates richer transmission channels and endogenous persistence featuring a more general utility specification and decreasing returns to labor, additionally allowing for a different degree of home bias for government spending compared to private consumption and for imported goods being used as intermediate inputs in production as a further channel for international linkages.

5.1 Model setup

Since the model is an extension of the simplified analytical model described above, we briefly describe only those parts that differ from the simple model. Variables that have the same meaning in both model versions (like the terms of trade or inflation rates) are defined in section 3. Appendix A1.6 gives a detailed overview of all equilibrium conditions. Domestic households maximize

$$E_0 \sum_{t=0}^{\infty} \beta^t \frac{\left(\left(C_t - \psi \overline{C}_{t-1}\right)^{\chi} (1 - N_t)^{1-\chi}\right)^{1-\sigma}}{1-\sigma}, \quad \chi, \beta, \psi \in (0,1), \sigma > 0.$$

This is a slight generalization of the standard specification of non-additively separable utility often used in the business cycle literature since King et al. (1988) to allow for habit formation. In particular, $\overline{C}_{t-1}$ is aggregate past consumption, such that habits are external (assuming that habits are internal leads to very similar results). The parameter ψ governs the strength of habit formation. Households in both countries own the firms in their respective countries, and have access to a complete set of internationally traded contingent claims, as well as to riskless local government bonds with gross nominal interest rate R_t.

Optimal choices thus imply

$$\begin{aligned}
\lambda_t &= \chi \left(\left(C_t - \psi \overline{C}_{t-1} \right)^{\chi} (1 - N_t)^{1-\chi} \right)^{-\sigma} \left(C_t - \psi \overline{C}_{t-1} \right)^{\chi - 1} (1 - N_t)^{1-\chi}, \\
W_t &= \frac{1-\chi}{\chi} \frac{\left(C_t - \psi \overline{C}_{t-1} \right)}{1 - N_t}, \\
\lambda_t &= \beta E_t \lambda_{t+1} \frac{R_t}{\pi_{t+1}},
\end{aligned}$$

where λ_t is the marginal utility of consumption. Trade in contingent claims implies the international risk sharing condition

$$\omega Q_t \lambda_t = \lambda_t^*, \tag{29}$$

where λ_t^* is the marginal utility of consumption of foreign households, who have the same utility function as home, and ω is a constant determined by initial conditions.

Total consumption consists of home and foreign produced goods as in (5). In addition, we assume that the government demands both home goods G_H and foreign goods G_F that aggregate to total government demand G_t according to

$$G_t = \left[(1-\gamma^G)^{1/\eta} G_{Ht}^{\frac{\eta-1}{\eta}} + \left(\gamma^G \right)^{1/\eta} G_{Ft}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}},$$

where η is the same substitution elasticity that governs consumption goods demand, but the government's share parameter $\gamma^G \in (0,1)$ is allowed to differ from the one of consumers γ, to realistically allow for a different degree of home bias for the government from the one of private households. Foreign government demand is similar with γ^{G*} denoting the steady state share of foreign-produced goods in foreign government demand. Due to a different composition of government demand, its price index P_t^G can differ from the CPI and is given by

$$P_t^G = \left[(1-\gamma^G) P_{Ht}^{1-\eta} + \gamma^G P_{Ft}^{1-\eta} \right]^{\frac{1}{1-\eta}}.$$

However, goods demanded by the government are the same as those demanded by consumers, such that the demand functions for individual varieties are the same (see 8) and the prices of individual varieties are the same for the government as for consumers.

Additionally, imported foreign (home) goods can serve as intermediate inputs in home (foreign) production. We assume that intermediate inputs aggregate in the same way as consumption across individual varieties. As a consequence, assuming the law of one price holds, the demand Y_{Hit} for the variety of goods produced by the i-th home firm is given by

$$Y_{Hit} = \left(\frac{P_{Hit}}{P_{Ht}} \right)^{-\theta} \left(C_{Ht} + C_{Ht}^* + G_{Ht} + G_{Ht}^* + V_t^* \right), \tag{30}$$

where V_t^* is the demand for home intermediate goods imported from foreign firms. The corresponding demand constraint for a foreign firm is

$$Y_{Fit} = \left(\frac{P_{Fit}}{P_{Ft}} \right)^{-\theta} \left(C_{Ft} + C_{Ft}^* + G_{Ft} + G_{Ft}^* + V_t \right),$$

where V_t is the demand of foreign firms for intermediate inputs imported from home.

The i-th domestic firms maximizes the present discounted value of profits on behalf of its domestic household-owners subject to price adjustment costs,

$$\sum_{t=0}^{\infty} E_0 \beta^t \frac{\lambda_{t+1}}{\lambda_t} \left[\frac{P_{Hit}}{P_{Ht}} Y_{Hit} - W_t \frac{P_t}{P_{Ht}} N_{it} - \frac{\zeta}{2} \left(\frac{P_{Hit}}{P_{Hit-1}} - 1 \right)^2 - \frac{P_{Ft}}{P_{Ht}} V_{it} - h(U_{Hit}) \right],$$

where V_{it} is imported intermediate inputs demanded by the i-th home firm. Maximization is subject to (30) and the production constraint

$$Y_{Hit} = Z_H U_{Hit} N_{it}^{\vartheta} V_{it}^{1-\vartheta}, \quad \vartheta \in (0,1), \tag{31}$$

such that $1-\vartheta$ is the production elasticity of imported intermediates, and Z_H a scaling constant denoting the technology level. In a symmetric equilibrium, each firm charges the same price and hires the same amounts of factor inputs. Letting Φ_t denote the multiplier on the demand constraint, the conditions for the optimal choices of labor, intermediates, prices, and technology utilization read

$$\begin{aligned} W_t P_t / P_{Ht} &= (1-\Phi_t)\, \vartheta Y_{Ht}/N_t, \\ P_{Ft}/P_{Ht} &= (1-\Phi_t)\,(1-\vartheta) Y_{Ht}/V_t, \\ Y_{Ht}\,(1-\Phi_t\theta) &= \zeta\,(\pi_{Ht}-1)\,\pi_{Ht} - \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \zeta\,(\pi_{Ht+1}-1)\,\pi_{Ht+1}, \\ (1-\Phi_t)\, Y_{Ht}/U_{Ht} &= h'(U_{Ht}), \end{aligned}$$

together with the symmetric aggregate version of the production constraint (31). Foreign firms are similar. The rest of the model is unchanged relative to the one in section 3.

5.2 Results

We set the parameters for which there are relatively uncontroversial benchmarks at values that are common in the literature, and show the sensitivity of the model results with respect to the more controversial parameters. The former group of parameters includes a discount factor $\beta = 0.99$, shock persistence $\rho = 0.9$, a steady state share of government expenditure in output of $G/Y_H = 0.2$, and a price elasticity $\theta = 10$ to produce a steady state price-marginal cost markup just above 10 percent. The Taylor rule parameter is chosen as $\xi = 2.4$ as in D'Alessandro et al. (2019). The utility parameters are chosen at $\sigma = 2$ and $\chi = 0.2781$ to produce a steady state labor supply of $n = 0.3$, as common in the literature. The price stability parameter ζ is chosen such that the current effect of a real marginal cost change in the New Keynesian Phillips curve is the same as in the corresponding Calvo model with a probability of price non-adjustment of 0.75 per quarter, resulting in $\zeta = 24.12$. We set the habit parameter to $\psi = 0.5$. For the trade elasticity, there exists a range of values used in the literature. We choose a relatively low value of $\eta = 0.5$ for the baseline parameterization, and explore the consequences of a high value as a sensitivity check. The production elasticity of imported intermediates is set at $1-\vartheta = 0.16$ based on the results in Lombardo and Ravenna (2014), but we also analyze the consequences of switching the imported intermediate channel off by setting ϑ to zero.

In the data, the average import share across G7 countries in the sample period used in the empirical section is 0.23. As in Cacciatore and Traum (2020), we assume that the import share of private consumption is three times as high as the one in government spending. Consequently, with an assumed government share of 20 percent of output, we choose $\gamma = 0.27$ and $\gamma^G = 0.09$ to reconcile these observations.

The solid lines in Figure 6 show the model responses to a one percent shock to domestic government spending for the baseline case for which we choose a low cost elasticity of $x = 0.3$ based on parameter estimate in Jorgensen and Ravn (2021). Domestic output and consumption respond positively with rising productivity and a decrease in the real interest rate and an increase in the terms of trade. Foreign consumption and output react positively, too, but less strongly than their domestic counterparts. The terms of trade depreciation is quantitatively much weaker than found empirically, such that the model has the same difficulty in rationalizing the large observed volatility of international prices that is often found in the literature and sometimes labelled exchange rate disconnect. In all other respects, however, the model results are broadly in line with the empirical evidence presented above. In particular, the foreign output response at its peak is about half as large as the domestic one, as in the data.

The dashed lines in Figure 6 show the case of a large value for the cost elasticity of technology utilization for the example $x = 10$ for comparison (in each of the following experiments, only the one parameter mentioned in the legend is changed while keeping all other parameters at their baseline values). In this case, the domestic productivity response is strongly subdued, such that consumption both in home and foreign declines while the real interest rate increases and the terms of trade appreciate. These results are counterfactual with respect to the empirical evidence, emphasizing our key point that a low cost elasticity is crucial for rationalizing an empirically plausible fiscal transmission process.

The positive international transmission found in the baseline case is subdued if the trade elasticity is high, as shown by the dash-dotted lines in the figure which are for $\eta = 1.5$, a value near the upper end of the range used in the literature. The reason is that with a higher price sensitivity of demand for foreign goods, the domestic terms of trade depreciation leads to a stronger crowding-out of imports from abroad, which is compatible with a weaker output and consumption expansion in the foreign economy. Switching off the intermediate input channel by setting $\vartheta = 0$ likewise reduces the foreign output expansion, as shown by the dotted lines in Figure 6. The reason is that if intermediate inputs are used in production, the adverse demand effect of a domestic depreciation on foreign goods is partly counteracted by the positive effect on foreign goods supply through increased use of cheaper intermediates imported from home.

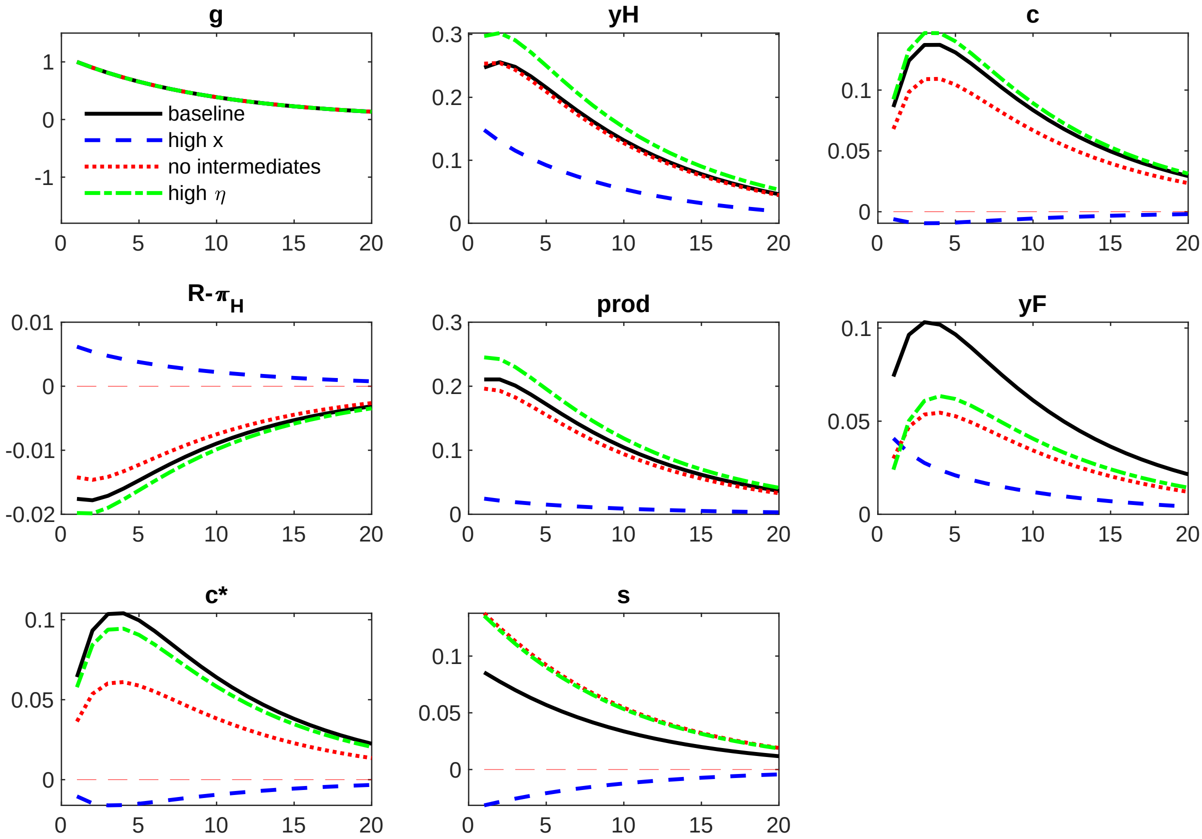

Figure 6: Impulse responses in enlarged model.

6 Conclusion

Using proxy-VAR evidence, we have shown that positive US government spendings shocks identified through external instruments tend to depreciate the terms of trade vis-a-vis the rest of the G7 countries, and raise private consumption both domestically and in the foreign economies. These responses are relatively precisely estimated and appear empirically robust. Moreover, higher fiscal spending is associated with a quick and strongly positive response of hourly private-sector labor productivity. We argue that the latter result, which in our view has received too little attention in the previous literature, is the key towards the theoretical understanding both of the domestic effects of fiscal policy and of its international transmission to trading partners.

In particular, we have analytically demonstrated that the signs of the empirically estimated responses to fiscal shocks, which have often been considered as theoretically puzzling in previous literature, can be explained through a simple extension of a standard two-country New Keynesian business cycle model. The crucial model feature is a high degree of goods supply flexibility, which we model (following Jorgensen and Ravn, 2021) as a low cost to varying technology utilization. For a low utilization cost elasticity, an increase in fiscal spending produces a concomitant increase in the supply of tradable goods that increases the terms of trade along with private consumption and output, both domestically and in the foreign economies. While the expenditure switching towards domestically produced goods through the real depreciation mitigates the spillover to foreign trading partners, for parameters as usually considered in the open economy macro literature the positive demand pull from higher spending dominates, and international spillovers are positive.

We have attributed the productivity increase resulting from positive government spending shocks to highly variable cyclical technology utilization. While we view this as the most plausible explanation, mostly because of the immediateness of the empirical productivity response, there are certainly other possible channels that might have a similar effect, and thus possibly comparable properties concerning the international adjustment. In particular, models of endogenous technological progress that show how innovation activity can respond to demand side disturbances, as e.g. in Moran and Queralto (2018), could provide alternative routes to explain the evidence. A comparison of the open economy consequences of these models to the mechanism put forth here appears to be an interesting direction of future research.

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Appendix

A1.1 Data description and sources

The following overview gives details on the construction of the variables used in the empirical section of the paper and specifies the data sources.

United States

Government spending: Real Government Consumption Expenditures and Gross Investment (FRED database GCEC1), divided by population level (FRED database CNP16OV).

Output: Real gross domestic product (FRED Datababse, GDPC1), divided by population level (FRED database CNP16OV).

Productivity: Real output per hour of all persons, nonfarm business sector, index 2012=100, (FRED database, OPHNFB).

Consumption: Real Personal Consumption Expenditures (FRED Database, PCECC96), divided by population level (FRED database CNP16OV).

Government deficit: Federal total expenditures (FRED database W019RCQ027SBEA) minus Federal total receipts (FRED database W018RC1Q027SBEA), divided by nominal GDP (FRED database GDP). The receipts series contains an outlier in 2017Q4 that we have linearly interpolated.

Real interest rate: Federal funds rate (FRED database FEDFUNDS) in decimal points minus annualized log-change in the GDP deflator (FRED database GDPCTPI).

Terms of trade: G6 export price deflator normalized to 2012=1 (see below) divided by US deflator for exports of goods and services normalized to 2012=1 (OECD Economic Outlook database), times nominal exchange rate (see below).

Military spending instrument: Annualized log-change in the ratio of real federal defense expenditures (FRED database B824RA3Q086SBEA) over population level (FRED database CNP16OV).

Real exchange rate: G6 consumer price index normalized to 2012=1 (see below) over US consumer price index for all urban consumers normalized to 2012=1 (FRED database CPI-AUCSL), times nominal exchange rate (see below).

Military news: Variable constructed by Valerie Ramey, downloaded from her website.

Forecast error instrument: 1966-2008: Auerbach and Gorodnichenko (2012), 2009-2019: own construction based on Survey of Professional Forecasters.

Goverment spending forecast: 966-2008: Auerbach and Gorodnichenko (2012), 2009-2019: own construction based on Survey of Professional Forecasters.

G6 countries

Nominal exchange rate: Inverses of FRED database measures of national currency to US dollar exchange rate, normalized to 2012=1 (Canada: CCUSMA02CAQ618N, France: CCUSMA02FRQ618N, Germany: CCUSMA02DEQ618N, United Kingdom: CCUSMA02GBQ618N, Japan: CCUSMA02JPQ618N, Italy: CCUSMA02ITQ618N).

Consumer price index: FRED database measure of total consumer price index for all items normalized to 2012=1 (Canada: CPALCY01CAM661N, France: FRACPIALLMINMEI, Germany: DEUCPIALLMINMEI, United Kingdom: GBRCPIALLMINMEI, Japan: JPNCPIALLQINMEI, Italy: ITACPIALLQINMEI).

Real GDP: Gross domestic product, national currency, volume, (OECD Quarterly National Accounts).

Real consumption: Private final consumption expenditure, national currency, volume (OECD Quarterly National Accounts).

Export prices: Deflator for exports of goods and services normalized to 2012=1 (OECD Economic Outlook). For Germany, the OECD export price index series is only available from 1991Q1 onwards. For the earlier periods, we use the price index for goods exports from the IMF International Financial Statistics and rebase it to have the same value as the OECD series in 1991Q1.

Real government consumption: Government final consumption expenditure, national currency, volume, (OECD Quarterly National Accounts).

A1.2 Additional figures

In Figure A1 we present the results of further robustness analyses, which show that the main empirical findings also hold up when varying the lag length, using a shadow policy interest rate to construct the real interest rate during the zero lower bound episode, measuring foreign real variables in per capita terms, or leaving out the turbulent Great Recession period by shortening the sample. Moreover, it shows the results to using an aggregate of G6 countries, instead of including the countries individually in a panel setup. The black solid lines represent the baseline case and are repeated from Figure 1 in the main text, along with the corresponding shaded confidence bands. The blue dashed lines show the impulse responses for a VAR model with 4 lags. The red dotted lines show the effect of replacing the Federal Funds rate by the shadow policy interest rate as constructed by Wu and Xia (2016) to measure the real interest rate during the zero lower bound period. The green dashed-dotted lines show the results when the empirical sample ends in 2007 to exclude the Great Recession episode. The yellow dashed-asterisked lines present the responses when measuring foreign real variables in per capita terms. To obtain quarterly population data for the G6 countries, we linearly interpolated from annual values. The magenta dashed-circled lines presents the results when we use an aggregate of G6 countries.

Figure A2 shows the response of foreign government spending which we add as additional variable to our baseline model.

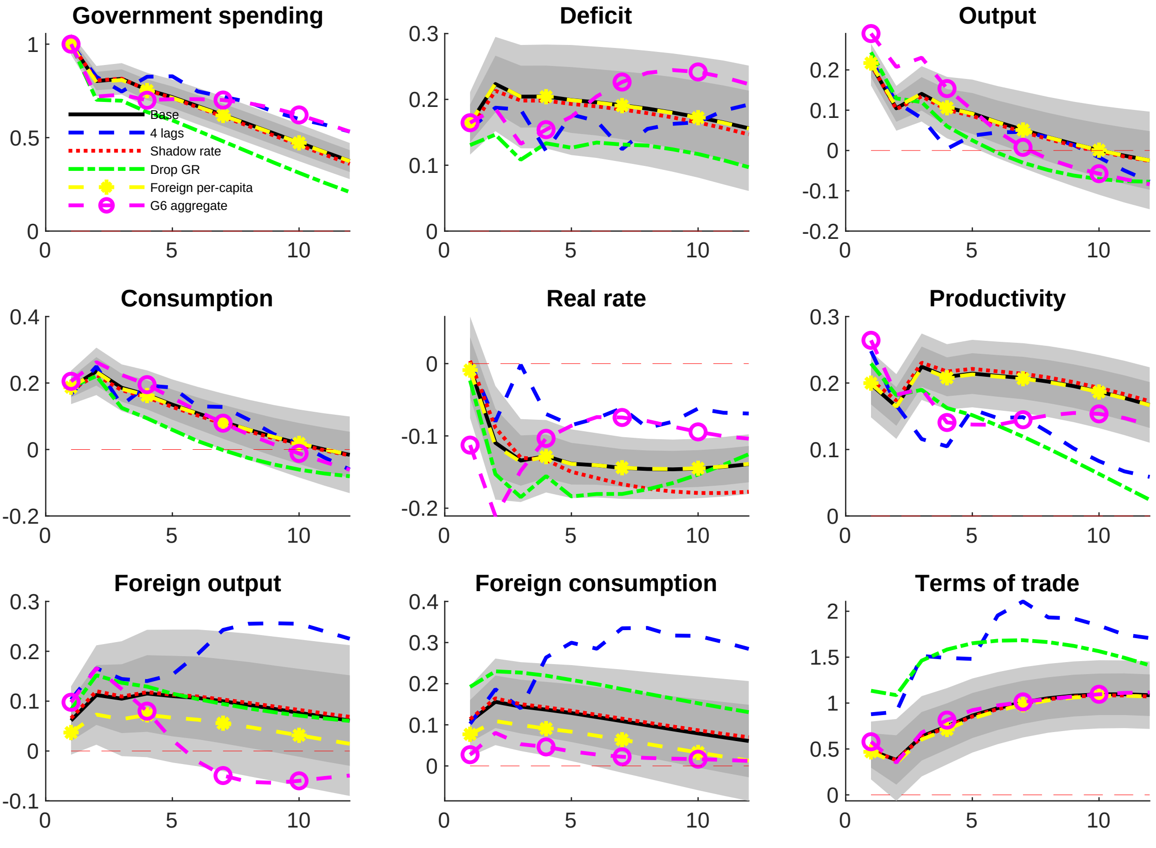

Figure A1: Robustness of empirical results.

Notes: Solid lines show point estimates. Shaded areas indicate 68% and 90% bootstrapped confidence intervals of our baseline model.

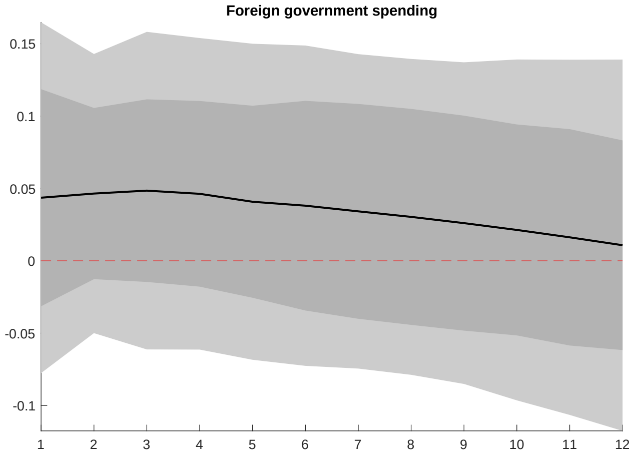

Figure A2: G6 government spending.

Notes: Solid lines show point estimates. Shaded areas indicate 68% and 90% bootstrapped confidence intervals of our baseline model.

A1.3 Summary of nonlinear equilibrium conditions of the model in section 3

The following conditions determine the symmetric equilibrium time paths of the endogenous variables $\{C,\ C^*,\ W,\ W^*,\ N,\ N^*,\ R,\ R^*,\ Q,\ S,\ P_H/P,\ P_F^*/P^*,\ \pi,\ \pi_H,\ \pi^*,\ \pi_F^*,\ C_H,\ C_F,\ C_H^*,\ C_F^*,\ G_H,\ G_F,\ G_H^*,\ G_F^*,\ Y_H,\ Y_F,\ U_H,\ U_F,\ \Phi,\ \Phi^*,\ G,\ G^*\}_t$ for the model in section 3.

Households:

$$
\begin{aligned}
W_t &= \chi N_t^{\phi} C_t \\
W_t^* &= \chi N_t^{*\phi} C_t^* \\
C_t^{-1} &= \beta E_t C_{t+1}^{-1} \frac{R_t}{\pi_{t+1}} \\
C_t^{*-1} &= \beta E_t C_{t+1}^{*-1} \frac{R_t^*}{\pi_{t+1}^*} \\
\omega Q_t C_t^{-1} &= C_t^{*-1}
\end{aligned}
$$

Relative prices:

$$
\begin{aligned}
S_t &= \frac{P_{Ft}}{P_{Ht}} = Q_t \frac{P_{Ft}^*}{P_t^*} \Big/ \frac{P_{Ht}}{P_t} \\
\frac{P_{Ht}}{P_t} &= \left[(1-\gamma) + \gamma S_t^{1-\eta}\right]^{-\frac{1}{1-\eta}} \\
\frac{P_{Ft}^*}{P_t^*} &= \left[(1-\gamma^*) S_t^{-(1-\eta)} + \gamma^*\right]^{-\frac{1}{1-\eta}}
\end{aligned}
$$

$$
\begin{aligned}
\pi_{Ht}/\pi_t &= \frac{\left[(1-\gamma) + \gamma S_t^{1-\eta}\right]^{-\frac{1}{1-\eta}}}{\left[(1-\gamma) + \gamma S_{t-1}^{1-\eta}\right]^{-\frac{1}{1-\eta}}} \\
\pi_{Ft}^*/\pi_t^* &= \frac{\left[(1-\gamma^*) S_t^{-(1-\eta)} + \gamma^*\right]^{-\frac{1}{1-\eta}}}{\left[(1-\gamma^*) S_{t-1}^{-(1-\eta)} + \gamma^*\right]^{-\frac{1}{1-\eta}}}
\end{aligned}
$$

Consumption and government demand:

$$
\begin{aligned}
C_{Ht} &= (1-\gamma) \left(\frac{P_{Ht}}{P_t}\right)^{-\eta} C_t \\
C_{Ft} &= \gamma \left(S_t \frac{P_{Ht}}{P_t}\right)^{-\eta} C_t \\
C_{Ht}^* &= (1-\gamma^*) \left(S_t^{-1} \frac{P_{Ft}^*}{P_t^*}\right)^{-\eta} C_t^* \\
C_{Ft}^* &= \gamma^* \left(\frac{P_{Ft}^*}{P_t^*}\right)^{-\eta} C_t^*
\end{aligned}
$$

$$
\begin{aligned}
G_{Ht} &= (1-\gamma)\left(\frac{P_{Ht}}{P_t}\right)^{-\eta} G_t \\
G_{Ft} &= \gamma\left(S_t\frac{P_{Ht}}{P_t}\right)^{-\eta} G_t \\
G^*_{Ht} &= (1-\gamma^*)\left(S_t^{-1}\frac{P^*_{Ft}}{P^*_t}\right)^{-\eta} G^*_t \\
G^*_{Ft} &= \gamma^*\left(\frac{P^*_{Ft}}{P^*_t}\right)^{-\eta} G^*_t
\end{aligned}
$$

Aggregate demand / market clearing:

$$
\begin{aligned}
Y_{Ht} &= C_{Ht} + C^*_{Ht} + G_{Ht} + G^*_{Ht} \\
Y_{Ft} &= C_{Ft} + C^*_{Ft} + G_{Ft} + G^*_{Ft}
\end{aligned}
$$

Domestic production:

$$
\begin{aligned}
Y_{Ht} &= Z_H U_{Ht} N_t \\
W_t\frac{P_t}{P_{Ht}} &= (1-\Phi_t)\, Y_{Ht}/N_t \\
Y_{Ht}\,(1-\Phi_t\theta) &= \zeta\,(\pi_{Ht}-1)\,\pi_{Ht} - \beta\zeta E_t\frac{C^{-1}_{t+1}}{C^{-1}_t}\,(\pi_{Ht+1}-1)\,\pi_{Ht+1} \\
(1-\Phi_t)\,Y_{Ht}/U_{Ht} &= h'(U_{Ht})
\end{aligned}
$$

Foreign production:

$$
\begin{aligned}
Y_{Ft} &= Z_F U_{Ft} N^*_t \\
W^*_t\frac{P^*_t}{P^*_{Ft}} &= (1-\Phi^*_t)\, Y_{Ft}/N^*_t \\
Y^*_{Ft}\,(1-\theta\Phi^*_t) &= \zeta\,(\pi^*_{Ft}-1)\,\pi^*_{Ft} - \beta\zeta E_t\frac{\lambda^*_{t+1}}{\lambda^*_t}\,(\pi^*_{Ft+1}-1)\,\pi^*_{Ft+1} \\
(1-\Phi^*_t)\,Y_{Ft}/U_{Ft} &= h'(U_{Ft})
\end{aligned}
$$

Monetary and fiscal policy:

$$
\begin{aligned}
R_t &= \frac{1}{\beta}\pi^{\xi}_{Ht} \\
R^*_t &= \frac{1}{\beta}\pi^{*\xi}_{Ft}
\end{aligned}
$$

$$
\begin{aligned}
G_t &= (1-\rho)G + \rho G_{t-1} + \varepsilon_t \\
G^*_t &= G^*
\end{aligned}
$$

A1.4 Summary of log-linearized equilibrium conditions of the model in section 3

Lower case letters denote log-deviations of a variable from the steady state, i.e. for any variable Z_t we use $z_t = \ln(Z_t/Z)$, where Z is a constant steady state value (and φ_t is lower case for Φ_t). We log-linearize around a steady state with price stability where all prices are normalized to unity, and technology utilization is $U_H = U_F = 1$.

Households:

$$w_t = \phi n_t + c_t$$
$$w_t^* = \phi n_t^* + c_t^*$$

$$c_t = E_t c_{t+1} - r_t + E_t \pi_{t+1}$$
$$c_t^* = E_t c_{t+1}^* - r_t^* + E_t \pi_{t+1}^*$$

$$q_t + c_t^* = c_t$$

Relative prices:

$$(\gamma^* - \gamma) s_t = q_t$$
$$p_{Ht} - p_t = -\gamma s_t$$
$$p_{Ft}^* - p_t^* = (1 - \gamma^*) s_t$$

$$\pi_{Ht} - \pi_t = -\gamma \left(s_t - s_{t-1}\right)$$
$$\pi_{Ft}^* - \pi_t^* = (1 - \gamma^*) \left(s_t - s_{t-1}\right)$$

Consumption and government demand:

$$c_{Ht} = \eta \gamma s_t + c_t$$
$$c_{Ft} = -\eta (1 - \gamma) s_t + c_t$$
$$c_{Ht}^* = \eta \gamma^* s_t + c_t^*$$
$$c_{Ft}^* = -\eta (1 - \gamma^*) s_t + c_t^*$$

$$g_{Ht} = \eta \gamma s_t + g_t$$
$$g_{Ft} = -\eta (1 - \gamma) s_t + g_t$$
$$g_{Ht}^* = \eta \gamma^* s_t + g_t^*$$
$$g_{Ft}^* = -\eta (1 - \gamma^*) s_t + g_t^*$$

Market clearing:

$$y_{Ht} = \frac{C_H}{Y_H} c_{Ht} + \frac{C_H^*}{Y_H} c_{Ht}^* + \frac{G_H}{Y_H} g_{Ht} + \frac{G_H^*}{Y_H} g_{Ht}^*$$
$$y_{Ft} = \frac{C_F}{Y_F} c_{Ft} + \frac{C_F^*}{Y_F} c_{Ft}^* + \frac{G_F}{Y_F} g_{Ft} + \frac{G_F^*}{Y_F} g_{Ft}^*$$

Domestic production:

$$y_{Ht} = u_{Ht} + n_t$$
$$w_t + \gamma s_t = -\frac{1}{\theta - 1}\varphi_t + y_{Ht} - n_t$$
$$\pi_{Ht} = \beta E_t \pi_{Ht+1} - \frac{Y_H}{\zeta}\varphi_t$$
$$-\frac{1}{\theta - 1}\varphi_t + y_{Ht} - u_{Ht} = x u_{Ht}$$

Foreign production:

$$y_{Ft} = u_{Ft} + n_t^*$$
$$w_t^* - (1 - \gamma^*) s_t = -\frac{1}{\theta - 1}\varphi_t^* + y_{Ft} - n_t^*$$
$$\pi_{Ft}^* = \beta E_t \pi_{Ft+1}^* - \frac{Y_F}{\zeta}\varphi_t^*$$
$$-\frac{1}{\theta - 1}\varphi_t^* + y_{Ft} - u_{Ft} = x u_{Ft}$$

Monetary and fiscal policy:

$$r_t = \xi \pi_{Ht}$$
$$r_t^* = \xi \pi_{Ft}^*$$
$$g_t = \rho g_{t-1} + \varepsilon_t$$
$$g_t^* = 0$$

A1.5 Derivations

With $\gamma = (1 - \gamma^*)$ and using the Euler equations and the definition of the producer price inflation rates we have

$$c_t = E_t c_{t+1} - r_t + E_t \pi_{Ht+1} + \gamma E_t \left(s_{t+1} - s_t\right)$$
$$c_t^* = E_t c_{t+1}^* - r_t^* + E_t \pi_{Ft+1}^* - \gamma E_t \left(s_{t+1} - s_t\right)$$

Denoting relative variables with R and world aggregate variables with W superscripts, as e.g. in $\pi_t^R = \pi_{Ht} - \pi_{Ft}^*$ and $\pi_t^W = \pi_{Ht} + \pi_{Ft}^*$, this can be written

$$c_t^R = E_t c_{t+1}^R - r_t^R + E_t \pi_{t+1}^R + 2\gamma E_t \left(s_{t+1} - s_t\right)$$
$$c_t^W = E_t c_{t+1}^W - r_t^W + E_t \pi_{t+1}^W$$

Using the Taylor rules $r_t^R = \xi \pi_t^R$ and $r_t^W = \xi \pi_t^W$ as well as the risk sharing condition $q_t + c_t^* = c_t$ and the definition of the terms of trade $(\gamma^* - \gamma)s_t = q_t$, this is equivalent to

$$s_t = E_t s_{t+1} - \xi \pi_t^R + E_t \pi_{t+1}^R \tag{A.2}$$
$$c_t^W = E_t c_{t+1}^W - \xi \pi_t^W + E_t \pi_{t+1}^W \tag{A.3}$$

Assuming balanced trade in the steady state ($Y_H = C + G$, $Y_F = C^* + G^*$), assuming the same steady state government share $\omega_g := G/Y_H = G^*/Y_F$ in both countries, and using $\gamma = 1 - \gamma^*$, the market clearing constraints with foreign government spending constant ($g_t^* = 0$) can be written as

$$
\begin{aligned}
y_{Ht} &= (1-\gamma)(1-\omega_g)c_t + \gamma(1-\omega_g)c_t^* + (1-\gamma)\omega_g g_t + 2\gamma(1-\gamma)\eta s_t \\
y_{Ft} &= \gamma(1-\omega_g)c_t + (1-\gamma)(1-\omega_g)c_t^* + \gamma\omega_g g_t - 2(1-\gamma)\gamma\eta s_t
\end{aligned}
$$

such that relative and world aggregate output are

$$
\begin{aligned}
y_t^R &= (1-2\gamma)(1-\omega_g)c_t^R + (1-2\gamma)\omega_g g_t + 4\gamma(1-\gamma)\eta s_t \\
y_t^W &= (1-\omega_g)c_t^W + \omega_g g_t
\end{aligned}
$$

Relative consumption follows from the definition of the terms of trade together with the CPI definition and the risk sharing condition as

$$
c_t^R = (1-2\gamma)s_t
$$

such that relative output can be written as

$$
\begin{aligned}
y_t^R &= \Xi s_t + (1-2\gamma)\omega_g g_t \\
y_t^W &= (1-\omega_g)c_t^W + \omega_g g_t
\end{aligned}
$$

with $\Xi = \left[(1-2\gamma)^2(1-\omega_g) + 4\gamma(1-\gamma)\eta\right] > 0$.

From the supply side, if the slopes of the Phillips curves are the same in both countries, which we achieve by normalizing steady state output levels to $Y_H = Y_F = 1$, we get

$$
\pi_t^R = \beta E_t \pi_{t+1}^R - \frac{1}{\zeta}\varphi_t^R \tag{A.4}
$$

$$
\pi_t^W = \beta E_t \pi_{t+1}^W - \frac{1}{\zeta}\varphi_t^W \tag{A.5}
$$

where the multipliers φ_t^R and φ_t^W need to solve the labor supply and demand, optimal utilization and production constraints, expressed in relative terms as

$$
\begin{aligned}
w_t^R &= \phi n_t^R + c_t^R \\
w_t^R + 2\gamma s_t &= -\frac{1}{\theta-1}\varphi_t^R + y_t^R - n_t^R \\
-\frac{1}{\theta-1}\varphi_t^R + y_t^R &= (x+1)u_t^R \\
y_t^R &= u_t^R + n_t^R
\end{aligned}
$$

and in world aggregate terms as

$$
\begin{aligned}
w_t^W &= \phi n_t^W + c_t^W \\
w_t^W &= -\frac{1}{\theta-1}\varphi_t^W + y_t^W - n_t^W \\
-\frac{1}{\theta-1}\varphi_t^W + y_t^W &= (x+1)\, u_t^W \\
y_t^W &= u_t^W + n_t^W
\end{aligned}
$$

Solving these for φ_t^R and φ_t^W and substituting them in the Phillips curves (A.4) and (A.5) yields, together with (A.2) and (A.3), the system in (19) to (22) discussed and solved in the main text.

A1.6 Summary of equilibrium conditions of the enlarged model in section 5

The following conditions determine the symmetric equilibrium time paths of the endogenous variables $\{C$, C^*, W, W^*, N, N^*, R, R^*, λ, λ^*, Q, S, P_H/P, P_F^*/P^*, P_H/P^G, P_F^*/P^{G*}, π, π_H, π_G, π^*, π_F^*, π_G^*, C_H, C_F, C_H^*, C_F^*, G_H, G_F, G_H^*, G_F^*, Y_H, Y_F, U_H, U_F, V, V^*, Φ, Φ^*, G, $G^*\}_t$ for the model in section 5.

Households:

$$
\begin{aligned}
\lambda_t &= \chi\left(\left(C_t - \psi C_{t-1}\right)^{\chi}\left(1-N_t\right)^{1-\chi}\right)^{-\sigma}\left(C_t - \psi C_{t-1}\right)^{\chi-1}\left(1-N_t\right)^{1-\chi} \\
W_t &= \frac{1-\chi}{\chi}\frac{\left(C_t - \psi C_{t-1}\right)}{1-N_t} \\
\lambda_t &= \beta E_t \lambda_{t+1}\frac{R_t}{\pi_{t+1}} \\
\lambda_t^* &= \chi\left(\left(C_t^* - \psi C_{t-1}^*\right)^{\chi}\left(1-N_t^*\right)^{1-\chi}\right)^{-\sigma}\left(C_t^* - \psi C_{t-1}^*\right)^{\chi-1}\left(1-N_t^*\right)^{1-\chi} \\
W_t^* &= \frac{1-\chi}{\chi}\frac{\left(C_t^* - \psi C_{t-1}\right)}{1-N_t^*} \\
\lambda_t^* &= \beta E_t \lambda_{t+1}^*\frac{R_t^*}{\pi_{t+1}^*} \\
\omega Q_t \lambda_t &= \lambda_t^*
\end{aligned}
$$

Relative prices:

$$
\begin{aligned}
S_t &= \frac{P_{Ft}}{P_{Ht}} = Q_t \frac{P_{Ft}^*}{P_t^*}\Big/\frac{P_{Ht}}{P_t} \\
\frac{P_{Ht}}{P_t} &= \left[(1-\gamma) + \gamma S_t^{1-\eta}\right]^{-\frac{1}{1-\eta}} \\
\frac{P_{Ft}^*}{P_t^*} &= \left[(1-\gamma^*) S_t^{-(1-\eta)} + \gamma^*\right]^{-\frac{1}{1-\eta}} \\
\frac{P_{Ht}}{P_t^G} &= \left[(1-\gamma^G) + \gamma^G {S_t}^{1-\eta}\right]^{-\frac{1}{1-\eta}} \\
\frac{P_{Ft}^*}{P_t^{G*}} &= \left[(1-\gamma^{G*}) {S_t}^{-(1-\eta)} + \gamma^{G*}\right]^{-\frac{1}{1-\eta}}
\end{aligned}
$$

$$\pi_{Ht}/\pi_t = \frac{\left[(1-\gamma)+\gamma S_t^{1-\eta}\right]^{-\frac{1}{1-\eta}}}{\left[(1-\gamma)+\gamma S_{t-1}^{1-\eta}\right]^{-\frac{1}{1-\eta}}}$$

$$\pi^*_{Ft}/\pi^*_t = \frac{\left[(1-\gamma^*)S_t^{-(1-\eta)}+\gamma^*\right]^{-\frac{1}{1-\eta}}}{\left[(1-\gamma^*)S_{t-1}^{-(1-\eta)}+\gamma^*\right]^{-\frac{1}{1-\eta}}}$$

$$\pi_{Ht}/\pi_{Gt} = \frac{\left[(1-\gamma^G)+\gamma^G S_t^{1-\eta}\right]^{-\frac{1}{1-\eta}}}{\left[(1-\gamma^G)+\gamma^G S_{t-1}^{1-\eta}\right]^{-\frac{1}{1-\eta}}}$$

$$\pi^*_{Ft}/\pi^*_{Gt} = \frac{\left[(1-\gamma^{G*})S_t^{-(1-\eta)}+\gamma^{G*}\right]^{-\frac{1}{1-\eta}}}{\left[(1-\gamma^{G*})S_{t-1}^{-(1-\eta)}+\gamma^{G*}\right]^{-\frac{1}{1-\eta}}}$$

Consumption and government demand:

$$C_{Ht} = (1-\gamma)\left(\frac{P_{Ht}}{P_t}\right)^{-\eta} C_t$$

$$C_{Ft} = \gamma\left(S_t\frac{P_{Ht}}{P_t}\right)^{-\eta} C_t$$

$$C^*_{Ht} = (1-\gamma^*)\left(S_t^{-1}\frac{P^*_{Ft}}{P^*_t}\right)^{-\eta} C^*_t$$

$$C^*_{Ft} = \gamma^*\left(\frac{P^*_{Ft}}{P^*_t}\right)^{-\eta} C^*_t$$

$$G_{Ht} = (1-\gamma^G)\left(\frac{P_{Ht}}{P_t^G}\right)^{-\eta} G_t$$

$$G_{Ft} = \gamma^G\left(S_t\frac{P_{Ht}}{P_t^G}\right)^{-\eta} G_t$$

$$G^*_{Ht} = (1-\gamma^{G*})\left(S_t^{-1}\frac{P^*_{Ft}}{P_t^{G*}}\right)^{-\eta} G^*_t$$

$$G^*_{Ft} = \gamma^{G*}\left(\frac{P^*_{Ft}}{P_t^{G*}}\right)^{-\eta} G^*_t$$

Aggregate demand / market clearing:

$$Y_{Ht} = C_{Ht} + C^*_{Ht} + G_{Ht} + G^*_{Ht} + V^*_t$$

$$Y_{Ft} = C_{Ft} + C^*_{Ft} + G_{Ft} + G^*_{Ft} + V_t$$

Domestic production:

$$
\begin{aligned}
Y_{Ht} &= Z_H U_{Ht} N_t^{\vartheta} V_t^{1-\vartheta} \\
W_t P_t / P_{Ht} &= (1-\Phi_t)\, \vartheta Y_{Ht}/N_t \\
S_t &= (1-\Phi_t)\,(1-\vartheta) Y_{Ht}/V_t \\
Y_{Ht}\,(1-\Phi_t\theta) &= \zeta\,(\pi_{Ht}-1)\,\pi_{Ht} - \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \zeta\,(\pi_{Ht+1}-1)\,\pi_{Ht+1} \\
(1-\Phi_t)\, Y_{Ht}/U_{Ht} &= h'(U_{Ht})
\end{aligned}
$$

Foreign production:

$$
\begin{aligned}
Y_{Ft} &= Z_F U_{Ft} N_t^{*\vartheta} V_t^{*1-\vartheta} \\
W_t^* P_t^* / P_{Ft}^* &= (1-\Phi_t^*)\, \vartheta Y_{Ft}/N_t^* \\
S_t^{-1} &= (1-\Phi_t^*)\,(1-\vartheta) Y_{Ft}/V_t^* \\
Y_{Ft}\,(1-\Phi_t^*\theta) &= \zeta\,(\pi_{Ft}^*-1)\,\pi_{Ft}^* - \beta E_t \frac{\lambda_{t+1}^*}{\lambda_t^*} \zeta\,(\pi_{Ft+1}^*-1)\,\pi_{Ft+1}^* \\
(1-\Phi_t^*)\, Y_{Ft}/U_{Ft} &= h'(U_{Ft})
\end{aligned}
$$

Monetary and fiscal policy:

$$
\begin{aligned}
R_t &= \frac{1}{\beta} \pi_{Ht}^{\xi} \\
R_t^* &= \frac{1}{\beta} \pi_{Ft}^{*\xi}
\end{aligned}
$$

$$
\begin{aligned}
G_t &= (1-\rho) G + \rho G_{t-1} + \varepsilon_t \\
G_t^* &= G^*
\end{aligned}
$$