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Abstract

The domestic and international transmission mechanism of fiscal policy shocks are analysed in large developed economies. Using a Bayesian VAR approach, we find that fiscal expansions are associated with increases in output, private consumption and, in many cases, with an increase in private investment. The terms of trade, which affect the international transmission of fiscal policy shocks, are found to depreciate in response to a fiscal expansion, thus transferring some of the increased domestic purchasing power abroad. A US government spending shock is expansionary for all non-US G7 members. A German government spending shock is expansionary for most, but not all European economies, both within and outside the Euro Area. The dynamics of the BVAR are rationalised using a dynamics stochastic general equilibrium model where heterogeneous households and firms face borrowing constraints.

JEL classifications: E62, F41, F42
Keywords: Fiscal policy, Bayesian VAR, DSGE modelling, International business cycles, spillovers.

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1 Introduction

Is government spending an effective macroeconomic stabilisation tool? While Great Recession reignited the debate on this issue and stimulated a large amount of research, the current pandemic has led to unprecedented fiscal measures, amounting to almost 12 percent of global GDP (IMF, 2020). Any scepticism surrounding the effectiveness of fiscal policy has been swept aside given the severity of the economic consequences caused by Covid-19. However, understanding the role that government spending has in affecting macroeconomic outcomes remains an important question on which there is as yet no clear answer. In light of this, we examine the transmission mechanism of fiscal policy surprises in the G7 group of economies.[1] Does a fiscal expansion really crowd out private investment? Does a domestic fiscal expansion lead to a loss of international competitiveness via a real appreciation? The focus of this paper is not just on the within-country transmission, but also on the cross-country transmission or international spillovers of fiscal policy shocks.

There are two key contributions of this paper. First, we analyse the macroeconomic impacts of government spending shocks and spillover effects on individual G7 economies on a wide range of variables. The majority of the empirical studies in this area overwhelmingly consider the US or adopt a panel approach, considering only a small selected set of variables. As a result, it is not clear how general the conclusions in the literature are. Second, our model provides a potential mechanism for understanding the manner in which spending shocks transmit through the economy.[2] The model suggests that the presence of liquidity-constrained households and nominal rigidities – in both prices and wages – are important in order to generate plausible responses to government spending shocks. While Corsetti and Müller (2013) argue that only when one allows for government spending reversals in a New Keynesian model can the theory align with the data, our model provides an alternative mechanism that is also consistent with the empirical evidence.

Using quarterly data, we analyse the effects of debt-financed fiscal expansions using a Bayesian Vector Autoregression (BVAR) to identify government spending shocks. We estimate the model for each of the G7 economies and also analyse the spillover effects of large open economies, such as the United States on the rest of G7 economies and Germany on other European economies.

[1] The G7 comprise the United States, Germany, France, Italy, UK, Canada and Japan

[2] We only consider the positive implications of government spending. Bilbiie et al. (2019) provide a clear normative analysis in a calibrated model that is highly relevant to the current environment.

Within the G7, we find that in almost all countries a government spending shock is expansionary in terms of GDP, crowds in consumption, worsens the trade balance and depreciates the terms of trade. Except in Italy and Canada, an unexpected increase in government spending also raises private sector investment. We also analyse international fiscal policy spillovers originating in the United States and in Germany. An unexpected increase in US government consumption causes the US terms of trade and effective real exchange rate to depreciate. It is also associated with an increase in domestic GDP in the other G7 economies and with a bilateral real appreciation vis-a-vis the US dollar everywhere except Japan. Government spending shocks originating in Germany affect the bilateral real exchange rate and real GDP of other European economies in a more heterogeneous fashion than is the case for US shocks on the G7. In terms of the real exchange rate, non-Euro Area countries experience a far greater volatility in response to a German fiscal policy shock than do Euro Area (EA) members. The largest positive effects on GDP are also found within the EA.

To make sense of the BVAR results, we put forward an open economy dynamic stochastic general equilibrium (DSGE) model that is able to match the salient features of the data. Specifically, we analyse a two-country DSGE model with nominal rigidities in the goods and labour markets, where households are divided into those with and without access to financial markets and where entrepreneurs face a constraint on their borrowing. Such a model, by construction, is able to generate a positive response of both consumption and investment to a government spending shock. We estimate a number of key parameters of our model using a strategy that minimises the distance between the impulse responses of the model and those of the BVAR.

2 Literature review

Much of the work on the impact of government spending shocks is linked to discussions on the feasibility of fiscal policy as a stabilisation tool and on quantifying spending multipliers.[3] Consequently, many of the papers in this area have focused on output as the key variable of interest. A general finding is that GDP rises following a government spending shock, with the largest effect sometimes being on impact (e.g. Goujard, 2017; Ravn et al., 2012).[4] Interestingly, Corsetti et al. (2012) find

[3] In this paper we focus on shocks to government spending only and not to other components of fiscal policy.

[4] Kim and Roubini (2008) find the spending effects to be contractionary but, as Monacelli and Perotti (2010) point out, their results stem from ordering output before the government deficit in estimating the VAR and the

that the initial output expansion eventually turns to contraction as government spending acts to stabilise the level of debt. Although expansionary, most of the literature finds that the peak effect on output occurs after a substantial lag.[5] In the case of Germany and Italy, Alloza et al. (2019) find that the peak (multiplier) occurs in the third year following the impulse, whereas in Spain over the same period the multiplier changes sign to equal -1.5. Similar results are obtained by Corsetti et al. (2012) and Corsetti and Müller (2013).support these long lags, which are then followed by modest output contractions. A more critical view is that of Mountford and Uhlig (2009), who use a structural VAR with sign restrictions estimated on US data over the period $1955Q1 - 2000Q4$. Their estimated impact multiplier from deficit spending is 0.65, turning to over -2 after twenty quarters.

Relatively fewer studies have considered the effect of fiscal policy shocks on the components of output but several important findings have emerged. Firstly, government spending shocks have a positive effect on consumption. This result is largely robust with the only discrepancy regarding dynamics, where the largest estimated impact is immediate (e.g. Goujard, 2017; Ravn et al., 2012) or with a lag, as in Galí et al. (2007), Monacelli and Perotti (2010) and Fatás and Mihov (2001). Research that considers investment is rarer and inconclusive. For example, Beetsma and Giuliodori (2011) and Fatás and Mihov (2001) report that investment increases following a spending shock, peaking after one year, while spending is found to crowd out investment in Corsetti et al. (2012) and Blanchard and Perotti (2002).

What about interest rates? On this, the estimates in Corsetti et al. (2012) and Corsetti and Müller (2013) indicate that long-term real rates rise (insignificantly) following the fiscal stimulus. Crucially, interest rates remain below their pre-shock levels after several quarters. Both Corsetti et al. (2012) and Corsetti and Müller (2013) rely on this result as key to their financial transmission mechanism of government spending shocks. Faccini et al. (2016) (for the US) also obtain a decline in interest rates, but this effect is not significant. The evidence on real short-term interest rates is inconclusive; in Fatás and Mihov (2001) they rise contemporaneously with the shock before reverting to their steady state whereas in Faccini et al. (2016) the reverse occurs, albeit insignificantly. As

consequences this has for identifying the fiscal policy shock.

[5]See Beetsma and Giuliodori (2011), Galí et al. (2007), Monacelli and Perotti (2010) (US, same Aus, UK), Fatás and Mihov (2001), Blanchard and Perotti (2002), Corsetti and Müller (2013)(US), Alloza et al. (2019)a,c, and Faccini et al. (2016))

for nominal rates, the results in Beetsma and Giuliodori (2011) – using an annual panel consisting of fourteen EU countries – indicate that they rise, reaching a peak five years after the shock.

Turning to open economy variables, evidence on the 'twin deficits' hypothesis is mixed. In the case of Corsetti et al. (2012), Corsetti and Müller (2006, 2013) and Kim and Roubini (2008) the correlation between the government budget and the trade balance, conditional on government purchases, is either insignificant or positive. But the reverse is found by Beetsma and Giuliodori (2011), Monacelli and Perotti (2010), Blanchard and Perotti (2002), and insignificantly by Faccini et al. (2016). Corsetti et al. (2012) and Corsetti and Müller (2013) interpret their findings as supportive of a financial, rather than a trade, channel for international spillovers of fiscal policy.

Despite the wide range of results concerning the trade balance, the government spending effects on the real exchange rate are generally found to be positive (a depreciation). In the case of Monacelli and Perotti (2010) for the UK and Faccini et al. (2016) for the US, the impact is immediate. Most findings suggest that the response is subject to substantial lags. This is the case in Ravn et al. (2012), who estimated a panel structural VAR with four countries as well as Corsetti and Müller (2013) for US spending vis-a-vis the EA and the UK. Monacelli and Perotti (2010) also report a delayed depreciation for the US, Australia and Canada. More relevant for this paper, Beetsma and Giuliodori (2011) find that the real exchange rate appreciates following a fiscal impulse, peaking in the third year.

2.1 International spillovers

Although partly alluded to the above discussion on the trade balance and the real exchange rate, one of the most important issues concerning stabilisation policy through government spending concerns international spillovers, as it will have implications for policy coordination. International spillovers from domestic spending impulses on foreign output are generally found to be positive and very persistent, often peaking after approximately two years. Corsetti and Müller (2013) and Faccini et al. (2016) both estimate international spillovers from US spending shocks. The former estimate them on the euro area (EA) and the UK, while the latter consider a range of countries and four regimes. In both cases, the spillovers are not always significant but it is worth noting that in Faccini et al. (2016) spillovers are largest in Canada and the UK. Blagrave et al. (2018) and

Auerbach and Gorodnichenko (2013b) also estimate state-dependent spillovers.[6] The former find that spillovers are significant only when recipient economies are at their effective lower bound and in the latter foreign output effects are largest during recessions.[7]

When restricting the sample to EU countries, fiscal spillovers can be large. For example, Beetsma and Giuliodori (2011) consider the effects of a spending shock of one percent of GDP emanating from one of the five largest EU economies on the remaining countries in their sample, finding a peak effect of 0.35% after two years. Beetsma et al. (2006) combine a structural VAR model to identify the spending shocks with a trade model to determine the size of fiscal spillovers. Their estimates indicate that a 1% of GDP government spending impulse in Germany raises output in Austria and Belgium-Luxembourg by over 0.4% after two years; for the other EU countries in the sample the magnitudes are somewhat smaller and as low as 0.1% in Italy. Moreover, the spillovers remain substantial for most of the countries they consider even after five years. Similarly, the estimated two-year multipliers of German government spending on French GDP in Alloza et al. (2019) 0.4, but insignificant on Italian output, which then turns strongly negative (almost -0.15) after three years. The lack of a positive spillover effect in Italy is attributed to the trade channel: it is the only country in their sample that does not exhibit a significant increase in exports following a fiscal expansion in the other member countries. Consistent with the above, Dabla-Norris et al. (2017) use sign restrictions to estimate spillovers across ten EA economies and these are all positive at the one-year horizon.[8] Some of these are large, such as Germany to the Netherlands (0.17) and France to Ireland (0.5); the size of the spillovers is attributed to the size and level of integration of the source economies.

[6] As argued by Mountford and Uhlig (2009), Uhlig (2010) as well as Ramey and Zubairy (2018), the approach adopted by Blanchard and Perotti (2002) and used by Auerbach and Gorodnichenko (2013b) in calculating multipliers in a dynamic setting is incorrect, given that they calculate it as the ratio of the peak output response to the initial government spending shock. This procedure does not take into account the persistence in government spending.

[7] The results in Blagrave et al. (2018) are based on fifty five recipient countries, with the spending shock originating in France, Germany, Japan, the UK and the US.

[8] Their multipliers and spillovers are calculated as the cumulative percentage change in output divided by its government spending counterpart. However, it should be noted that they include government investment within their spending measure.

2.2 The theoretical impact of government spending shocks

A standard neoclassical or New Keynesian model cannot produce the positive response of consumption to government spending shocks found in the time series evidence cited above. As a result, the multiplier in such models is inevitably less than one. Monacelli and Perotti (2010) use a New Keynesian small open economy model with complete markets to focus on the joint response of the trade balance, consumption and the real exchange rate to government spending shocks. The model produces several puzzles at odds with the empirical evidence, among which are that private consumption falls and that the real exchange rate appreciates. Recent extensions to the standard models have been successful in overcoming some of these limitations. Galí et al. (2007) use a conventional New Keynesian model which is modified by allowing a proportion of households to be non-Ricardian. This element, in combination with sticky prices, is sufficient to generate a positive response of consumption to spending shocks.[9] For their baseline calibration this produces a consumption multiplier of one and an output multiplier close to two; hours and real wages rise and investment falls. By contrast, Corsetti et al. (2012) extend a New Keynesian model by introducing a debt-stabilising response of government spending. The fiscal shock, given that it will be reversed in the future, results in a decrease in long-term real interest rates, explaining the increase in consumption and the real exchange rate depreciation. Although short-run investment dynamics are similar to those in Galí et al. (2007) in that it contracts following the shock, the model then predicts an expansion following a substantial lag, while the reverse holds for the trade surplus.

Using a similar approach, Corsetti et al. (2010) develop a two-country model with frictions in prices, wage-setting and in the ability of some households to access financial markets. Many of the effects arising from the government spending impulse are similar to those obtained above given that they also consider spending reversals. A major addition is their inclusion of foreign variables to enable an analysis of fiscal spillovers. The spending shock leads to an increase in foreign output as all its components – bar government spending – increase. As in Corsetti et al. (2012), the mechanism by which this occurs is through a decrease in real long-term interest rates, rather than through the trade channel. A related model is that of Corsetti and Müller (2013), based on Chari et al. (2002) and consists of two goods and two countries with sticky prices and wages

[9] Labour market structure also matters. Galí et al. (2007) consider both a competitive and an imperfectly competitive labour market. The required proportion of non-Ricardian households is much more plausible in the latter.

but unlike Corsetti et al. (2012) there is no investment or capital accumulation. The presence of spending reversals leads to a decrease in the real long-term interest rate, with the result that the real exchange rate depreciates, consumption and output rise, while the trade balance falls.

The models discussed above are all parameterised. Ravn et al. (2012) develop a two-country model with deep habits where several key model parameters are estimated via impulse response-matching to a pooled structural VAR (SVAR) using data on Australia, Canada, the UK and the US. The model can match the impulse responses for is consumption, output and the trade balance but it cannot fully replicate the dynamics of the real exchange rate. In a similar vein, Cwik and Wieland (2011) use five different estimated models – including Smets and Wouters (2003) – to determine whether the multiplier is likely to be greater than one on the euro area and to quantify the potential size of fiscal spillovers. The models they consider all incorporate Keynesian features and forward-looking expectations to varying degrees. Their findings indicate that the multiplier is likely to be less than one and that spillovers, rather than being large may even be negative due to the fiscal expansion in one country resulting in the euro appreciating. A similar point is made by Wieland (2010) in assessing Corsetti et al. (2010), who points out that any expansionary effects from fiscal policy arise not from the increase in government spending but from the promise of future spending cuts; thus the normative policy advice during recessions of announcing spending consolidations in the future and not altering policy in the present. While this may be one implication from the results in Corsetti et al. (2012), as Gürkaynak (2011) notes the conclusions in Cwik and Wieland (2011) arise because they rely on models with strong Ricardian features where small multipliers are inevitable.

Lastly, Blagrave et al. (2018) use the calibrated New Keynesian model in Blanchard et al. (2017), but with flexible exchange rates. While output spillovers are positive, they are much larger when the effective lower bound (ELB) is binding in the recipient country.

3 Identifying fiscal policy shocks in the data

There is an ongoing debate in the literature on how fiscal policy shocks should be identified (see Ramey, 2011a, 2016, for a review of the literature). Extant literature on the effects of government spending is mostly based on a structural VAR model with a small set of three to six core variables, while the propagation of the shock to other variables of interest is studied using a marginal approach by adding one variable at a time to the small VAR model (see Blanchard and Perotti, 2002; Corsetti et al., 2012). There are three common strategies of identifying fiscal policy shocks in structural VARs in the literature: the recursive or Blanchard-Perroti approach which involves imposing zero restrictions on the contemporaneous matrix, the sign restriction approach (e.g. Mountford and Uhlig, 2009), and the instrument or proxy VAR approach (e.g. Ramey, 2011b; Romer and Romer, 2010; Fisher and Peters, 2010)

The use of small fiscal SVARs in the literature is beset with two major problems: first, the identified government spending shock potentially suffers from the problem of non-fundamentalness or non-invertibility. This is caused by anticipation effects of changes in fiscal policy as a result of decision and implementation lags, a phenomenon known as fiscal foresight that has been examined in the literature in relation to tax shocks (e.g. Leeper et al., 2013; Yang, 2007) and government spending shocks (e.g. Ramey, 2011b; Forni and Gambetti, 2016). The second problem is related to the potential for omitted variable bias in the small VAR specifications, with adverse consequences for the structural analysis. This is known as the information insufficiency issue and estimated VAR models with this problem produce inconsistent results. As a consequence, econometricians cannot fully recover the true structural shocks from the data.

To resolve these problems – non-fundamentalness and information insufficiency – the recent empirical studies on fiscal policy employ Bayesian VAR model with informative priors that utilise a large information set while relying on standard identification strategy (see Ellahie and Ricco, 2017; Forni and Gambetti, 2016).[10] This model has also been used to analyse monetary policy shocks in the literature (see Giannone et al., 2015; Bańbura et al., 2010).

In this paper, we estimate a fiscal VAR model using full Bayesian technique with Gibbs sampling to examine the domestic effects of government spending shocks in the G7 economies and the cross-border effects of changes in US government spending on the rest of G7 economies as well as German government spending on other European economies. In setting the prior distribution, we follow the standard practice by using the Minnesota prior. As Bańbura et al. (2010) note, the underlying

[10] An alternative approach involves using factor models or factor-augmented VAR (FAVAR) models of Stock and Watson (2005) and Bernanke et al. (2005), where a large dataset is used to construct several common factors, which are then used to augment the standard fiscal VAR to provide more information (see, for instance, Laumer, 2020; Fragetta and Gasteiger, 2014; Forni and Gambetti, 2010, 2014).

principle behind this prior specification is that more recent lags in the VAR system provide more information than the older ones and that own lags should have high explanatory power than lags of other variables. Thus, this prior simply shrinks the diagonal elements of the lag matrix in the VAR system towards one and the remaining elements towards zero. Since we intend to analyse the propagation of government spending shocks on a reasonably large number of domestic and foreign variables, this approach is suitable to address the curse of dimensionality problem relating to estimating large numbers of parameters in VAR models.

3.1 Bayesian VAR Specification and Identification

Let $X_t = (x_{1,t}\ x_{2,t}\ ...\ x_{n,t})'$ be a vector of random variables. A VAR(p) model can be specified as:

$$\begin{aligned}
X_t &= c + A_1 X_{t-1} + ... + A_p X_{t-p} + u_t \qquad (1)\\
E(u_t' u_s) &= \Sigma \ \text{ if } t = s\\
E(u_t' u_s) &= 0 \ \text{ if } t \neq s\\
E(u_t') &= 0
\end{aligned}$$

where $c = (c_1, ..., c_n)'$ is an n-dimensional vector of constants, $A_1, ..., A_n$ are $n \times n$ lag matrices, while u_t is an n-dimensional vector of normally distributed white noise terms.

For our analysis of the domestic effects of fiscal policy in the G7 economies, we set up a VAR model that contains nine country-specific variables in the following order: government consumption spending, g_t;[11] OECD government spending growth forecast, Δg_t^{fc}; output, y_t; the 10-year bond rate, r_t; the terms of trade, tot_t; the real effective exchange rate, $reer_t$; the trade balance-to-GDP ratio, tby_t; private consumption, c_t, and investment, i_t. Government spending, output, consumption and investment variables are all defined in real terms using the GDP-price deflator. Following Ramey (2016), we transform the GDP component series using the Gordon and Krenn (2010) procedure by dividing them with trend GDP.[12] This transformation is useful for two reasons:

[11] We also considered total government consumption and investment spending, but the data series for public investment is only available for five of the G7 economies. The results of the VAR model with this series are not substantially different from those of government consumption spending alone, since government consumption accounts for more than 70% of total government spending in G7 economies.

[12] The Gordon-Krenn transformation procedure involves estimating a polynomial GDP trend and dividing the GDP

first, it produces similar impulse responses as log-level transformation, but with relatively narrower confidence intervals. Second, the Gordon-Krenn transformation circumvents the ad-hoc approaches to computing fiscal multipliers, as the multiplier can be computed directly from the estimated impulse responses of trend-adjusted GDP and government spending.

Both the terms of trade and the real effective exchange rate are defined in log levels such that an increase implies a depreciation. All the variables are multiplied by 100 so that the impulse responses can be interpreted as percent change or percentage-point changes for interest rate. Further information about the variables are presented in Table 1. The country-specific vector of endogenous variables is given by:

$$x_t = [g_t \;\; \Delta g_t^{fc} \;\; y_t \;\; r_t \;\; tot_t \;\; reer_t \;\; tby_t \;\; c_t \;\; i_t]'.$$

In line with the existing literature, we order the government spending variable first and identify the government spending shock using Cholesky decomposition. However, we deviate from most previous work in this area (e.g. Ilzetzki et al., 2013) by explicitly controlling for anticipation effects of changes in fiscal policy in order to uniquely identify the unanticipated shock to government spending. Specifically, we include in our model government spending growth forecast, as in Born et al. (2013), and long-term interest rate to control for fiscal foresight as previous studies (e.g. Forni and Gambetti, 2010, 2016; Yang, 2007) have shown that market-based forward-looking variables, such as interest rates, stock prices and exchange rates, helps to alleviate the foresight problem in the fiscal VAR model. Ellahie and Ricco (2017) have also shown that using a Bayesian VAR with large information set is able to overcome the non-fundamentalness issues associated with anticipation effects.

Given the cross-country nature of this analysis, we rely on macroeconomic series from the OECD Statistical and Projection database at quarterly frequency for the period 1995Q1–2019Q4.[13] The choice of this data period is motivated by the longest sample period available for each of the G7 countries in our sample in order to ensure comparability of results across countries. While some of the G7 countries have longer time series, data for Japan, Italy and some European countries in our

component series with this trend GDP. However, due to the end-point problem with the estimation of GDP trend both in polynomial estimation and in Hodrick-Prescott filter, we instead rely on the recently proposed Hamilton (2018)'s procedure to extract the GDP trend.

[13] The government spending growth forecast from the Projection database, which is originally reported semi-annually, is interpolated to a quarterly series using a mid-point averaging method.

Table 1: Data definitions and sources

Variables in VAR	Defintion	Detrended by	Construction	Countries*
g_t	real government consumption	Hamilton trend of GDP (Y_{ht}^T)	$100 \times (\ln G_t - \ln Y_{ht}^T)$	G7
Δg_t^{fc}	government spending growth forecast		see text	G7
y_t	real GDP	Hamilton trend of GDP (Y_{ht}^T)	$100 \times (\ln Y_t - \ln Y_{ht}^T)$	G7 + E15
r_t	10-year bond rate		$100 \times \ln(1 + R_t/100)$	G7
tot_t	terms of trade		$100 \times \ln(P^{imports}/P^{exports})$	G7
$reer_t$	real effective exchange rate		$100 \times \ln(1/REER)$	G7
tby_t	trade balance/GDP		$100 \times (tbal/GDP)$	G7
c_t	real private consumption	Hamilton trend of GDP (Y_{ht}^T)	$100 \times (\ln C_t - \ln Y_{ht}^T)$	G7
i_t	real investment	Hamilton trend of GDP (Y_{ht}^T)	$100 \times (\ln I_t - \ln Y_{ht}^T)$	G7
y_t^*	foreign real GDP	Hamilton trend of GDP* (Y_{ht}^{T*})	$100 \times (\ln Y_t^* - \ln Y_{ht}^{T*})$	G6 + E14
rer_t	bilateral real exchange rate		$100 \times \ln(S \times P^*/P)$	G6 + E14

All data are from the OEDC database and span the period 1997Q4–2019Q4 . * G7 = USA, Japan, Germany, France, UK, Italy and Canada. G6 = G7 - USA, E15 = Germany, France, UK, Italy, Spain, Netherlands, Belgium, Austria, Ireland, Finland, Portugal, Greece, Switzerland, Sweden, Norway, Denmark. E14 = E15 - Germany.

spillover analysis are only available from mid-1990s.

The use of OECD data for our analysis is beneficial in a number of ways. First, the OECD data and projections are prepared using a unified methodology for all the countries, thereby eliminating any bias or complications that may arise in the way different countries compile and report their data. Second, the OECD prepares semi-annual forecasts for several macroeconomic variables (the so-called OECD Economic Outlook) such as output, inflation, government spending and fiscal balance. These forecasts are consistently available for all G7 countries since the mid-1980s and incorporate a good amount of information on domestic and global developments for each country. The forecasts are very popular in both academic and policy circles; perform comparably well with other forecasts from country-specific sources, such as the Survey of Professional Forecasters in the US and the Office for Budgetary Responsibility in the UK; and they have been used in other academic research (e.g. Auerbach and Gorodnichenko, 2013a; Born et al., 2013). Third, the OECD database is publicly available, which make any quest to replicate an analysis based on such database very easy.

3.2 Domestic effects of fiscal policy shocks

Figures 1 to 7 show impulse responses to a one percent shock to domestic government consumption for each of the G7 economies.

Although there is some qualitative heterogeneity in the responses across countries, a broad and consistent picture emerges. An unanticipated increase in government consumption raises output in each of the G7 economies. Many of the responses of the remaining variables in our VAR run counter to the intuition arising from standard flexible price macroeconomic models.

Private consumption, far from being crowded out by an increase in government spending, rises everywhere, except in Italy.[14] Private investment, which one would expect to be crowded out by higher government spending, responds positively to an increase in government consumption everywhere, except in Canada, where it falls, and Italy where the response is not significant. It is noteworthy that although the crowding in of consumption is a common finding, the effects on investment are less commonly studied. Our results are consistent with those in Beetsma and Giuliodori (2011), despite the fact that they used annual data for 14 EU countries and covered a different time period ($1970-2004$). We also find that the trade balance relative to GDP worsens in every country bar Italy. Most of the literature cited above also found this deterioration in the trade balance, such as Beetsma and Giuliodori (2011) and Monacelli and Perotti (2010), and in contrast to Corsetti et al. (2012)

The effective real exchange rate also behaves in a counter-intuitive fashion. In a standard flexible price open economy model, one would expect the real exchange rate to appreciate following a positive demand shock. In our VAR, the effective real exchange rate depreciates in all countries, except in the UK and in Italy. Most related studies found similar results (e.g. Ravn et al., 2012; Corsetti and Müller, 2013), although exceptions include Beetsma and Giuliodori (2011) and Beetsma et al. (2006). We also include the terms of trade, defined as the price of imports relative

[14] We find that the responses of Italy are often different from most other G7 countries. This feature is not new as Alloza et al. (2019) report that the domestic multiplier is negative, albeit insignificant, on impact unlike the other countries they consider.

to exports, in the VAR. Apart from in Italy and the UK, where the response of the terms of trade is not statistically significant, the terms of trade are positively correlated with the effective real exchange rate. This suggests that the dynamics of the real exchange rate are not primarily driven by the dynamics of the relative price of non-traded goods.

Thus for the five biggest G7 economies, a government spending shock is expansionary for the components of GDP, worsens the trade balance and depreciates the real exchange rate. For the three smallest economies in our sample, the UK, Italy and Canada, the multiplier on GDP is around 0.2, whereas for the four biggest economies, the multiplier is around 0.8. In the UK and Italy, we observe an appreciation of the real exchange rate which could offset some of the expansionary impetus coming from the fiscal expansion, whereas in Canada, the modest effect on output could be related to the fall in investment associated with an increase in government spending.

To help identify the the government spending shock, we include the 10-year government bond rate in the VAR. In the United States, a fiscal expansion is associated with an increase in government bond yields. In Germany, France and the United Kingdom we also observe rises in the costs of government borrowing, albeit the rise is not statistically significant and this is very similar to the results in Beetsma and Giuliodori (2011). In Japan, Italy and Canada bond rates fall.

Finally, we include a measure of expected government spending in the VAR. Except in the Japanese data, an increase in government spending leads to expectations of lower future government spending. This is consistent with the findings for the US in Corsetti et al. (2012), who used this result to explain the crowding-in of private consumption following a government spending shock.

3.3 International spillovers

How do government spending shocks in the United States and in Germany, the largest economy in the world and the biggest in Europe respectively, affect output and relative prices abroad? To answer this question, we augment the VAR for the US and Germany with foreign output, y_t^*, and replace the effective real exchange rate of the US and Germany with bilateral real exchange rates of the partner country, rer_t. Foreign output has been transformed with the foreign GDP trend using the same procedure discussed above, while the bilateral real exchange rate is defined in log levels such that an increase implies a real currency depreciation for the foreign economy. The vector of endogenous variables in the bilateral VAR model is given by:

$$x_t = [g_t \;\; \Delta g_t^{fc} \;\; y_t \;\; r_t \;\; tot_t \;\; rer_t \;\; tby_t \;\; c_t \;\; i_t \;\; y_t^*]'.$$

International transmission of government spending shocks can be viewed as operating through two distinct channels: the trade channel via greater US demand for foreign goods and the wealth channel, operating via the real exchange rate. Faccini et al. (2016) and Corsetti and Müller (2013) argue in favour of a 'financial channel' where the fiscal stimulus is accompanied by future spending reversals, which have the effect of lower long-term interest rates and thereby producing positive spillovers. This mechanism is put forward as an alternative to the trade channel given that they find an insignificant effect on the US trade balance (vis-a-vis the EA and the UK) following the government spending shock. Our results are not supportive of such a channel as we find an increase in long-term interest rates in both the US and Germany following the increase in spending at the same time that the trade balance deteriorates. Therefore, our results and potential mechanisms, are closer to those in Beetsma and Giuliodori (2011) and Monacelli and Perotti (2010).

As shown in Figure (8), a positive US government spending shock has a significant positive effect on GDP of the remaining six G7 economies. This is consistent with Corsetti and Müller (2013) for the EA, among others. In all cases, output rises on impact and remains positive for at least as long as US output remains above trend.

Given that the US effective real exchange rate depreciates following a government spending shock, it is not surprising that, except in Japan, the bilateral real exchange rates of the other G7 economies, relative to the US dollar, appreciate on impact. The initial US depreciation shifts some of the purchasing power of US consumers onto foreign consumers. After about five quarters, this second transmission channel is reversed and the US's trading partners experience a real depreciation.

To analyse the transmission mechanism of a government spending shock originating in Germany, we look at responses of output and the bilateral real exchange rate of the 10 biggest EA economies and 5 non-Euro Area economies. Figures 9 to 10 show that within the EA, a German government spending shock has a significantly positive effect on GDP for seven out of the ten countries in our sample. Only in Greece, Portugal and Ireland do we observe either a fall in output or an effect that is not significantly different from zero. Using annual data, Dabla-Norris et al. (2017) find a large output impacts of German spending shocks after one year in Finland and the Netherlands (of almost 0.2), although in contrast to our results, they obtain the largest spillover multiplier in Ireland. For the remaining big-three EA economies (France, Italy and Spain) output rises on impact, after which Italy and Spain experiencing output contractions prior to returning to the steady state. Alloza et al. (2019) also considered fiscal spillovers but only within the four biggest EA members, finding that the peak impacts all occur after a lag and in the case of Italy, the output effect is largely contractionary. The estimated spillovers in Beetsma et al. (2006) from a German spending shock within the EU again indicate a substantial degree of heterogeneity, with some of the smallest impacts in Greece and Italy, with the largest taking place in the Netherlands.

The output responses on non-EA countries to a government spending shock are generally smaller or insignificant than for the average EA member and this is largely consistent with the effects reported in Beetsma et al. (2006). Within the single currency, real exchange rate changes, even in the short run, only reflect changes in relative prices and not movements in the nominal exchange rate. The real exchange rate response to a German government shock is up to an order of magnitude larger in non-EA economies than in the member countries. Within the Euro Area, only Greece experiences a real exchange rate change similar in magnitude to that on non-EA countries. Here, the real exchange rate responds with a 'hump-shaped' and persistently depreciates. A depreciation amounts to a negative wealth effect for households and accounts for the decline in output. Another potential reason why the Greek real exchange rate is so much more volatile than that of other EA countries are differences in the composition of the Greek consumer goods basket relative to the German one. The greater the degree of consumption home-bias or the greater the share of non-traded goods, relative to the partner country, the more volatile is the real exchange rate.

4 A dynamic stochastic general equilibrium model

The challenge in trying to capture the dynamics of the BVAR in a DSGE model lies in the fact that private sector consumption and investment increase in response to a fiscal expansion. We address this challenge using a two-country dynamic stochastic general equilibrium (DSGE) model. In order for private consumption to rise in response to a bond-financed fiscal expansion, we introduce two types of households into the model: households with and without access to financial markets. Financially unconstrained households react to higher current period government spending and the corresponding higher future tax rates with extra savings to pay for future taxes. Therefore, we need to introduce a second class of households, for whom Ricardian equivalence need not hold if aggregate consumption is to rise following a rise in government spending. Galí et al. (2007) have shown that the presence of hand-to-mouth consumers alone is not sufficient to generate an increase in aggregate consumption in response to a fiscal expansion, we also need nominal rigidities in the goods and labour markets.

In order for investment to rise, we need to separate the decision to accumulate capital from the financially unconstrained household, whose savings increase in order to pay future taxes in response to a fiscal expansion. We do this by introducing an entrepreneur who accumulates capital which is rented out to wholesale firms. Entrepreneurs differ from the financially unconstrained households by virtue of being less patient and by being subject to a binding collateral constraint when borrowing for investment.[15] This way, investment responds to higher aggregate demand and not to anticipated higher taxes.[16] Government spending is initially bond-financed, while a tax rule ensures that the debt-to-GDP ratio remains stationary. In what follows, we give an outline of the model used, with a full set of model equations presented in Table 2.

4.1 Households

There are two types of households in the model. Households that are financially unconstrained, that can borrow and save in the form of bonds; and those without access to financial markets. We refer to the former type as Ricardian households and to the latter type as rule-of-thumb households.

4.1.1 Ricardian households

Ricardian households receive utility from the consumption of goods, c', and dis-utility from providing work hours, n'. A single prime denotes the variables pertaining to Ricardian households. Households form external habits over consumption, such that the expected utility of the Ricardian

[15] We ensure that the borrowing constraint is binding by assuming (a) 'sufficient' impatience and (b) that shocks hitting the economy are relatively small.

[16] We also assume that the entrepreneur does not pay taxes.

Table 2: Equations of the model

Description	Model equation	
FOC c_t (hf)	$\frac{\Gamma_c}{c'_t - \epsilon_c \bar{c'}_{t-1}} = \lambda'_t$	[i]
FOC n_t (hf)	$-\phi_0 n_t'^{\eta} + \lambda'_t \frac{w_t}{x_{w,t}} = 0$	[ii]
FOC b_t (h)	$-\lambda'_t + \beta E_t \lambda'_{t+1}(1+r^*_t)\phi_t \frac{\Delta e_{t+1}}{\pi_{t+1}} = 0$	[iii]
FOC b^*_t (f)	$-\lambda'^*_t + \beta E_t \lambda'^*_{t+1}(1+r^*_t)\frac{1}{\pi^*_{t+1}} = 0$	[iv]
FOC d_t (h)	$-\lambda'_t + \beta E_t \lambda'_{t+1}(1+r_t)\phi_t \frac{1}{\pi_{t+1}} = 0$	[v]
RoT BC (hf)	$c''_t = \frac{w_t n''_t}{x_{w,t}} - tax''_t$	[vi]
RoT FOC c_t (hf)	$\frac{\Gamma''_c}{c''_t - \epsilon_c \bar{c''}_{t-1}} = \lambda''_t$	[vii]
RoT FOC n_t (hf)	$-\phi''_0 n_t''^{\eta} + \lambda''_t \frac{w_t}{x_{w,t}} = 0$	[viii]
Ent BC (hf)	$c^e_t = \rho^k_t k_{t-1} - x_t + d^e_t - (1+r_{t-1})\frac{d^e_{t-1}}{\pi_t}$	[ix]
Ent KC (hf)	$k_t = (1-\delta)k_{t-1} + \left(1 - \frac{\psi}{2}\left(\frac{x_t}{x_{t-1}} - 1\right)^2\right) x_t$	[x]
Ent BorrC (hf)	$(1+r_t)d^e_t = (1-\rho^D) M q_{t+1} k_t \pi_{t+1}(1-\delta) - \rho^D(1+r_{t-1})\frac{d^e_{t-1}}{\pi_t}$	[xi]
Ent FOC c_t (hf)	$\frac{\Gamma_c}{c^e_t - \epsilon_c \bar{c^e}_{t-1}} = \lambda^e_t$	[xii]
Ent FOC k_{t+1} (hf)	$q_t = E_t \frac{\beta^e \lambda^e_{t+1}}{\lambda^e_t}\left(q_{t+1}(1-\delta) + \rho^k_{t+1}\right) + \Delta_t (1-\rho^D) M q_{t+1}(1-\delta)\pi_{t+1}$	[xiii]
Ent FOC x_t (hf)	$1 = q_t \left[\left(1 - \frac{\psi}{2}\left(\frac{x_t}{x_{t-1}} - 1\right)^2\right) - \psi\left(\frac{x_t}{x_{t-1}} - 1\right)\frac{x_t}{x_{t-1}}\right] + ...$	[xiv]
	$...\beta^e E_t q_{t+1} \frac{\lambda^e_{t+1}}{\lambda^e_t} \psi \left(\frac{x_{t+1}}{x_t} - 1\right)\left(\frac{x_{t+1}}{x_t}\right)^2$	
Total consumption (hf)	$c_t = c^e_t + \mu c''_t + (1-\mu)c'_t$	[xv]
Total hours (hf)	$n_t = \mu n''_t + (1-\mu)n'_t$	[xvi]
Firms Output (hf)	$y_{h,t} = a_t n_t^{1-\alpha} k^{\alpha}_{t-1}$	[xvii]
Firms FOC n_t (hf)	$(1-\alpha) y_{h,t} p_{h,t} = x_{p,t} w_t n_t$	[xviii]
Firms MPK (hf)	$\alpha y_{h,t} p_{h,t} = x_{p,t} r_{k,t} k_{t-1}$	[xix]
Price inflation PC (hf)	$\log(\pi_{h,t}/\bar{\pi}) = \beta E_t \log(\pi_{h,t+1}/\bar{\pi}) - \frac{(1-\theta_\pi)(1-\beta\theta_\pi)}{\theta_\pi}\log(x_{p,t}/\bar{x_p})$	[xx]
Wage inflation PC (hf)	$\log(\omega_t/\bar{\pi}) = \beta E_t \log(\omega_{t+1}/\bar{\pi}) - \frac{(1-\theta_w)(1-\beta\theta_w)}{\theta_w}\log(x_{w,t}/\bar{x_w})$	[xxi]
Price inflation (hf)	$\omega_t = \pi_t \frac{w_t}{w_{t-1}}$	[xxii]
Wage inflation (hf)	$\pi_{h,t} = \pi_t \frac{p_{h,t}}{p_{h,t-1}}$	[xxiii]
Monetary policy (hf)	$R_t = R^{r_R}_{t-1}\left(\frac{\pi_t}{\bar{\pi}}\right)^{(1-r_R)r_\pi}$	[xxiv]
Government BC (h)	$tax_t + b^g_t = g_t + (1+r^*_{t-1})\phi_{t-1}\frac{\Delta e_t}{\pi_t} b^g_{t-1}$	[xxv]
Government BC (f)	$tax^*_t + b^{*g}_t = g^*_t + (1+r^*_{t-1})\frac{1}{\pi^*_t} b^{*g}_{t-1}$	[xxvi]
Fiscal rule (hf)	$tax_t = \zeta_g b^g_{t-1} + \bar{g}$	[xxvii]
	$g_t = gs_t \frac{\bar{g}}{\bar{y}}$	[xxviii]
	$\log(gs_t) = \rho_g \log(gs_{t-1}) + \epsilon_{g,t}$	[xxix]
Market clearing (h)	$y_{h,t} = (1-(1-N)\gamma)p^{-\theta}_{h,t}(c_t + x_t + g_t) + (1-N)\gamma {p^*}^{-\theta}_{h,t}(c^*_t + x^*_t + g^*_t)$	[xxx]
Market clearing (f)	$y_{f,t} = (1-N\gamma){p^*}^{-\theta}_{f,t}(c^*_t + x^*_t + g^*_t) + \frac{N}{1-N}(1-N)\gamma p^{-\theta}_{f,t}(c_t + x_t + g_t)$	[xxxi]
Current account	$c_t + x_t + g_t + b_t = (1+r^*_{t-1})\phi_{t-1}\frac{\Delta e_t}{\pi_t} b_{t-1} + y_{h,t} p_{h,t}$	[xxxii]
Terms of trade	$T_t = P_{f,t}/P_{h,t}$	[xxxiii]
Real exchange rate	$rer_t^{1-\theta} = \frac{N\gamma + (1-N\gamma)T_t^{1-\theta}}{((1-(1-N)\gamma) + (1-N)\gamma T_t^{1-\theta}}$	[xxxiv]
Relative prices	$p^{\theta-1}_{h,t} = (1-(1-N)\gamma) + (1-N)\gamma T_t^{1-\theta}$	[xxxv]
	$p^{\theta-1}_{f,t} = (1-(1-N)\gamma)T_t^{\theta-1} + (1-N)\gamma$	[xxxvi]
	${p^*}^{\theta-1}_{h,t} = N\gamma + (1-N\gamma)T_t^{1-\theta}$	[xxxvii]
	${p^*}^{\theta-1}_{f,t} = N\gamma T_t^{\theta-1} + (1-N\gamma)$	[xxxviii]

Notes: (h) = home, (f) = foreign, (hf) = applies to home and foreign, FOC = first order condition, BC = budget constraint, RoT = rule-of-thumb, Ent = entrepreneurs, KC = capital accumulation constraint, BorrC = borrowing constraint, MPK = marginal product of capital, PC = Phillips curve, $p_{h,t} = P_{h,t}/P_t$, $p_{f,t} = P_{f,t}/P_t$, ${p^*}_{h,t} = P^*_{h,t}/P^*_t$, ${p^*}_{f,t} = P^*_{f,t}/P^*_t$

household can be described as:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\Gamma_c \log(c_t' - \epsilon_c \bar{c'}_{t-1}) - \frac{\phi_0}{1+\eta} n_t'^{1+\eta} \right) \tag{2}$$

where $\Gamma_c = (1-\epsilon)$ is a constant that ensures that steady state consumption is not affected by the presence of external habits, with $\bar{c}_t'$ denoting aggregate consumption of all Ricardian households. The inverse of the labour supply elasticity is given by η, ϵ determines the strength of consumption habits and ϕ_0 the disutility of labour. Households consume a constant elasticity of substitution (CES) aggregate of home and foreign-produced final goods:

$$c_t' = \left[\nu^{\frac{1}{\theta}} \left(c'^h_t \right)^{\frac{\theta-1}{\theta}} + (1-\nu)^{\frac{1}{\theta}} \left(c'^f_t \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \tag{3}$$

where θ denotes the constant elasticity of substitution between home and foreign-produced intermediate goods and ν is the share of home-produced intermediate goods in total home-consumption. Households maximise expected utility subject to the following flow budget constraint:

$$\begin{aligned} c_t' + b_t + d_t + b_t^g + d_t^e &= \frac{w_t n_t'}{x_{w,t}} + (1+r_{t-1}^*)\phi_{t-1}\frac{\Delta e_t}{\pi_t} b_{t-1} + (1+r_{t-1})\frac{d_{t-1}}{\pi_t} \\ &+ (1+r_{t-1}^*)\phi_{t-1}\frac{\Delta e_t}{\pi_t} b_{t-1}^g + (1+r_{t-1})\frac{d_{t-1}^e}{\pi_t} - tax_t' + div_t. \end{aligned} \tag{4}$$

Households are able to smooth consumption by holding two types of assets: domestic and foreign-currency denominated bonds, respectively. The CPI inflation rate is denoted by $\pi_t = P_t/P_{t-1}$ and domestic currency bonds, of which there are two types, are held by domestic residents only. Households use domestic bonds to lend to one another, d_t and for households to lend to entrepreneurs, d_t^e. Foreign currency denominated bonds are held by households and governments in both countries. We denote with b_t and b_t^g the holdings of private sector and government issued bonds.[17] The nominal interest rate on domestic bonds is r_t while the rate on foreign bonds is r_t^*. When holding foreign-currency bonds, domestic agents face a convex bond holding cost, ϕ_t that increases along with the degree of net indebtedness. In addition to holding assets, the household receives

[17] The currency of denomination of bonds is fairly arbitrary in our model. Since departures from uncovered interest rate parity due to bond holding costs are extremely small, changing the denomination of bonds has no meaningful effects on our results.

wage income, pays lump-sum taxes and receives dividend income from owing monopolistically competitive retailers. Real wages are adjusted by the wage mark-up, $x_{w,t}$, arising from monopolistic competition in the labour market. Equations [i] to [v] in Table 2 capture the Ricardian household's optimal choice of consumption, hours and bond holdings.

4.1.2 Rule-of-thumb households

A proportion μ of households have no access to financial markets; their only source of income is from wages. Variables pertaining to rule-of-thumb households are denoted by ″. The representative member of this class of households maximises the same type of utility function as the $1-\mu$ of Ricardian households.

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\Gamma_c \log(c_t'' - \epsilon_c c_{t-1}'') - \frac{\phi_0}{1+\eta} n_t''^{1+\eta} \right) \tag{5}$$

Just as for Ricardian households, consumption of rule-of-thumb households is a CES aggregate of home and foreign-produced final goods

$$c_t'' = \left[\nu^{\frac{1}{\theta}} \left(c''^h_t \right)^{\frac{\theta-1}{\theta}} + (1-\nu)^{\frac{1}{\theta}} \left(c''^f_t \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \tag{6}$$

Rule-of-thumb household's consumption is constrained to equal their net of tax wage income.

$$c_t'' = \frac{w_t n_t''}{x_{w,t}} - tax_t'' \tag{7}$$

Both types of households supply labour to the same market and thus receive the same mark-up adjusted real wage. Given the constraints faced by the rule-of-thumb agents, they make optimal choices over consumption and hours worked.

4.2 Entrepreneurs

The third set of agents in the model are entrepreneurs. The way we model entrepreneurs follows Kamber and Thoenissen (2013). Entrepreneurs produce the capital goods that are rented out to the intermediate goods producers. Entrepreneurs receive utility from consumption and are assumed to be less patient than households, implying that the discount factor applicable to entrepreneurs, denoted β^e is lower than that of Ricardian households. The entrepreneur maximises expected utility defined over consumption of final goods:

$$E_0 \sum_{t=0}^{\infty} \beta^{e,t} \left(\Gamma_c \log(c_t^e - \epsilon_c c_{t-1}^e) \right) \tag{8}$$

subject to a flow budget constraint,

$$c_t^e = \rho_t^k k_{t-1} - x_t + d_t^e - (1 + r_{t-1}) \frac{d_{t-1}^e}{\pi_t} \tag{9}$$

a capital accumulation constraint,

$$k_t = (1 - \delta) k_{t-1} + \left(1 - \frac{\psi}{2} \left(\frac{x_t}{x_{t-1}} - 1 \right)^2 \right) x_t \tag{10}$$

and, because the entrepreneur is assumed to be impatient, a borrowing constraint:

$$(1 + r_t) d_t^e = (1 - \rho^D) M q_{t+1} k_t \pi_{t+1} (1 - \delta) - \rho^D (1 + r_{t-1}) \frac{d_{t-1}^e}{\pi_t} \tag{11}$$

where ρ^D is a parameter that smoothes the effect of borrowing constraint. The entrepreneur's optimality conditions for the choice of consumption, capital stock, investment and borrowing are equations [xi] to [xiv] in Table 2.

4.2.1 Aggregate households

Aggregate consumption, in either of the two countries, consists of the weighted sum of Ricardian and rule-of-thumb consumption plus entrepreneur's consumption. Aggregate labour effort is defined as the weighted sum of Ricardian and rule-of-thumb labour efforts.

$$c_t = c_t^e + (1 - \mu) c_t' + \mu c_t'' \tag{12}$$

$$n_t = (1 - \mu) n_t' + \mu n_t'' \tag{13}$$

where μ denotes the share of rule-of-thumb households in the economy.

4.3 Firms

In order to capture nominal price rigidities, we differentiate between flexible price wholesale firms and final goods firms that operate under monopolistic competition and face price adjustment costs.

4.3.1 Wholesale firms

Wholesale firms rent capital from entrepreneurs and hire labour services from households. They maximise the following profit function

$$\max p_{h,t} \frac{y_t}{x_{p,t}} - w_t n_t - r_{k,t} k_{t-1} \tag{14}$$

where $p_{h,t} = \frac{P_{h,t}}{P_t}$ is the relative price of home-produced final good and $x_{p,t}$ denotes the price markup of the final over the wholesale good. Wholesale goods production is characterised by a standard Cobb-Douglas production function defined over capital and labour.

$$y_{h,t} = a_t n_t^{1-\alpha} k_{t-1}^{\alpha} \tag{15}$$

4.3.2 Final goods firms

There are Calvo-style nominal rigidities in prices and wages in the final goods sector. Final good firms buy wholesale goods in competitive markets, differentiate these goods at no cost and sell them at a markup $x_{p,t}$ over their marginal cost. Given the well-understood Calvo mechanism, where $1 - \theta_p$ denotes the probability that a final goods firm is able to set prices in a given period, this setup yields a forward-looking Phillips curve that, after linearisation, can be written as:

$$\log(\pi_{h,t}/\bar{\pi}) = \beta E_t \log(\pi_{h,t+1}/\bar{\pi}) - \frac{(1-\theta_\pi)(1-\beta\theta_\pi)}{\theta_\pi} \log(x_{p,t}/\bar{x_p}). \tag{16}$$

An analogous process is used for wage setting. Here, labour unions bundle homogeneous labour services supplied by households into differentiated labour services, where ω_t denotes nominal wage inflation and $x_{w,t}$ the markup of differentiated labour services over homogeneous labour services supplied by households and $1-\theta_w$ the constant probability of re-pricing in the labour market.

$$\log(\omega_t/\bar{\pi}) = \beta E_t \log(\omega_{t+1}/\bar{\pi}) - \frac{(1-\theta_w)(1-\beta\theta_w)}{\theta_w}\log(x_{w,t}/\bar{x_w}) \tag{17}$$

Wage and price inflation of the home-produced final good are liked to overall inflation as follows:

$$\omega_t = \pi_t \frac{w_t}{w_{t-1}} \tag{18}$$

$$\pi_{h,t} = \pi_t \frac{p_{h,t}}{p_{h,t-1}}. \tag{19}$$

4.4 Monetary policy

Monetary policy follows a simple Taylor-type rule that responds to deviations in CPI inflation from its steady state value.

$$R_t = R_{t-1}^{r_R}\left(\frac{\pi_t}{\bar{\pi}}\right)^{(1-r_R)r_\pi} \tag{20}$$

4.5 Fiscal policy

The fiscal authority funds government spending by raising taxes and by borrowing from the international capital markets. The public sector faces the following borrowing constraint:

$$tax_t + b_t^g = g_t + (1+r_{t-1}^*)\phi_{t-1}\frac{\Delta e_t}{\pi_t} b_{t-1}^g \tag{21}$$

Taxes are set according to a simple tax rule where taxes respond with a lag to additional government borrowing, whilst maintaining a balanced budget in the steady state.

$$tax_t = \zeta_g b_{t-1}^g + \bar{g} \tag{22}$$

The fiscal impulse, gs_t, is modelled as an AR(1) process that affects the amount of government spending relative to GDP.

$$g_t = gs_t \frac{\bar{g}}{\bar{y}} \tag{23}$$

$$\log(gs_t) = \rho_g \log(gs_{t-1}) + \epsilon_{g,t} \tag{24}$$

4.6 Market clearing and relative prices

To close the model, we impose market clearing conditions for home and foreign-produced goods and consolidate the household's, the entrepreneur's and government's budget constraints to obtain an expression for the current account in the home country.

5 Reconciling the model to the BVAR

We have now built a model that has the required features to allow both consumption and investment to rise in response to a positive government spending shock. We assess the performance of the baseline model, applied to Germany, using a strategy that minimises the distance between the impulse responses of the BVAR, estimated for Germany, and the impulse responses of the DSGE model similar to Bodenstein et al. (2018). In doing so, we distinguish between calibrated and optimised parameters. The calibrated parameters are listed in the top half of Table 3 and the parameters optimised to allow the impulse responses of the model match those of the BVAR are found at the bottom of the table. We optimise parameters for which there is insufficient empirical evidence.

Given the values of the calibrated parameters—stacked in the vector Θ^c—we estimate the remaining ones—stacked in the vector Θ^e—by minimising the weighted distance between the empirical impulse response functions from the BVAR for Germany, denoted by G, and the impulse response function implied the theoretical model, denoted by $G(\Theta^c, \Theta^e)$:

$$\hat{\Theta}^e = argmin_{\Theta^e}[G - G(\Theta^c, \Theta^e)]'\Omega^{-1}[G - G(\Theta^c, \Theta^e)]. \tag{25}$$

The diagonal weighting matrix Ω is obtained from the variance of the median IRF at each observation of the BVAR. Ω penalises those elements of the estimated impulse responses with wide error bands. We minimise the objective (25) over the first twenty periods after the shock. Specifically, we try to match the model to the BVAR impulse responses for government consumption, output, private consumption, investment, the trade balance and the real exchange rate.

In a Bayesian VAR, we do not have a single variance-covariance matrix of the estimated impulse response functions, hence we cannot derive the standard errors associated with our estimates.

Table 3: Model parameters

Parameter	Description	Value
	Calibrated parameters	
β	Discount rate Ricardian household	1/1.01
β^e	Discount rate impatient entrepreneur	1/1.015
η	Inverse of Frisch elasticity	1
α	Share of capital in output	0.33
δ	Depreciation rate	0.025
$\bar{x_p}$	Steady state markup prices	1.1
$\bar{x_w}$	Steady state markup wages	1.1
ϕ^b	Bond holding cost	0.001
N	Country size	0.25
$\frac{G}{Y}$	Government to GDP ratio	0.2
M	Loan-to-value ratio	0.5
ρ^D	Borrowing constraint smoothing	0.8
r_R	Taylor rule coefficient on lagged r	0.9
r_π	Taylor rule coefficient on inflation	1.5
	Optimised parameters	
ρ^G	AR(1) government spending	0.799
θ	Trade elasticity	0.749
μ	Share of rule-of-thumb agents	0.323
γ	Openness parameter	0.124
Ψ	Investment adjustment costs	9.483
ϵ	Consumption habits	0.6
ζ_g	Tax rule parameter	0.155
θ_p	Calvo prices	0.892
θ_w	Calvo wages	0.874

Because of this, we refer to the parameters in the bottom half of the table as optimised instead of estimated.

Our calibration is quite standard and the ability of the model to match the salient features of the analysed subset of the data does not depend on any specific calibrated parameter values. We set the share of government consumption in GDP to 0.2 which is the average observation of G/Y over the sample in the German data. The relative size of Germany, N, depends very much on the the context of the two-country model. If the 'foreign' economy is modelled as the rest of the world, N would need to be close to zero. Since we are interested in whether the model can match spillovers between Germany and other European economies, we set N to 0.25, which is the approximate size of Germany in the European Union. The parameters of the monetary policy rule assume that the central bank reacts only to deviations of inflation from target and changes the policy rate in a very smooth fashion. We analyse two versions of the baseline model, one where both countries conduct monetary policy independently and one where there is a single currency.

Figure 12 shows the extent to which the baseline model is able to replicate the impulse responses from the German BVAR. The optimised parameters for this exercise are listed at the bottom half of Table 3. The dynamics of government consumption are captured by a value of $\rho^G = 0.799$. The trade elasticity, θ, determines the volatility of the real exchange rate in the model. The lower is θ, the less substitutable are home and foreign-produced goods for households, firms and the government and the more relative prices have to move in response to demand shocks. Hence, the for a given government spending shock, a lower θ implies a greater real exchange rate response. The optimised parameter value to match the BVAR response is 0.749. The share of rule-of-thumb consumers, μ, affects the response of total consumption to a government spending shock. Since consumption of rule-of-thumb consumers rises and that of Ricardian consumers falls in response to a government spending shock, the greater is the relative size of the rule-of-thumb cohort, the greater will be the overall response of consumption. The closest fit between model an BVAR is for a value of $\mu = 0.323$. The openness parameter, which is linked via the relative country size to the degree of home-bias, affects both the response of domestic variables and also the extent to which the shock spills over into other countries. The more open the economy, the smaller is the effect of a government spending increase at home, and the larger is its effect abroad. A value of $\gamma = 0.124$, is the optimal value for matching the German BVAR and helps the model to come close to matching the response of French GDP to a German government spending shock.

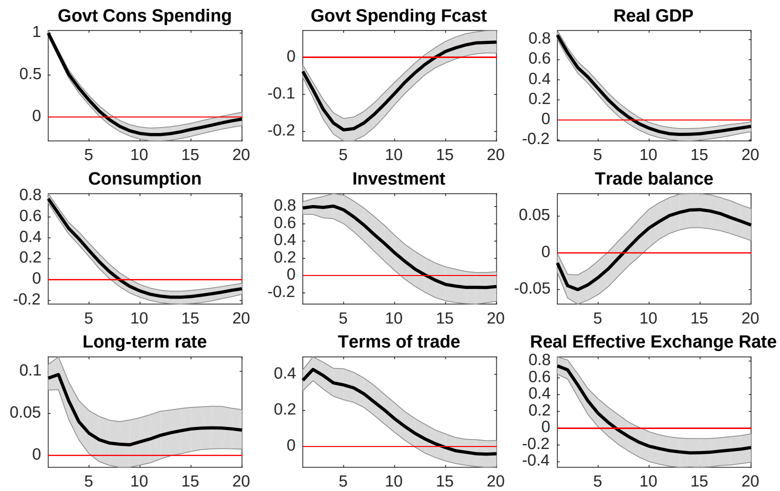
Given these optimised parameters, the model is able to easily match the dynamics of government consumption, real GDP, consumption and investment. Where the model struggles to match the data is in the shape, but not in the sign, of the response of net trade and the real exchange rate. In the model, net trade falls, but unlike in the data, most of the fall occurs in the initial period. Just as in the data, the real exchange rate depreciates on impact and continues to depreciate beyond the horizon of our IRFs. The model cannot, however, match the 'hump' shape of the real exchange rate in the BVAR. This is perhaps less surprising as the only source of deviations from purchasing power parity in the model come from the home-bias in consumption channel. A richer model allowing for dynamics in the price of non-traded goods might provide greater real exchange rate volatility. The panel on the bottom row of Figure 12 plots the response of foreign output to a German government spending shock and the BVAR impulse response for French GDP in response to a German fiscal expansion. No attempt has been made to match these IRFs in our optimisation. Nonetheless, the magnitude and path of the foreign output response is roughly consistent with French data. As we show in Appendix A, most of the features included in the model – such as habits, the presence of non-Ricardian households, price and wage stickiness – are essential if the model is to have any success in capturing the key dynamics in the data following a government spending shock.

Figure 13 shows the impulse responses of a version of our DSGE model where the home and foreign economy are in a monetary union. To turn our baseline model into a currency union, we set the nominal depreciation, $\Delta e_t = 0$, define a union-wide inflation rate, a union-wide policy rate as well as a union-wide Taylor rule. This version of the model also closely matches the response of GDP and its components in the BVAR, but with a constant nominal exchange rate, the real exchange rate remains virtually constant on impact. This version of the model also generates rather more international spillovers, with foreign output rising by twice as much as in the baseline model. These results corresponds to the BVAR results, which suggest that a German shock to government consumption has a larger effect on the real exchange rate of non-Euro Area countries and has larger spillovers in Euro Area economies.

6 Conclusion

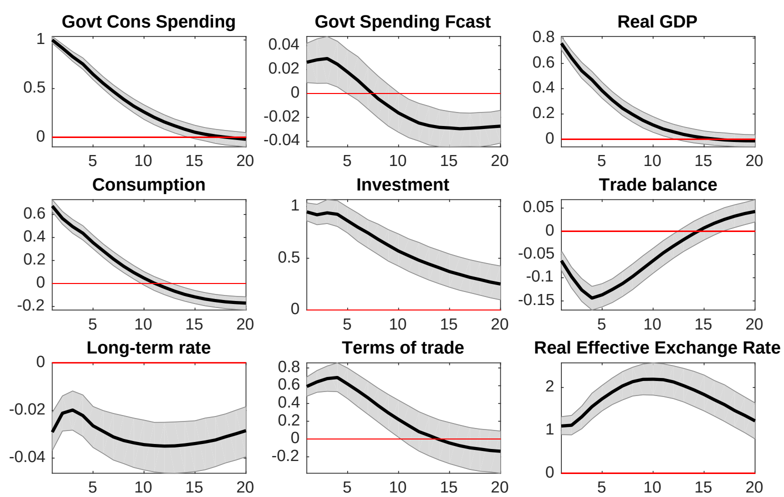
Using data from the late 1990s until 2019 for the G7 economies, we find that an increase in government spending is expansionary. It raises output, consumption and in many countries crowds in private sector investment. The increase in domestic absorption does not come at the cost of an appreciated real exchange rate. Indeed, the relative price of home-produced goods actually falls, causing the real exchange rate and terms of trade to depreciate. The expansionary effects of government spending are not confined to the home economy. Spillovers between the US and the G7 countries are positive, as are those between Germany and her European neighbours. The dynamics of the macroeconomy implied by the VAR pose a challenge for macroeconomic modelling. We have shown that a model with heterogeneous households, firms facing borrowing constraints and nominal rigiditiestrained firms can explain the key salient empirical features following a government spending shock.

Figure 1: Unanticipated shock to government consumption spending in the United States of America



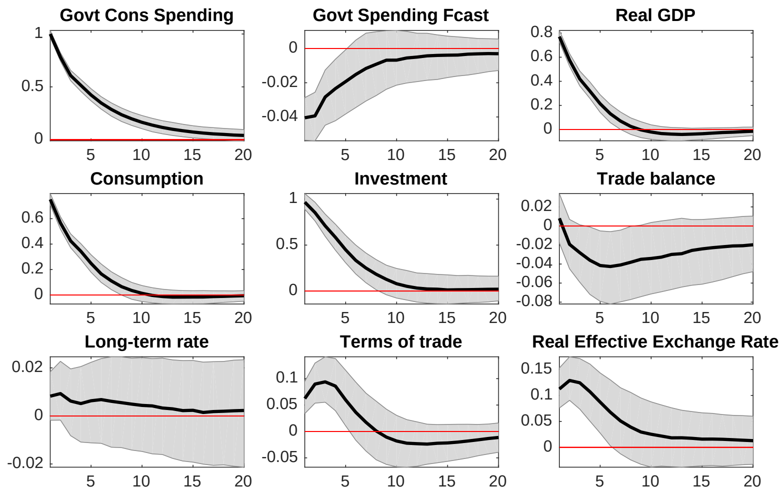
Note: The black solid line denotes the median impulse response of the data a shock a unit shock to government consumption. The grey shaded area is the 16-84 percentile draw band. All data definitions are reported in Table 1

Figure 2: Unanticipated shock to government consumption spending in Japan



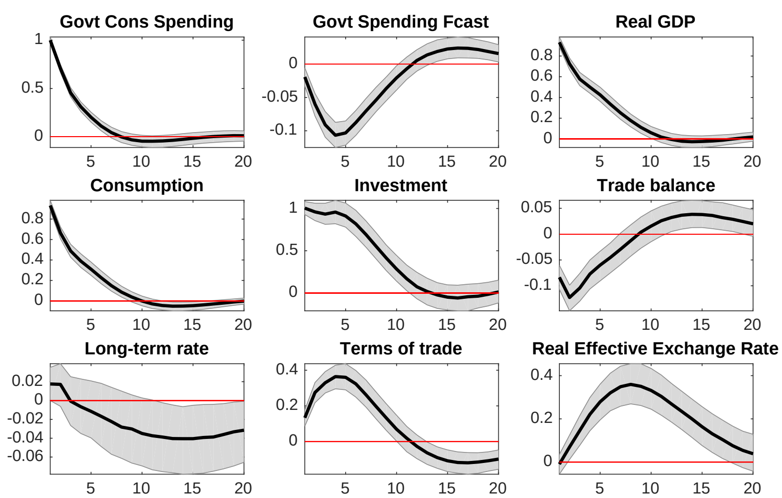
Note: The black solid line denotes the median impulse response of the data a shock a unit shock to government consumption. The grey shaded area is the 16-84 percentile draw band. All data definitions are reported in Table 1

Figure 3: Unanticipated shock to government consumption spending in Germany



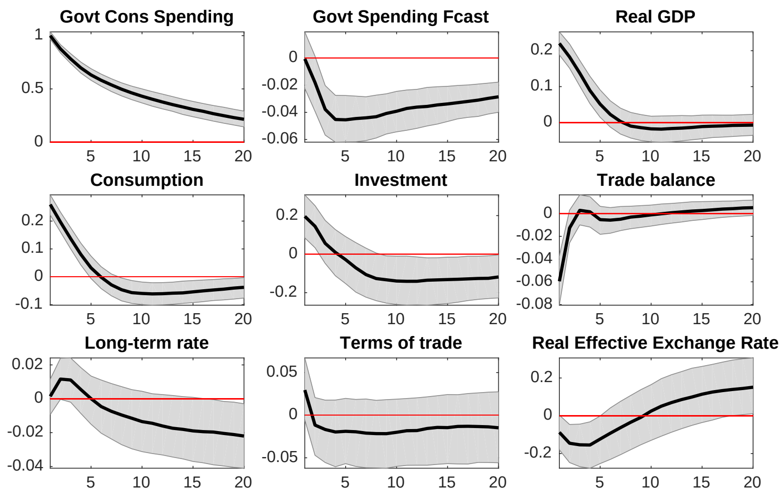
Note: The black solid line denotes the median impulse response of the data a shock a unit shock to government consumption. The grey shaded area is the 16-84 percentile draw band. All data definitions are reported in Table 1

Figure 4: Unanticipated shock to government consumption spending in France



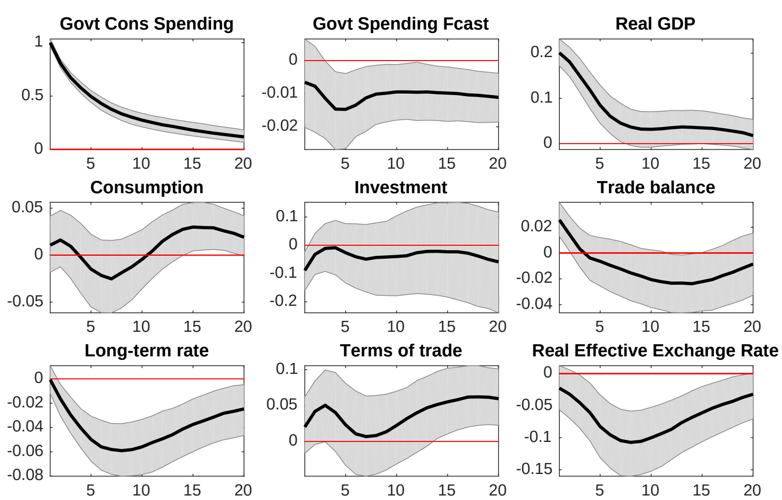
Note: The black solid line denotes the median impulse response of the data a shock a unit shock to government consumption. The grey shaded area is the 16-84 percentile draw band. All data definitions are reported in Table 1

Figure 5: Unanticipated shock to government consumption spending in the United Kingdom



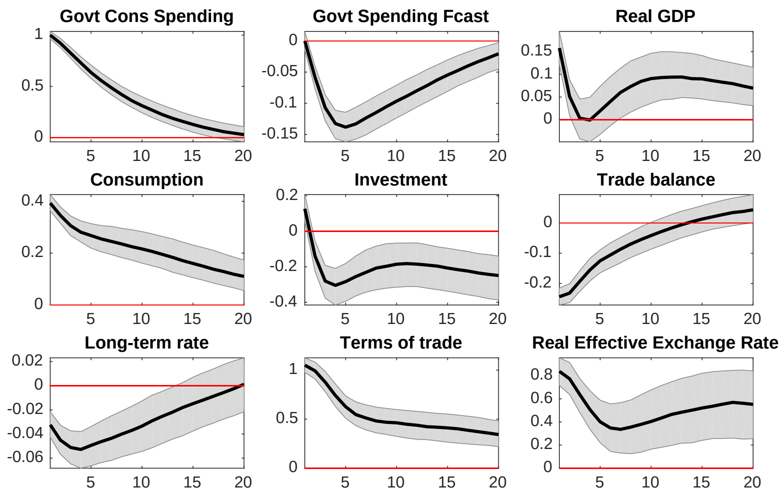
Note: The black solid line denotes the median impulse response of the data a shock a unit shock to government consumption. The grey shaded area is the 16-84 percentile draw band. All data definitions are reported in Table 1

Figure 6: Unanticipated shock to government consumption spending in Italy



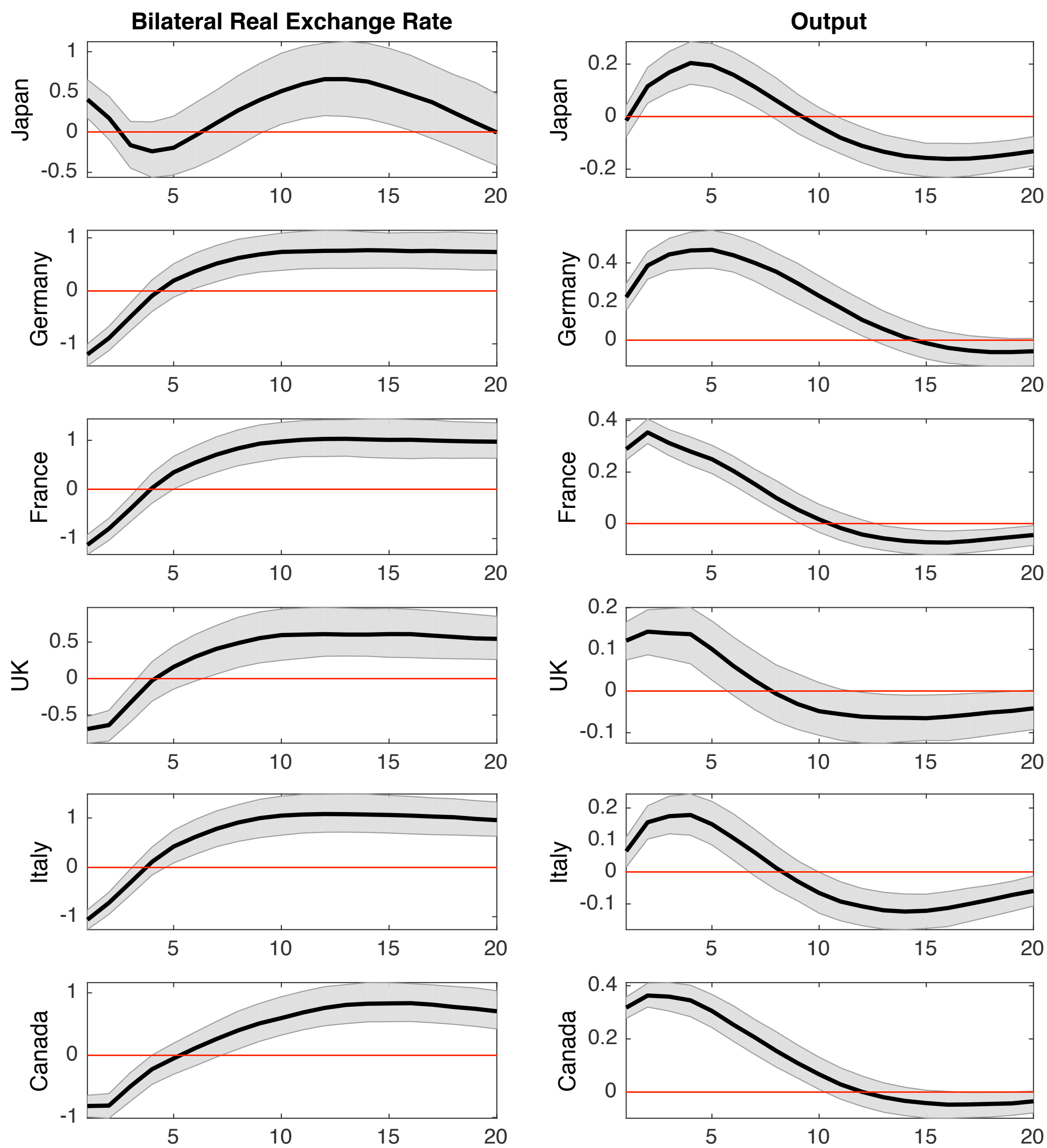
Note: The black solid line denotes the median impulse response of the data a shock a unit shock to government consumption. The grey shaded area is the 16-84 percentile draw band. All data definitions are reported in Table 1

Figure 7: Unanticipated shock to government consumption spending in Canada



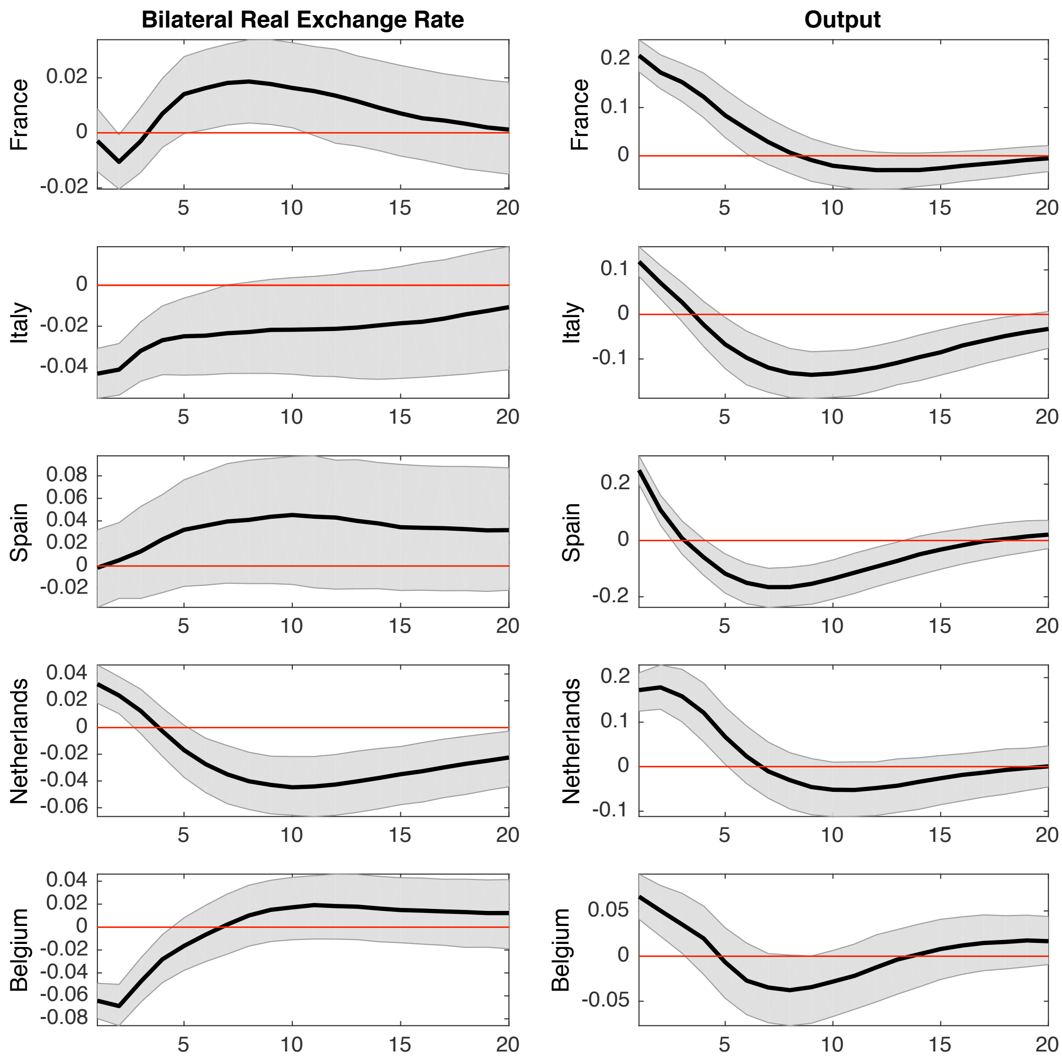
Note: The black solid line denotes the median impulse response of the data a shock a unit shock to government consumption. The grey shaded area is the 16-84 percentile draw band. All data definitions are reported in Table 1

Figure 8: US government consumption spillovers to G7



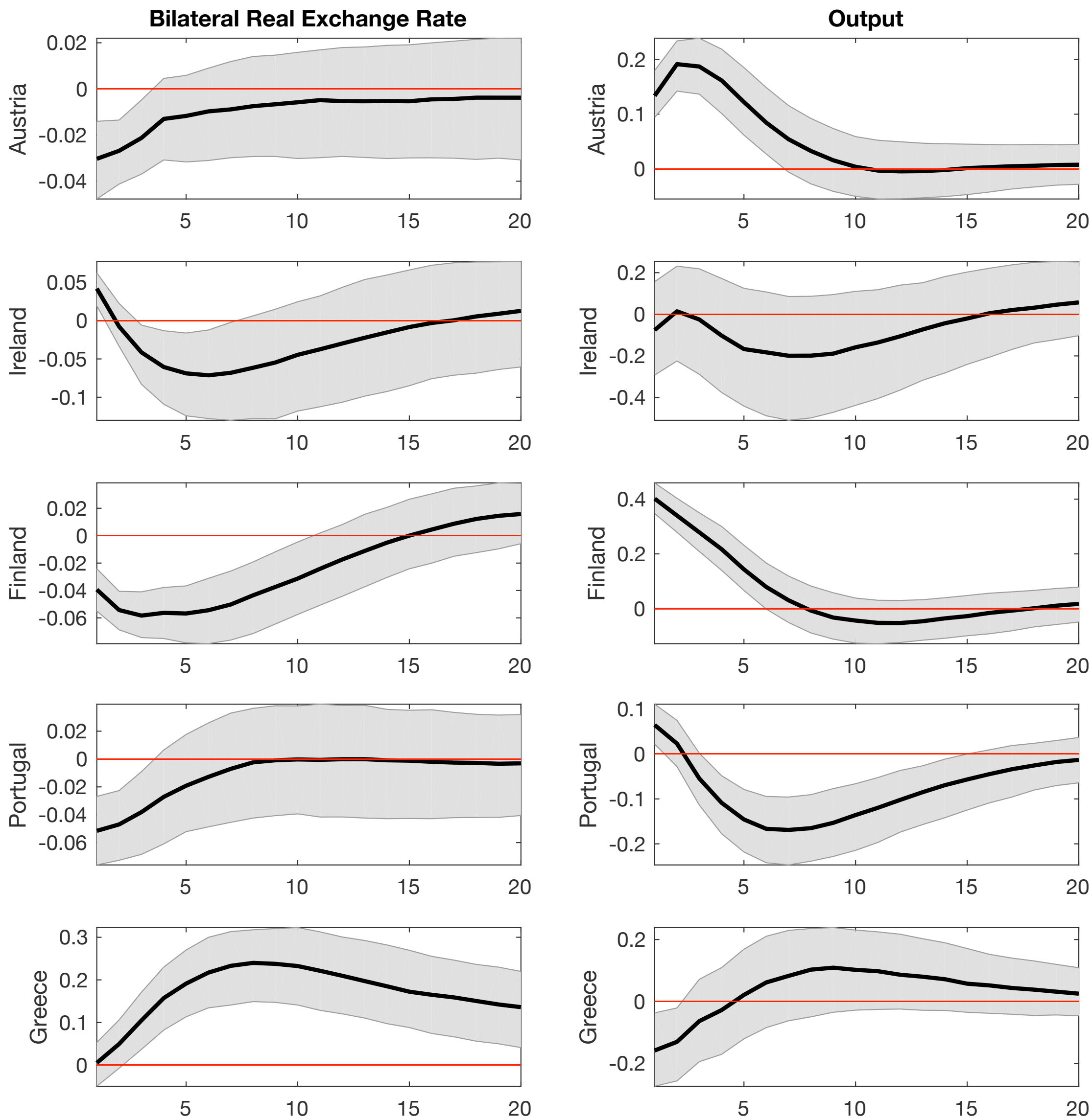
Note: The solid black lines are the median responses of the bilateral real exchange rate and GDP in G7 economies following a shock to US government consumption. The grey shaded area is the 16-84% confidence interval. A increase in a country's real exchange rate denotes a real depreciation in that country's real exchange rate. All data definitions are reported in Table 1

Figure 9: German government consumption spillovers to Euro Area Europe (i)



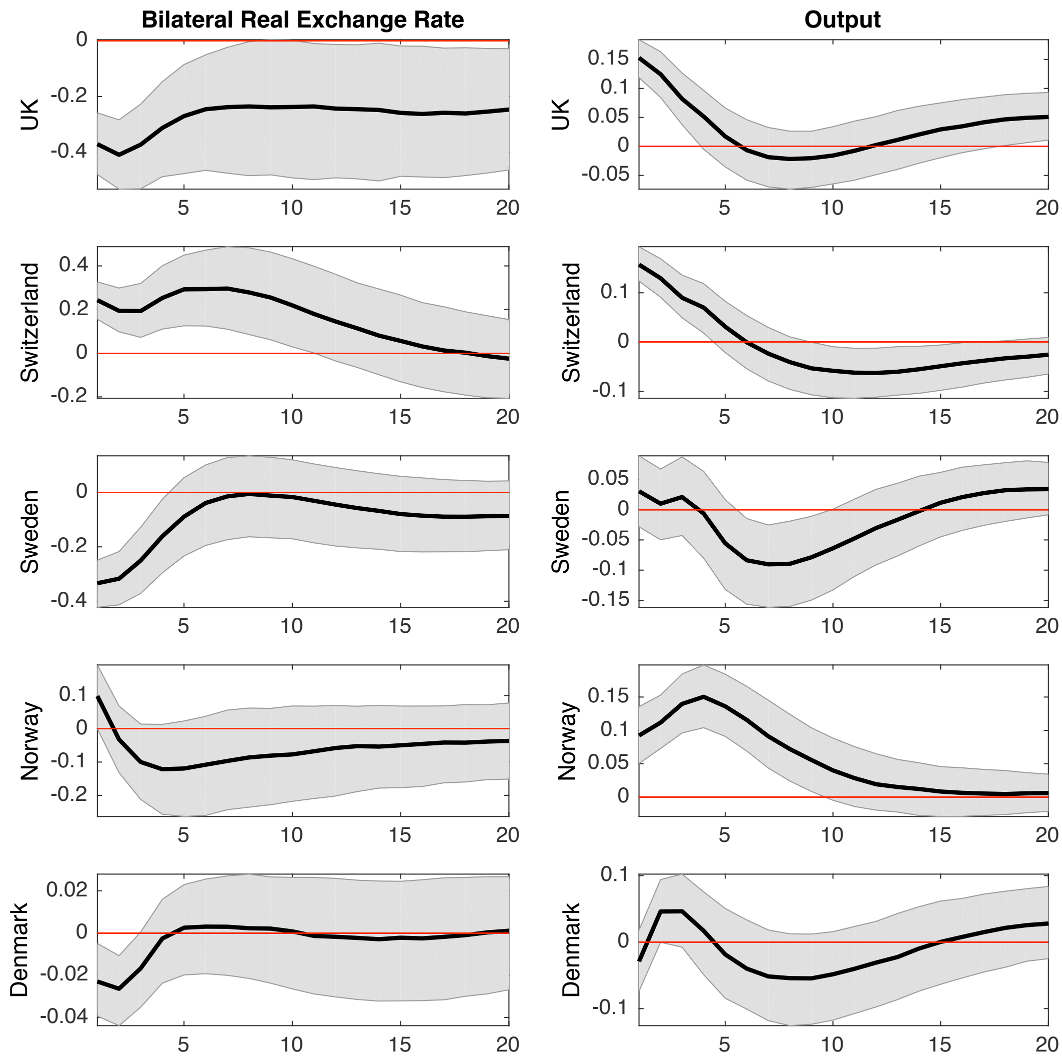
Note: The solid black lines are the median responses of the bilateral real exchange rate and GDP in Euro Area economies following a shock to German government consumption. The grey shaded area is the 16-84 percentile draw band. A increase in a country's real exchange rate denotes a real depreciation in that country's real exchange rate. All data definitions are reported in Table 1

Figure 10: German government consumption spillovers to Euro Area (ii)



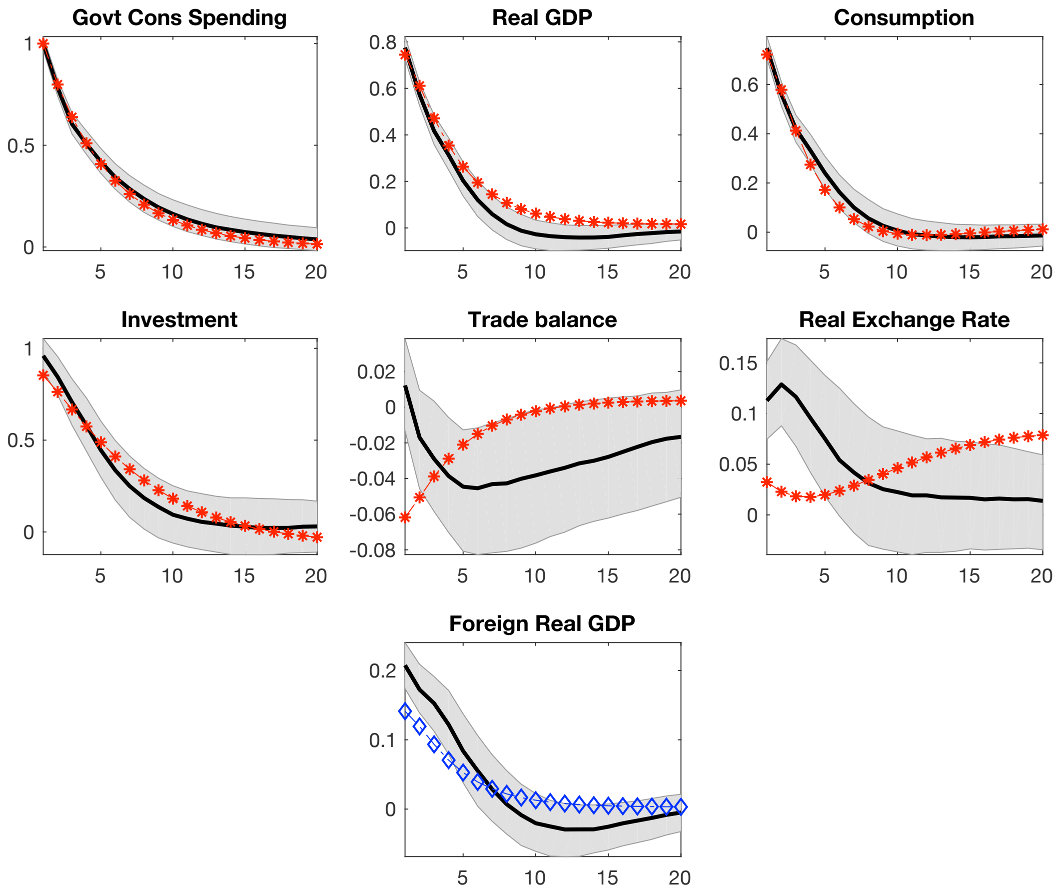
Note: The solid black lines are the median responses of the bilateral real exchange rate and GDP in Euro Area economies following a shock to German government consumption. The grey shaded area is the 16-84 percentile draw band. A increase in a country's real exchange rate denotes a real depreciation in that country's real exchange rate. All data definitions are reported in Table 1

Figure 11: German government consumption spillovers to non-Euro Area Europe



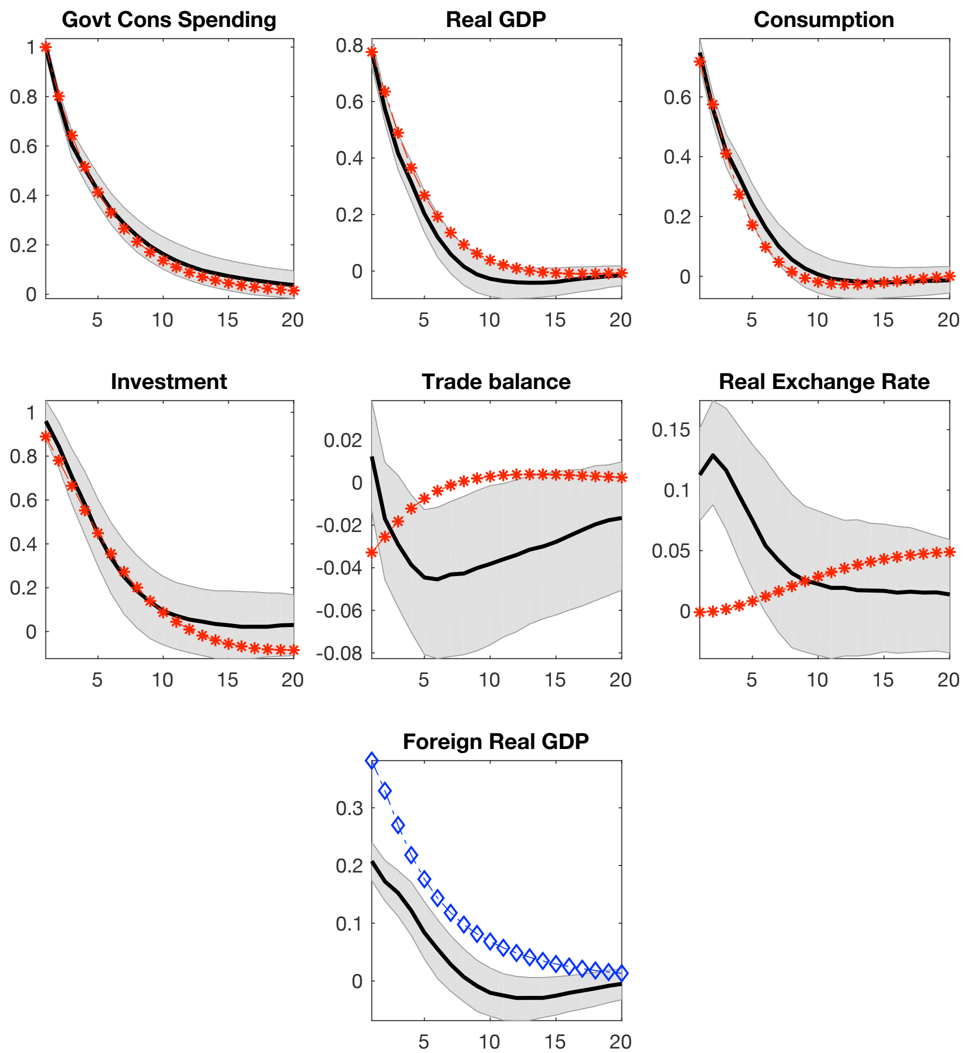
Note: The solid black lines are the median responses of the bilateral real exchange rate and GDP in non-Euro Area economies following a shock to German government consumption. The grey shaded area is the 16-84 percentile draw band. A increase in a country's real exchange rate denotes a real depreciation in that country's real exchange rate. All data definitions are reported in Table 1.

Figure 12: Unanticipated shock to government consumption spending in Germany and the DSGE model



Note: The solid black lines and the grey shaded area corresponds to the German VAR. The red dashed star line refers to the IRFs generated by the DSGE model. Foreign Real GDP VAR taken from the reaction of output in France to government spending shock in Germany and the blue dashed diamond line corresponds the the IRF of the foreign economy in the DSGE model.

Figure 13: Unanticipated shock to government consumption spending in Germany and the DSGE model - single currency.



Note: The solid black lines and the grey shaded area corresponds to the German VAR. The red dashed * line refers to the IRFs generated by the DSGE model. Foreign Real GDP VAR taken from the reaction of output in France to government spending shock in Germany and the blue dashed diamond line corresponds the the IRF of the foreign economy in the DSGE model. Optimised parameters: $\rho^G = 0.801$, $\theta = 0.556$, $\mu = 0.314$, $\gamma = 0.1$, $\Psi = 8.999$, $\epsilon = 0.598$, $\zeta_g = 0.130$, $\theta_p = 0.920$, $\theta_w = 0.873$

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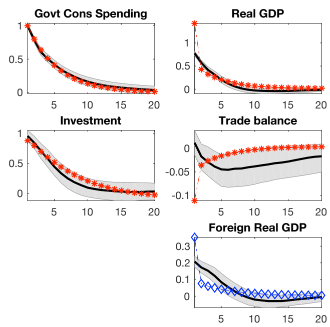
A Sensitivity analysis

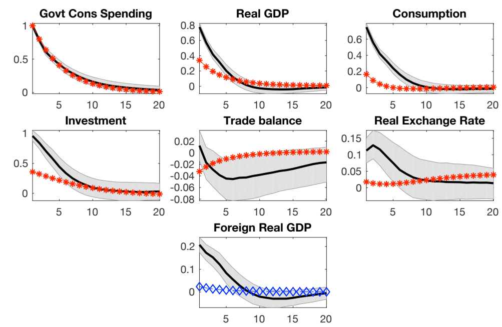
The appendix shows the sensitivity of the DSGE model to changes in model parameters. Throughout, the baseline model takes the model parameters from Table 3 with each panel in Figures 14 and 15 departing from baseline model (Figure 12) in one dimension.

Figure 14: Sensitivity analysis - DSGE model

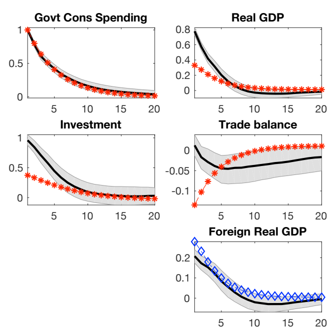
(a) No habits



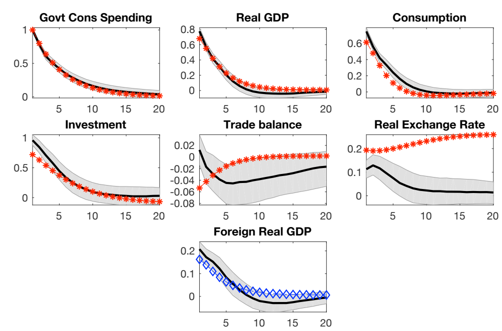
(b) No RoT agents



(c) High trade openness



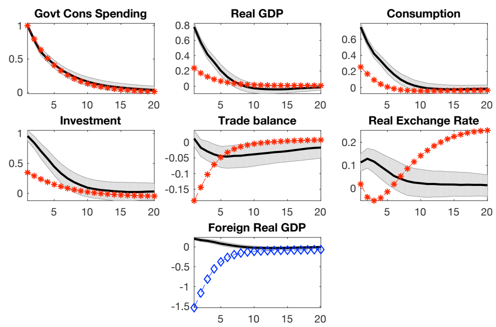
(d) Low trade elasticity



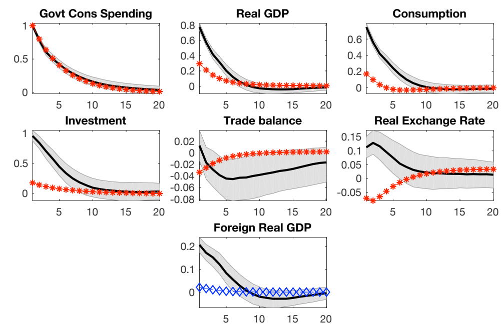
Note: The solid black lines and the grey shaded area corresponds to the German VAR. The red dashed star line refers to the IRFs generated by the DSGE model. Foreign Real GDP VAR taken from the reaction of output in France to government spending shock in Germany and the blue dashed diamond line corresponds the the IRF of the foreign economy in the DSGE model. Optimised parameters: As reported in Table 3, except in (a) $\epsilon = 0$, in (b) $\mu = 0$, in (c) $\gamma = 0.8$ and in (d) $\theta = 0.5$.

Figure 15: Sensitivity analysis - DSGE model

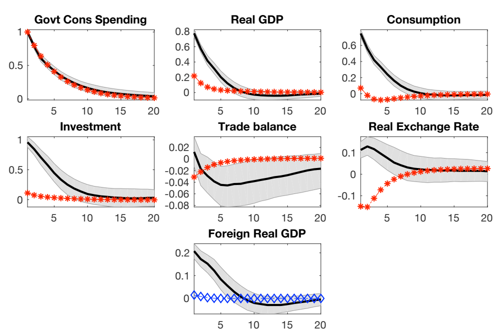
(a) Low wage stickiness



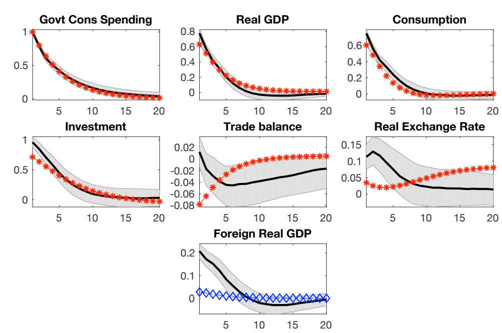
(b) Low price stickiness



(c) Low wage and price stickiness



(d) Small home country



Note: The solid black lines and the grey shaded area corresponds to the German VAR. The red dashed star line refers to the IRFs generated by the DSGE model. Foreign Real GDP VAR taken from the reaction of output in France to government spending shock in Germany and the blue dashed diamond line corresponds the the IRF of the foreign economy in the DSGE model. Optimised parameters: As reported in Table 3, except in (a) $\theta_w = 0.4$, in (b) $\theta_p = 0.4$, in (c) $\theta_w = \theta_p = 0.4$ and in (d) $N = 0.05$.