Essays in Macroeconomics: The International and Inter-sectoral Propagation of Aggregate Economic Shocks

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“ Know thyself ”

— Socrates

Declaration

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Michail Litainas
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Abstract

This thesis is composed of three chapters, focusing on the international and the intersectoral propagation of economic shocks. The first two chapters are devoted to the exploration of the effects of fiscal policy. My third chapter looks at the sectoral effects of oil supply shocks.

The first chapter studies the international spillovers of the US government spending shocks. The analysis focuses on the differences between anticipated ("news") and unanticipated ("surprise") government spending shocks. To identify government spending news, I use forecasters survey data. Spillovers are estimated in a multi-country model. Results show that anticipated government spending changes have profoundly different effects than unanticipated ones. Anticipated fiscal changes in the US have a positive demand effect domestically and increase the demand for exports for other countries. The unanticipated shock has a negative effect on domestic demand and therefore, negative spillovers for the rest of the countries. I find that the shock is mainly transmitted through trade.

In my second chapter I study the effects of a government spending shock in a production network of 16 UK sectors. I estimate a GVAR model with a sectoral dimension, where sectors can be directly affected by government spending but also indirectly, through public spending in the rest of the industries. The model creates a direct link between the aggregate and the sectoral output responses. I exploit this link to calculate sectoral-level government spending multipliers. I attempt to explain the differences across sectoral multipliers. Sectoral multiplier differentials can be explained by the relative position of each sector in the production network. Multipliers are higher for sectors which serve as important suppliers for other sectors. Other characteristics that account for differences across the multipliers are of sectoral exports and sectoral price rigidity. Particularly, multipliers are larger for sectors that are important exporters and those which prices are more rigid. Finally, I find that Input-Output linkages account for a sizable fraction of the overall fiscal effect and can

amplify the aggregate fiscal multiplier by around 30%.

In the third chapter I estimate the sectoral effects of oil supply shocks for 16 UK sectors. I estimate a multi-sector VAR model where sectors can be directly affected by the oil shock, as well as indirectly through input-output linkages. I identify the oil supply news shock using a high-frequency instrument and a proxy-SGVAR methodology. The main results are the following. First, there is significant heterogeneity on how sectors experience the effects of the oil shock, as the sectors using oil intensively experience a negative supply shock while other sectors face lower demand. Overall, the negative supply and negative demand shocks dominates the economy. However in the short run, a rise in exports of the Mining and the Manufacturing sector produces some positive effects for the economy. At later horizons though, the negative supply and demand shocks dominate and output declines in all sectors. Input-Output linkages magnify the negative effects of the oil shock.

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Chapter 1

“News” and “Surprises”: Opening Up Fiscal Policy Shocks

1.1 Introduction

Although the great recession of 2007-2009 has spurred a large volume of research concerning the impact of fiscal expansion on key macroeconomic variables, research on international spillover effects of fiscal policy is rather scanty.[1] In recent decades, after the financial crisis of 2008, large fiscal stimulus packages have been put forward in many countries around the world, mainly due to the ineffectiveness of monetary policy to stimulate aggregate demand. At the same time, the liberalization of international trade and capital markets has facilitated the international transmission of fiscal policy shocks. Due to the pivotal role that the US plays in the world economy, I seek to investigate the international effects of US government spending shocks.

Fiscal research highlights the importance of differentiating between anticipated and unanticipated government spending shocks. Often, changes in government spending are anticipated several quarters ahead, a phenomenon referred to as fiscal foresight (Ramey and Shapiro (1998); Leeper et al. (2013)). These anticipated effects generally arise due to government communication of future fiscal policies or institutional processes, and are likely to be of great relevance to the transmission of fiscal policy shocks.[2] In the presence of anticipation effects the

[1] See Ramey (2016, 2019) for an overview of the research on the effects of fiscal shocks on the domestic economy.

[2] Institutional processes might include delays between proposals, legislation, and the implementation of new fiscal measures.

fiscal shock is not a typical policy change but rather a change in agents' expectations about future government spending, known as a *fiscal news* shock. Conversely, changes in government spending that become apparent to private agents only at the moment and (not before) they occur are unanticipated shocks and are often referred to as *fiscal surprises*.

The presence of fiscal foresight burdens the empirical identification of fiscal policy shocks. The difficulty arises from the misalignment between the information sets of the econometrician and of the economic agents. Traditional identification schemes rely on actual changes of government spending overlook the impact of fiscal foresight (Blanchard and Perotti (2002)). As a result the information used in model fails to capture the forward-looking behaviour of the agents. From a statistical standpoint, a VAR model that does not convey enough information to capture the real-time expectations of the economic agents, has a non-fundamental moving average (MA) representation and thus, fails to recover the structural shock.[3] The conventional solution to alleviate the problem of fiscal foresight is to augment the information set of the VAR with a measure of fiscal news or fiscal expectations that aims to capture the representative agent's real-time beliefs (see Ramey (2011)). [4]

Studies in the area of fiscal policy can generally be classified into two broad categories, based on the type of shock identified in each study. A number of papers analyze the effects of government spending surprises while others the effects of government spending news.

In the first category, authors use a government spending forecast error measure to identify unanticipated changes to government spending (Corsetti and Müller (2013); Auerbach and Gorodnichenko (2013)). Other studies augment the VAR with a government spending expectations variable to account for fiscal expectations, while treating the actual change in government spending as the fiscal shock (see e.g. Born et al. (2013); Ilori et al. (2022)). With both approaches the government spending shock is interpreted as an unanticipated or "surprise" shock. In the second category, studies examining the effects of fiscal news shocks augment the model with a fiscal expectations variable and treat the innovation in the expectations as the fiscal shock (Ramey (2011); Forni and Gambetti (2016); Caggiano et al. (2015); Ricco et al. (2016)).[5]

In many cases the selection of shock type is made without a clear methodological basis. Interestingly, the effects of these two types of shocks—fiscal news and surprise shocks—can

[3]Non-fundamentalness implies that the MA representation of the VAR model is non-invertible: VAR residuals depend on expectations about future values of the variables considered in the VAR model. For further detail on the fiscal foresight problem, see Ramey (2011) and Leeper et al. (2013)

[4]This method is also known as EVARs or Expectational VARs Perotti (2011)

[5]Fiscal expectations variables in the US can include the Ramey (2011) narrative measure of military build-ups, the measure of Fisher and Peters (2010) based on innovations to the accumulated excess returns of large US military contractors, or fiscal forecasts or forecast revisions constructed using survey data as in Forni and Gambetti (2016); Ricco et al. (2016)

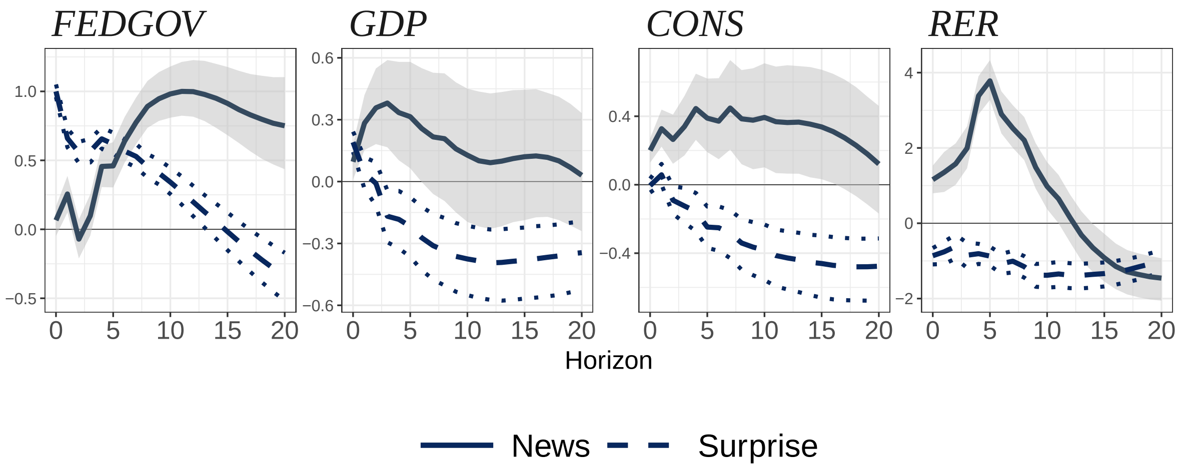


Figure 1.1: Replication of Forni and Gambetti (2016)

Replication of Figures 3 and 6 of Forni and Gambetti (2016). Differences in the IRF of output and the real exchange rate to an anticipated (News) and an unanticipated (Surprise) shock. Sample 1981Q3:2013Q3. A positive response of the real exchange rate indicates an appreciations of the currency. IRFs have been re-scaled so as the maximum response of government spending is 1% for both shocks.

vary significantly in the U.S. economy. Ramey (2011) uncovers the differences between news and surprise shocks in a closed economy framework and Forni and Gambetti (2016) extend the analysis in an open economy variables. To illustrate the importance of such differences, figure 1.1 replicates the results of Forni and Gambetti (2016) and shows the pronounced disparities in the responses of government spending, output,consumption and the real exchange rate to the two shocks. The responses to the news shock indicate expansionary effects that align with the standard theoretical models. On the other hand, the effects of the surprise shock produce responses with opposite signs that are counter-intuitive and hard to reconcile with theory. These conflicting effects on U.S. economic variables suggest that the type of fiscal shock under consideration plays a crucial role in assessing the broader impacts of fiscal policy. Furthermore, the differing responses of open economy variables indicate that the two types of shocks have distinct effects on the U.S.'s trade partners, highlighting the importance of considering shock type in international fiscal spillover analysis.

This is the first study to integrate recent developments in the modelling of fiscal shocks ('news' and 'surprise' shocks) in a fully-fledged open economy setting accounting for higher-order spillovers and country asymmetries. This chapter contributes to the literature of fiscal spillovers along the following dimensions.

First, I address the problem of **fiscal foresight**. I estimate the international spillovers for both types of fiscal shocks; a *fiscal news* and a *fiscal surprise* shock. Despite that a number of paper have highlighted the differences between fiscal news and surprises on open economy variables (Forni and Gambetti (2016); Auerbach and Gorodnichenko (2016); Ferrara et al. (2021)), previous literature on international fiscal spillovers has focused entirely on estimating the spillover effects of unanticipated fiscal shocks (see Corsetti and Müller (2013); Faccini et al. (2016); Ilori et al. (2022) among others). The international spillovers of fiscal news remain an overlooked area. This chapter seeks to address this gap by estimating the cross-border effects of US fiscal news and by examining the differences between the spillovers of fiscal news and fiscal surprises.

I follow the suggestion of Forni and Gambetti (2016) and identify fiscal news and surprise shocks based on data from the Survey of Professional Forecasters (SPF). Specifically, I build a proxy of news as the *real federal government consumption and expenditure* forecast revisions, using data from the Survey of Professional Forecasters (SPF). My baseline identification is modelled as a recursive Cholesky scheme, where the news variable is ordered second after the real federal Government spending. The residual of the news equation of represents the *fiscal news shock* while the residual of the government spending equation is the *surprise shock*.

The second contribution relates to the model used to capture the international spillover effects. Most studies in the literature use two-country econometric frameworks; by doing so, they overlook the presence of **higher-order spillovers**.[6] For example, Corsetti et al. (2012), Ilori et al. (2022) and Kim and Roubini (2008) use a two-country VAR to study the global impact of US fiscal policy shocks.[7] Although bilateral models are straightforward to implement and not computationally demanding, they fail by definition to account for the indirect (i.e., high-order) spillover effects.

This turns out to be an important omission. Georgiadis (2017) demonstrated that because bi-lateral models do not account for higher-order spillover effects, they are subject to a bigger bias, and a larger mean squared error (MSE), than those produced from a multilateral setting. Moreover, Chudik and Pesaran (2011) also consider the estimation of VAR models in which the number of economies and sample size approach infinity. They suggest distinguishing between "neighbour" or "non-neighbour" economies. When the set of neighbour economies exceeds one, then the multilateral framework is the proper framework to capture spillover effects.[8] In line

[6] Higher-order spillover effects refers to the indirect effects that a country received from a neighbouring economy, which was affected by a common shock. For example, an expansionary fiscal shock can have a direct positive impact on the UK's net trade and an indirect impact by increasing the output of euro area countries, which in turn increase imports from the UK.

[7] For other papers that has used a two-country VAR to study the international spillover effect of US monetary policy (see e.g. Kim, 2001; Canova, 2005; Nobili and Neri, 2006).

[8] Chen et al. (2012), Feldkircher and Huber (2016). Georgiadis (2017) used such a framework to estimate the impact of the US monetary policy shock on a large number of spillover-receiving economies simultaneously. Alternatively, Canova and Ciccarelli (2013) suggested using Bayesian panel VAR to model spillover effects

with that literature, our work examines the spillover of US fiscal shocks by implementing a structural Bayesian multi-country VAR.[9] This setting allows us to consider a realistic and fully-fledged multi-country dimension such as to account for both direct and indirect (i.e., through a third country) spillover effects.

The GVAR models offers additional advantages that are relevant to the analysis. An important concern is the structural breaks that can potentially be present given the long cross-sectional and time dimension of the sample. The model is quite resilient to structural breaks, especially to those in the parameters. Individual VARX models are specified conditionally on star variables. Thus, it is possible to have breaks in processes for the individual variables, but at the same time obtain a stable conditional model if there is evidence of co-breaking across the variables in the global economy (Chudik and Pesaran (2016)). For example, the model takes into account the possible breaks that occurred at the time of the global financial crisis, or at the time of the adoption of the Euro in the case of European countries.

Our empirical results provide some key observations, which contain valuable information both for policymakers and academics who focus on the impact that fiscal policy changes have on domestic and foreign economies.

Domestic effects: Focusing on the domestic effects of a fiscal policy shock, the results of my analysis corroborate the findings of Forni and Gambetti (2016). Results show that an expansionary *fiscal news* shock has positive effects on the US economy. A positive news shock leads to a gradual and persistent increase in government expenditure, and a positive response of GDP and consumption, while the exchange rate appreciates and net trade deteriorates consistently. In contrast, the findings show that a surprise shock results in lower output and consumption. Following an expansionary surprise shock, government spending peaks on impact and then decreases and becomes negative after 12 quarters. The surprise shocks is accompanied by a very short-lived increase in output and consumption that turn negative a few quarters later. Investment falls, the exchange rate depreciates and the trade balance improves.

While the responses to the news shock can be understood through the lens of standard theoretical models, the responses to the surprise shock are more challenging to interpret. The difficulty lies in reconciling the surprise shock responses with conventional theoretical expectations, where someone would typically anticipate a clearly positive effect on output

across many countries. Other applications include examining monetary policy asymmetries (Georgiadis, 2015), labor-market reforms (Bettendorf and León-Ledesma, 2019), pollution abatement (Attílio et al., 2023), growth and redistribution (Attílio, 2024).

[9] The framework used was proposed by Pesaran et al. (2004) and developed further by Dees et al. (2007).

along with a currency appreciation and a deterioration in the trade balance. However, this is not the only study that reports such counter-intuitive results. Such responses are frequently observed in studies that empirically analyse unexpected government changes in post-1980s samples (see Forni and Gambetti (2016); Ellahie and Ricco (2017); Mumtaz and Theodoridis (2020); Ascari et al. (2023)).

Responses to the fiscal surprise shock, can be rationalised through a spending reversal mechanism as described by Corsetti et al. (2012). Spending reversals work through a financial channel that captures the combined effect of fiscal and monetary policy on long-term interest rates. Specifically, reversals are modelled by allowing the dynamics of government spending to respond to the stock of public debt. Hence, after an unanticipated shock, agents expect that the fiscal expansion will be followed by future government spending cuts, higher taxes and monetary tightening that aim to constrain inflation. As a result, agents revise their expectations downwards, pushing long-term interest rates downwards leading to a depreciation of the currency and an improvement of the trade balance. The implications of such a model are particularly relevant to this study, as the my sample starts in the early 1980s, a period characterised by stronger fiscal discipline and the active efforts of the FED to stabilise inflation (see Corsetti et al. (2012); Ascari et al. (2023)).

As in Forni and Gambetti (2016), I show that spending reversals are present in the news shock as well, but they materialise in longer horizons, after a period of persistent increase of government spending. Hence, the key factor that explains the difference in the responses of the news and the surprise shock is the timing of the spending reversals.

International spillovers: Upon examining the international spillovers there several key findings.

First, there is evidence suggesting that the transmission mechanism of the fiscal shocks operates mainly through the trade channel, that is through exports and the exchange rate. In the case of a *fiscal news* shock, I observe that exports respond strongly in all countries in the sample.[10] Given that the news shock increases the US imports, the rest of the countries experience higher demand for exports. Higher exports result to an increase in foreign output and consumption. The financial channel is also at play, counteracting the positive effects of trade. The long-term interest rates increase in all countries but the effect is overall muted by the trade channel. The only country that the financial channel seems to dominate is the UK.

Second, countries can be grouped into two distinct categories based on their responses of net trade and the real exchange rate to a positive US fiscal shock. The first group, compris-

[10] This result holds in the case of the surprise shock but the signs of the responses are the opposite.

ing the North Euro Area (NEA) countries—France, Germany—and Japan, experienced an improvement in net trade, primarily driven by a depreciation of the real exchange rate.[11] In contrast, the second group, which includes the South Euro Area (SEA) countries and the UK, saw a deterioration in net trade due to currency appreciation. However, in the UK's case, despite the appreciation of the real exchange rate, net trade improves as a result of reduced domestic consumption and lower long-term interest rates.

Finally, the third finding underlines the importance of our global framework used in the analysis of international spillovers. When analysing the global impact of the US fiscal Surprise shock, high-order spillovers may have amplified direct spillovers. For example, the fall of net trade in the UK and France following the US fiscal Surprise shock is not only driven by direct effects generated by the fall of US imports, but also by indirect effects induced by the negative response of output and imports in all other euro area countries, which are the main trade partners of both countries.[12] Therefore, the negative impact of the US import fall on the UK exports has been intensified by the drop of output and imports of the euro-area countries following generated by the negative demand shock emanating from the US.

The international propagation mechanism of the *surprise shock* is similar the news shock. However, in the case of fiscal surprises spillovers, responses have the opposite signs reflecting the negative effect the surprise shock instigates in the US. The spending reversal in the US are accompanied by a significant drop in consumption and US imports, have a negative demand effect on the rest of the countries. Foreign exports decline and GDP and consumption falls.

The rest of the study is organised as follows; Section 1.2 summarises the empirical literature on the international transmission of US fiscal policy shocks. Section 1.3 describes the Global VAR model used for the multi-country analysis. Section 1.4 shows how I use government spending forecast revisions to derive fiscal News. Section 1.5 describes the data and model assignments used for the empirical exercises. In Section 1.6, I present the results for both the domestic effects of US fiscal shocks and their international spillovers on the G7, and other major economies. Section 1.7 concludes.

[11] Following Gopinath et al. (2017), Regan (2017), and others, for the euro area countries we can distinguish between southern and northern Europe. The latter tend to have relatively higher productivity, strong net trade positions, an implicit model of export-led growth and focus on export competitiveness, and lower financing costs.

[12] Note that more than 50 per cent of the UK net trade is linked to the euro area countries over our sample.

1.2 Literature Review of Fiscal Spillover Effects

A central focus of the fiscal-policy spillover literature has been the "exchange rate puzzle" and the twin deficit hypothesis. This refers to the theoretical expectation that an increase in government spending should cause a depreciation of the real exchange rate and an improvement in the trade balance—a proposition that may not align with empirical data. Forni and Gambetti (2016) show that the exchange rate puzzle vanishes once the fiscal foresight problem (anticipated fiscal shocks) is taken into account, an aspect that the had been overlooked by the original literature.

Given this, the first criteria that I use to classify studies on international fiscal spillovers are the identification and separation of anticipated (News) and unanticipated (Surprise) shocks.

My second criterion is based on the empirical framework used to estimate those spillovers. Most studies on international fiscal spillovers used a two-country framework overlooking higher-order spillovers (i.e., the indirect effects through the impact of a fiscal shock on other neighborhood economies), or else modeled such linkages in a highly reduced form, non-structural manner.

Surprise Shocks Literature Table 1.1 summarizes some of the relevant literature. Panel A relates to the effects of Surprise (unanticipated) US government spending changes. The seminal paper of Kim and Roubini (2008) spurred a large volume of research aiming to explain the exchange rate puzzle and the violation of the twin deficit crisis. For example, while both Müller (2008) and Monacelli and Perotti (2010), using Cholesky decomposition, show that an unexpected increase in government spending leads to depreciation of the real exchange rate, only the former study provides further evidence of trade balance improvement. Enders et al. (2011) and Faccini et al. (2016), using sign restrictions to identify a fiscal policy shock, provide evidence consistent with the exchange rate puzzle. The same conclusion is reached by Ilori et al. (2022), though they consider only a government consumption shock.

News Shocks Literature Panel B addresses studies that consider the impact of fiscal News (i.e., anticipated) shocks on trade and real exchange rate. Forni and Gambetti (2016), using a proxy of fiscal News shock based on the SPF, show that an appreciation of the real exchange rate and deterioration of net trade follow as a response to a fiscal News shock – implying that there is no puzzle (see also Popescu and Shibata, 2017). Auerbach and Gorodnichenko (2016), using a novel measure of daily government spending, shows that the US dollar immediately and strongly appreciates following announcements for future government spending. More recently, Ferrara et al. (2021) provide evidence that supports a US dollar appreciation and a worsening

Table 1.1: Papers exploring US Government spending effects on open economy specifications

Related Literature	Model Identification	Expectations proxy	Exchange Rate	Trade Balance
Panel A: Unexpected US government spending changes				
Kim and Roubini (2008)	Cholesky	No	-	+
Müller (2008)	Cholesky	No	-	+
Monacelli and Perotti (2010)	Cholesky	No	-	
Enders et al. (2011)	Sign Restr.	No	-	-
Corsetti et al. (2012)	Cholesky	FE (SPF)	-	
Faccini et al. (2016)	Sign Restr.	No	-	
Ilori et al. (2022)	Cholesky	OECD Forecasts	-	
Panel B: Expected US government spending changes				
Forni and Gambetti (2016)	Cholesky	CF or FR (SPF)	+	-
Auerbach and Gorodnichenko (2016)	Local Projections	Procur. Anounc.	+	-
Popescu and Shibata (2017)	Cholesky	CF (SPF)	+	-
Ferrara et al. (2021)	Ext. Instrument	Ramey Defence	+	-

Notes: *This table lists some past studies of the effects of government spending shocks in an open-economy setting. The abbreviations are* ***Chol:*** *Cholesky,* ***SR:*** *Sign Restrictions,* ***LP:*** *Local Projections;* ***Ext. Inst.:*** *External Instruments;* ***FE:*** *Forecast Error;* ***CF:*** *Sum of Cumulative forecasts;* ***FR:*** *Forecast Revisions;* ***SPF:*** *Survey of Professional Forecasters;* ***Procur. Announc:*** *Procurement Announcements; and* ***Ramey Defence*** *refers to the Ramey (2011) narrative measure of US military expenses announcements. The final two columns indicate the sign of the medium-run response of the real exchange rate and trade balance.*

trade balance, using a proxy SVAR to identify a government expenditure shock.[13]

Table 1.1 shows that the finding of Forni and Gambetti (2016), regarding the responses of open economy variables to anticipated and unanticipated government spending changes, are generally confirmed by the literature.

Although the literature summarised in table Table 1.1 examines the impact of fiscal shocks in an open economy framework, it does not consider cross-country spillover effects. Table 1.2 includes the key studies, which investigate the cross-country impact of fiscal shock, originating from the US. An important insight from table Table 1.2 is that in all studies, no matter if analysis controls for fiscal expectations, the shock has an "unanticipated" interpretation. For example, Corsetti et al. (2012), using a two-country New-Keynesian model with spending reversal, shows that a positive government spending shock leads to the decline of long-term interest rate, the depreciation of real exchange rate and the improvement of the trade balance. Their empirical approach relies on identifying an unanticipated government spending shock

[13] Ferrara et al. (2021) use the Ramey (2011) narrative measure as an external instrument for the identification of US public spending shocks.

Table 1.2: US Government spending cross-country effects

Related literature	Recipient Countries	Model and Identification	Shock Definition-Expectations proxy	Channel of transmission
Corsetti and Müller (2013)	UK, EA	Bi-VAR Cholesky	Unanticipated FE (SPF)	Financial
Nicar (2015)	CA, JP, UK	Bi-VAR Sign Restr.	Unanticipated	Trade
Faccini et al. (2016)	UK,DE, FR, CA, JP	Bi-VAR Sign Restr.	Unanticipated	Financial
Ilori et al. (2022)	G7	Bi-VAR Cholesky	Unanticipated OECD Forecasts	Trade

Notes: *This table lists some past studies of the spillover effects of government spending shocks in an open-economy setting. See also notes to Table 1.1. The two letter country symbols are standard, but for completeness are matched in Table A.1, with EA denoting the euro area.*

using data on government forecast error. Nicar (2015) also uses a two-country SVAR to test the cross-border effects of a US fiscal shock in the UK, Japan and Canada. The identification of the fiscal shock was achieved based on the sign restriction of Mountford and Uhlig (2009). The empirical results suggest that fiscal shocks have a positive and statistically significant impact on foreign output at least in the short run. However, the response of the trade balance and exchange rate differs across recipient countries. Faccini et al. (2016) estimate a regime-dependent factor model with sign restrictions to quantify the international transmission of the US government spending shock. While there is no conclusive evidence of regime-dependent effects, spillovers on foreign output are positive.[14] Finally, Ilori et al. (2022) investigate the cross-border effects of US government consumption on the relative prices and output of the G7 countries, using a bi-country Bayesian SVAR based on recursive identification. Their empirical finding suggests that a fiscal expansion in the US generates positive output spillovers for the remaining G7 countries, mainly propagating through the trade channel.

The studies presented in Table 1.2, using a bi-country empirical framework, overlook indirect spillover effects that may exist through the impact of fiscal policy on neighbouring economies of the recipient country. A handful of studies employ a multi-country analysis to capture higher-order spillover effects. For example, Hebous and Zimmermann (2013); Ricci-Risquete and Ramajo-Hernández (2015); Eller et al. (2017); Belke and Osowski (2019) use a GVAR model to explore the spillover effects of government spending among the countries of the European Union. However, the fiscal policy shocks simulated by these studies were reduced form without any direct policy implication. Starting from this premise, the framework presented in the next section overcomes the identification problem by distinguishing between

[14] Similar to Corsetti and Müller (2013), their evidence corroborates the transmission of the shock through the decline in the domestic and foreign interest rates.

"news" and "surprise" fiscal shocks. This is accomplished by constructing a "news" series, using data from the Survey of Professional Forecasters. To the best of my knowledge, there is no study that explores the effects of US government spending shocks (news or surprises) in a GVAR setting. The only paper that is close to the spirit of our study is the study of Metelli and Natoli (2021). The latter, use a GVAR model to investigate the international propagation of US tax cuts.

1.3 Econometric Framework

The curse of dimensionality is an important challenge when assessing spillover effects in a multi-country framework. To address this challenge, I use a GVAR model, which enables the investigation of temporal dynamics and geographical spread of structural shocks. Alternative models such as FAVAR, Panel VARs (PVAR) and large Bayesian VAR have been suggested to model the cross-section dependence. However, FAVAR models condense the information of a large number of variables into a small number of factors that are challenging to identify, whereas PVAR models and large BVAR, when dynamic interference is present, become operational through parameter shrinkage. The GVAR model addresses the dimensionality issue by breaking down large-dimension VARS into smaller conditional models, connected by cross-sectional averages. Therefore, the GVAR model, rather than limiting the dynamics of individual country sub-models, imposes an intuitive structure on cross-sectional interlinkages.

The GVAR, first introduced by Pesaran et al. (2004) and further expanded upon by Dees et al. (2007) consists of two main steps. The first step involves the estimation of a small-scale country-specific VAR model augmented by country-specific exogenous variables. In the second step, individual country-specific VARX* models estimated in the first step are stacked into a global model that is used to estimate the dynamic diffusion of a shock originating from an individual country to the rest of the countries included in the model.

1.3.1 GVAR Model

We consider for each country $i = 0, .., N$, a VARX$^*(p_i, q_i)$ model where $p_i = 1$ and $q_i = i$ indicates the lag order of domestic and foreign variables:

$$\mathbf{X}_{it} = \boldsymbol{\alpha}_{\mathbf{0,i}} + \boldsymbol{\alpha}_{1,i}t + \sum_{j=1}^{p_i} \mathbf{\Phi_{i,j}} \mathbf{X}_{i,t-j} + \sum_{j=0}^{q_i} \mathbf{\Lambda_{i,j}} \mathbf{X}^*_{i,t-j} + \mathbf{u_{i,t}} \tag{1.1}$$

$\mathbf{X}_{it}$ is $k_i \times 1$ vector of domestic variables reflecting domestic macroeconomic conditions; $\mathbf{X}^*_{i,t}$ is a $k^*_i \times 1$ vector of country-specific foreign variables which represent the influence of the rest $N-1$ countries on country i and capture the relative cross-sectional spillovers. The star variables are calculated as weighted averages of the corresponding sectoral variables of the other sectors. Specifically, star variables are described by equation (1.2).

$$\mathbf{X}^*_{i,t} = \sum_{j\neq i}^{N} w_{i,j}\mathbf{X}_{j,t} \quad \text{with} \quad \sum_{j\neq i}^{N} w_{ij} = 1 \tag{1.2}$$

where $w_{i,j}$ is a deterministic weight that rules the strength of the effect of country j on country i. Weights $w_{i,j}$ rely on the international trade flows. $\boldsymbol{\alpha}_{\mathbf{0,i}}$ and $\boldsymbol{\alpha}_{1,i}$ are $k_i \times 1$ vectors of intercept and time-trend coefficients respectively; $\mathbf{\Phi_{i,j}}$ are $k_i \times k_i$ matrices corresponding to the lagged coefficient of domestic variables while $\mathbf{\Lambda_{i,j}}$ for$j=0,1$ are $k_i \times k_i^*$ coefficients matrices of foreign variables; $\mathbf{u_{i,t}}$ is a $k_i \times 1$ vector of country-specific shocks which is assumed to follow a white noise process with variance-covariance matrix $\mathbf{\Sigma}_{u_i}$: $\mathbf{u}_{i,t} \sim iid(\mathbf{0}, \mathbf{\Sigma}_{u_i})$.[15]

Next, once each country-specific VARX* model is estimated, it can be written as

$$\mathbf{A_{0,i}Z_{it}} = \boldsymbol{\alpha}_{\mathbf{0,i}} + \boldsymbol{\alpha}_{1,i}t + \mathbf{A_{1,i}Z_{i,t-1}} + \mathbf{u_{i,t}} \tag{1.3}$$

where $\mathbf{Z}_{i,t} = (\mathbf{X}'_{i,t}, \mathbf{X}^{*'}_{i,t})'$, is a $k_i+k_i^* \times 1$ vector, $\mathbf{A}_{0,i} = (\mathbf{I}_{k_i}, -\mathbf{\Lambda}_{i,0})$ and $\mathbf{A}_{1,i} = (\mathbf{\Phi}_i, \mathbf{\Lambda}_{i,1})$. We can then write $\mathbf{Z}_{it}$ and (1.3) in terms of a $k = \sum_i k_i$-dimensional vector $\mathbf{X}_t = (\mathbf{X}'_{0,t}, \mathbf{X}'_{1,t}, \ldots \mathbf{X}'_{N,t})$ by using a $(k_i + k_i^*) \times k$ link matrix $\mathbf{W}_i$ (constructed based on the country-specific trade weights) such as $\mathbf{Z}_{i,t} = \mathbf{W}_i\mathbf{X}_t$ and

$$\mathbf{A}_{0,i}\mathbf{W}_i\mathbf{X}_t = \boldsymbol{\alpha}_{\mathbf{0,i}} + \boldsymbol{\alpha}_{i,1}t + \mathbf{A}_{1,i}\mathbf{W}_i\mathbf{X}_{t-1} + \mathbf{u}_{i,t} \tag{1.4}$$

By stacking the $\mathbf{A}_{0,i}\mathbf{W}_i$ and $\mathbf{A}_{1,i}\mathbf{W}_i$ for all the countries in the model, we obtain:

$$\mathbf{GX}_t = \boldsymbol{\alpha}_{\mathbf{0,i}} + \boldsymbol{\alpha}_{1,i}t + \mathbf{HX}_{t-1} + \mathbf{u}_t \tag{1.5}$$

where

$$\mathbf{G} = \begin{pmatrix} \mathbf{A}_{0,0}\mathbf{W}_0 \\ \mathbf{A}_{0,1}\mathbf{W}_1 \\ \vdots \\ \mathbf{A}_{0,N}\mathbf{W}_N \end{pmatrix}, \quad \mathbf{H} = \begin{pmatrix} \mathbf{A}_{1,0}\mathbf{W}_0 \\ \mathbf{A}_{1,1}\mathbf{W}_1 \\ \vdots \\ \mathbf{A}_{1,N}\mathbf{W}_N \end{pmatrix}, \quad \boldsymbol{\alpha}_0 = \begin{pmatrix} \boldsymbol{\alpha}_{00} \\ \boldsymbol{\alpha}_{10} \\ \vdots \\ \boldsymbol{\alpha}_{N0} \end{pmatrix}, \quad \boldsymbol{\alpha}_1 = \begin{pmatrix} \boldsymbol{\alpha}_{10} \\ \boldsymbol{\alpha}_{11} \\ \vdots \\ \boldsymbol{\alpha}_{1N} \end{pmatrix}, \quad \mathbf{u}_t = \begin{pmatrix} \mathbf{u}_{0t} \\ \mathbf{u}_{1t} \\ \vdots \\ \mathbf{u}_{Nt} \end{pmatrix} \tag{1.6}$$

The global covariance matrix $\mathbf{\Sigma}_u$ is block diagonal, with each individual block of the main

[15] $w_{i,j}$ is the the trade share of country j for country i over the total trade of country i.

diagonal, $\mathbf{\Sigma}_{u,i}$, calculated from the individual country-model residuals.[16] Assuming that $\mathbf{G}$ is a non-singular matrix a pre-multiplication of (6) by $\mathbf{G}^{-1}$ yields the GVAR model:

$$\mathbf{X}_t = \boldsymbol{\beta}_0 + \boldsymbol{\beta}_1 t + \mathbf{F}\mathbf{X}_{t-1} + \mathbf{v}_t \tag{1.7}$$

where $\mathbf{b}_0 = \mathbf{G}^{-1}\boldsymbol{\alpha}_0$, $\boldsymbol{\beta}_1 = \mathbf{G}^{-1}\boldsymbol{\alpha}_1$, $\mathbf{F} = \mathbf{G}^{-1}\mathbf{H}$ and $\mathbf{v}_t = \mathbf{G}^{-1}\mathbf{u}_t$. The error term in Eq. (1.7) is correlated between and within countries, as $\mathbf{G}$ matrix encapsulates the contemporaneous correlation among countries.

1.3.2 Identification of structural shock

In order to identify shocks in the GVAR, one needs to specify a block matrix of structural coefficients $\mathbf{P}$ so as to express the reduced form residuals from equation (1.5), as a linear combination of structural shocks, as follows:

$$\mathbf{u}_t = \mathbf{P}\epsilon_t \tag{1.8}$$

where $\mathbf{P}$ is a block matrix:

$$\mathbf{P} = \begin{bmatrix} \mathbf{P}_{0,0} & \mathbf{P}_{0,2} & \dots & \mathbf{P}_{0,N} \\ \mathbf{P}_{1,0} & \mathbf{P}_{1,2} & \dots & \mathbf{P}_{1,N} \\ \dots & \dots & \dots & \dots \\ \mathbf{P}_{N,0} & \mathbf{P}_{N,2} & \dots & \mathbf{P}_{N,N} \end{bmatrix} \tag{1.9}$$

and ϵ_t is the vector of structural shocks, normalised to have unit variance $E(\epsilon_\mathbf{t}\epsilon'_\mathbf{t}) = \mathbf{I}$. In practice, once I am interested in identifying structural shocks in the US (the numeraire country $i = 0$), I need to identify a matrix $\mathbf{P}_{0,0}$ that determines the contemporaneous correlation of the variables within the US model. Particularly, I am interested in identifying the first two columns of $\mathbf{P}_{0,0}$ that correspond to the contemporaneous impact of the "surprise" and the "news" shock respectively.

To identify $\mathbf{P}_{0,0}$, I use a recursive identification scheme where the proxy of fiscal "news" is ordered second after government spending and before of the rest of the macroeconomic variables. In this setting, the stochastic component of the news variable will be the news shock, while the unobserved component of the government spending equation will be purged from expectation effects and can be interpreted as a surprise shock. As described in the next section, I calculate a fiscal news proxy following a procedure suggested by Forni and Gambetti

[16]We assume that $\mathbf{\Sigma}_u$ is block diagonal as the interactions between different countries should be captured by the foreign variables.

(2016). Thus, the block-element $\mathbf{P}_{0,0}$ will be the Cholesky factor of the covariance matrix of the US model $chol(\mathbf{\Sigma}_{u_0})$.

For the rest of the diagonal blocks of $\mathbf{P}$, we assume that are Identity matrices. We restrict the off-diagonal blocks, that show the cross-country correlation of the residuals to $\mathbf{0}$. Cross-sectional correlation is expected to be very low as the domestic models are conditioned on foreign variables that account for common factors. Under the identification assumptions $\mathbf{P}$ has the following form:

$$\mathbf{P} = \begin{bmatrix} chol(\mathbf{\Sigma}_{u_0}) & 0 & ... & 0 \\ 0 & I & ... & 0 \\ ... & ... & ... & ... \\ 0 & 0 & ... & I \end{bmatrix} \tag{1.10}$$

Finally, I calculate IRFs following Pesaran et al. (2004).

$$\mathbf{\Delta Y_j}(h|y_t, \epsilon_{0,t}) = \mathbf{F^h G^{-1} P d_j} \tag{1.11}$$

where $\mathbf{\Delta X}_j(h|y_t, \epsilon_{0,t})$ is the response at time $t+h$ of the global vector of variables, when a shock is imposed at time t, on j^{th} element of $\mathbf{X}_t$. The $k \times 1$ selection vector d_j selects the j^{th} element of $\mathbf{X}$. In our case, where government spending is ordered first in the global vector so for the surprise shock $\mathbf{d}_{j=1}^{Surprise} = 1$ and $\mathbf{d}_{j\neq 1}^{Surprise} = 0$. The News shock proxy is ordered second so: $\mathbf{d}_{j=2}^{News} = 1$ and $\mathbf{d}_{j\neq 2}^{News} = 0$.

1.4 The Government Spending News Shock

Different measures that can account for fiscal foresight have been suggested in the News literature. Ramey's narrative measure based on defence expenses is probably the most popular, which however, as noted by Ramey has very low predictive power over government spending for samples not including the WWII and the Korean War. Therefore, we follow Forni and Gambetti (2016), Caggiano et al. (2015) and Ricco et al. (2016) and build a fiscal news measure, based on the expectations revisions using data from the Survey of Professional Forecasters of the Philadelphia Fed.

To better illustrate the construction of fiscal foresight proxy, Figure 1.2 describes the information flow of the SPF. Every quarter, a panel of professional forecasters provide their forecasts on a set of macroeconomic variables for the current and the next four quarters.[17]

[17] In practice, forecasts are reported for the levels of the variables for the current and the next 5 quarters. However, as the base year has changed several times over the years, the transformation of the levels into QoQ

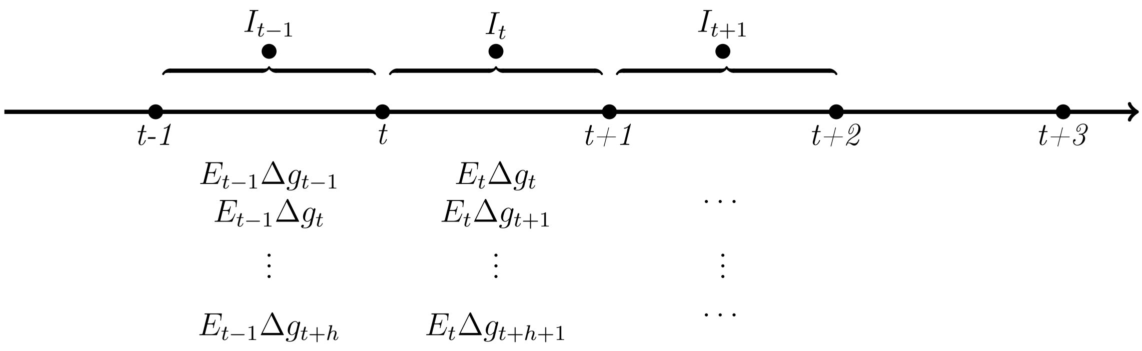


Figure 1.2: The information flow in the Survey of Professional Forecasters

Official data are released with a lag, so in each period forecasters can observe only a recent vintage of the official data. Therefore, the information set I_{t-1} available to the forecasters at time $t-1$ incorporates past realisations of macroeconomic variables and signals concerning current and future fiscal policy changes. Forecasters, given the available information at time $t-1$ -I_{t-1}- report their forecasts for the current and future government spending. At time t, the information set of forecasters is updated by the realised values of macroeconomic variables of the past quarter and signals about future government spending received between time $t-1$ and t. The new information that forecasters acquire between periods, namely the difference between $I_{t+s} - I_{t+s-1}, s = 0, 1, 2..$, is what is refer to as fiscal news. If the period of foresight h is known, then the problem of non-fundamentals can be solved by augmenting the traditional VAR model with the conditional at time t h-step ahead forecast of the growth rate of government spending $E_t\Delta g_{t+h}$ or the h-step ahead forecast revision: $(E_t\Delta g_{t+h} - E_{t-1}\Delta g_{t+h})$. However, if the number of anticipation periods is not known, then the consideration of the "wrong" forecast horizon will not contain the news shock. Forni and Gambetti (2016) address this issue by proposing to use the sum of the expectation revision up to the maximum forecast horizon H:

$$News_{1,h} = \sum_{h=1}^{H}(E_t\Delta g_{t+h} - E_{t-1}\Delta g_{t+h}) \tag{1.12}$$

The right-hand side of Eq. (1.12) is a sum of three forecasts as the maximum forecast horizon $H = 4$. Note that we drop now-cast revisions: $h \neq 0$. Now-cast revisions are not consistent with the news definition[18].

growth rates is often preferable. After the transformation in growth rates, forecasts are available only for the current and the next four quarters.

[18] This is because Now-cast revision concerns expectations about fiscal policy changes that occur at period t and not $t+s$

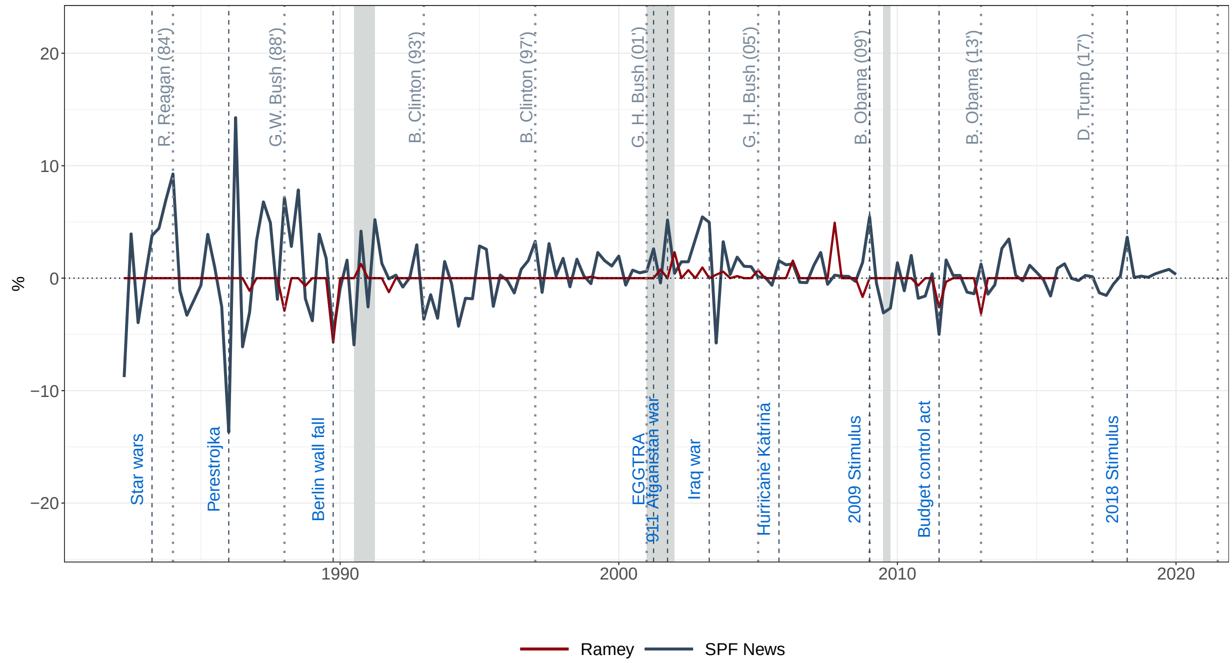


Figure 1.3: Fiscal News - Forecast Revisions and Military Buildups

Notes: *The figure plots a measure of fiscal news calculated as the forecast revisions of the median federal government spending and gross investment growth rate. The red line is Ramey's 2011 measure of defense news. Grey areas indicate NBER Business Cycle contraction dates. Vertical dotted and dot-dashed lines, respectively, indicate dates of significant political and fiscal events: yellow for Presidential elections, and green for specific events which are labeled. The former are the elections of (in chronological order) Reagan, Reagan, Bush, Clinton, Clinton, G. W. Bush, G. W. Bush, Obama, Obama, Trump, Biden.*

Figure 1.3 shows both updated $News_{1,h}$ variable as produced following Forni and Gambetti (2016) and some important political and fiscal events. For the reason of comparison, I also include Ramey's defence measure.

Positive values indicate that professional forecasters revise their expectations about future spending upward. The variable displays positive spikes coinciding with major strategic events and war episodes. For example, spikes are observed at the time of the Gulf War (1990Q3), the 911/War in Afghanistan (2001Q4) and the Iraq War (2003Q1). Other spikes are observed at the time of the Strategic Defense Initiative also known as the "Star Wars" program (1983Q2) or the fiscal stimuli programs/acts of Bush (EGGTRA 2001Q2), Obama (2009Q1) and Trump (2018Q2). On the contrary, we can observe negative spikes in correspondence with events that signal spending cuts. The Perestroika reforms(1986Q1) and the Berlin Wall fall(1989Q4) are associated with the end of the Cold War and cuts in military spending, while the Budget Control Act (2011Q3) was a series of measures for the reduction of the public debt.

1.5 Data

I use data for 19 countries, covering a period from 1980Q1 to 2019Q4. Together these 19 economies account for around 55% of world GDP. Table A.1 summarises the countries and the data availability in the sample. Data was collected from the Economic Outlook datasets of the OECD and the International Financial Statistics (IFS), and the Direction of Trade (DoT) datasets of IMF. Trade-flow weights were calculated using DoT data. The proxies of fiscal news were calculated on data from the Survey of Professional Forecasters from Philadelphia Fed.

I specify a VARX model for each of the 19 countries. All variables are in real terms. Where applicable, variables where transformed in log-levels and per capita terms. Each country model contains domestic endogenous variables and foreign variables that represent the spillover effects. Table 1.3 shows the specifications of the US and non-US models.

Table 1.3: US Government spending shock - model specification

Specification		**US model**		**Non-US model**		**Transformation**
Variables		Domestic	Foreign	Domestic	Foreign	
Real Government Spending	g_t	•				100* log-level
Fiscal News	$News_t^G$	•				%Rate
Real Tax Revenues	t_t	•				100*log-level
Real Output	gdp_t	•	•	•	•	100*log-level
Real Private Consumption	$cons_t$	•		•	•	100*log-level
Real Private Investment	inv_t	•			•	100*log-level
Long term Interest rate	$ltir_t$	•		•	•	%Rate
Real effective exchange rate	rer_t	•		•		100*log-level
Real Exports	exp_t	•		•		100*log-level
Real Imports	imp_t	•		•		100*log-level

Notes: *This table shows which variables enter the US and Non-US model and their categorization as domestic or foreign variables. Consistent with the exercise of examining the impact and spillover of US fiscal changes and its status as the leading financial economy, foreign outputs enter the US model, and foreign output, consumption and long-term interest rates enter the 'foreign block' of the non US model.*
** A higher $rexr_t$ value indicates an appreciation of the domestic currency.*
***Where applicable, variables where turned in per capita terms.*

The US model (numeraire country) includes ten endogenous variables and one foreign variable. In particular, the vector of the endogenous US variables are the real federal government spending and gross investment (g_t), the forecast revisions used as a proxy of fiscal News ($News_t$), the real federal tax revenues (rev_t), real output (gdp_t), real private consumption ($cons_t$), real investment (inv), the real long-term interest rate ($ltir_t$), the real effective exchange rate ($rexr_t$), and the real exports and imports (respectively, exp_t and imp_t)[19]. I treat the US as the hegemon in the global economy. Accordingly, I allow for spill-back effects to the US only through output not any other variables. Therefore, the only foreign variable included in the US $VARX$ model is the weighted average of the 18 foreign outputs.

The non-US models include six endogenous variables and three foreign variables. In the non-US models, I exclude government expenditures, tax revenues, real investment and fiscal news from the endogenous vector for primarily two reasons; first, data covering the sample period for the individual countries are not available and second; whilst government spending is available, the inclusion of domestic government expenditure will complicate the identification of the direct impact that the US fiscal policy shock has on domestic variables. [20]

The vector of the foreign variables in the non-US models contains the real foreign output, the real foreign long term interest rate and the real foreign consumption. I exclude trade variables from the foreign vector based on Greenwood-Nimmo et al. (2012) who argue that in a model that considers the majority of the world trade exports and imports, the exports of a particular country will be equal to the corresponding foreign imports; $ex_{it} = im^*_{it}$. The real effective exchange rate is by definition a cross-sectional weighted average and thus very close to the star variables definition.

I construct the foreign variables as the weighted average of the corresponding domestic variables of all other countries in the sample. For example, for country i, foreign output is given by

$$gdp^*_{it} = \sum_j w_{ij} gdp_{jt}$$

where the trade weight $w_{ij} \geq 0$ represents the trade share of country j to the total trade share of country i such that $\sum_j w_{ij} = 1$ and $w_{ii} \equiv 0$. For each country, the trade weights are constructed over 2000-2018.

Table 1.4 shows some heat-mapped US trade weights with the 18 partner countries.[21] The highest weights are naturally among $NAFTA$, followed by Japan and South Korea, and then European economies (barring Ireland) which are characterized by smaller weights (in a $0.04 - 0.20$ range).

[19] The real effective exchange rate measures the real value of a currency against a weighted average of foreign currencies. By construction, an increase in the value of the variable indicates an appreciation of the domestic currency.

[20] Faccini et al. (2016) show that the indirect impact of domestic government spending on domestic variables was frail. I experimented with a model that the non-US country-specific model includes domestic government spending, however the results remain qualitatively similar.

[21] Appendix Table A.2 reports the *full* matrix of cross-country trade weights.

Table 1.4: Trade Weights Relative to the US

Country	Weight	Country	Weight	Country	Weight
DE	0.13	DK	0.10	JP	0.40
GB	0.18	ES	0.07	KR	0.38
AU	0.12	FR	0.10	MX	0.85
BE	0.10	IE	0.29	NL	0.10
CA	0.82	IT	0.12	NO	0.06
CH	0.16	SE	0.08	PT	0.04

Notes: *Trade weights were calculated using data from the IMF Direction of Trade dataset. Annual data were averaged over the 2000-2018 period.*

1.6 Results

This section reports on results from the time profile of news and surprise shocks. I consider both the domestic and international spillovers of both shocks. By treating the US as the numeraire country, identification of government spending shock is achieved by a Cholesky decomposition of the US covariance matrix $\boldsymbol{\Sigma}_{u_0}$ as described in Section 1.3.2. The endogenous variables in the US VARX model are ordered as follows: Real government spending followed by the News variable, tax revenues, [22] real output, real consumption, the long-term interest rate, the real effective exchange rate, real exports and real imports. In this setting, the residual of the News equation represents the *fiscal News shock*, while the residual of the government spending equation is the *fiscal Surprise shock*.

1.6.1 The domestic effects of US government spending

This section look purely at the domestic effect of US spending shocks. First I discuss the results of the fiscal News and then the fiscal Surprise shock. In the subsequent subsections, I discuss assess the impact of the two shocks on the rest of the G7 economies, then the remaining economies in our model sample.

Fiscal News This section presents the domestic effects of an expansionary US government spending news shock. Figure 1.4 reports the impulse response functions results. The solid line shows the median responses, while as is standard in Bayesian VAR papers, the shaded areas indicate 68% central posterior credible set, which is approximately one standard deviation intervals for a normal distribution. It is important to note that the responses have been

[22] Note, I follow the definition of Blanchard and Perotti (2002) and define tax revenues in real terms. Taxes are defined as federal tax receipts plus contributions for government social insurance, minus corporate income taxes from the Federal Reserve Banks divided by population, and then deflated by the GDP deflator.

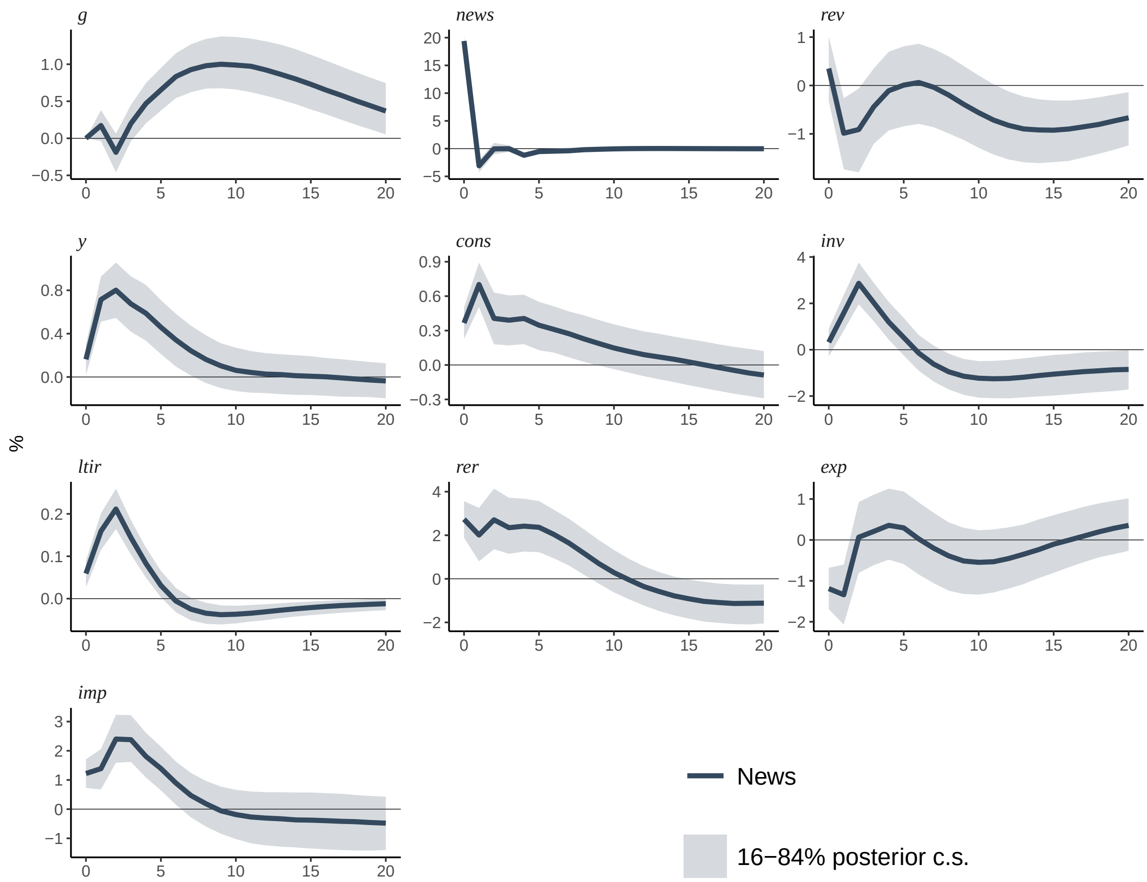


Figure 1.4: The domestic effects of the fiscal news shock.

Notes: *This figure shows the dynamic impact of a positive US fiscal News shock on key domestic variables. The vertical axis have been adjusted, so the peak of government spending is 1%. The figure depicts median impulse responses and their 68% central posterior credible set (c.s). All y-axis values are in percentage change. Positive response of the rer indicate a real appreciation of the $USD against a basket of foreign currencies*

adjust so as government spending peaks at 1%. However, this is equivalent to an increase in fiscal revisions by 20%. Therefore, the magnitude of the effects is suggestive and must be interpreted accordingly.

There is evidence of a strong positive responses. In line with the concept of a news shock, government spending remains unresponsive for three quarters and starts increasing gradually and persistently from the third quarter onwards. Government spending reaches a maximum after ten quarters and then it declines gradually towards zero. The plunge in tax revenues reflect the debt-financed deficits. The response is similar to other studies using the same identification method (see e.g. Forni and Gambetti, 2016; Caggiano et al., 2015; Popescu and Shibata, 2017). In addition, I observe a rather significant increase in GDP and consumption. Both variable responses remain entirely on the positive area seven and nine quarters respectively, following the news shock. Investment increases for a year, but then falls and becomes negative.

Furthermore, a strong and persistent increase (appreciation) of the real exchange rate is observed, which lasts for more than two years before the credible set includes zero. The real exchange rate appreciation is due to an increase in long-term interest rate, which rises immediately, reflecting the anticipated increase of spending growth and the decline in tax revenue and potential inflationary pressures. Results corroborate the view that forward looking variables react on impact to fiscal news shock (see e.g. Beetsma et al., 2021). The appreciation of the real exchange rate leads to an overall deterioration of the trade balance. Exports fall on impact and remain negative for three quarters, indicating a loss in competitiveness. Imports increase significantly and remain in the positive area for approximately two years. The increase in imports aligns with the view of an expenditure switching channel.

Overall, the results of the news shock confirm the view of the twin deficits hypothesis, as they show that a budget deficit is followed by an appreciation of the US dollar and a consistent worsening of the trade balance. Finally, there are two noteworthy points. First, results show a positive comovement of the interest rate with consumption and investment. This finding is a bit puzzling in relation with standard theory, in the sense that only under certain assumptions models can predict an increase in consumption and investment after an expansionary government spending shock.[23] Second, the strong appreciation of the currency and the persistent increase in imports increase the demand for exports in the rest of the countries. Hence, the expansionary fiscal news shock is expected to produce positive spillovers effects.

Fiscal Surprises Figure 1.5 plots the impulse responses to a surprise shock. Government spending increases on impact and declines gradually to become negative after three years. The shift in the sign of the government spending response at later horizons indicates evidence of spending reversals, which is consistent with the drop in the long-term interest rate and the positive but short-lasting response of GDP and consumption. Output and consumption eventually turn negative after 3 quarters. Investment drops significantly immediately. The interest rate declines along with the exchange rate. The plunge in tax revenues reflect the

[23]Often empirical finding indicate that expansionary government sending shocks are accompanied by positive consumption and investment responses. In theoretical models consumption and investment can increase after an expansionary fiscal shocks only under specific assumptions. Such assumptions aim to alter the standard theoretical (RBC and NK) models so they can accommodate the empirical findings. Such alteration include modifying preferences: adopting non-separable utility or deep habits, introducing two types of households: Ricardian and non-Ricardian, allowing future government spending to decrease as a tool to reduce public debt (spending reversals), or introducing additional agents in the model (e.g.entrepreneurs that accumulate capital). For a survey of the effects of fiscal shock on macroeconomic aggregates see Hebous (2011) .

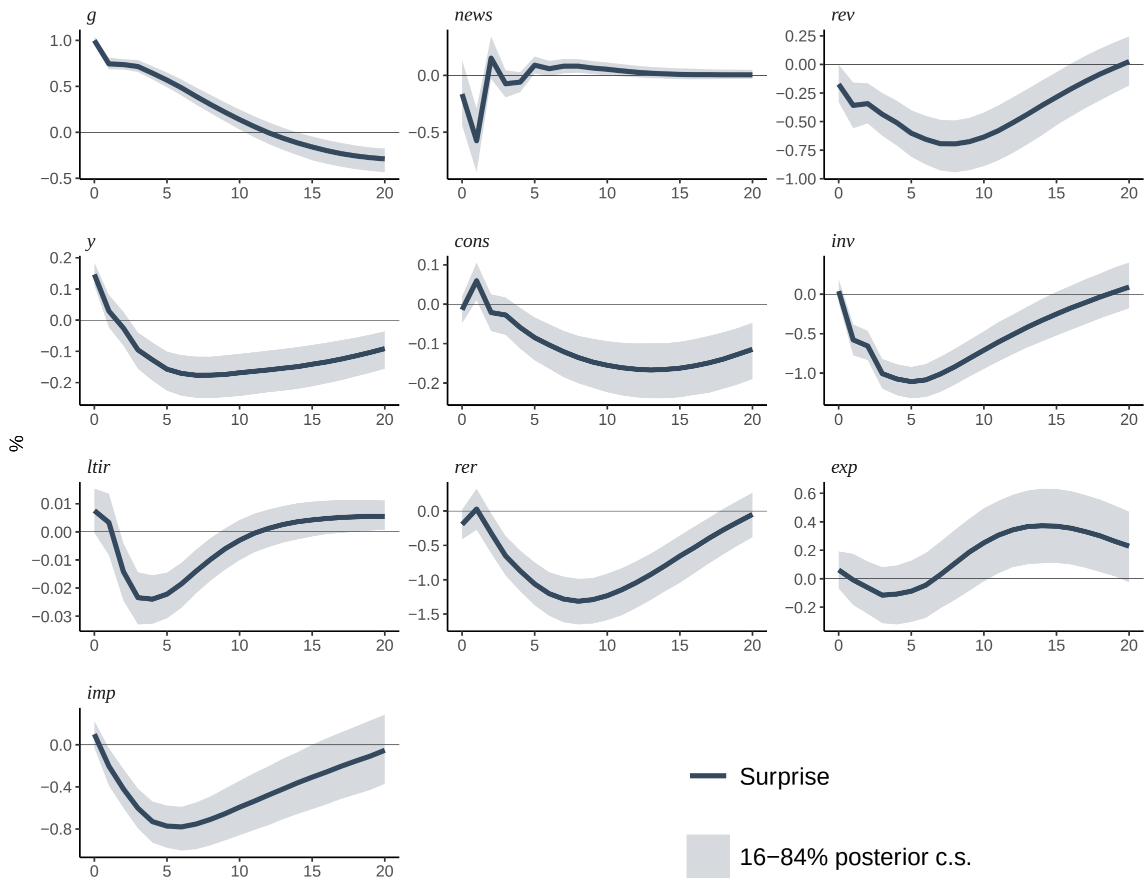


Figure 1.5: The domestic effects of the fiscal surprise shock.

Notes: *This figure shows the dynamic impact of a positive US fiscal News shock on key domestic variables. The vertical axis have been adjusted, so the peak of government spending is 1%. The figure depicts median impulse responses and their 68% central posterior credible set (c.s). All y-axis values are in percentage change. Positive real effective exchange rate (rer) responses indicate an appreciation of the $USD against a basket of foreign currencies.*

debt-financed deficits. Finally, exports gradually increase while imports fall strongly.

Although we do observe a strong and persistent real exchange rate depreciation, exports remain muted for two years and increase afterwards (consistent with a J-curve dynamic). Imports fall and remain negative for more than five years. The downturn of imports is due both to the negative wealth effects generated by the depreciation, and to Ricardian behavior of households reflected by the fall of private consumption.

It is also worth stressing the positive correlation between the response of exports and the response of the real exchange rate: after the seventh quarter, while the exchange rate starts increasing (appreciates), exports instead of falling start increasing faster. The counter-intuitive positive correlation between exports and the real exchange rate implies that results are not driven by the fall of long-term interest rate but rather by the fall of output, consumption and investments.

An interesting point is that the difference between the results of this study (and the paper of Forni and Gambetti (2016) as well) and the results of Kim and Roubini (2008) is that in my sample the response of output turns negative soon after the shock. Hence, the exchange rate puzzle depreciation should not be considered puzzling, as it is followed by slower economic activity and lower interest rate. What is puzzling though, is the fact that a fiscal expansion leads to an economic slowdown. Some authors (e.g.see Corsetti et al., 2012; Bianchi and Melosi, 2014; Ascari et al., 2023) support that after the great moderation, advanced economies are in a different regime with stronger fiscal discipline that mitigates the effects of fiscal policies. It is also possible that agents can observe the policy regime and they adopt a Ricardian behavior, decreasing their consumption. Nevertheless, the surprise shock leads to economic slowdown and is expected to work as a negative demand shock for the rest of the countries.

1.6.2 The international effects of US government spending

In this section, I examine the international transmission of the US fiscal policy shocks. Due to the high volume of results, I provide a detailed analysis for the rest of the G7 countries and Spain. Results for the remaining countries in the sample are summarised later on.

A general conclusion drawn from the results is that the news shock increases aggregate domestic demand and produces positive spillover effects the trade partners of the US. On the other hand, the surprise shock is produces a negative demand effect in the US and negative demand effect for the rest of the countries in the model.

Prior to the analysis of the empirical results, it is worth looking into the two main channels through which a fiscal policy shock originating from the US may affect the rest of the world. The first channel operates through the trade, which in turn affects foreign variables through either the expenditure boosting channel and/or through an expenditure switching channel. The former mechanism implies that following a fiscal expansion in the US, foreign countries can experience an income increase through higher export demand from the US. The expenditure switching channel implies that a fiscal expansion in the US will lead to the depreciation of the foreign real exchange rate, which in turn will boost foreign countries' exports.

The second channel through which fiscal policy shocks diffuse across countries is the financial channel. A fiscal expansion in the US will increase domestic interest rates, which in turn can impact foreign financial variables through financial linkages. The direction of spillover effects depends on whether the mechanism of spending reversal is active or not.[24]

[24] Corsetti and Müller (2013) show that expansionary fiscal policy can lead to a decrease in interest rates,

Spending Reversals Similar to Forni and Gambetti (2016) spending reversals are present in the news shock as well. For the News shock the government spending turns negative in longer horizons, after a period of persistent increase of government spending. Hence, in my case the key factor that explains the striking differences between the two shock is the timing of the spending reversals. Appendix A.4 shows the differences in responses of government spending between the two shocks. For the Surprise shock government spending peaks on impact and turns negative after 14 quarters. The effect on government spending is more persistent in the case of the news shock where government spending increases gradually and turns negative after 28 quarters.

1.6.3 The international effects of the news shock

This section presents the international effects of a positive government spending news in the US. Results show that a positive news shock in the US produces a positive spillover effect for the rest of the countries. Evidence shows that the effect is propagated mainly through trade, supporting the findings of view Nicar (2015) and Ilori et al. (2022). Specifically, there is evidence for a strong expenditure boosting channel, as a significant increase in exports is observed in almost all countries. Results are mixed regarding the expenditure switching channel, as the response of the real exchange rate differs across countries. Finally, the financial channel, captured by the fluctuations in the long term interest rates, seems to be working in the opposite direction from the trade channel. In contrast with the findings of Corsetti et al. (2012) and Faccini et al. (2016), interest rates increase in all countries, putting a drag on the magnitude of spillovers on foreign output.

Figure 1.6 shows the IRF of the G7 countries to a positive government spending news shock in the US. The rows represent the country, whereas the columns represent the response of the relevant variable. Although such results are mainly suggestive, I believe they provide useful information on the propagation mechanism.

There is evidence of homogeneous and positive response of all variables except for the real exchange rate (*rer*). The trade channel dominates the propagation of the shock, especially through the expenditure boosting effect, as exports increase in all countries. The increase in exports is stronger in Canada and Japan due to the close trade connections with the US.

The real exchange rate appreciates in Canada, the UK and certain countries in the South Euro area (SEA), such as Italy and Spain. The opposite trend is observed in the North Euro

by assuming that agents expect a subsequent spending reversal. Alternatively, a standard portfolio balance model predicts that an expansionary fiscal policy will lift both domestic (US) and foreign interest rates leading to lower foreign output.

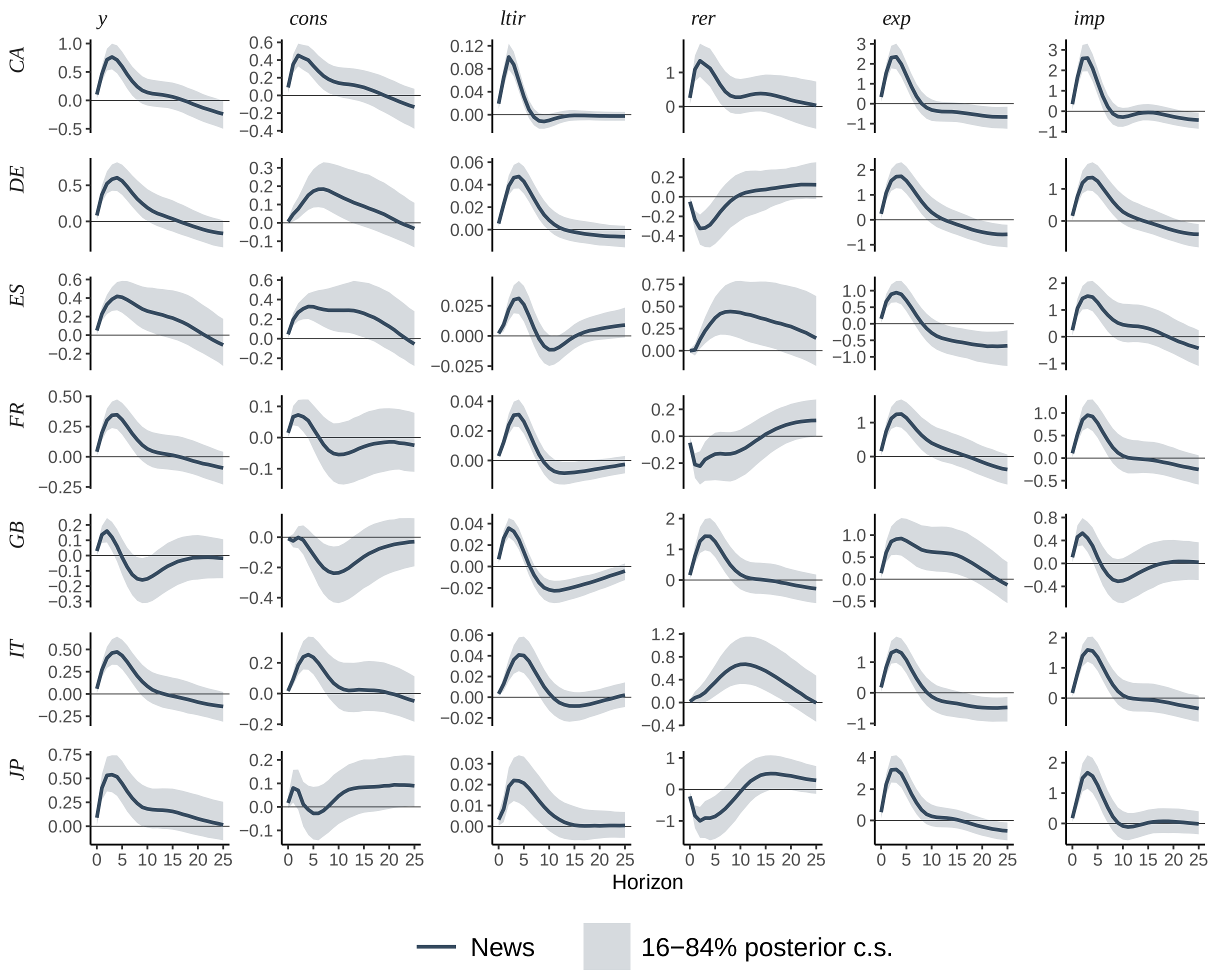


Figure 1.6: The international effects of the fiscal news shock - G7.

Notes: *The plot shows the international effects of a government spending News shock on the G7 countries. The shock has been normalised, in order for the US government spending to peak at 1%. The figure depicts median impulse responses and their 68% central posterior credible set.Positive real effective exchange rate (rer) responses indicate an appreciation of the domestic currency against a basket of foreign currencies.*

area (NEA), including France and Germany, as well as in Japan. The different exchange rate responses imply mixed evidence regarding the expenditure switching channel. The depreciation of the exchange rate in the NEA group and Japan is expected given the export oriented growth of these economies. The depreciation of the currency in these countries further amplifies the surge in exports. As a result, the trade channel dominates the increase in the interest rate (financial channel), and output, consumption and imports increase.

The SEA countries and Canada experience a currency appreciation. The rise in currency burdens the exports and stimulates consumption and imports. Indeed in these countries the trade deteriorates.[25]. The currency appreciation is further fueled by the rise in interest rates. The channel through which output increases remains unclear. On net, the effect on consumption due to stronger domestic currency should prevail the negative trade balance and the high interest rates, so as for output to increase. These findings align with a sizable literature on capital misallocation and productivity slowdown observed in SEA, induced by the adoption of a single currency. [26]

The UK is a noticeable exception and results indicate that different effects dominate over different horizons. Right after the shock, exports increase more than imports and the output and the interest rate rises, indicating that the exports effect dominate. However at later quarters, output, consumption and imports decrease, indicating that the financial channel becomes prevalent.

1.6.4 The international effects of the surprise shock

Figure 1.7 shows the impulse responses of foreign variables to a US fiscal policy surprise shock. Results are consistent with the negative demand scenario in the US and as discussed in 1.6.2. Similar to the fiscal news shock, there is significant homogeneity in the responses. The surprise shock produces a very short-lived positive effect on impact for the group of G7 (G6 plus ES) countries, yet this modest positive influence is abruptly dominated by substantially negative

[25]For ease of exposition, Figure A.3 in the appendix presents only the responses of exports and imports shown in Figure 1.6

[26]A number of papers in the literature support that the downturn of net export in Italy, Portugal and Spain was driven by both a demand (Import) driven growth model -import growth led model (IGLM)- and a decline in productivity due to capital misallocation following the introduction of euro and a subsequent credit abundance due to capital inflows. Regan (2017) argues that South Euro-Area (SEA) economies like Italy, Spain, Greece and Portugal, rely more on increased domestic consumption as a mechanism of economic growth. In doing so, the SEA countries follow an import-led growth model (IGLM). Rivera-Batiz and Romer (1991) and Esfahani (1991) show that imports of intermediate goods and technologies can boost domestic economic growth. Giavazzi and Spaventa (2011) show that the negative relation between real exchange rate and net trade in SEA countries was driven by a decline in productivity. In the case of Spain, the capital misallocation is caused by investment in sectors of low productivity, such as the housing market. Alternatively, in Italy, Hassan and Ottaviano (2013) describe the fall of TFP as a result of capital misallocation as "great unlearning".

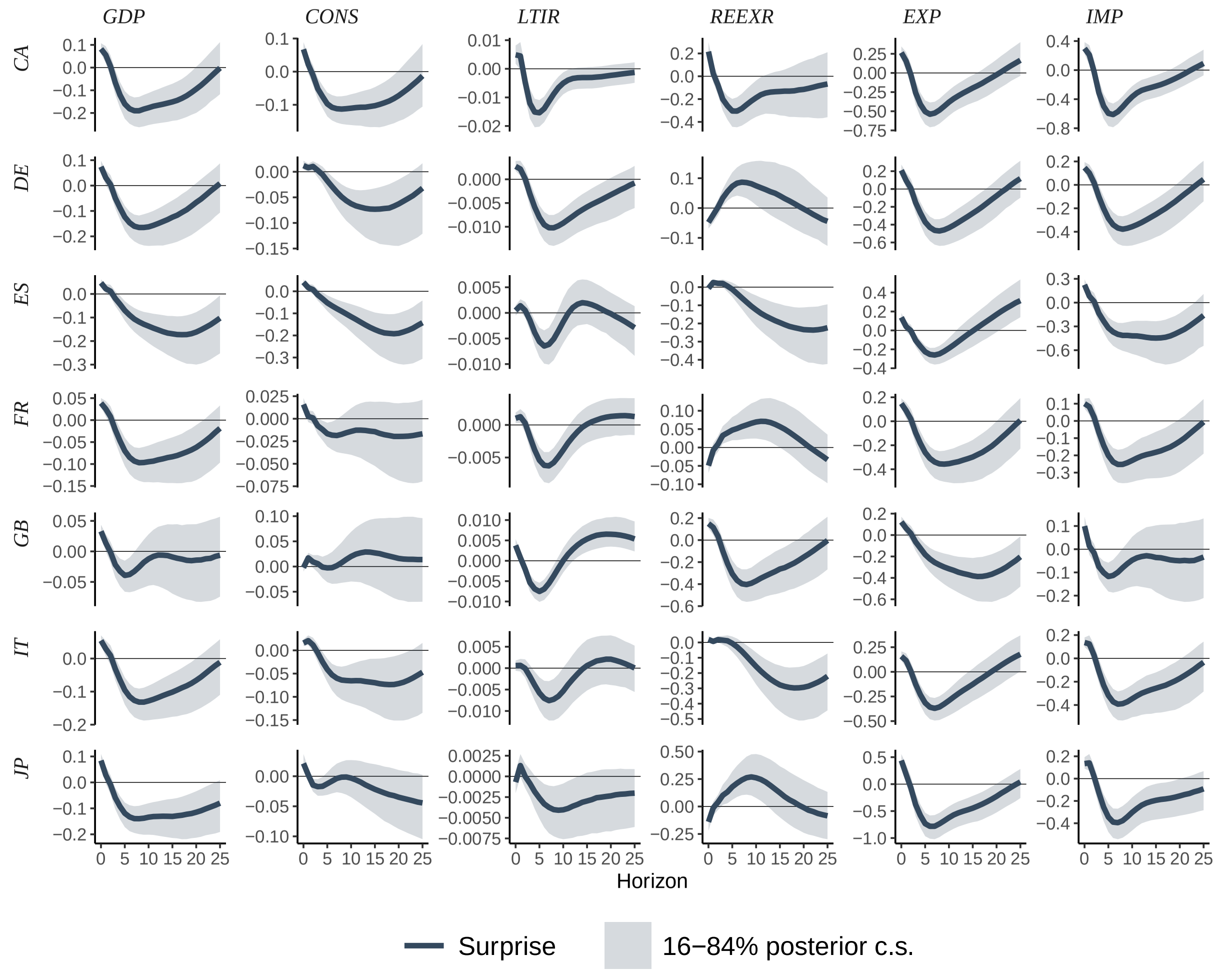


Figure 1.7: The international effects of the fiscal news - G7.

Notes: *The plot shows the international effects of a government spending Surprise shock on the G7 countries. The shock has been normalised, in order for the government spending to peak at 1%. The figure depicts the median impulse responses and their 68% central posterior credible set.*

effects. The responses of the surprise shock are almost a reflection of the responses to the news shock. All variables react negatively with the only exception being the real exchange rate, for which results are mixed, but as in the case of the news shock, countries can be classified accordingly. Overall, the size of the effects is quite small.

The international propagation mechanism of the shock is similar to the news shock, as variables responses are very similar but to the opposite direction. The propagation of the shock works through the negative response of the domestic (US) imports and the subsequent drop in exports in the foreign countries. The negative demand effect in the US has a direct negative effect on the exports of the foreign countries.

Similar to the case of the news shock, the responses of the exchange rate are mixed. In the NEA group and Japan, the exchange rate appreciates enhancing the negative response of exports. The trade balance deteriorates accordingly (exports fall more than imports). In the SEA group, the exchange rate depreciates, pushing exports to the opposite direction (to rise). Indeed, in these countries the trade balance improves (exports fall less than imports). However, the negative effect prevails and then consumption and output decrease.

The financial channel counteracts the negative effects of trade as the long-term interest rates declines in all countries. Overall the effect is muted by the strong trade channel. The only country that the financial channel seems to dominate is the UK. In the UK, Output decreases only slightly, consumption is unresponsive and imports fall only temporarily. The UK responses can be explained by a strong financial channel.

Finally it should be underlined that the results for both shocks can be driven by indirect spillover effects. For example, while the trade weights between the US and the individual SEA countries are low, the trade links between the US and NEA countries and the links of the latter with SEA are relatively high.[27] Therefore, a change in the US imports has an indirect impact on the SEA exports through its impact on the output of NEA and the UK. This complex sequences of trades uncovered further underscore the important of a rich well-specified open economy framework.

1.6.5 An overview of the effects on the whole panel of countries

This section summarises the results for the whole panel of the 19 countries. Figure 1.8 shows the IRF of GDP and consumption for each country and for the two different shocks. Each point represents the peak or trough of the median IRF. Bars indicate the 68% posterior credible set. The numbers on each row indicate the horizon at which the IRF peaks/plunges. Presenting the results in this way provides a better understanding of the relative size of the shocks across

[27] The full set of trade weights are reported in Table A.2

countries. However, as explained above, the comparison of the results is meaningful only across countries and not across shocks.

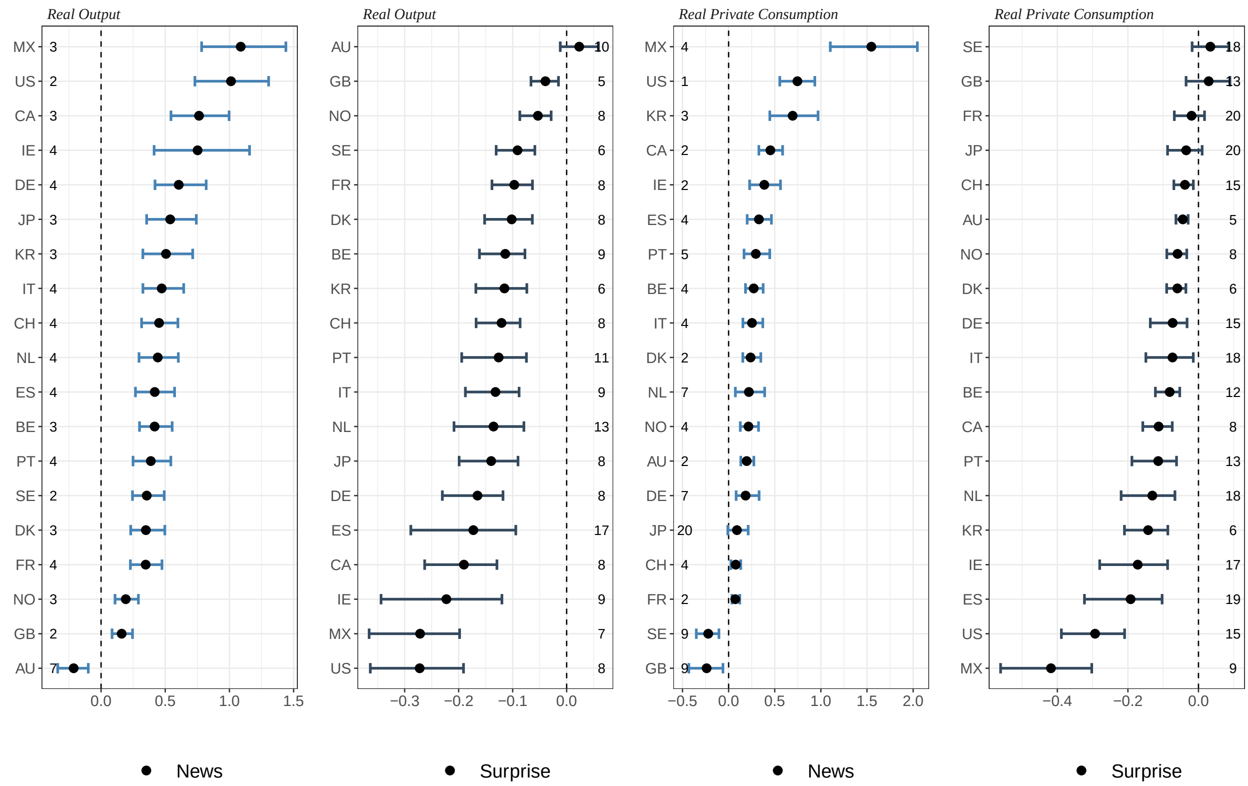


Figure 1.8: The international effects of the fiscal shocks on Output and Consumption - Total sample

Notes: *IRF functions of GDP and consumption to a government spending news and surprise shock in the US. Each point represents the peak or trough of the median IRF. Bars indicate the 68% posterior credible set. The numbers on each row indicate the horizon at which the IRF peaks/plunges.X-axis is normalised so that the US government spending peak is at 1%.*

Output and consumption responses are consistent with the aforementioned G7 results. The first two panels show that output increases for all countries except Australia in response to a positive fiscal News shock while it declines in response to a positive Surprise shock. The absolute strength of those effects maps somewhat to the trade shares shown in earlier Table 1.4. For the news shock, the maximum response is observed for Mexico, where the peak of the response is even higher that the one of the US. On the other hand, the surprise shock produces negative responses for all countries, with Mexico being affected most. The two right panels show that in terms of consumption, a similar conclusion can be drawn. In the majority of countries, there is a positive impact on consumption following a news shock, whereas the opposite holds true for the surprise shock. Mexico stands out as the country that is influenced the most by the shocks originating from the US. For both shocks, the least affected countries are Sweden and the UK.

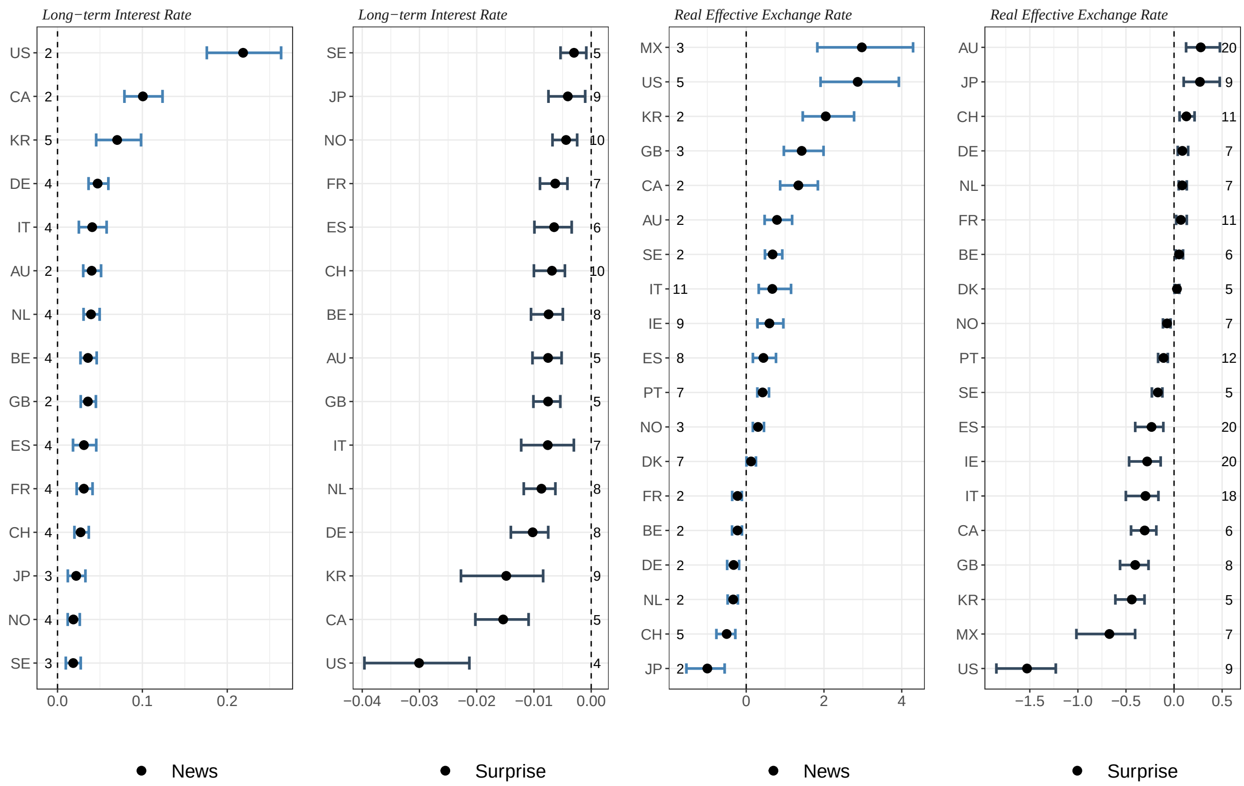


Figure 1.9: The international effects of the fiscal shocks on LTIR and REEXR - Total sample

Notes: *IRF functions of GDP and consumption to a government spending news and surprise shock in the US. Each point represents the peak or trough of the median IRF. Bars indicate the 68% posterior credible set. The numbers on each row indicate the horizon at which the IRF peaks/plunges.X-axis is normalised so that the US government spending peak is at 1%. Positive responses indicate a real appreciation of the domestic currency against a basket of foreign currencies.*

Figure 1.9 illustrates the IRF of the long-term interest rate and the real effective exchange rate. The responses of the former uniformly increase in all countries after the News shock and decline after the Surprise shock with the home country most affected. In both shock, the interest rate captures future expectations about inflation and the future stat of the economy. The interest rate responses indicate that the shock is propagated through a financial channel and counteracts the positive/negative effects of the trade channel. Finally the last two panels to the right show the responses of the exchange rate, which mirror the responses of the long-term interest rates: appreciate in response to a News shock; depreciate in response to a Surprise shock. As discussed in previous sections the exchange rate responses are characterised by heterogeneity, enhancing or undermining the trade effect in depending on the shock and the country.

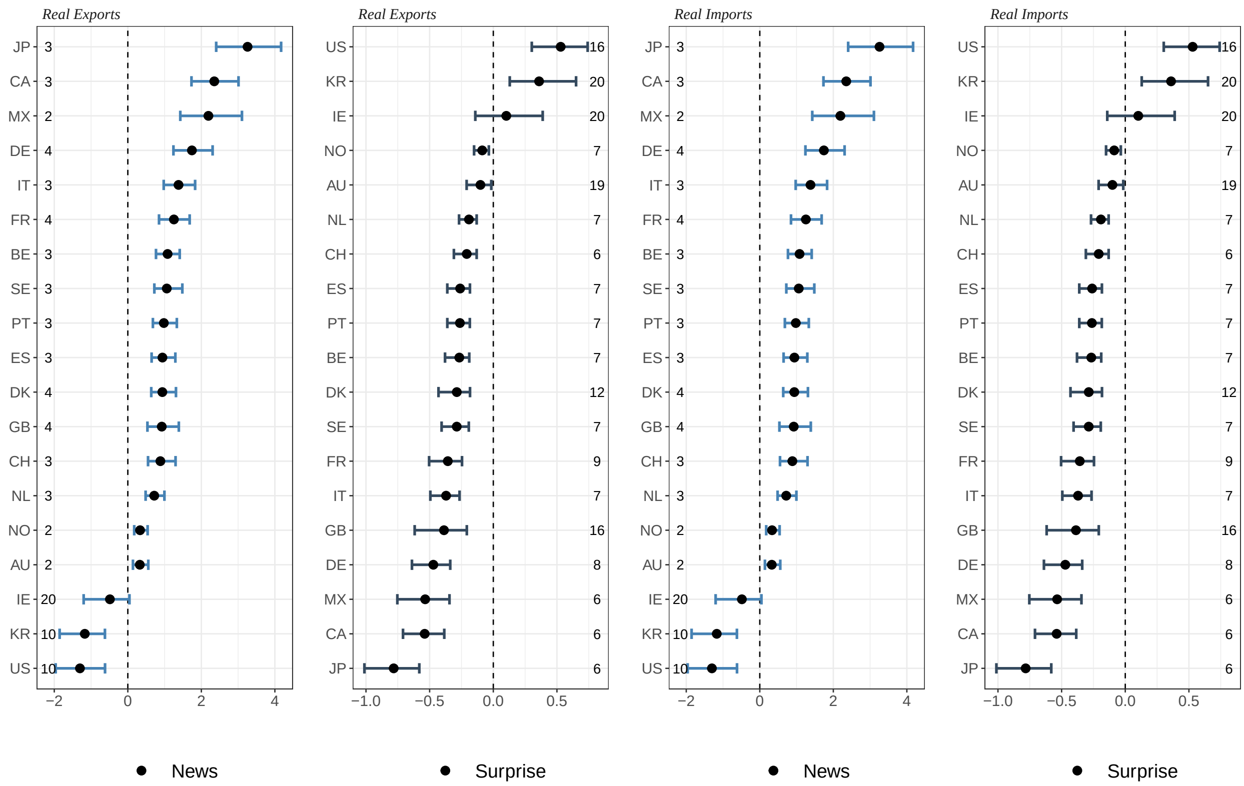


Figure 1.10: The international effects of the fiscal shocks on Exports and Imports - Total sample

Notes: *IRF functions of GDP and consumption to a government spending news and surprise shock in the US. Each point represents the peak or trough of the median IRF. Bars indicate the 68% posterior credible set. The numbers on each row indicate the horizon at which the IRF peaks/plunges.X-axis is normalised so that the US government spending peak is at 1%.*

Finally, Figure 1.10 shows the responses of exports and imports, which follow a similar pattern to the reactions of output and consumption: an increase in response to a news shock and a decline following a surprise fiscal shock. As in previous analyses, we observe a significant degree of variation in country-specific responses, which reflect the strength of the relevant trade linkages and the underlying growth models of the recipient economies.

1.6.6 Robustness checks

Results are robust to a number of checks. Particularly, I re-estimate the model with different number of lags, additional or alternative variables. I consider a model where the US is a dominant unit. Robustness checks results are presented in appendix A.5. Due to the great volume of results I present only the international effects of the fiscal news shock.

1.7 Conclusion

In response to the great recession and COVID-19, a large volume of research focused on the effects of fiscal policy on domestic macroeconomic variables. Research on international spillover effects of fiscal policy is scarce. This chapter has attempted to fill this gap in the literature by measuring the international spillovers of government spending shocks originated from the US.

My contribution to the existing literature of fiscal spillovers is two-fold. First, contrary to previous studies that estimate international fiscal spillovers, I distinguish between anticipated (“News”) and unanticipated (“Surprise”) government spending shocks. I identify government spending news and surprise shocks using forecasters survey data. Second, previous work in the area relies on a bi-lateral analysis that examines the effects between two countries. Although bilateral models are easy to implement, they do not account for the indirect (higher-order) spillover effects by a third or more economies. In this chapter, I estimate the cross-country spillovers within a Bayesian GVAR framework that allows the joint modelling of multiple economies, accounting for both direct and indirect (through a third country) spillover effects.

The main results of this study are as follows:

First, focusing on the domestic effects of a fiscal policy shock, the results indicate that a *fiscal news* shock leads to a gradual and persistent increase in government expenditure, and a positive response of GDP and consumption, while the exchange rate appreciates and net trade deteriorates consistently. This accounts for the evidence of the exchange rate puzzle noted by Kim and Roubini (2008).The surprise shock has a strong crowding out effect on US consumption and is leads to a a significant drop in the output. The interest rate declines and the exchange rate depreciates. Such results indicate a significant negative demand effect in the US. Results of the fiscal surprise shock can be explained through a spending reversal mechanism (Corsetti et al. (2012))

Regarding the international spillover effects, US fiscal News shocks impact other countries primarily through the trade channel, with the caveat that for the UK, both trade and financial channels matter; this observation is compatible with the UK’s extensive financial services share. Exports respond strongly in all countries in the sample. Higher exports result to an increase in foreign output and consumption. The responses of the real effective exchange rate are mixed.

The opposite effect is observed for the *surprise shock*. The crowding out effect on US consumption has a negative demand effect on the rest of the countries. Foreign exports decline and GDP decreases. The international propagation mechanism of the shock is similar to the news shock, as variables responses are very similar to the news shock, but to the opposite direction.

Finally, I stress the importance of higher-order spillovers. SEA countries show persistent net trade improvement due to larger import declines (relative to exports) – while the UK, France, and Japan experience net trade downturns exacerbated by output and import declines in both the US and other countries in the sample.

My findings underscore the importance of taking into account the global perspective when analyzing the international transmission of fiscal policy shocks, and distinguishing between different types of shocks. This chapter should be useful to other researchers that are interested in assessing the consequences of significant policy changes in the global economy. Similar consideration might well apply when analyzing the national and international dimension of other shocks, such as monetary and macro-prudential policies.

Chapter 2

Sectoral government spending multipliers: An empirical study for the UK

2.1 Introduction

In the aftermath of the financial crisis of 2008, government purchases of goods and services has played a prominent role as a tool for economic stabilisation. A substantial body of research has focused on estimating government spending multipliers, which quantify the overall impact of government expenditure on output. Despite advancements in understanding fiscal multipliers (see Ramey (2019)), prevalent practice in empirical studies is to treat output as a homogeneous product and government spending as a large single transaction. Exploring the overall effect of "big G on big Y" can be insightful for the overall assessment of government spending effects, but often lacks practical usefulness for the effective navigation of fiscal policies[1]. Recognising the importance of the sectoral dimension in the propagation of fiscal shock in the economy, *this chapter uses an empirical framework to calculate sectoral fiscal multipliers for the UK*.

Total output is not a homogeneous product. The economy consists of a wide range of sectors interconnected through the exchange of intermediate goods and services, forming a complex production network. Similarly, government spending is not a singular transaction. It functions through a vast system of agencies and departments, each with distinct procurement processes and responsibilities. The overall expenditure is the result of a multitude of transactions distributed across various firms and sectors of the economy.

When the government directly purchases products or services from a specific sector, it causes fluctuations in sectoral demand. However, the impact of government spending is not necessarily limited to that sector. The fiscal shock can spread to other sectors through the

[1] Cox et al. (2020) refer to aggregate government spending as the "Big G"

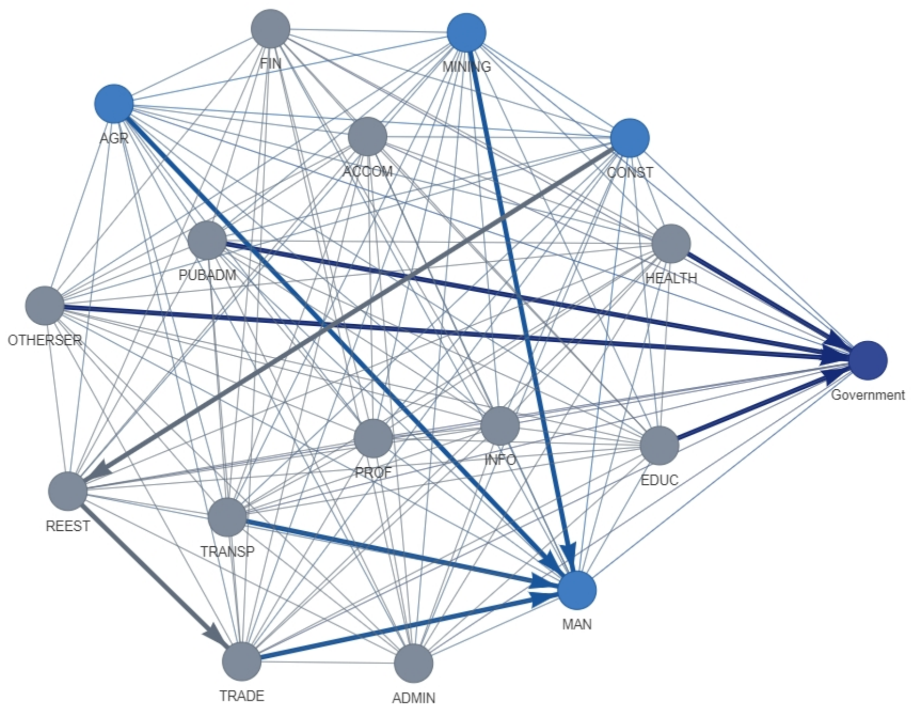


Figure 2.1: A representation of the government spending in a production network.

The graph is a representation the demand channels running across the government and production network digraph associated with the 16 sector version of the input-output tables provided by OECD. Data were averaged over the 1997-2019 period. Blue dots indicate Goods producing sectors. Grey dots indicate Service producing sectors. Arrows point to sectors that act as significant "Buyers". Thick lines indicate a strong intersectoral trade links where more than 15% of sector i total sales go to sector j (pointed by the arrow).

intersectoral trade of intermediate goods. Essentially, a sector directly affected by the fiscal shock ramps up production to meet the increased demand from the government. To do this, it requires more inputs from its suppliers, which leads to higher demand in those supplier industries. As a result, the fiscal shock continues to propagate throughout the economy. Thus, the overall effect of government purchases on the economy can be viewed as the outcome of various sector-specific shocks, which are either amplified or dampened within the broader production network. Figure 2.1 visualises the aforementioned idea, using UK Input-Output data. The graph represents the UK economy as a production network of 16 sectors along with the distribution of government purchases across the nodes of the network[2].

[2]The production network is described in detail in section 2.5.3. For interpretation of the elements of the graph see the caption of figure (2.1).

Contribution: This chapter contributes to the empirical literature of fiscal policy in several dimensions.

First, to the best of my knowledge, this is the first study that **calculates government spending multipliers at the sectoral level** using an empirical model. Many authors have analysed the effects of fiscal policy using model with multiple sectors (see Ramey and Shapiro (1998); Cox et al. (2020); Bouakez et al. (2023)). However, there is still a lack of substantial econometric evidence. Existing empirical studies (see Nekarda and Ramey (2011); Acemoglu et al. (2012); Barattieri et al. (2023); Bouakez et al. (2023)) utilise disaggregated industry-level data, but they primarily focus on the average impact of fiscal policies on the aggregate output. The individual sectoral effects have been overlooked so far. This paper addresses this gap by empirically examining the sectoral effects of government spending shocks for the UK economy.

The scarcity of empirical evidence on the sectoral effects of government spending is often due to data unavailability, that poses important constraints for sectoral analysis. For example, sector specific government spending or sectoral output data are not always available or they are reported only in annual frequency and for only short samples. This makes individual sectors' analysis fragile.[3] The UK is an interesting case as disaggregated data are available for a quite long sample. The second contribution of this chapter is the **proposal of multi-sector time-series model** that circumvents the data availability constraints and can be used to calculate sectoral fiscal multipliers.

Expanding upon the work of Perotti et al. (2007); Ramey (2011) and Acemoglu et al. (2016) among others, my empirical analysis relies on three types of data: Aggregate data, sector-level data and Input-Output tables. My sample spans from 1997 to 2019. Exploratory analysis of UK input-output tables reveal the following **3 stylised facts for the UK economy**.

Fact 1: The relative shares of the sectors, measured as sectoral Gross Value Added (GVA) over total economy GVA, have remained stable over time. The main exceptions are the Mining, Energy & Water sector, which has experienced a significant decline, and the Information sector, which has shown strong growth.

Fact 2: Government demand is heavily and systematically concentrated in three sectors, accounting for 93.1% of government expenditure. These are Public Administration and Defence (38.6%), Health (38%), and Education (16.5%). The rest 7% is spread to the rest of the industries.

Fact 3: The intersectoral trade flows of intermediate inputs, measured in relative terms,

[3] Existing studies (see Nekarda and Ramey (2011); Acemoglu et al. (2016) among others) often use datasets that cover only the manufacturing sector and its sub-sectors, and not for the whole economy.

remain remarkably stable over time.[4] Notably, only 4 out of 225 time series for intermediate input demand exhibit a standard deviation exceeding 5%.

Empirical Methodology I exploit these three stylised fact to estimate a Bayesian GVAR model with a sectoral dimension to study the sectoral effects of an aggregate government spending shock. This empirical approach provides a convenient framework where aggregate and sectoral variables are directly linked and the structural shock can be recovered using standard VAR identification methods.

Specifically, I estimate a GVAR model with 17 units; the 16 sectors and one unit that represents the total market. For each unit I specify a VARX model that is conditioned on the variables in the rest of the units. The total market VARX contains all the aggregate macroeconomic variables except aggregate output and employment. The dynamics of these two variables are determined in the sectoral VARXs. The total market unit affects directly each sectoral unit, depending on the sectoral composition of government spending. The model accounts for higher order effects arising from intersectoral linkages, as described by input-output tables.

I identify the government spending shock using a recursive identification scheme and by controlling for fiscal foresight. I simulate a 1% expansionary aggregate fiscal shock. The interpretation of the shock is equivalent to a simultaneous 1% increase of government spending in every sector. It should be underlined that as the model accounts for the uneven sectoral distribution of government spending as described in **Fact 2**, the absolute government spending increase across sectors will vary significantly.

The modelling approach has several advantages. First, unlike other methods, this model captures fully the heterogeneity across industries and allows me to obtain IRFs for each individual industry variables. Second, I demonstrate that estimating a government spending shock that preserves the historical average sectoral composition, creates a direct mapping between the aggregate output response, as estimated with an aggregate variables VAR and the individual sectoral responses estimated with the multi-sector model. By exploiting the direct link between sectoral and aggregate outcomes, I analyse how each sector contributes to the aggregate output response and the aggregate fiscal multiplier. Additionally, the model itself creates several feedback loops between sectoral and aggregate variables, enabling the distinction between direct and indirect government spending effects. A restricted version of the model, where the intersectoral trade channel is shut down, uncovers the magnifying role of the production network in the transmission of the shock and how it contributes to the

[4] I measure the intersectoral trade flows between sector A (supplier) and sector B (client), as the value of product of A used in production of sector B over the total value of intermediate inputs used by sector B.

aggregate output response.

Findings This chapter answers the following three questions:

1. What are the sectoral output multipliers?

   Findings indicate that the aggregate fiscal multiplier in the UK is 0.43 on impact and it converges to 0.73, four quarters after the shock. The highest sectoral multipliers are initially observed for Public Administration, Education and Healthcare; the three industries that systematically receive over 90% of the total government spending. At later horizons, when the shock is transmitted to other sectors through the Input-Output linkages, the multipliers of three (public) sectors shrink and increase in the remaining industries. Eight quarters after the shock, the larger multipliers are observed for Trade, Manufacturing and Finance. These three sectors contribute over 60% to the overall multiplier. Additionally, Mining and Real Estate are the only sectors with negative multipliers.

2. What sectoral characteristics can explain the differences across sectoral output multipliers?

   Differences across sectoral multipliers can be explained by the sectoral upstreamness, a metric that describes the importance of each sector as a supplier. The intuition for this result is that industries that serve as important suppliers in the production network, raise their production to meet not only the higher government demand, but also the additional demand for intermediate inputs from other sectors. Other characteristics that can explain the cross-sectoral multiplier differentials are the sectoral exports and the sectoral price rigidity. Specifically, I find that sectors that are export-oriented have higher multipliers. The explanation is again that sectors that are export-oriented, face higher demand triggered by government spending on top of the demand from the external sector. Finally, multipliers are larger for sectors with higher price rigidity (measures as sectoral price deflator volatility).

3. What is the role of the production network in the propagation of the fiscal shock?

   Finally, I find that the production network works as an amplifier of the effect of the fiscal shock. Results from the restricted model with no sectoral interactions, show that the multiplier is 30% lower than the one of the baseline model. This result reveals the importance of the intersectoral trade in the propagation of the fiscal shock and the overall importance of the production network on the effectiveness of fiscal policies.

The remainder of the chapter is organised as follows: Section 2.2 provides a brief review of the literature that examines the sectoral effects of government spending. Section 2.3 discusses the individual components of the GVAR model, the estimation, the identification and the dynamic analysis. Section 2.4 describes the aggregate and sectoral data used in the analysis, and discusses the specification of the individual VARX models. Section 2.5 establishes some stylised facts for the structure of the UK production network as summarised by the Input-Output tables. Section 2.6 discusses the results and Section 2.7 concludes.

2.2 Literature Review

This chapter studies the sectoral effects of government spending in the UK, by employing a global VAR model with a sectoral dimension. In this section, I provide a summary of the relevant empirical evidence from existing literature, that informs this study. A number of papers had previously considered the sectoral dimension of government spending. I group the existing studies in two categories; First, the studies that consider the sectoral dimension without taking into account the inter-sectoral connections and second, the studies that account for intersectoral linkages. Finally, I discuss some papers that model sectoral data using a GVAR approach.

2.2.1 Studies on the sector-level effects of fiscal policy that do not account for intersectoral linkages

Nekarda and Ramey (2011) study the effects of industry-specific government spending shocks on sectoral hours, real wage and labour productivity. By combining data from IO tables, the BEA and the NBER-CES Manufacturing Industry Database authors build a dataset that links sector-specific government demand with other sectoral variables. Their dataset consists of 274 industries spanning from 1960 to 2005. Results of panel data analysis corroborate the predictions of a neoclassical model where sectoral specific government spending increases sectoral output and hours, whereas markups remain unchanged, and productivity and wages decrease. A recent paper from Sabaj et al. (2023) studies the direct effects of sector-specific government consumption and investment on sectoral production for a panel of OECD countries. The results report strong heterogeneity depending on the type of public spending (investment or consumption) and across sectors. Differences are explained by different degree of price stickiness and the relative position of each sector in the production network. Bouakez et al. (2023) investigate the effects of aggregate government spending shocks in a New-Keynesian model of a highly disaggregated multi-sector economy. They report that the fiscal multiplier in their multi-sector model is 75% higher than the baseline single-sector model. The amplification of the multiplier is primarily attributed to input-output interactions and to a lesser degree to the heterogeneity in sectoral price-rigidity, as often indicated for the transmission of monetary policy shocks. While their contribution is mostly theoretical, they empirically confirm that the sectoral multipliers increase with the upstreamness of the sector within the production network[5].

2.2.2 Studies on the sector-level effects of fiscal policy in a multi-sector framework accounting for intersectoral linkages

Acemoglu et al. (2016) is the first paper to provide empirical evidence on the sectoral effects of fiscal policy by taking into account input-output linkages. Authors develop a theoretical static multi-sectoral model that predicts strong downstream propagation of supply-side disturbances but stronger upstream propagation for demand shocks. The theoretical predictions of the model are empirically tested considering the case of a government spending shock, as a proxy for a demand side disturbance. Using a dataset similar to the one of Nekarda and Ramey that combines industry level data and IO tables from 1991 to 2009, sector specific government spending shocks are found to propagate through the input-output network. Empirical results corroborate the strong upstream propagation of the public spending shock. Sectoral value added and employment increase with spending in sector's important "customer" industries. Their results do not support the downstream propagation of the public spending shock.

The study of Barattieri et al. (2023) is complementary to the work of Acemoglu et al. (2016). Authors study empirically the government spending effects on the US production network, by broadening the analysis in the following two directions: First, they identify government spending shocks at the sectoral level, using a novel IV approach. For the construction of their instrument, they use disaggregated procurement data from the *USASpending.gov* database. Second, they explore the role of sectoral prices in the propagation of the shock. They observe that there is an increase in both output and employment in the industries directly affected by the shock, as well as in their suppliers (upstream industries). Sectoral prices rise due to higher government demand and demand for intermediate inputs. The rise in prices accounts for the crowding out of employment in downstream industries.

[5] The definition of upstreamness and downstreamness often varies across the applied literature. Here I follow the definition of Acemoglu et al. (2016) where upstream industries are considered those that are important suppliers, while downstream industries are those that serve as important consumers.

2.2.3 Studies using the GVAR approach to model sectoral interconnectedness

The GVAR model as proposed by Pesaran et al. (2004), allows the joint modelling of different units/economies (see Chudik and Pesaran (2016)). This model is a valuable tool for examining the propagation of shocks across units, by effectively reducing the dimensionality of the model. While the vast majority of studies in the GVAR literature focus on the international propagation of economic shocks, it is worth noting that GVAR does not necessarily requires a country dimension.

This paper aligns with the literature where GVAR is used to model sectoral data. Hiebert and Vansteenkiste (2010) estimate a GVAR model to examine how different shocks, such as trade openness and technology shocks, affect the labour markets across various sectors within the US manufacturing industry. Holly and Petrella (2012) adopt the GVAR ("sectoral VAR" as they name it) approach to study the propagation of an aggregate technology shock in a highly disaggregated panel of manufacturing sectors. In a more recent paper, Dragomirescu-Gaina and Elia (2021) use a GVAR for 13 one-digit sectoral disaggregation, to study the effects of an investment-specific and neutral technology shock on sectoral employment and sectoral job creation.

This study improves upon the existing literature in the following directions. First, it employs a framework that is used to estimate the effects of government spending on each sector by taking into accounts the effects of inter-sectoral trade and by fully taking into account the sectoral heterogeneity. For example, the work of Acemoglu et al. (2016) and Barattieri et al. (2023), while takes into account I-O linkages and intersectoral heterogeneity, rely on a panel data data methods with homogeneous estimators. This means that authors can report only average effect. My approach, is based on a sector-by-sector estimation and allows me to report IRF for each individual sector.

Another important advancement is the Bayesian approach that I follow to estimate of the model. To large extend, previous work is bounded by the limited time dimension of the sample as sectoral data are not available for long sample. I worked around this problem using Bayesian shrinking for the parameters of my model.

Finally, previous work on the GVAR literature relies on reduced form estimation. My work is close to Dragomirescu-Gaina and Elia (2021) who identify a structural aggregate-technology shock in a the GVAR using a dominant unit approach. Specifically, they consider a GVAR with a sectoral dimension and assume that the technology shock is emanated by an independent unit that represent the aggregate economy. However, their setting assumes that the technology shock affects symmetrically all the sectors in the economy. This study is the first to use the GVAR approach with a sectoral dimension to study the propagation of a structural policy shock in a multi-sectoral framework by accounting for the uneven effects of the structural shock across sectors[6].

2.3 Model

The GVAR is an econometric model that models a number of economic units simultaneously. The model works in two steps: The first step requires the estimation of a VARX* model for each unit. Here, the total number of units equals to the number of sectors, plus a unit for "Total Market" that represents the aggregate economy. In my baseline setting, the dynamic of all aggregate variables, except output and employment, are determined within the Total Market model [7]. Therefore, in the Total Market model, all aggregate economy variables are endogenous, while output and employment are treated as exogenous. All sectoral models are identical, with the employment and output being endogenous, while the Total market variables are included as exogenous. The second step of the model is purely mechanical. The estimated coefficients of the first step, that dictate the relationship between variables across units, are rearranged so that the model is given a VAR(1) formation, namely the global representation. The global representation can be used to trace the dynamic propagation of shocks as in ordinary VAR analysis.

In the following sections, I provide the details of the sectoral and the Total Market models, along with the global solution of the model. In addition, I discuss the actual specification of the VARX*s, the identification and the estimation methods.

2.3.1 The Sectoral Model

Each sectoral model is augmented with two types of variables that, at the stage of estimation, are treated as weakly exogenous. The first type is the *foreign* or the *star* variables, as commonly referenced in the GVAR literature, which account for intersectoral effects. The second type capture the direct impact of government on each sector and are typically referred to as *common factors*. Sectoral models are identical across all sectors and are described by equation Eq. (2.1) as follows:

[6] This paper is also related to the literature that explores the sectoral effects of government spending using less granular definitions of sectors. For example Monacelli and Perotti (2008); Tagkalakis (2015); Cuaresma and Glocker (2023); Cardi and Restout (2023)

[7] The baseline Total Market model includes the fiscal variables, the interest rates, the stock index and the exchange rate.

$$\mathbf{Y}_{it} = \sum_{l=1}^{p_i} \mathbf{\Phi}_{i,l}\mathbf{Y}_{i,t-l} + \sum_{l=0}^{q_i} \mathbf{\Lambda}_{i,l}\mathbf{Y}^*_{i,t-l} + \sum_{l=0}^{q_i} \mathbf{\Gamma}_{i,l}\mathbf{S}_i\mathbf{X}_{t-l} + \mathbf{u}_{i,t} \tag{2.1}$$

where $\mathbf{Y}_{i,t}$ is a k_i-dimensional vector of sector-level endogenous variables. $\mathbf{Y}_{t-1}$ contains the autoregressive term. The k_i^*-dimensional vector $\mathbf{Y}^*_{i,t}$ contains the sector-specific *star* variables which represent the influence of the rest $N-1$ sectors on sector i and capture the relative spillovers. Given that sectoral models are identically specified, they have the same number of star variables, thus $k_i^* = k_i$. Star variables are calculated as weighted averages of the corresponding sectoral variables of the other sectors, with weights based on Input-Output linkages. Specifically, star variables are described by Eq. (2.2).

$$\mathbf{Y}^*_{i,t} = \sum_{j\neq i}^{N} m_{i,j}\mathbf{Y}_{j,t} \quad \text{with} \quad \sum_{j=1}^{N} w_{ij} = 1 \tag{2.2}$$

where I assume that $m_{i,j}$ is a weight that shows the strength of the effect of sector j on sector i. Weights $m_{i,j}$ rely on the intersectoral trade and are calculated by the UK Input-Output tables as discussed in section Section 2.5.3.

$\mathbf{X}_t$, is the k_x vector of the common variables, the dynamics of which are determined in the Total Market model[8]. $\mathbf{S}_i$ is a $k_x \times k_x$ diagonal matrix of deterministic weights. $\mathbf{S}_i$ is sector-specific, such that the j^th element of the main diagonal defines the strength of the effect of the j^{th} common factor on sector i. For instance, common factors such as interest rate, are not sector-specific and are expected to have a priori, the same weight in all sectoral models. Thus, the corresponding diagonal element will be equal to 1. On the other hand, government spending is unevenly distributed across sectors, as each sector receives a different proportion of the total government purchases. In this case, the corresponding diagonal element of S_i, will be equal to the share of government purchases from sector i. Finally, common variables can be excluded by setting the relative diagonal element of $\mathbf{S}_i$ equal to 0. The sector-specific elements of $\mathbf{S}_i$ were extracted from Input-Output tables and are discussed in detail in Section 2.5.2.

Finally, $\mathbf{\Phi}_{i,t}$, $\mathbf{\Lambda}_{i,l}$, and $\mathbf{\Gamma}_{i,l}$, with l =1,2,...p_i/q_i, are matrices of coefficients with dimensions $(k_i \times k_i)$, $(k_i \times k_i^*)$ and $(k_i \times k_x)$ respectively. $\mathbf{u_{i,t}}$ is a $k_i \times 1$ vector of sector-specific shocks that follows a white noise process with variance-covariance matrix $\mathbf{\Sigma}_{u,i}$: $\mathbf{u}_{i,t} \sim iid(\mathbf{0}, \mathbf{\Sigma}_{u,i})$.

2.3.2 The Total Market Model

I consider the total market unit to be the *dominant unit* of the model (see Chudik and Pesaran (2016)). The dominant unit can have a contemporaneous effect on the other units of the model

[8] k_x is the number of the endogenous variables of the Total Market model, described in Section 2.3.2.

but receives feedback effects only with a lag. Intuitively, this implies that, for the purpose of estimation, aggregate variables are determined independently of sectoral variables[9]. Sectoral variables can affect aggregate variables, but not within the same quarter (feedback effects). The inclusion of contemporaneous terms of sectoral variables would made the estimation of the model impossible as it would introduce a simultaneous equation bias. The dynamics of the total market model are described by Eq. (2.3).

$$\mathbf{X}_t = \sum_{l=1}^{p_i} \mathbf{\Phi}_{x,l}\mathbf{X}_{t-l} + \sum_{l=1}^{q_i} \mathbf{\Lambda}_{x,l}\mathbf{Y}_{x,t-l} + \mathbf{u}_{x,t} \tag{2.3}$$

where $\mathbf{X}_t$ is the k_x-dimensional vector including aggregate macroeconomic variables. The autoregressive terms are represented by $\mathbf{X}_{t-1}$. Sector-level variables are excluded from $\mathbf{X}_t$, as they are determined in the sectoral models as described in section 2.3.1. $\mathbf{Y}_x$ is a $k_i \times 1$ vector of feedback effects capturing the overall effect of sectoral variables on government[10]. Feedback effects are cross-sectoral sums as follows;

$$\mathbf{Y}_{x,t} = \sum_{i=1}^{N} \mathbf{Y}_{i,t}$$

For example, if the endogenous variables for each sector are output and employment, the dimension of vector $\mathbf{Y}_{x,t}$ will be 2×1. In this case, the cross-sectoral sum of employment and output will be equivalent to aggregate output and employment [11]. $\mathbf{\Phi}_l$, and $\mathbf{\Lambda}_l$ with l $=1,2,...p_i/q_i$ are matrices of coefficients with dimensions $k_x \times k_x$ and $k_x \times k_x^*$ respectively. Finally, $u_{x,t}$ is a k_x vector of aggregate shocks that follows a white noise process with variance-covariance matrix $\mathbf{\Sigma}_{u,x}$: $\mathbf{u}_{x,t} \sim iid(\mathbf{0}, \mathbf{\Sigma}_{x,i})$.

The described setting resembles a typical VAR system with aggregate variables. In this system, the fiscal and other variables are ordered first in the endogenous vector, whilst output and employment are at the bottom. Eliminating the last two equations of such a VAR system, would results in a system identical to the total market model described above.

[9]This assumption is made for the estimation stage. In the global representation of the model all variables are endogenous

[10]As described in section Section 2.3.1, k_i is the number of endogenous variables in the sectoral models.

[11]Usually, in the GVAR literature, the star variables are the weighted sum/average of the cross-sectional variables. Here I assume that the feedback effect is equal to aggregate GDP and employment. However, when I solve the model, I impose that the feedback of each sector on the aggregate economy is analogous to its relative size

2.3.3 The global solution of the model

In the second step of the GVAR model, the estimated coefficients of the government and the sectoral models are rearranged and solved as a complete global VAR model. In the global representation, the aggregate and sectoral variables are all directly related to each other. The model can be written as an ordinary VAR(1) process, which is used for conducting dynamic analyses such as Impulse Response Functions (IRFs).

In order to derive the global representation of the model, I rewrite each sub-model described by Eq. (2.3) and Eq. (2.1) as follows:

Let,

$$\mathbf{Z}_{x,t} = \begin{pmatrix} \mathbf{X}_{i,t} \\ \mathbf{Y}^*_{x,t} \end{pmatrix} \quad \text{and} \quad \mathbf{Z}_{i,t} = \begin{pmatrix} \mathbf{Y}_{i,t} \\ \mathbf{Y}^*_{i,t} \\ \mathbf{X}^*_{i,t} \end{pmatrix} \tag{2.4}$$

where $\mathbf{Z}_{x,t}$ is a $(k_x + k^*_x\ )$-dimensional vector of stacked common factors and feedback effects as described by Eq. (2.3). Similarly, vector $\mathbf{Z}_{i,t}$ is $(k_i + k^*_i\ )$-dimensional and represents the stacked sectoral, sector-specific foreign variables and common variables included in each sectoral model. Now I can write each sub-model as a VAR:

$$\mathbf{A}_{s,0}\mathbf{Z}_{s,t} = \sum_{l=1}^{p_i} \mathbf{A}_{s,l}\mathbf{Z}_{s,t-l} + \mathbf{u}_{s,t} \quad s \in (x, i) \quad \text{and} \quad l = 1, 2, ...p \tag{2.5}$$

where for the total market model $\mathbf{A}_{x,0} = (\mathbf{I}_{kx}, \mathbf{0})$ and $\mathbf{A}_{x,l} = (\mathbf{\Phi}_{x,l}, \mathbf{\Lambda}_{x,l})$. For each sectoral model $\mathbf{A}_{i,0} = (\mathbf{I}_{ki}, -\mathbf{\Lambda}_{i,0})$ and $\mathbf{A}_{i,l} = (\mathbf{\Phi}_{i,l}, \mathbf{\Lambda}_{i,l})$. $p = max_i(p_i, q_i)$ and define $\mathbf{\Phi}_{s,l} = 0$ for $l > p_i$ and $\lambda_{s,l} > q_i$.

If $k = k_x + \sum_{i=1}^{N} k_i$, then let $\mathbf{Y_t} = (\mathbf{X}_t, \mathbf{Y}_{1,t}, \ldots \mathbf{Y}_{N,t})$ be the k-dimensional *global vector*, containing all the endogenous variables of the model, with the government variables are ordered first before the sectoral variables. By exploiting the fact that the star variables are weighted sums of the endogenous variables, I write $\mathbf{Z}_{x,t}$ and $\mathbf{Z}_{i,t}$ in terms of the global vector as follows:

$$\mathbf{Z}_{x,t} = \begin{pmatrix} \mathbf{X}_{i,t} \\ \mathbf{Y}^*_{x,t} \end{pmatrix} = \mathbf{W'_x Y_t} \quad \text{and} \quad \mathbf{Z}_{i,t} = \begin{pmatrix} \mathbf{Y}_{i,t} \\ \mathbf{Y}^*_{i,t} \\ \mathbf{X}^*_{i,t} \end{pmatrix} = \mathbf{W'_i Y_t} \tag{2.6}$$

where $\mathbf{W}_x$ is a $(k_x + k^*_x) \times k$ government specific matrix that selects $\mathbf{Z}_{x,t}$. Similarly, $\mathbf{W}_i$ is of dimensions $(k_i + k^*_i) \times k$, is sector-specific and selects $\mathbf{Z}_{i,t}$[12]. From (2.6) I can write the following generalised form:

[12] To see why $\mathbf{W}_x$ selects $\mathbf{Z}_{x,t}$, I further split it in two sub-matrices$\mathbf{W}_x = (\mathbf{E}'_x, \mathbf{M}'_x)$. $\mathbf{E}_i$ is $(k \times k_x)$ and selects $\mathbf{X}_t$, namely $\mathbf{X}_t = \mathbf{E}'_x \times Y_t$. $\mathbf{M}'_x$ is $(k \times k^*_x)$ and selects the feedback effect: $\mathbf{Y}^*_{x,t} = \mathbf{M}'_x \times \mathbf{Y}_t$.

$$\mathbf{Z}_{s,t} = \mathbf{W}'_{\mathbf{s}}\mathbf{Y}_{\mathbf{t}} \tag{2.7}$$

Using (2.7) in (2.5) yields:

$$\mathbf{A}_{s,0}\mathbf{W}'_s\mathbf{Y}_{\mathbf{t}} = \sum_{l=1}^{p_i}\mathbf{A}_{s,l}\mathbf{W}'_s\mathbf{Y}_{t-1} + \mathbf{u}_{s,t} \tag{2.8}$$

and stacking the individual models for $i = \omega, 1, 2, ...N$, we obtain

$$\mathbf{G}_0\mathbf{Y}_t = \sum_{l=1}^{p_i}\mathbf{G}_l\mathbf{Y}_{t-1} + \mathbf{u}_t \tag{2.9}$$

where

$$\mathbf{G}_0 = \begin{pmatrix} \mathbf{A}_{x,0}\mathbf{W}_x \\ \mathbf{A}_{1,0}\mathbf{W}_1 \\ \vdots \\ \mathbf{A}_{N,0}\mathbf{W}_N \end{pmatrix}, \quad \mathbf{G}_l = \begin{pmatrix} \mathbf{A}_{x,l}\mathbf{W}_x \\ \mathbf{A}_{1,l}\mathbf{W}_1 \\ \vdots \\ \mathbf{A}_{N,l}\mathbf{W}_N \end{pmatrix}, \quad \mathbf{u}_t = \begin{pmatrix} \mathbf{u}_{x,t} \\ \mathbf{u}_{1,t} \\ \vdots \\ \mathbf{u}_{N,t} \end{pmatrix} \tag{2.10}$$

With $\mathbf{G}_0$ a non-invertible matrix, we obtain the reduced form global solution by pre-multiplying (2.9) by $\mathbf{G}_0^{-1}$.

$$\mathbf{Y}_t = \sum_{l=1}^{p_i}\mathbf{F}_l\mathbf{Y}_{t-1} + \tilde{\mathbf{u}}_t \tag{2.11}$$

where $\mathbf{F}_l = \mathbf{G}_0^{-1}\mathbf{G}_l$ for $l = 1, 2, ..., p$ and $\tilde{\mathbf{u}}_t = \mathbf{G}_0^{-1}\mathbf{u}_t$. Matrix $\mathbf{G}_0$ enclose the contemporaneous correlation among sectors and the aggregate economy model. The solution of the global model has the form of a standard VAR. $\mathbf{u}_t \sim N(0, \Sigma_{\mathbf{u}})$ with $\mathbf{\Sigma}_{\tilde{\mathbf{u}}} = \mathbf{G_0}^{-1}\mathbf{\Sigma}_u\mathbf{G_0}^{-1'}$. The error term in the global model can be correlated within units as in standard VAR but also between units. The Covariance matrix of the reduced form global model is:

$$\mathbf{\Sigma}_{\mathbf{u}} = \begin{bmatrix} \mathbf{\Sigma}_{\mathbf{u_x}} & \mathbf{\Sigma}_{\mathbf{u_x},\mathbf{u_1}} & ... & \mathbf{\Sigma}_{\mathbf{u_x},\mathbf{u_N}} \\ \mathbf{\Sigma}_{\mathbf{u_1},\mathbf{u_x}} & \mathbf{\Sigma}_{\mathbf{u_1}} & ... & \mathbf{\Sigma}_{\mathbf{u_N}} \\ ... & ... & ... & ... \\ \mathbf{\Sigma}_{\mathbf{u_N},\mathbf{u_x}} & \mathbf{\Sigma}_{\mathbf{u_N},\mathbf{u_1}} & ... & \mathbf{\Sigma}_{\mathbf{u_N}} \end{bmatrix} \tag{2.12}$$

where the block $\mathbf{\Sigma}_{u_i,u_j}$ is the covariance matrix between unit i and unit j and $\mathbf{\Sigma}_{u_i}$ is the covariance matrix of unit i. The off-diagonal blocks of the covariance matrix are expected to be close to 0 as cross-units covariance is taken into account by the common and star variables.

2.4 Data, model specification and identification

2.4.1 Data

I use three types of data: aggregate UK economy data, sector-level data and data from Input-Output tables. Time-series were in quarterly frequency covering a period from 1997Q1 to 2019Q4. The length of the sample is restricted by the availability of the sectoral data, but it coincides with the years the Bank of England has gained operational independence from the government to set monetary policy.

The common variables vector $\mathbf{X}_t$ contains aggregate time series collected from the Economic Outlook No 112 - November 2022 dataset of OECD. Variables contained in this vector are: The real government spending (G_t), the real government spending growth forecast (ΔG_t^{fc}), real tax revenues (T_t), the short term interest rate (R_t^S), the long term interest rate (10-year government bond rate) (R_t^L), the real effective exchange rate (broad basket of currencies) (S_t) and the real stock market index (V_t).

In line with other studies (Born et al. (2013); Auerbach and Gorodnichenko (2013); Ilori et al. (2022)), I used the EO projection for government spending from recent and older vintages of the EO, to create a measure of expected government spending growth, proxying for fiscal expectation in the VAR analysis. Given that Economic Outlook projections are published biannually, I interpolated the series to a quarterly frequency, using a mid-point averaging. I did not opt for alternative sources of historical forecasts for the UK economy, like the Office for Budgetary Responsibility, historical forecast data are provided in annual frequency and for shorter samples.

The analysis relies on a 16-sector disaggregation. This specific disaggregation is equivalent to the 2-digit standard industry classification (SIC), but with certain sectors further grouped together to facilitate the analysis, due to data availability constraints. In the baseline analysis, each vector $\mathbf{Y_{i,t}}$ contains sectoral employment and sectoral output series. Sectoral variables were collected from the ONS databases. For the sectoral output, I used the sectoral Real Gross Value Added (GVA) series that serves as a proxy for sectoral GDP. Real sectoral GVA series data was collected from the *GDP output approach – low-level aggregates: gdpolowlevelaggregates2022q4* dataset. Sectoral employment data was collected from the *Employment by industry: emp13* dataset. Finally, I checked the robustness of the baseline results by estimating a model where sectoral units are augmented with a sectoral GVA deflator measure. For the sectoral GVA deflator, I used data from the *Experimental industry deflators: industryleveldeflatorsexperimental* dataset from ONS. Data were transformed in log-levels or percent rates where applicable. Where needed, data was seasonally adjusted using the *X-13*

Table 2.1: Data definitions and sources

Variable in VAR	Definition	Construction	Source
	Panel A: Total economy data		
G_t	Government spending	log-level	OECD
ΔG_t^{fc}	Government spending growth forecast	growth rate	OECD
T_t	Tax revenues	log-level	OECD
R_t^S	Short term interest rate	rate	OECD
R_t^L	Long term interest rate	rate	OECD
S_t	Real exchange rate (Broad basket)	log-level	BIS
V_t	Equity market	log-level	OECD
	Panel B: Sectoral data		
Y_t	Sectoral Output (GVA)	log-level	ONS
N_t	Employment	log-level	ONS
P_t	Sectoral GVA deflator	log-level	ONS

Data span the period 1997Q1–2019Q4. IO tables are published in annual frequency are available for the same period by OECD: *IOTs* database. A positive change in the real effective exchange rate (S_t) indicates an appreciation of the domestic currency against a basket of foreign currencies. Date were transformed in log-levels or % rates where applicable.

ARIMA-SEATS procedure. Table 2.1 provides an overview of the data used in the analysis.

Finally, industry Input-Output tables are provided by OECD, using a 48-industry disaggregation. I aggregated IO table data to match the industry disaggregation of the ONS sectoral series.[13]

2.4.2 Model specification and identification

A fundamental aspect of fiscal policy actions is that economic agents continually receive and respond in advance to information regarding the forthcoming changes in fiscal policy. Agents' expectations are typically shaped by the institutional processes through which these policy changes are implemented. This fiscal foresight poses a challenge the empirical identification of fiscal policy shocks with SVARs. The problem arise when the econometric model does not contain information that can capture the expectations that agents form about future fiscal policy changes, as this results in a non-invertible MA representation of the VAR model.

[13]Input-Output tables are discussed in Section 2.5.3

Identification of government spending shocks under fiscal foresight has been studied by Ramey (2011); Forni and Gambetti (2016); Ellahie and Ricco (2017) and more recently by Ascari et al. (2023).

A frequently suggested approach to address the issue of fiscal foresight is to expand the information set of the SVAR model with a variable that serves as a proxy for the agents expectations regarding forthcoming fiscal policy changes. Such a variable can account for the role of expectations in economic dynamics. Identification in the GVAR model is not different than in standard SVAR models. Following the existing literature (see Born et al. (2013); Ilori et al. (2022)), I augment the total market model with a measure of government spending growth forecast that explicitly accounts for agents expectations.

Another issue reported in the literature is that information in small scale VAR models variables that play an important role in the transmission of the fiscal shock are potentially omitted. As a result the information is insufficient to recover the structural shock. Moreover, Ellahie and Ricco (2017) underline the importance of forward looking variables in approximating the flow of information received by economic agents. Although the GVAR model is already of larger scale, I specify a medium scale total market model with many forward looking variables and other variables that are relevant to the transmission of the fiscal shock but might be omitted in parsimonious specifications. The specification of the total market is given by equation (2.13):

$$\mathbf{X}_t = \begin{bmatrix} G_t & \Delta G_t^{fc} & T_t & R_t^S & R_t^L & S_t & V_t \end{bmatrix} \quad \mathbf{Y}_{x,t} = \begin{bmatrix} Y_t & N_t \end{bmatrix} \tag{2.13}$$

where $\mathbf{X}_t$ is the vector of aggregate variables and $\mathbf{Y}_{x,t}$ is the vector of feedback effects that is equivalent to aggregate output and employment. In the sectoral models the vector of endogenous variables $\mathbf{Y_{i,t}}$ contains sectoral output and employment. The corresponding vector of foreign variables $\mathbf{Y^*_{i,t}}$ contains the weighted averages of output and employment of the rest of the sectors. The vector of common variables is identical to vector $\mathbf{X}_t$ in Eq. (2.13). The sectoral model is represented by (2.14).

$$\mathbf{Y}_{i,t} = \begin{bmatrix} Y_{i,t} & N_{i,t} \end{bmatrix}, \quad \mathbf{Y}^*_{i,t} = \begin{bmatrix} Y^*_{i,t} & N^*_{i,t} \end{bmatrix} \tag{2.14}$$

Each VARX model was estimates with 1 lag for the endogenous and the star variables ($p_i = q_i = 1$). The estimation of the individual VARX* models is Bayesian. I employed standard macroeconomic priors like the "Minnesota" and the "sum-of-coefficient" prior, sampling form a Normal-Inverse Wishart distribution using a Gibbs sampling algorithm.

In order to identify shocks in the GVAR, one needs to specify a block matrix of structural coefficients $\mathbf{P}$ so as to express the reduced form residuals from equation 2.9, as a linear combination of structural shocks as follows:

$$\mathbf{u}_t = \mathbf{P}\epsilon_t \tag{2.15}$$

where $\mathbf{P}$ is a block matrix:

$$\mathbf{P} = \begin{bmatrix} \mathbf{P}_{x,x} & \mathbf{P}_{x,2} & ... & \mathbf{P}_{x,N} \\ \mathbf{P}_{1,x} & \mathbf{P}_{1,2} & ... & \mathbf{P}_{1,N} \\ ... & ... & ... & ... \\ \mathbf{P}_{N,x} & \mathbf{P}_{N,2} & ... & \mathbf{P}_{N,N} \end{bmatrix} \tag{2.16}$$

and ϵ_t is the vector of structural shocks, normalised to have unit variance $E(\epsilon_\mathbf{t}\epsilon_\mathbf{t}') = \mathbf{I}$.

In practice, I am interested in identifying only the fiscal shock within the government unit. Therefore, I need to make specific assumptions about sub-matrix $\mathbf{P}_{x,x}$ that rules the contemporaneous relationship of the variables in the total market model. At this stage, the empirical shock identification collapses to a typical VAR identification problem. Following the empirical literature on the identification of government spending shocks, I employ a standard Cholesky decomposition scheme, a la Blanchard and Perotti (2002) where the government spending variable is ordered first in the global vector of variables, before the proxy of government spending expectations and other macroeconomic and sectoral variables. In this case the matrix $\mathbf{P}_{x,x}$ will be the Cholesky factor of the $\mathbf{\Sigma}_{u,x}$, the covariance matrix of the total market model. This is equivalent to the assumption that government decision for spending is not affected any other variable within the same quarter but other variables can be affected by government spending contemporaneously. Accounting for anticipation effects of changes in government policy allows to uniquely identify unanticipated shocks to government spending in the presence of fiscal foresight.

For the non diagonal elements of $\mathbf{P}$, I will assume that are $\mathbf{0}$. This is equivalent to the assumption that the macroeconomic variables of the government unit and the star variables capture the common factors in the residual. In other words, I assume that the fiscal shock affect each sector directly or through the government spending in the rest of the sectors. Under the identification assumptions $\mathbf{P}$ has the following form.

$$\mathbf{P} = \begin{bmatrix} chol(\mathbf{\Sigma_{u_x}}) & \mathbf{0} & ... & \mathbf{0} \\ \mathbf{0} & \mathbf{I} & ... & \mathbf{0} \\ ... & ... & ... & ... \\ \mathbf{0} & \mathbf{0} & ... & \mathbf{I} \end{bmatrix} \tag{2.17}$$

Finally, I calculate IRFs following Pesaran et al. (2004) as follows:

$$\mathbf{\Delta Y_j}(h|y_t, \epsilon_{0,t}) = \mathbf{F^h G_0^{-1} P d_j} \tag{2.18}$$

where $\mathbf{\Delta Y}_j(h|y_t, \epsilon_{0,t})$ is the response at time $t+h$ of the of the global vector of variables, when a shock is imposed at time t, on j^{th} element. Matrices $\mathbf{F}^h$ and $\mathbf{G_0}^{-1}$ enclose the coefficient from the reduced global model. $\boldsymbol{P}$ is the identified matrix of structural coefficients and d_j is a $k \times 1$ selection vector with unity at the j^{th} element, corresponding to the position of a particular variable in the global vector and zeros elsewhere. In this case, government spending is ordered first in the global vector, so $d_{j=1} = 1$ and $d_{j\neq 1} = 0$.

2.5 Exploratory analysis: Sectoral disaggregation, government spending compositions and IO tables

This section offers a descriptive analysis of the UK sectoral dimension, the distribution of the UK government spending across different economic sectors and a discussion of the UK production network, as described by the industry Input-Output tables.

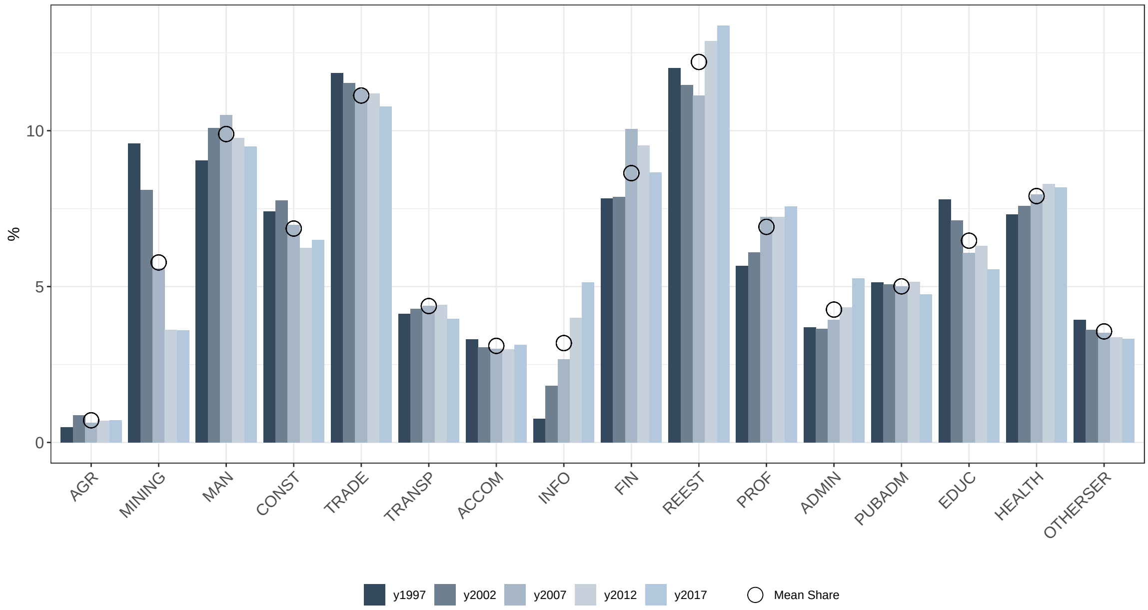
2.5.1 Sectoral disaggregation

The economy is broken down to the following 16 sectors: (1).Agriculture, (2).Mining, Energy & Water, (3).Manufacturing, (4).Construction, (5).Trade, (6).Transportation, (7).Accommodation, (8).Information, (9).Financial, (10).Real Estate, (11).Professional Services, (12).Administration, (13).Public Administration & Defence, (14).Education, (15).Health and (16).Other Services[14]. Figure 2.2 demonstrates the proportionate contribution of each sector to the total GDP along with the change in the relative size of each sector at five-year intervals from the beginning of the sample. The circles indicate the average size of each sector over the whole sample. Real Estate and Trade are the largest sectors as their relative size is over 10% over the whole sample period. The smallest sector is Agriculture, contributing less than 1% to the total output. Most of the industries maintain a relatively consistent size throughout the sample period. The only exceptions are the Mining, Energy & Water industry which shows a significant declining trend over the years, and the Information industry which was less than 1% of GDP in 1997, but over 5% in 2017, in line with the technology advancements.

The proportional size of each sector is an important metric in my analysis, as it determines the magnitude of the impact that each sector has on the overall economy unit. Specifically, the average relative size of each sector is used as a weight in the global solution of the model,

[14] A complete description of the sectors and their sub-divisions is available in the appendices Appendix B and Appendix D

Figure 2.2: Relative size of each sector



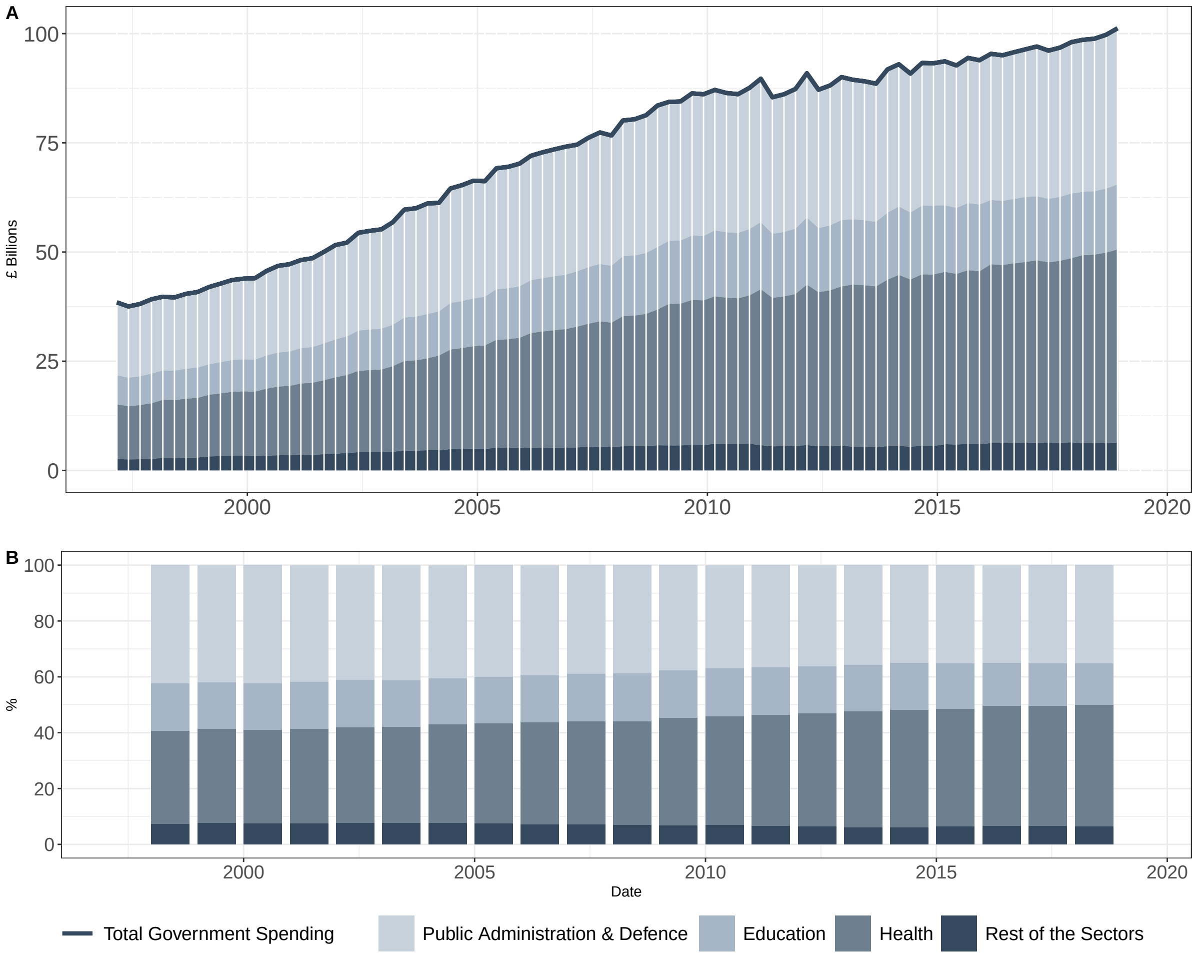
Notes: *The plot shows the proportional contribution of each sector to the total GDP along with the change in the relative size of each sector at five-year intervals from the beginning of the sample. The circles indicate the average size of each sector over the whole sample. See Table B.1 for a description of the sectors and abbreviations.*

as outlined in Section 2.3.3, to quantify the influence of each sector on the variables within the governmental model. Besides, the sectoral share is used to calculate the contribution of each industry in the aggregate output response and the sectoral multipliers. The relative share of each sector is fairly stable over the sample and the averaging data is innocuous, hence not expected to affect the analysis.

2.5.2 Government spending allocation across industries

In this section, I discuss the aggregate government spending data and how government purchases are allocated across the sectors of the economy. The government spending measure considered in the analysis is the total UK Government Final Consumption Expenditure (GFCE), or "G", as often referred in the income identity or the government component of the GDP when measured with the expenditure approach. GFCE consists of two components: Government Consumption and Government Gross Investment. The two measures could be defined as follows: Government consumption is the total government spending on the production and provision of goods and services directly to the public. Government Gross Investment consists of spending by the total government sector for fixed assets that benefit the public or that are

Figure 2.3: Final Government Consumption Expenditure.



Notes: *The plot shows the total UK government spending (GFCE) from 1997 to 2019 and its allocation over the UK industries. Panel A depicts the data in absolute terms, whilst panel B shows the respective percentages.*

used by government agencies in their production activities. In contrast with common parlance, this measure includes only social "transfers in kind", excluding any direct money transfers, like social benefits, grants and subsidies. For example, it includes the cost of running schools, hospitals, the social protection and national defence (including the wages of employees), but not state pensions or child benefits.

Government spending is the allocation of funds across diverse goods and services. The overall expenditure consists of a multitude of transactions across various industries of the economy. Figure 2.3 shows the total UK government spending (GFCE) from 1997 to 2019 and its allocation over the UK industries[15] Panel A depicts the data in absolute terms, whilst panel

[15]Detailed sectoral government spending time-series are presented in Figure B.1 and Figure B.2.

B shows the respective percentages. The total public spending shows an upward trend until 2008, and decelerates in the following years. It becomes evident that the lion's share (more than 90%) of the total public expenditures over time goes mainly to three industries: Public Administration and Defence, Health, and Education. The share of Public Administration ranges from 35% to 40%, the share received by the Health industry varies from 32% to 42%, and the share of Education is relatively constant, reverting around 15%.

The rest of the sectors systematically receive less than 10% of the total spending. Figure 2.4 shows the average distribution of public expenditures across the remaining 13 sectors. Dots indicate the average share, while segments show one standard deviation. Among the remaining industries, Mining, Manufacturing and Other Services receive over 1% each, whereas sectors like Agriculture, Construction, Accommodation, Finance, Real Estate and Administration receive nearly 0%.

In my analysis, I assumed that each sector is directly affected by shifts in government spending according to the average share of public funding it receives over the sample[16]. For example, according to data in Figure 2.3 and Figure 2.4, I assume that a 1-billion increase in government expenditure would increase the funds allocated to Education by £150 million (£1bn × 15%), whereas Manufacturing would receive only £14 million (£1bn × 1.45%). Overall, I believe that this assumption will hardly affect the results, as the composition of government spending exhibits a relatively stable pattern throughout the sample period. Therefore, I can confidently average data to estimate the sectoral effects of an average government spending shock.

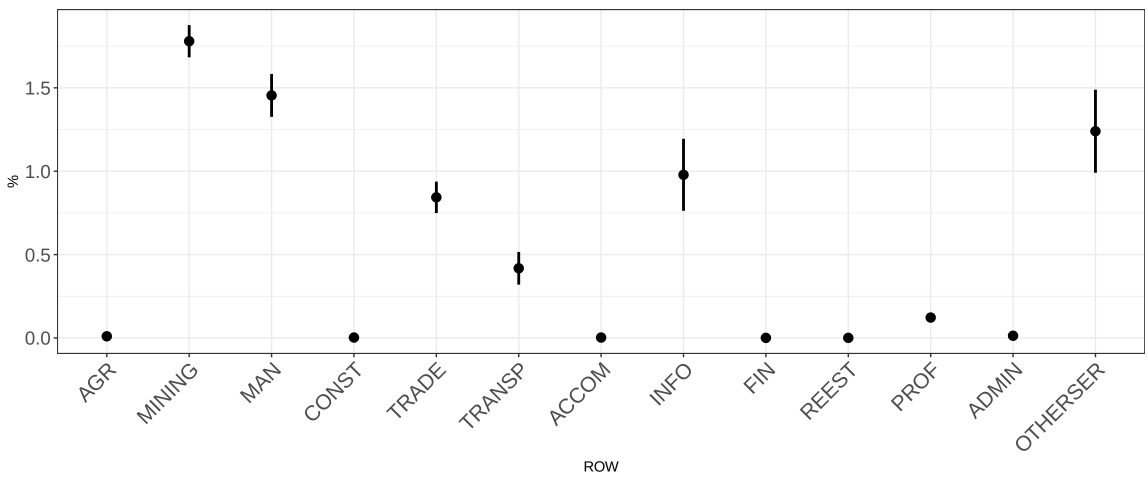
As explained in section 2.3.1, the relative sectoral distribution of government spending is used to specify the deterministic matrix $\mathbf{S}_i$ that rules the strength of the effect of government shock on each sector and further the direct sectoral effect of the structural shock.

2.5.3 Input-Output tables - The UK production network

All sectors in the economy are interconnected, as the production process requires the intersectoral exchange of intermediate inputs. Understanding intersectoral trade is essential to comprehend how idiosyncratic shocks within specific sectors ripple through the economy, affecting other sectors and in turn, influencing the overall performance of the economy. The intersectoral trade is described by Input-Output (IO) tables, a technology introduced by Leontief (1936). IO tables provide a snapshot of the flow of inputs across industries within a specific period, usually a year. Statistical authorities publish IO tables every year and their use is essential in constructing national accounts.

[16]Data for the distribution of government purchases across sectors was extracted from Input-Output tables and is discussed in detail in section 2.5.3.

Figure 2.4: Final Government Consumption Expenditure across sectors - (excluding Health, Education and Public Administration and Defence.)



Notes: *The plot shows the average distribution of public expenditures across the the 13 sectors of the sample – Health, Education and Public administration and Defence are excluded. Dots indicate the average share of the total government spending going to each sector over time. Segments show one standard deviation.*

In this section, I describe the format of a typical IO table. By representing the sectoral interconnectedness as a (production) network, I calculated the centrality of each sector. Centrality is a metric that describes the importance of each sector as a supplier or a customer within a production network. The centrality of each sector can explain how vulnerable sectors are in different kind of shocks. Finally, I discuss how IO table information was used to create the weight matrix that defines the interaction of the GVAR model units.

Table 2.2 provides the basic outline of a typical IO table of a simplified economy with only 3 industries. The core component of an IO table describing the intersectoral trade is typically given in the form of a matrix, where sectors in rows are the "Suppliers" and sectors in columns are the "Customers". In table Table 2.2, the IO matrix, denoted as M, is given by the grey shaded area. Each element $m_{i,j}$, shows the real £GBP value of inputs flowing from supplier sector i to the production of the customer sector j. Effectively, this is the value all goods and services, of all the firms belonging to sector i, that are used as intermediate inputs in the production of firms that belong to sector j. The diagonal elements of M represent self consumption, that is the flow of inputs from firms in a given sector to firms of the same sector. In the IO matrix, the sum of each row of ($\sum_i m_{i,j}$) represents the total value of goods and services produced in sector i and which are used as intermediate inputs in the production of other sectors. On the other hand, the sum of each column of ($\sum_j m_{i,j}$) indicates the total cost of intermediate inputs in the production of the column sector j.

Table 2.2: Input-Output tables

		Customer sectors			
	Sectors	Sector 1	Sector 2	Sector 3	Final Consumption
Supplier sectors	Sector 1	$m_{1,1}$	$m_{1,2}$	$m_{1,3}$	fi_1
	Sector 2	$m_{2,1}$	$m_{2,2}$	$m_{2,3}$	fi_2
	Sector 3	$m_{3,1}$	$m_{3,2}$	$m_{3,3}$	fi_3
	Wages	w_1	w_2	w_3	
	Dividends	r_1	r_2	r_3	
	Taxes	t_1	t_2	t_3	
	Net profit	π_1	π_2	π_3	

Notes: *The table provides the basic outline of a typical IO table of a simplified economy with only 3 industries.* $fi_i = c_i + g_i + i_i + ex_i$ *represents the final-user demand and it is the value of the product of sector* i *directly consumed by households* (c_i) *and the government* (g_i)*, the value of product used for investment* (i_i) *and the value of product being exported* (ex_i)*.*

Sectors do not solely provide inputs to other industries; they also sell their product directly to end users for consumption. Following the national accounting, the end users are split into households/consumption (C), the government (G), investment (I) and exports (EX). The final column of Table 2.2 represents the end user consumption for each sector, noted as $fi_i = c_i + g_i + i_i + ex_i$. Therefore, the gross demand for the product of a sector i is given by equation:

$$Y_i = \sum_j m_{i,j} + (c_i + g_i + i_i + ex_i) = \sum_j m_{i,j} + fi_i \tag{2.19}$$

where sectoral product is either used as input in the production of other industries or is directly consumed by the final demand. Notably, the Gross Domestic Product (GDP) is not the sum of all Y_i, but the sum of the end user consumption.

The representation of the simplified IO table is completed with the last three rows of table Table 2.2. The production of goods and services in "Customer" sector j does not only require intermediate inputs, but also involves other costs, such as wages (w_j) to employees, compensation of capital holders (r_i), taxes (t_j) and other payments like net profits (π_i).

The difference between a sector's gross demand Y_j and the cost of intermediate inputs ($\sum_i m_{i,j}$) is the sectoral Gross Value Added ($GVA_j = Y_j - \sum_i m_{i,j}$) and is used as a proxy of sectoral GDP[17]. The sum of GVA across all "Customer" sectors is equal to the total GDP.

[17]The sectoral GVA measure used as a proxy of sectoral output in the analysis is reported by ONS in quarterly frequency.

This yields the following equality:

$$GDP = \sum_j (c_i + g_i + i_i + ex_i) = \sum_j (Y_j - \sum_i m_{i,j}) \tag{2.20}$$

Production network centrality

The intersectoral flows of intermediate inputs can be seen as a network. Sectors are the nodes of the network and are connected to other nodes through edges that represent the flows of intermediate inputs. Given the 16-sector disaggregation used in the analysis, the UK economy is described as a production network with 16 nodes. The nodes can be indexed by 1,...,16. The network is represented with adjacency matrix Γ of dimension 16×16. Each element $\gamma_{i,j}$ is equal to the corresponding element $m_{i,j}$ of the IO matrix, divided by the gross demand of sector j, Y_j:

$$\gamma_{i,j} = \frac{m_{i,j}}{Y_j} \tag{2.21}$$

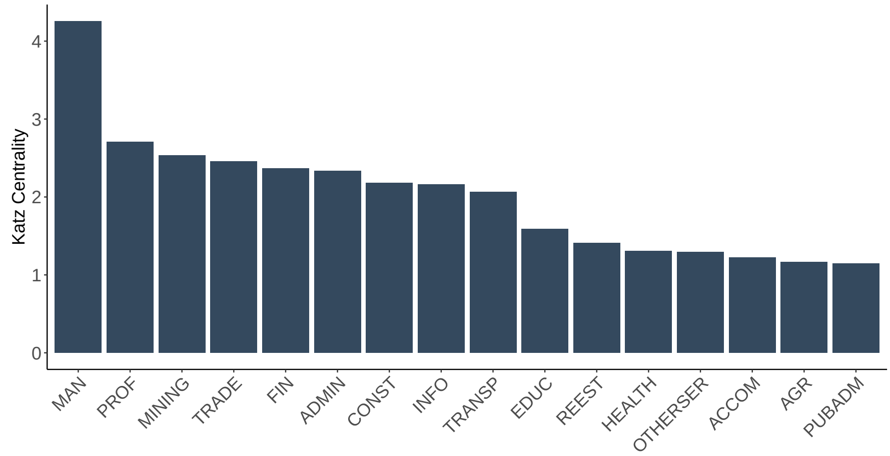
Each $\gamma_{i,j}$ represents the percentage cost of each intermediate input i in the production of sector j.

Centrality is one of the numerous methods used to measure the comparative significance of each node in a network. As a measure, centrality takes into account not only the interconnections of an industry with others, but also the intensity of these connections and the overall interconnectedness of the other industries. In this way, an industry will have a higher centrality if it is connected to other industries with high centrality. I measure sectoral centrality using the Katz-Bonacich measure as follows:

$$k' = \beta'(I - \Gamma')^{-1} \tag{2.22}$$

where k' is the vector of sectoral centrality, β' is the shares of sectoral contribution to GDP, and $(I - \Gamma')^{-1}$ is the Leontief inverse associated with the transposed Γ matrix. Figure 2.5 shows the centrality of each sector. The most important supplier is Manufacturing, meaning that manufacturing goods are largely used as inputs in the production of other industries, which subsequently act as crucial suppliers to other sectors. Defense sector, Agriculture and Accommodation are considered the least important suppliers, which means that the products of these industries are predominantly used for final consumption, rather than as intermediate input.

Figure 2.5: Centrality of the production network.



Notes: *The plot shows the Katz-Bonacich centrality of each sector in my sample. Centrality is a metric the shows the comparative significance of each node in a network. Here centrality shows the comparative significance of each sector as a supplier within the UK production network.*

From Input-Output tables to the GVAR weighting matrix

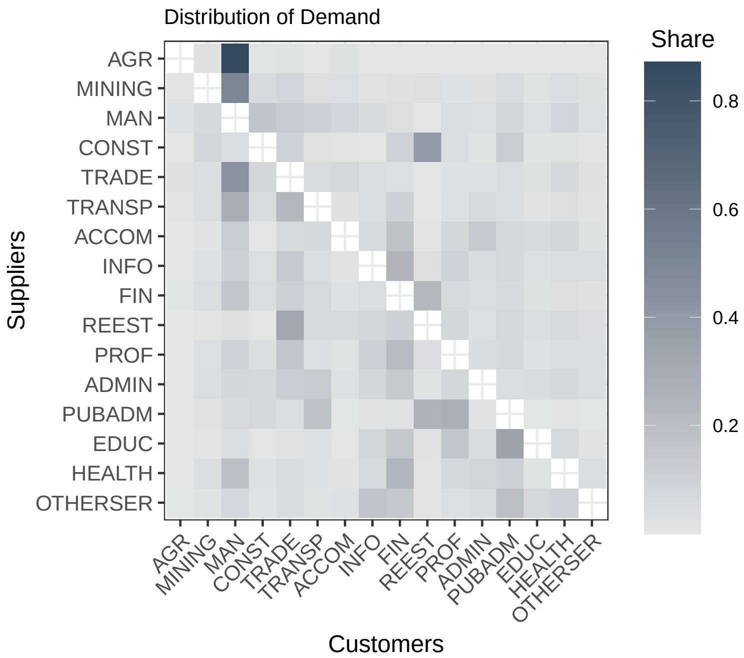
Input-Output table data can be used for the construction of the sector specific selection matrices W_s, as discussed in equation Eq. (2.8). As is common in the GVAR literature, the information needed to build each W_s can be consolidated in a $N \times N$ weight matrix named $\tilde{W}$, where in this case $N = 16$, standing for the 16 sectors of my sample.

$\tilde{W}$ is constructed as the row normalised IO matrix M (see Section 2.5.3). Each element of the weight matrix shows how row-units (suppliers) are affected by column-units (customers). Weights in each row represent how sector's i product demand is distributed across other industries. In a simple 3 sector economy example, the weight that indicates how sector 3 affects sector 1, is given by element $\tilde{w}_{1,3} = \frac{m_{1,3}}{(\sum_{j=1}^{3} m_{1,j})}$, where the numerator is the value of product of sector 1 demanded by sector 3, and the denominator is the the total value of sector's intermediate demand. The diagonal element of $\tilde{W}$ are *0* ($\tilde{w}_{i,i} = 0$). This assumption excludes self-industry effects, as the autoregressive terms in the individual models will take care of them.

Figure 2.6 shows the structure of matrix $\tilde{W}$. Darker colours indicate higher weights and light colours indicate lower weights. An important insight arising from the fourth column, is that the Manufacturing sector is a significant customer for many industries, including Agriculture, Mining and Trade. Other important connections observed are those between Real Estate and Construction, and Real Estate and Financial Services.

The weights used for the selection of common factors in the sectoral VARX models and

Figure 2.6: GVAR weight matrix.



Notes: *The plot shows the* $\tilde{\mathbf{W}}$ *matrix used for the GVAR estimation. Each element of the matrix shows the share of sector's* $\boldsymbol{i}$ *(row) product demanded by sector* $\boldsymbol{j}$ *(column)*

the feedback effects in the total market model are not shown in Figure 2.6. These weight are discussed in sections 2.5.2 and 2.5.1.

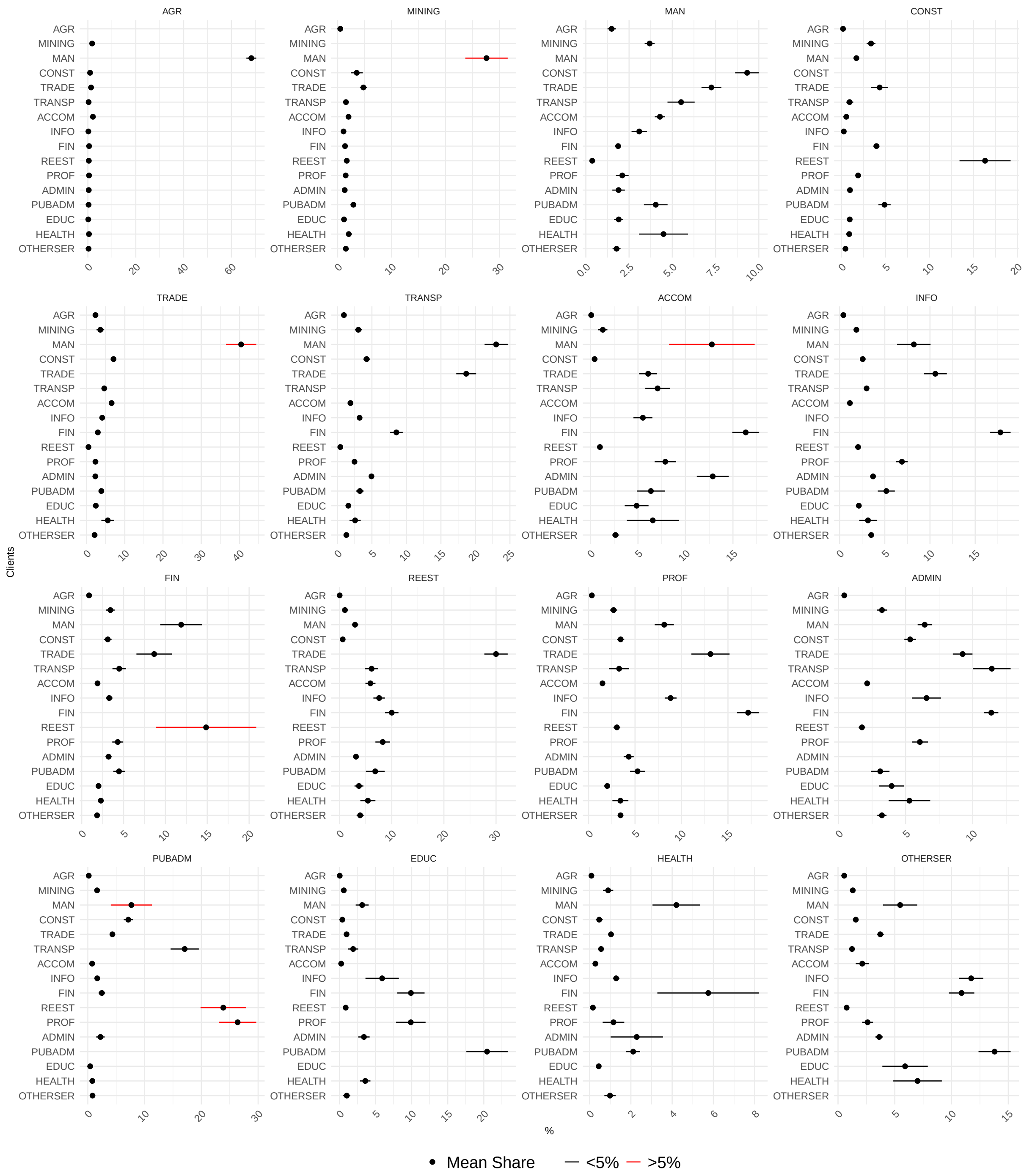
Another critical consideration in GVAR applications is the stability of the $\tilde{\mathbf{W}}$ matrix over time. In the baseline model, I constructed $\tilde{\mathbf{W}}$ by averaging IO data over time. To ensure that averaging will not significantly affect the results, I calculated the variability of each element of $\tilde{\mathbf{W}}$ over time.

Figure 2.7 is an alternative representation of the weighting matrix, showing the variability of each element of $\tilde{\mathbf{W}}$ over time. Each individual panel corresponds to a row from matrix $\tilde{\mathbf{W}}$. The points displayed indicate the average output share of the "Supplier" sector on the top of each panel, that is sold as intermediate input to the "Customer" sectors, represented on the vertical axis. Average shares are identical to those of Figure 2.6. Segments indicate one standard deviation around the mean.

For example, the first panel at the top shows the demand distribution for Agricultural. Manufacturing is the most important customer for the agricultural sector. Around 69% of the agricultural product is used as intermediate input in Manufacturing. The remaining 31% is demanded by the rest the industries and the Government.

Typically, the distribution of intersectoral demand is stable over time. There are only few

Figure 2.7: The stability of the production network.



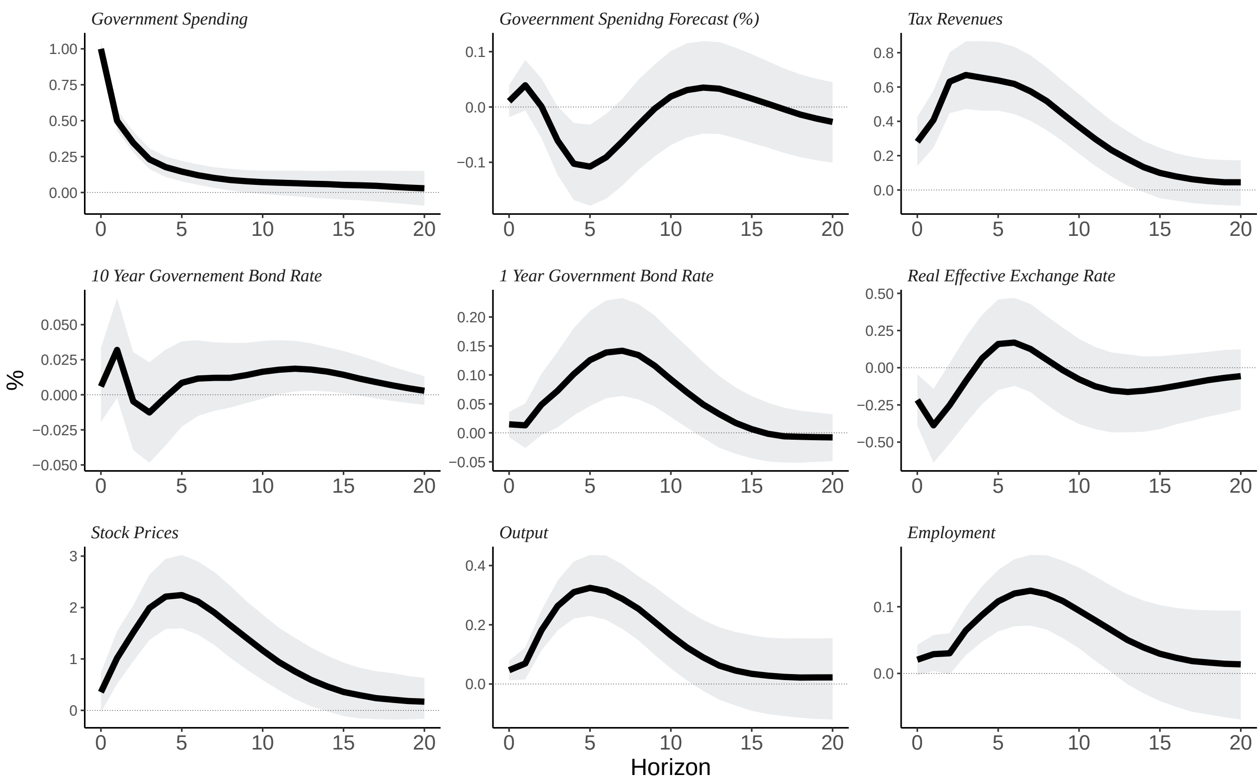
Notes: *The plot shows the the variability of each element of* $\tilde{\mathbf{W}}$ *over time. Each individual panel corresponds to a row from matrix* $\tilde{\mathbf{W}}$*. The points displayed indicate the average output share of the "Supplier" sector on the top of each panel, that is sold as intermediate input to the "Customer" sectors, represented on the vertical axis. Average shares are identical to those of 2.6. Segments indicate one standard deviation around the mean.*

instances, indicated with red color, where deviation is above 5 percentage points. Overall, there are no significant shifts in the structure of the production network. Hence, I expect that averaging IO data over time will have no sizable effect on the GVAR results.

2.6 Empirical Findings

2.6.1 Aggregate economy VAR against GVAR

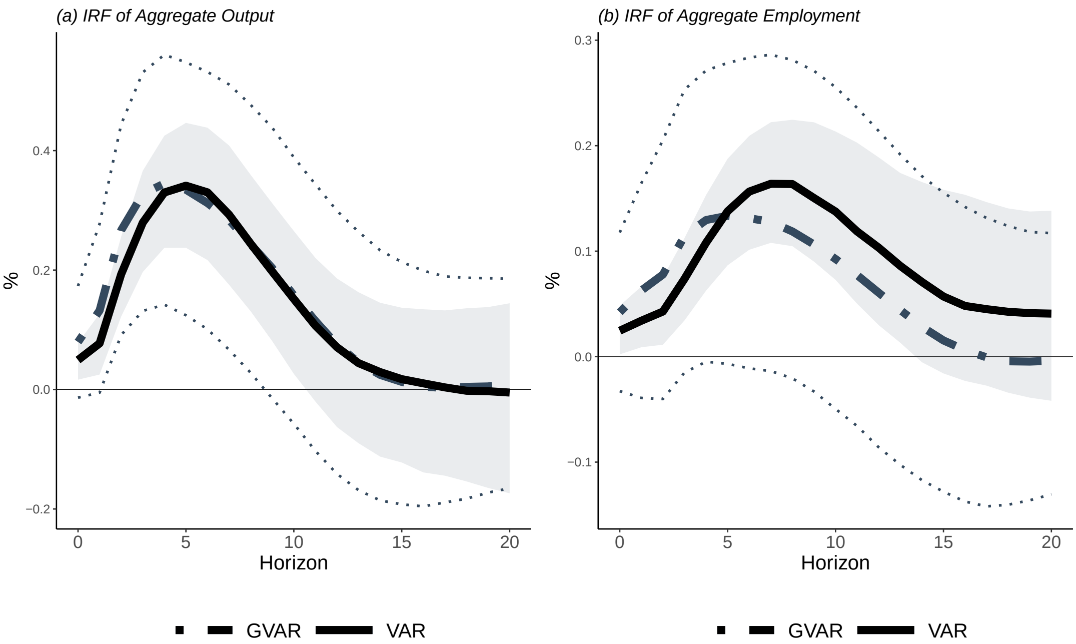
Figure 2.8: Aggregate economy SVAR.



Notes: *The plot shows the dynamic impact of an expansionary unanticipated government spending shock. The vertical axis have been adjusted, so the peak of government spending is 1%. The figure depicts median impulse responses and their 68% central posterior credible set (c.s). All y-axis values are in percentage change. Positive response of the Real Effective Exchange Rate indicate a real appreciation of the £GBP against a basket of foreign currencies.*

Preserving the government spending composition across industries and the relative stability of the production network, links meaningfully the sectoral output responses with the responses of the total output. Specifically, given that the sectoral distribution of government spending is taken into account, the link of the two models is as follows: a 1% increase in aggregate

Figure 2.9: IRF of Aggregate Output and Employment - VAR vs GVAR.



Notes: *The plot compares the responses of Output and Employment obtained from SVAR, estimated using aggregate series, and from the multisector VAR (GVAR). The figure depicts median impulse responses and their 68% central posterior credible set (c.s). Solid lines and the grey areas shows the SVAR results. Dash and dotted lines represent the GVAR results. All y-axis values shows percents.*

government spending is equivalent to a simultaneous 1% increase of government spending in every sector.

In order to validate that the model produces reasonable estimates of the sectoral multipliers, I contrasted the aggregated output IRFs from the GVAR model with the response of the total output obtained by a typical SVAR using aggregate UK data.

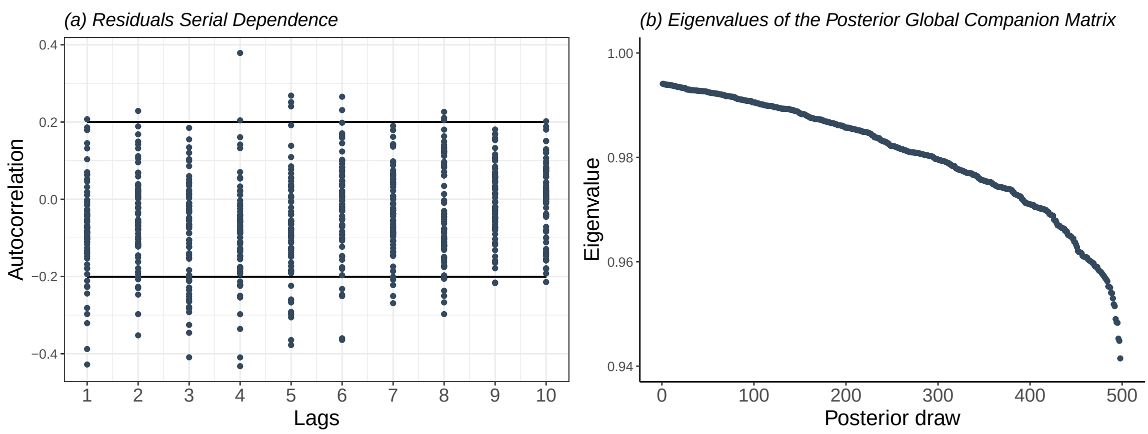
The specification of the aggregate economy model is similar to the total market model described in Eq. (2.3), but without any exogenous variables and with aggregate output and employment considered as endogenous.

Figure 2.8 presents the Impulse Response Functions (IRF) of 1% unexpected increase in total government spending. Overall the effect of the shock is positive, with both output and employment to increase. In the upper left panel, the response of total Government Spending peaks on impact and gradually decreases. The effect is persistent as the response of government spending remains positive for 10 quarters. Expectations turn negative in line with the decreasing rate of the total spending response (a result similar to Forni and Gambetti (2016) and Ilori et al. (2022) for the US). Following the positive response of output, tax revenues increase strongly. The response of the long term interest rate is not clear. The long-term rate increases on impact but the response is entirely on the positive area after ten quarters. The short-term rate remains muted for three quarters and then increases, peaking at 15 basis points six quarters after the shock. Such a response can reflect an accommodating stance of the monetary policy that react to the shock with some lag. The real effective exchange rate drops on impact, reflecting a depreciation of the UK pound against a a basket of foreign currencies. Finally, the stock index increases following the increase in the output.

The GVAR model can replicate reasonably well the response of aggregate output and employment. To establish the similarity of the results obtained by the two models, I contrast the median response of the VAR model (as presented in figure Figure 2.8 against the aggregated median responses of sectoral output and employment obtained from the GVAR model. The aggregate GVAR responses is the sum of the individual sectoral responses, weighted by the relative share of each sector. Figure 2.9 contrasts the responses of the two models. The solid line is the VAR responses, whereas the dotted-dashed line is the aggregated sectoral responses of the GVAR model. The left panel *(a)* depicts the median IRFs of output, while the right panel *(b)* shows the responses of employment. The GVAR model can replicate the magnitude and the timing of the aggregate responses of both variables quite well. The responses of output are almost identical, allowing the estimation of individual sector responses with a certain confidence.

2.6.2 Sector-level responses

Figure 2.10: Diagnostic checks of the multi-sectoral model.



Notes: *Panel (a) shows the serial dependence of the residuals of all variables of the model. Panel (b) shows the eigenvalues of the Global companion matrix obtained for each posterior distribution.*

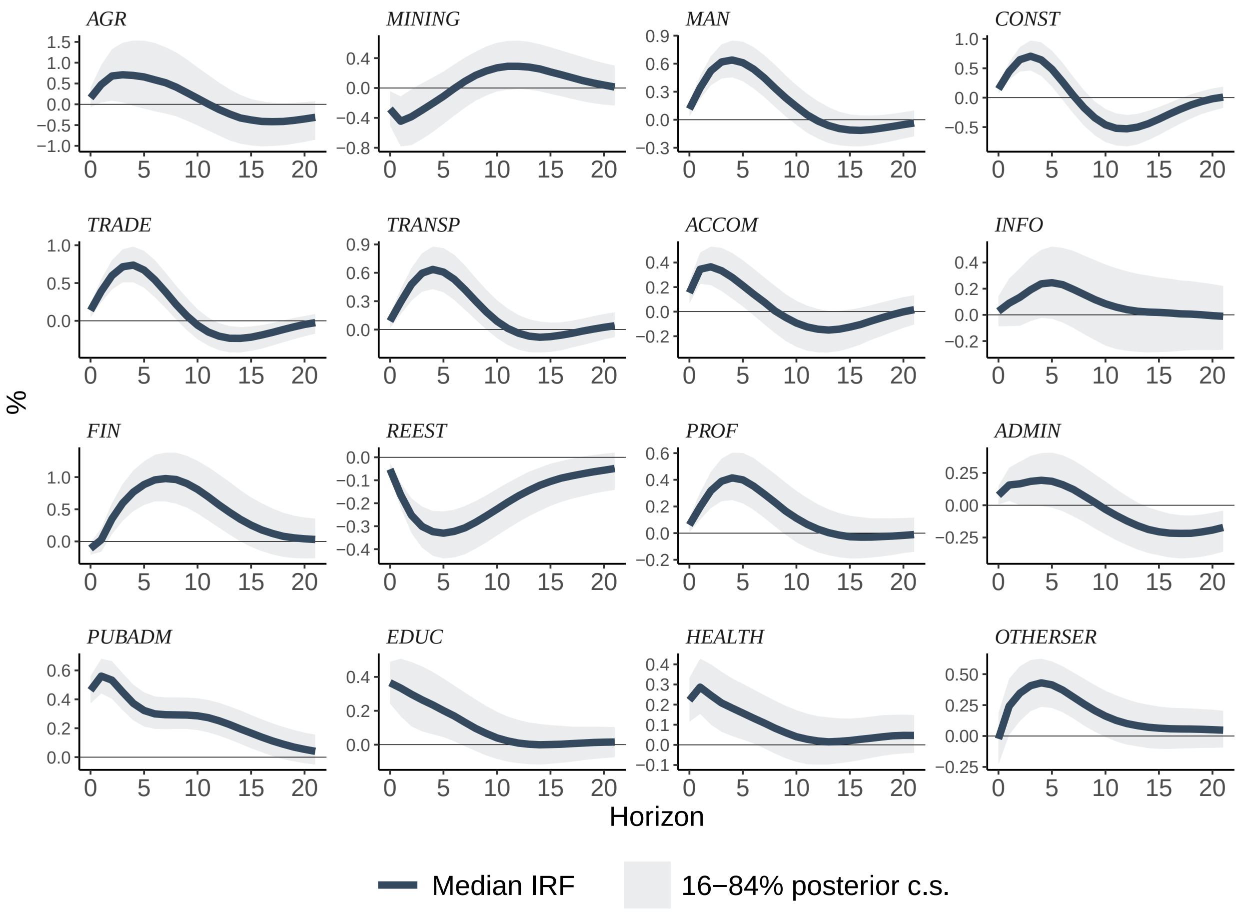
In this section, I discuss the sector-level results obtained from the GVAR model. The baseline model was estimated by using 1 lags for the endogenous and the star variables ($q_i =$

$p_i = 1$). The model adequately captures the serial correlation of the model variables. Panel (a) of Figure 2.10 depicts the autocorrelation function of the residuals for all the variables in the model. Most residuals are serially uncorrelated, indicating that the model captures the persistence in the data. Another important issue in the GVAR literature is the stability of the global model. Panel (b) pictures the eigenvalues of the global companion matrices obtained for each of the 2000 posterior draws. It is clear that all values are inside the unit circle. The model can capture the complex interaction of the variables and at the same time is stable, so the shock will die out after some horizons.

Next, I present the impulse responses of the sector-level output and the corresponding multipliers. I prioritise presenting the sector-level results as the responses of the total economy model closely follow the aggregate VAR responses presented in Figure 2.8 and are omitted for the economy of space.

Figure 2.11 shows the sectoral output responses to an average 1% unexpected government spending increase. For the majority of the sectors, the response of the output to an unexpected government spending shock is positive and significantly different from zero. The positive responses of sectoral output remain consistent regardless of the proportion of government spending allocated to each sector. This highlights the pivotal role of the production network in the propagation of the spending shock. The output of Public Administration, Education and Health, the three industries that systematically receive over 90% of the total spending shock, increases on impact by 0.4%, 0.3% and 0.2% respectively. The response of Public Administration remains positive for 15 quarters, while the effect on Education and Health lasts for a period of 5 quarters after the shock and then gradually fades out. The response of the rest of the industries, receiving only a small fraction of public spending, is zero on impact and gradually increases in later horizons. For the majority of sectors, output response peaks within the first 5 quarters. In some sectors, such as Construction, Trade and Administration services, the responses turn negative in the mid run. The difference in the timing that responses peak is another important indication of higher order intersectoral spillovers. Finally, there are two sectors the response of which is negative. First, the output of Mining decreases upon impact, but the response shows a positive trend at a later horizon. The negative effect on Real Estate can be associated with the increase in the interest rates that reduce the demand for housing. Another explanation that has been proposed in the literature is the crowding out of sectoral product due to the rise in the cost of intermediate inputs (Barattieri et al. (2023)). I test this possibility later on as a robustness exercise.

Figure 2.11: Sectoral output IRF.



Notes: *The plot shows the individual sectoral output IRF to a 1% Unexpected Government spending shock. The figure depicts the median impulse responses (solid line) and the 68% central posterior credible set (grey area).*

2.6.3 Sectoral Multipliers

Calculating fiscal multipliers using aggregate data is often a not straightforward task (Ramey (2019)). The calculation of fiscal multipliers at the sectoral level is even more complicated. Below I explain why the typical approach for the calculation of fiscal multiplier becomes problematic when calculating multipliers at the sectoral level. Then, I propose an alternative method that allows the calculation of sectoral multipliers indirectly, exploiting the link between the aggregate and sectoral output responses.

A standard way of calculating multipliers in VARs is the "cumulative multiplier" approach of Mountford and Uhlig (2009).

$$M^{(h)} = \frac{E_t \sum_{t=0}^{h} (\prod_{j=0}^{h} R_{t+j}^{-1}) \Delta Y_{t+h}}{E_t \sum_{t=0}^{h} (\prod_{j=0}^{h} R_{t+j}^{-1}) \Delta G_{t+h}} \times \frac{\bar{Y}}{\bar{G}} \tag{2.23}$$

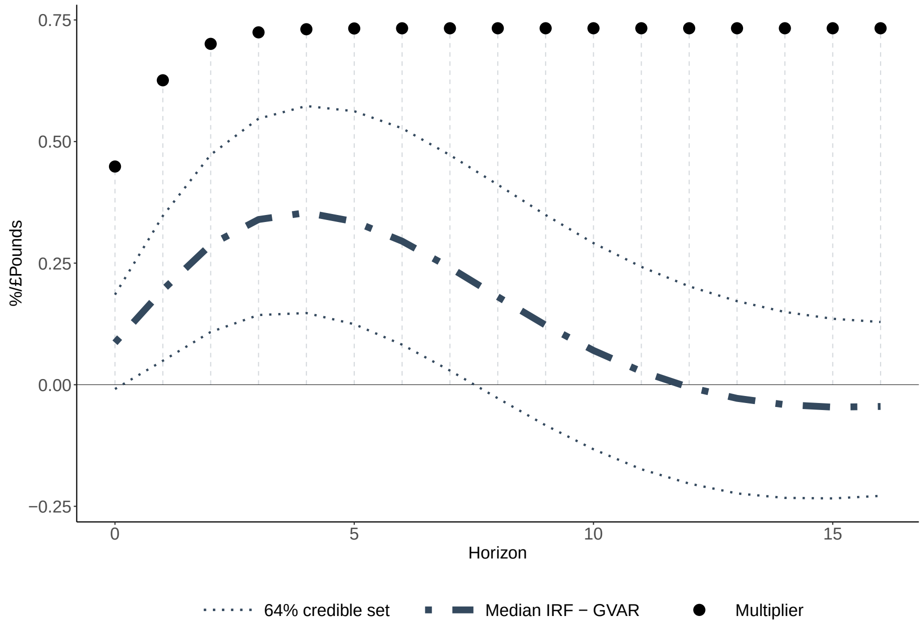
As indicated by Eq. (2.23)), the cumulative multiplier M, h quarters after the shock, is equal to the product of two terms. The first term is the present discounted value of the output response ΔY_{t+h}, h periods after the shock, divided by the present discounted value of the government spending response ΔG_{t+h} over the same period. R^{-1} is the discount factor and usually depends on a short term interest rate. The second term $\frac{Y}{G}$ is an ad hoc conversion ration and it is equal to the average ratio of aggregate output over the total government spending over the sample. When data are in log-level form, the first term is just the government spending elasticity of output. The conversion term transforms the elasticity in a more meaningful currency-equivalent measure.

To calculate the sectoral multiplier, one could divide the present discounted values of sectoral output and sectoral specific government spending and then multiply the result by a sector specific ad hoc conversion factor. In this application, there are two issues occurring with this approach. First, the observed response of sectoral output is the outcome of a simultaneous and uneven increase of public spending in every sector. In other words, the sectoral response does not only reflect direct effects, but also second order effects that occur through spending in the the rest of the sectors, within the production network. The components of the first term, that is the numerator and the denominator, are unclear. Following the Mountford and Uhlig (2009) approach would result in an incorrect multiplier. The second issue arising is associated to the conversion term. Based on my assumption for the industry distribution of the fiscal shock, certain sectors receive only a small fraction of the overall government spending. In such instances, the sector-specific conversion term tends to a significantly high number, resulting in a vaguely very large multiplier.

I attempted to address these challenges by calculating the sectoral multipliers indirectly. First, I calculated the aggregate output multiplier and then I used the relative contribution of each sector to the aggregate output response to infer the sectoral multiplier. It is worth mentioning that the definition of a sectoral multiplier is different than the conventional one: I calculated the pound equivalent growth of sectoral output associated with a one-pound increase in government expenditure, that maintains the typical distribution of spending across various industries. To do so, I followed the below steps:

First, I used the weighted sum of sectoral output responses obtained from the GVAR model to calculate the equivalent aggregate output response. Using the aggregate response, I calculated the aggregate multiplier for different horizons according to Eq. (2.23). As shown in Figure 2.9, the responses of a VAR with aggregate data and the aggregated sectoral responses

Figure 2.12: Aggregate output response - Aggregate multiplier



Notes: *The plot shows the aggregate government spending multiplier calculated using the GVAR responses. The dashed line is the median total output response, whereas the dotted lines indicate the 64% posterior credible set. Dots show the aggregate multiplier for different horizons.*

are very close and the inferred multipliers do not differ.

Figure 2.12 shows the aggregate output response as obtained from the individual sectoral responses and the aggregate multiplier. The dashed line is the median response, whereas the dotted lines indicate the 64% posterior credible set. The multiplier for different horizons is given by the dots. The multiplier was calculated using the short term interest rate, the average value of which during the sample was 2.5%. The average conversion term ratio was 5. Overall, the aggregate multiplier is less than 1. The multiplier is 0.4 on impact and becomes 0.62 a period after the shock. It finally converges to 0.73 at period 4 and remains consistent in the following quarters. This finding is striking close to Bhattarai and Trzeciakiewicz (2017), who using an estimated DSGE model, find that the aggregate output multiplier for the UK is 0.76 4 quarters after the shock.

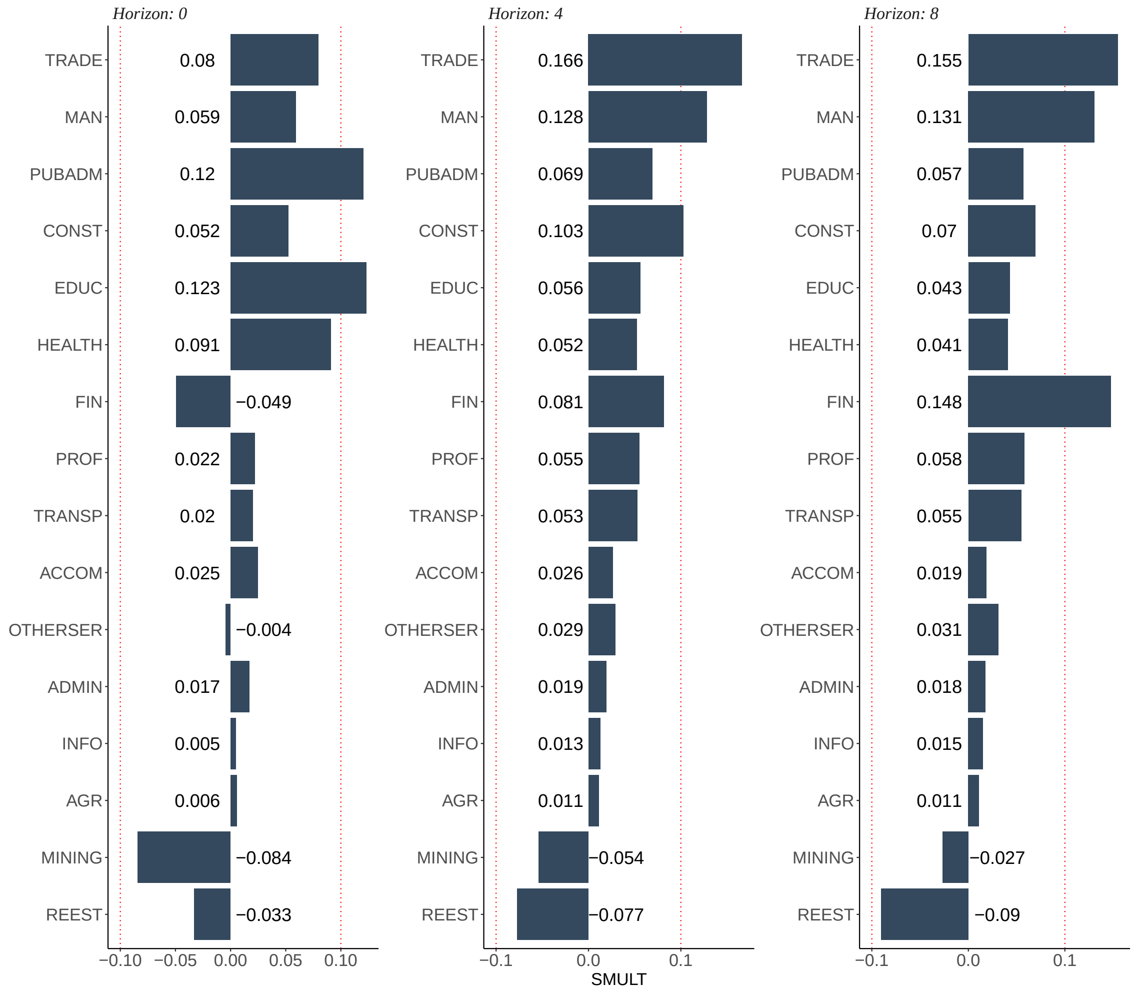
To determine the relative contribution of each sector to the aggregate output response for each horizon, I exploited the direct connection between the aggregate and sectoral output responses. The contribution (θ_i^h) is given by the cumulative effect of sector i at horizon h $(\Delta y_i^{(j)})$, weighted by the relative size of the sector $(\frac{y_i}{y})$, over the cumulative effect of aggregate output $\Delta Y^{(j)}$ for the same horizon as follows:

$$\theta_i^h = \frac{\sum_{j=0}^{h} \Delta y_i^{(j)} \times \frac{\bar{y}_i}{\bar{y}}}{\sum_{j=0}^{h} \Delta Y^{(j)}} \tag{2.24}$$

The sum of the contribution of all sectors i at every horizon equals to the aggregate output response, therefore the sum of all θ_i^h within the same horizon is 1. The sectors that have a negative output response, contribute a negative share on the response. Finally, the sectoral multiplier is the sectoral contribution, multiplied by the aggregate multiplier.

$$M_i^{(h)} = \theta_i^h \times M^{(h)} \tag{2.25}$$

Figure 2.13: Sectoral multipliers



Notes: *The plot shows the sectoral multipliers. The sectoral multiplier is the £pound equivalent sectoral output growth associated with a one-pound increase in government expenditure, that maintains the average sectoral distribution. Bars and numbers equally represent multipliers.*

Figure 2.13 shows the sectoral multipliers for 0, 4 and 8 quarters after the shock. Bars shows the sectoral multipliers. For clarity numbers have been included. By construction, the sum of multipliers on impact sums up to 0.43. However, in horizons 4 and 8, the sum is 0.73. While the aggregate multiplier remains constant after the 4th quarter, sectoral multipliers vary due to the change in the relative sectoral contribution θ_i^h[18]. For readability, numbers indicate the sectoral multiplier. The red line indicates the 10p (or £0.1) point.

On impact, the three public sector industries of the Public Administration, Education and Health exhibit the highest multipliers. The multipliers are 0.12, 0.123 and 0.091 respectively, meaning that on average, for every pound spent by government, the three sectors receive around 90p and the their output increases by 35p right away.[19] High multipliers are also observed for the Trade sector (0.08), Manufacturing and Construction (0.052). Finance, Mining and Real Estate display negative multipliers of -0.49, -0.084 and -0.033 respectively.

At later horizons the shock is transmitted to other sectors through the Input-Output linkages. As a result, the multiplier of the three sectors initially receiving the largest share of the spending drops and increases in the rest of the industries. The industries with the highest multipliers, one and two years after the shock, are Trade, Manufacturing, Construction and Finance. Eight quarters after the shock, the three sectors contribute over 60% to the overall multiplier. Notably, the multiplier of the financial sector from horizon 4 to 8 almost doubles, jumping from 0.81 to 0.148. The multiplier for Mining and Real Estate remains negative for all horizons.

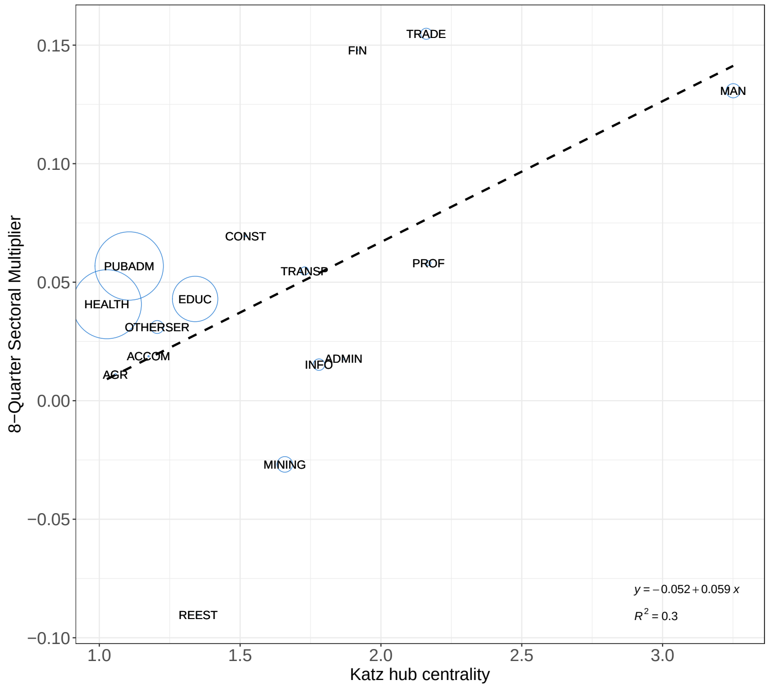
2.6.4 Explaining the differences across sectoral multipliers

In this section I attempt to uncover the factors behind the sectoral output responses differentials. One factor that has been found to explain the dispersion of the sectoral responses is the position of the sector within the production network. According to the explanation provided in Bouakez et al. (2023), the response is higher for industries with high centrality. Upstream industries that serve as important suppliers in the production network, increase their production to meet not only the higher government demand, but also the additional demand for intermediate inputs from other sectors. The findings of my analysis align with this view. Figure 2.14 shows a positive relationship of the 8-quarter sectoral multipliers and the Katz's centrality statistic. Centrality can explain 30% of the variation in the sectoral multipliers. This is in line with the findings of Acemoglu et al. (2016) for upstream propagation of demand shocks and with the results of Bouakez et al. (2023), which indicate that important suppliers benefit more from an increase public spending. One could potentially think that the positive

[18]Table (B.2) shows the relative sectoral contribution for different horizons.

[19]The three industries receive around 90% of the total spending

Figure 2.14: Sectoral multipliers against sectoral upstreamness



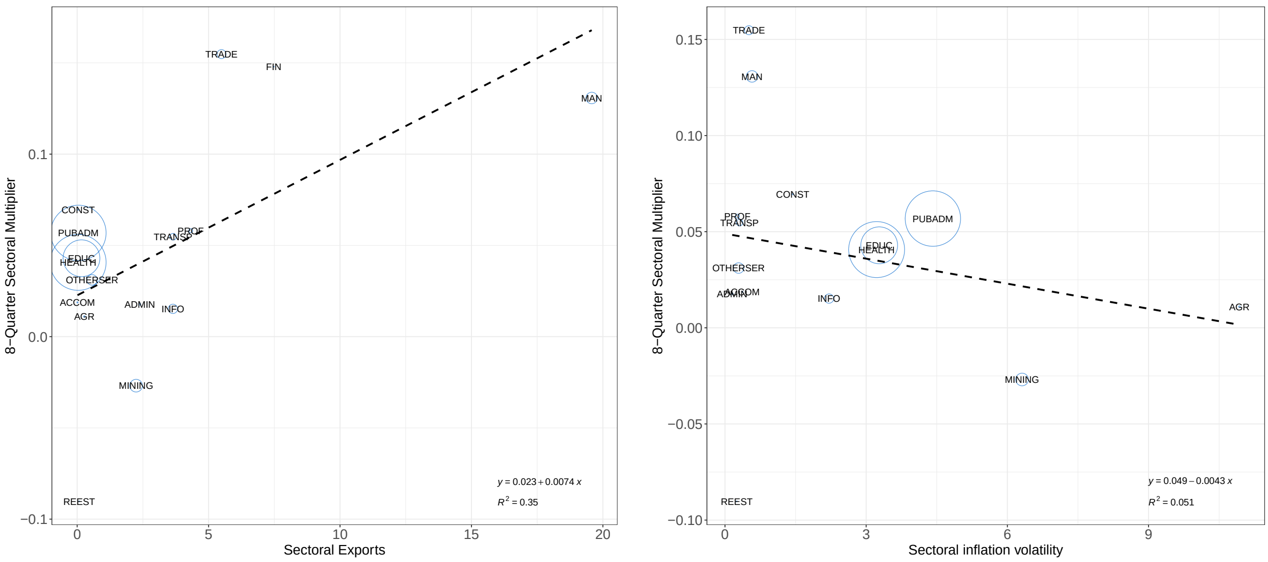
Notes: *The figure shows the correlation between 8-quarters sectoral multiplier and sectoral centrality.*

correlation is the result of concentration of public spending in upstream industries. However, as indicated by the blue bubbles, the biggest share of the public spending is on industries with low centrality.

Other sectoral characteristics that explain the dispersion of sectoral responses to fiscal shocks are the sectoral exports and the degree of sectoral price rigidities. A number of studies (see Monacelli and Perotti (2010); Cuaresma and Glocker (2023)) argue that trade openness makes tradable sectors more responsive in positive government spending shocks, whilst alleviating the negative effects of fiscal austerity. Figure 2.15a shows the positive correlation between sectoral multipliers and the sectoral exports measured as the share of the sectoral product that is consumed by the external sector. The correlation is quite strong, with sectoral exports explaining 35% of sectoral multipliers variability.

Figure 2.15b shows the negative correlation of sectoral multipliers with the volatility of sectoral inflation calculated as the first logarithmic differences of sectoral GVA deflator series. The correlation is weaker than in the case of upstreamness and sectoral exports, with sectoral inflation volatility explaining only 5% of sectoral multiplier differentials. This result is consistent with the view that the fiscal effect is stronger in sectors with higher price rigidity. However, in accordance with Bouakez et al. (2023), I find that this relationship is weak.

Figure 2.15: Explaining the difference across sectoral multipliers



(a) Sectoral multipliers VS sectoral exports share.

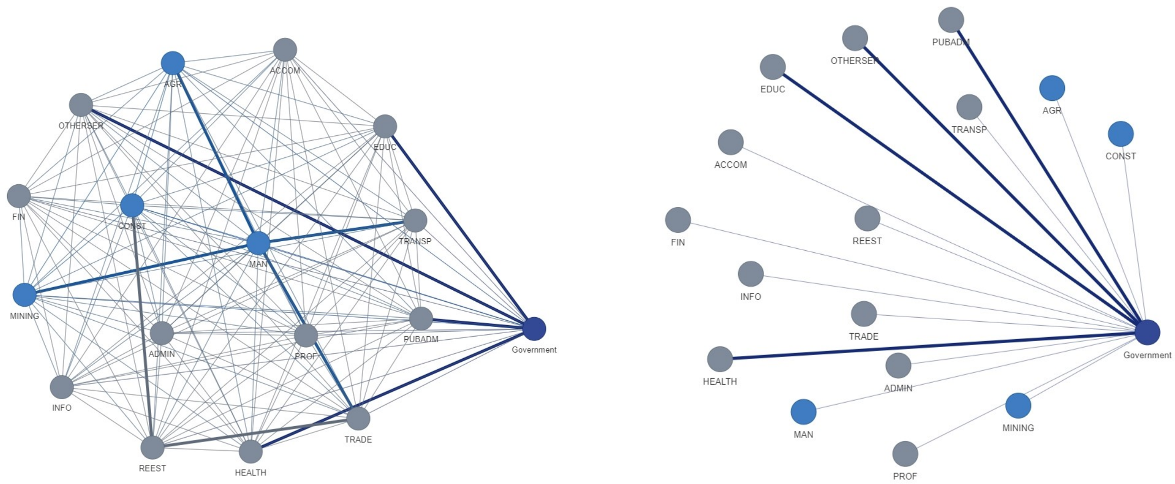
(b) Sectoral multipliers VS sectoral inflation volatility.

Notes: *Panel (a) shows the correlation of sectoral multipliers and sectoral exports. Panel (b) shows the correlation of sectoral multipliers and the sectoral inflation volatility. The size of the bubbles indicate the share of the total government spending allocated to each sector.*

2.6.5 The role of the production network in the propagation of the fiscal shock

Analysis so far has shown that the overall government spending multiplier for the UK is £0.74. The multiplier is the result of a simultaneous increase of government spending in all sectors that increases sectoral demand both directly and indirectly, through the increase in demand for intermediate inputs. This section investigates the role of the production network in amplifying (or reducing) the effects of a fiscal shock.

In the spirit of Georgiadis (2017), I assess the role of the network effects, by comparing the IRFs of the baseline model, as described by Figure 2.16a, with those of a simplified model with no sectoral interactions, as described by Figure 2.16b. In the baseline model, the fiscal shock affects each sector directly and is further propagated through intersectoral trade. The simplified model is similar to the baseline model, but the sectoral interactions channel is shut down. In this way, sectoral responses of the simplified model reflect solely the direct effect of government model on each sector, without any first or higher order indirect effect originating from intersectoral linkages. Dropping sectoral interactions from Eq. (2.26), each sector specific model boils down to:



(a) Baseline model
With sectoral interactions.

(b) Simplified model
No sectoral interactions.

Notes: *The figure shows a schematic representation of the baseline model and a model with no Input-Output linkages. Figure (a) depicts the baseline model with sectoral interactions. Figure (b) depicts the simplified model with no sectoral interactions. Blue dots indicate goods-producing sectors. Grey dots indicate service-producing sectors. Thick lines indicate a weight greater than 25%. Plots show averaged Input-Output table data over the period of the sample*

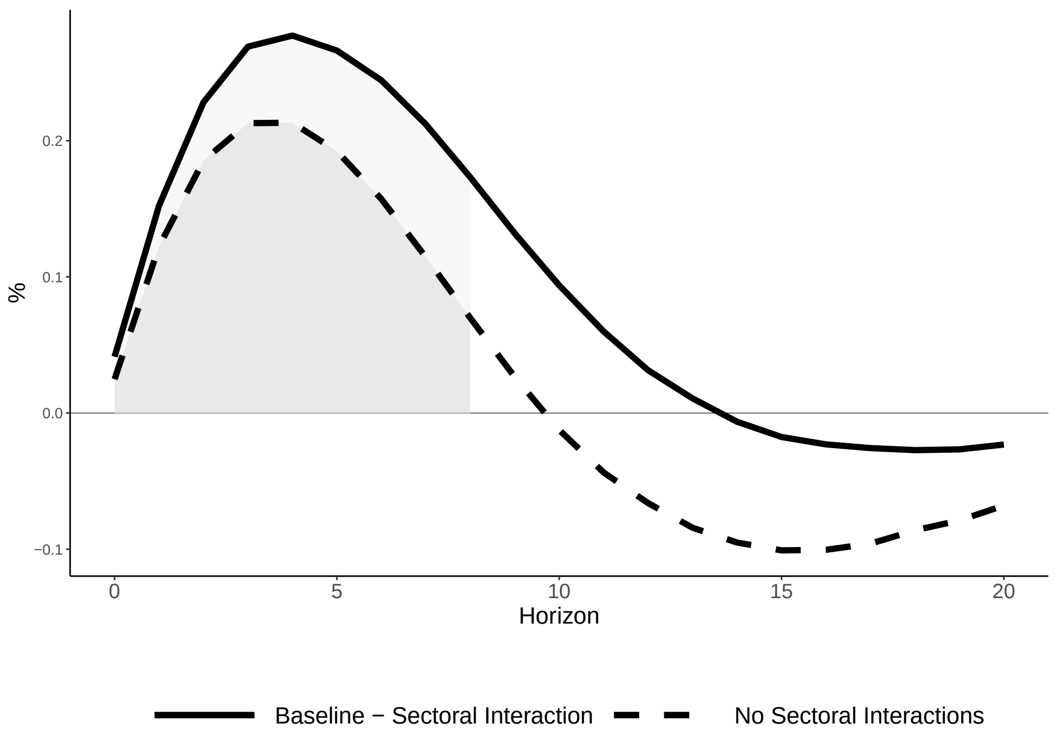
$$\mathbf{Y}_{it} = \sum_{l=1}^{p_i} \mathbf{\Phi}_{i,l}\mathbf{Y}_{i,t-l} + \sum_{j=0}^{q_i} \mathbf{D}_{i,l}\mathbf{S}_i\mathbf{X}_{t-l} + \mathbf{u}_{i,t} \tag{2.26}$$

The simplified model keeps the same baseline specification in terms of the endogenous and star variables, the lag structure and the identification strategy. The government model is identical to the baseline version.

To quantify how the production network affects the overall effectiveness of the government spending shock, I contrast the aggregate multipliers obtained from the baseline model and the simplified model. Figure 2.17 contrasts the two responses. The solid line represents the aggregated sectoral output responses of the baseline model and the dashed line those of the simplified model. Grey areas indicate the 8-quarter ahead cumulative effects. The 8-quarter ahead multiplier associated with the simplified model is 0.52. That is that sectoral linkages account for about $(1 - \frac{0.52}{0.74}) \times 100 = 30\%$ of the overall government spending effect.

The shape of the simplified IRF aligns with the concept of slow propagation of shocks across sectors. On impact the IRFs are very close as they reflect the simultaneous increase of spending across industries. The distance between the two lines gets more pronounced over the cross-sectoral channel is diffused and the higher order effects are not captured. However, the importance of the sectoral linkages might be underestimated here as the effect of common variables (that is not shut down) may capture some of the common factor effects on sectoral variables.

Figure 2.17: Aggregate output IRF.



Notes: *The figure shows the IRFs of aggregate output to a 1% Unexpected Government spending shock. The solid line represents the aggregated sectoral output responses of the baseline model. The dashed line represents the aggregated sectoral output responses of the simplified model with no sectoral interactions.*

2.7 Conclusion

Using aggregate and sectoral data, and Input-Output table information, this study has provided empirical evidence on the sectoral effects of fiscal policy in the UK. I estimated a novel GVAR model with a sectoral dimension to uncover the sectoral effect of an unexpected UK government spending shock. Contrary to previous empirical approaches, my model fully captures the heterogeneity of the direct government effects across sectors, as well as the indirect cross-sectoral effects. A direct link between the prediction of the multi-sectoral model and the prediction of standard time-series methodologies allows me to calculate sectoral government spending multipliers.

Results indicate that the aggregate fiscal multiplier is 0.43 on impact and it converges to 0.73, 4 quarters after the shock. The higher sectoral multipliers are initially observed for Public Administration, Education and Health, the 3 industries that consistently receive the lion share of the total government spending. At later horizons, the shock is transmitted to other sectors through the Input-Output linkages. Trade, Manufacturing and the Financial sector have the highest multipliers, with a combined contribution of over 60% to the overall multiplier.

Differences across sectoral multipliers can be explained by the sectoral upstreamness, sectoral exports and to a lesser extend, by price stickiness. Finally, the production network plays an important role in the propagation of the shock working as an amplifier. By estimating a restricted model where intersectoral trade channels are shut down, I find that the the overall multiplier associated with the restricted model is 30% lower.

The above findings have important implications for the planning of fiscal policies. The overall effect of government spending can vary depending on the sectoral composition of public purchases. Stimulating fiscal plans can achieve a stronger positive impact if policy makers take into account the complementarity among sectors. For example, upstream industries benefit from fiscal expansions even when they receive a small fraction (or no) of total public spending. The same conclusion holds for industries producing tradeable goods.

Chapter 3

The Sectoral effects of oil supply news shocks; a UK proxy-Sectoral VAR

3.1 Introduction

Recent events such as the Russian invasion of Ukraine and the Iran-Israeli conflict, have reignited interest in a longstanding question regarding the macroeconomic effects of oil shocks (see e.g. Hamilton (1983); Baumeister and Kilian (2016); Känzig (2021)). Such events have the potential to disrupt oil supply and trigger surges in oil prices. From a policy standpoint, oil supply shocks are of particular interest as they can decelerate economic activity and create inflationary pressures. As a result, these shocks present significant challenges for fiscal and monetary authorities striving to simultaneously stabilise prices and output.

Oil price is determined by international forces of demand and supply, and disruptions in the oil market have far-reaching consequences for economies worldwide. Within an economy, sectors vary in their exposure to oil price shocks. The conventional view suggests that a negative oil price shock (an increase in oil price) constitutes a negative supply shock, as it raises production costs and lower production. However, research suggests that not all sectors experience oil price rises as negative supply shocks (Lee and Ni (2002)). Negative demand effects can also occur due to lower consumers' discretionary income, lower intersectoral demand for intermediate inputs or lower demand from the external sector, as the oil shock affects a country's trade partners around the same time (Edelstein and Kilian (2009); Baumeister et al. (2018)). In some cases, the substitution of oil-intensive inputs can lead to more productive allocation of resources, boosting productivity. Finally, specific sectors can benefit from a positive demand effect. Such sectors are those that produce energy-efficient goods or export-oriented industries that benefit from external demand (mainly from oil-exporting countries).

Identifying the effects of the oil shock at the sector level is essential for the understanding of the propagation mechanism of the shock. The sectoral analysis identifies potential winners and losers and allows policymakers to recognise which sectors are most vulnerable. Consequently, such insights can guide fiscal or monetary policymakers in designing targeted policy interventions to mitigate adverse effects or seize opportunities arising from these shocks. Building on this premise, this chapter examines the effects of oil supply news shocks across the UK economic sectors.

Contribution: The contribution of this study to the literature is threefold:

1. First, to the best of my knowledge, this is the first study that assesses the effects of **oil supply shocks for the UK at the sectoral level**. Overall, I examine the effect of oil supply disturbances 64 sectoral variables.

2. Second, this chapter advances the the literature methodologically, by proposing a **modelling framework that reconciles the time series literature with the literature of production networks**. Specifically, I use a Global VAR model, that accounts for the upstream and downstream propagation of shocks and takes the analysis closer to a general equilibrium framework.

3. I identify the oil shock using the **high frequency identification** of Känzig (2021). In a significant paper Kanzig shows that this identification approach is more powerful than the pre-existing ones and can explain a significant part of the historical oil price variations. I use this tool to provide evidence for the UK economy.

The existing empirical work analysing the macroeconomic effect of oil market disturbances has mainly been focused on the US economy (see Kilian (2009); Baumeister and Peersman (2013); Herrera and Rangaraju (2020); Känzig (2021)) among others. A number of papers explore the effects of oil shocks in a multi-country framework. For instance, Mohaddes and Pesaran (2016) use a GVAR model to estimate the effects of international oil demand and supply shock to a number of countries. Mohaddes and Pesaran (2017) estimate the effects of a negative oil supply shock in Iran and how it affects different panels of oil importer and exporter countries.

The UK economy is an interesting case to study as it is one of the largest oil producers in Europe. However, there are only a few studies that focus entirely on the consequences of the oil shocks on the UK economy. Millard and Shakir (2013) estimate the effects of different types of oil shocks (Oil supply, World demand, Oil-specific demand) on the UK output growth, inflation and interest rates. Their analysis relies on sign restrictions identification and a time-varying parameters VAR model, emphasising how the impact of oil price shocks have developed over time. They find that oil supply shocks have a more negative impact on output and trigger higher inflation relative to oil demand shocks. In a similar spirit, Lorusso and Pieroni (2018) identify supply and demand-side international oil shocks following the identification of Kilian and Park (2009). The estimated structural shocks are used as exogenous variables in a UK VAR. They find that demand-side shocks do not depress the economy but the GDP growth decreases immediately after a supply shock. This chapter complements the two previously mentioned studies on the UK by offering additional insights into the effects of supply news shocks. This topic has not been extensively explored in the UK context before. Importantly, the chapter broadens the analysis to the sectoral level, providing a deeper understanding of how oil shocks are transmitted across different sectors within the economy.

A number of papers have empirically explored the asymmetries of sectoral responses to oil shocks. For example, Lee and Ni (2002) estimate the effect of oil price shock on the output and prices on a number of US manufacturing industries. Jo et al. (2019) replicate the work of Lee and Ni (2002) and extend the work of the latter methodologically. Jiménez-Rodríguez (2008) estimates the oil price effects on the output of the main manufacturing industries in six OECD countries, while Otero (2020) estimates the impact of oil shocks on a panel of sectors in Colombia. Besides, another line of the literature focuses on the differential effects of oil on different stock market industries (see Kilian and Park (2009); Känzig (2021); Arampatzidis et al. (2021); Alsalman et al. (2023)).

A potential limitation of papers that aim to analyse the effect of the shock on multiple sectors is that they conduct the analysis for each sector independently, neglecting the interconnections of the sectors. Jo et al. (2019) expand the work of Lee and Ni (2002) using a factor-augmented VAR approach, where factors are extracted from sectoral output and price data. Otero (2020) while preserving the sector-by-sector estimation, he augments each sectoral VAR with the sum of variables in the rest of the industries. While both methods enrich the information of the model, they have certain limitations. For instance, Otero's method considers fluctuations in the rest of the industries but overlooks the complementarities between sectors arising from intersectoral trade. On the other hand, factor models often struggle with interpretability, and neither approach fully captures the heterogeneity across different sectors.

This study proposes an alternative methodology that can be used for the estimation of the sectoral effects. Specifically, I estimate a GVAR model with a sectoral dimension and a macroeconomic block. In this setting, the shock is identified within the macro-block and then propagates across sectors. The model allows the shock to affect each sector directly but also indirectly through other industries. My approach follows the production network literature, so I specify the model in a way that distinguishes between upstream and downstream propagation channels of shocks Acemoglu et al. (2012, 2016).

An important advantage of the model is that it can effectively reduce the dimensionality of the data and at the same time fully capture the sectoral heterogeneity. The model is estimated on a sector-by-sector basis and then it is solved to a global representation where all the variables of the model are endogenous and directly connected. Using the global form of the model, I conduct IRF analysis and obtained individual responses for sectoral output, sectoral employment, sectoral prices and sectoral total factor productivity (TFP). In an extension, I considered the effect on sectoral consumption and sectoral exports as well. Overall, I estimate the effects of the oil shock on 64 sectoral variables.

Previous studies on the UK have primarily estimated oil shocks using two approaches. The first approach treats the oil price as exogenous to the VAR system. The second approach involves identifying oil demand and supply shocks within a global oil market VAR, using the recursive identification method of Kilian and Park (2009). The identified shocks are then applied in a UK-specific VAR, as seen in studies like Lorusso and Pieroni (2018).

In a very influential paper, Känzig (2021) identifies an aggregate shock to oil supply expectations, by exploiting institutional features of the OPEC and information contained in high-frequency data. The idea is that OPEC, the biggest player in the global oil market, can significantly influence current oil prices through its announcements about future oil production. For example, when OPEC announces a future reduction in oil production (negative news regarding future oil supply), it immediately triggers an increase in oil price. Känzig exploits fluctuations in oil futures prices around OPEC announcements to derive a proxy for oil price changes driven by expectations of future supply shocks. Oil futures are forward looking variables and contain information about the future state of the business cycle. Therefore, by looking at the change of the futures prices within a reasonably tight window around the announcements, he isolates exogenous variations in the oil price due to the supply news shock. Notably, changes in the expectations of future oil supply is found to be an important driver of the word oil price fluctuations and can explain many significant historical changes in the oil price.

Findings: I identify the oil shock using Känzig's approach. I use the proxy-SVAR methodology of Stock and Watson (2012) and Mertens and Ravn (2014) adjusted to the GVAR framework. I use the Känzig (2021) oil surprise proxy as an external instrument. My findings can be summarised as follows:

1. The oil shock has a negative impact on real macroeconomic variables; output decreases and unemployment rises. The negative effects can be explain through two channels: A negative supply and a negative demand effect. On the supply side productivity and employment falls significantly. On the demand side, the oil shock leads to rising prices, prompting monetary policy tightening, which in turn reduces overall demand.

2. While the oil shock has a negative impact on economic activity overall, some transitory positive effects are observed. Consistent with previous research, such effects occur in oil-exporting countries that gain short-term benefits from rising international oil prices. I find that the real exchange rate depreciates boosting exports.

3. Sectoral analysis reveals that there is great heterogeneity in how sectors experience the effects of the oil shock. In some sectors such as Mining, Energy & Water, Construction and Trade negative supply effect prevail. In others sectors, such as the Real Estate, Administration and Other Services are affected by negative demand forces. In other cases the effects are mixed.

4. Notably there are case, such as for Manufacturing, Transportation and Finance, where sectors experience positive demand effects. I show that these positive effects primarily originate from highly exporting activity in these sectors. However, such effects are temporary and are soon dominated by negative demand and supply effects.

5. Finally, a counterfactual IRF analysis showed that the Input-Output linkages play a significant role in the transmission of the shock, by amplifying the negative effects.

I conducted several checks to ensure the robustness of the results. First, I validated that the multisector model can replicate the predictions of a VAR estimated with aggregate data series. In addition, I confirmed the robustness of the results under different specifications, different identification instruments and additional variables.

The rest of the chapter is organised as follows. Section 3.2 describes the empirical analysis: the model, the data, the specification and the identification approaches. Section 3.3 presents the results of the baseline model, some extensions of the analysis and some robustness checks. Finally, Section 3.4 concludes.

3.2 Empirical analysis

3.2.1 Model

I model the UK economy using a GVAR with a sectoral dimension. The model consists of two blocks. The first block is a system of 16 sectoral VAR models in which cross-sectoral interactions are taken into account. The second block is a VAR model for common factors that affect all the sectors, for example, the oil price, the monetary policy or the exchange rate. This type of modelling allows changes in aggregate variables (e.g. the oil price) to affect each sector directly but also indirectly through Input-Output linkages. Besides, the model can capture feedback effects, so common factors like monetary policy can endogenously respond to economic developments at the sectoral level.

The dynamics of each sector are described by a VARX(p_i, q_i) as follows:

$$\mathbf{Y}_{it} = \alpha_{0,i} + \alpha_{1,i}t + \sum_{l=1}^{p_i} \mathbf{\Phi}_{i,l}\mathbf{Y}_{i,t-l} + \sum_{l=0}^{q_i} \mathbf{\Lambda}_{i,l}\mathbf{Y}^*_{i,t-l} + \sum_{l=0}^{q_i} \mathbf{\Gamma}_{i,l}\mathbf{X}_{t-l} + \mathbf{u}_{i,t} \tag{3.1}$$

where $\alpha_{0,i}$ is a vector of intercepts and $\alpha_{1,i}$ is the coefficient of a linear trend; $\mathbf{\Phi}_{i,t}$, $\mathbf{\Lambda}_{i,t}$, and $\mathbf{\Gamma}_{i,l}$ are matrices of coefficients and $\mathbf{u}_{i,t}$ is a vector of idiosyncratic sector-specific shocks which are assumed to be serially uncorrelated zero-mean processes with full covariance matrix $\mathbf{\Sigma_{ii}}$. $\mathbf{Y}_{i,t}$ is a k_i-vector of sector-level endogenous variables with $i = 1, 2, ...N$ and N being the number of sectors. $\mathbf{Y}_{i,t-1}$ represents the autoregressive term. The vector $\mathbf{Y}^*_{i,t}$ contains the sector-specific variables (henceforth *the star variables*) which represent the influence of the rest $N-1$ sectors on sector i and capture the relative cross-sectoral spillovers. The star variables are calculated as weighted averages of the corresponding sectoral variables of the other sectors, with weights based on Input-Output linkages. Specifically, star variables are described by equation Eq. (3.2).

$$\mathbf{Y}^*_{i,t} = \sum_{j\neq i}^{N} m_{i,j}\mathbf{Y}_{j,t} \quad \text{with} \quad \sum_{j\neq i}^{N} m_{ij} = 1 \tag{3.2}$$

where $m_{i,j}$ is a deterministic weight that shows the strength of the effect of sector j on sector i. Weights $m_{i,j}$ rely on the intersectoral trade and are calculated by the UK Input-Output tables. $\mathbf{X}_t$ is a vector of common variables affecting directly each sector. The dynamics of $\mathbf{X}_t$ follow an autoregressive process with feedback effects from the sectoral variables as described by equation Eq. (3.3).

$$\mathbf{X}_t = \alpha_{0,x} + \alpha_{1,x}t + \sum_{l=1}^{px_i} \mathbf{\Phi}_{x,l}\mathbf{X}_{t-l} + \sum_{l=1}^{qx_i} \mathbf{\Lambda}_{x,l}\mathbf{Y}_{x,t-l} + \mathbf{u}_{x,t} \tag{3.3}$$

where $\alpha_{0,x}$ is a vector of intercepts and $\alpha_{1,x}$ is the coefficient of a linear trend; $\mathbf{\Phi}_{x,t}$ and $\mathbf{\Lambda}_{x,t}$ are matrices of coefficients; $\mathbf{u}_{x,t}$ is a vector of idiosyncratic shocks which are assumed to be serially uncorrelated zero-mean processes with full covariance matrix $\mathbf{\Sigma_{xx}}$. $\mathbf{X}_t$ is the k_x-vector of the aggregate macroeconomic variables; $\mathbf{X}_{t-1}$ represents the autoregressive terms. $\mathbf{Y}_{x,t-l}$ is the vector of the feedback effects, accounting for endogenous responses of the aggregate variables to changes jointly happening at the sectoral level. Feedback effects are cross-sectoral weighted averages of all endogenous sectoral variables.

3.2.2 Data and specification

For the empirical analysis, I combined three types of data: aggregate UK economy data, sector-level data and data from Input-Output tables. Time-series were in quarterly frequency covering a period from 1997Q1 to 2019Q4. Aggregate and sectoral series were collected from ONS datasets, while IO tables covering the sample are available at the OECD *"IOTs"* database.

Table 3.1: Data definitions and sources

Variable in VAR	Definition	Construction	Source
	Panel A: Aggregate economy variables		
P^{Oil}	Real Price of Brend Oil	100*log-level	Fred
U_t	Unemployment Rate	% Rate	ONS
R_t^S	Short term interest rate	% Rate	OECD
R_t^L	Long term interest rate	% Rate	OECD
S_t	Real effective exchange rate (Broad Basket)	100*log-level	BIS
m_t	Oil-supply surprises	% Rate	Känzig (2021)
	Panel B: Sectoral variables		
Y_t	Real Sectoral Output (GVA)	100*log-level	ONS
N_t	Employment (People)	100*log-level	ONS
P_t	Sectoral GVA deflator	100*log-level	ONS
Z_t	Sectoral TFP	100*log-level	ONS
	Panel C: Sectoral variables - Synthetic measures		
C_t	Real Final Private Consumption Expenditure	100*log-level	OECD & ONS
X_t	Real Exports	100*log-level	OECD & ONS

Data spans the period 1997Q1–2019Q4. IO tables are published in annual frequency and are available for the same period by OECD: *IOTs* database. A positive change in the real effective exchange rate (S_t) indicates an appreciation of the domestic currency against a basket of foreign currencies. Date were transformed in log-levels or % rates where applicable.

The aggregate variables used in the analysis are the real Brent oil price (P^{Oil}), the unemployment rate (U_t), the real effective exchange rate (S_t), the 1-Year (R_t^S) and the 10-year

(R_t^L) UK government bond rates. The real effective exchange rate shows the value of the UK pound against a weighted average of a number of foreign currencies. A positive change in the exchange rate shows an appreciation of the £GBP against the $US dollar. The instrument used for the identification of the oil shock was taken from Känzig (2021). The instrument series are constructed in monthly frequency. I transformed the series in quarterly frequency by summing the monthly observations within each quarter. Panel A of Table 3.1 summarises the aggregate data.

My dataset covers 16 two-digit SIC economic sectors[1]. The sectoral level variables are: real gross value added (GVA) as a proxy for sectoral output (Y_t), sectoral employment (N_t), sectoral total factor productivity (TFP) (Z_t), a sectoral GVA deflator (P_t), real sectoral final private consumption expenditure (C_t) and real sectoral exports (X_t). The GVA deflator was calculated as the the nominal over the real sectoral GVA ratio from ONS series. Sectoral consumption (C_t) and exports (X_t) were calculated as synthetic measures using the annual sectoral distribution of the aggregate variables from the IO tables and the aggregate ONS series. Sectoral variables are in real terms and were transformed in log-levels. Panel B and C of Table 3.1 provides a summary of the sectoral series.

Finally, Industry Input-Output tables are provided by OECD with a 48-industry disaggregation. I aggregated IO table data to match the industry disaggregation of the ONS sectoral series.

Overall, the analysis required the specification of 17 individual VARX models. The 16-sector VARX models were specified identically, as follows:

$$\mathbf{Y}_{i,t} = \begin{bmatrix} Y_{i,t} & N_{i,t} & P_{i,t} & Z_{i,t} \end{bmatrix}, \quad \mathbf{Y}^*_{i,t} = \begin{bmatrix} Y^*_{i,t} & N^*_{i,t} & P^*_{i,t} & Z^*_{i,t} \end{bmatrix} \tag{3.4}$$

The endogenous sectoral variables: sectoral output, employment, prices and productivity are contained in vector $\mathbf{Y}_{i,t}$. With respect to the *star* variables that capture the cross-sectoral spillovers, I considered sector-specific weighted averages of sectoral GVA, sectoral employment, sectoral prices and sectoral productivity. Under this setting, the model can capture two distinct channels through which the shock propagated across sectors. The first channel works through intersectoral demand. For example, changes in output or employment in a sector can affect the output of the sector's suppliers through changes in demand for intermediate inputs. The second channel works through cost. Particularly, a surge in the price of oil increases the production cost in the sectors for which oil is a significant input in production. In turn, higher prices in a sector imply higher cost of intermediate inputs for the sector's customers. The oil price can affect sectoral productivity as well. I assume that a change in the productivity of a

[1] The sectoral disaggregation is presented in Table C.1

sector has a direct cost impact on sector's customers.

To capture the difference between the demand and the cost channel, I built sector-specific averages using IO tables data that reflect the sectoral composition of demand and the sectoral cost for each industry.[2]

For the aggregate economy VARX, it is necessary to specify two vectors as follows:

$$\mathbf{X}_t = \begin{bmatrix} P_t^{oil} & UR_t & R_t^S & R_t^L & S_t \end{bmatrix}, \quad \mathbf{Y}_{x,t} = \begin{bmatrix} Y_{x,t} & N_{x,t} & P_{x,t} & Z_{x,t} \end{bmatrix} \tag{3.5}$$

The endogenous vector of the aggregate economy, X_t, consists of all the aggregate economy variables. $\mathbf{X}_t$ enters the sectoral model as an exogenous, as it captures the direct effects of common factors on each sector. The vector of feedback effects contains the aggregated sectoral variables.

3.2.3 Estimation and Identification

The model estimation proceeds on a sector-by-sector basis following Pesaran et al. (2004). Given the limited length of the sample, all individual VARX models were estimated using a Bayesian approach. Specifically, I used a natural conjugate prior for the VAR parameters implemented via dummy observations as in Bańbura et al. (2010).

For each sectoral model, I selected a parsimonious specification with two lags for the endogenous variables, $p_i = 2$ and one lag for the exogenous variables, $q_i = 1$. For the aggregate economy VARX, I used a similar lag structure by fixing $p_x = 2$ and $q_x = 1$.

Once all individual sectoral VAR models have been estimated, the coefficients of the individual models can be solved to have a GVAR representation. To write the GVAR representation, I exploited the fact that the endogenous and sector-specific star variables can be written as linear combination of the global vector $\mathbf{Y_t}$. Let $\mathbf{Y_t} = (\mathbf{X}_t, \mathbf{Y}_{1,t}, \ldots \mathbf{Y}_{N,t})$' of dimension $(k_x + \sum_1^N k_i) \times 1$. By omitting any deterministic terms, I can write each individual model as:

$$\mathbf{A}_{s,0}\mathbf{L}_s'\mathbf{Y_t} = \sum_{l=1}^{p_s} \mathbf{A}_{s,l}\mathbf{L}_s'\mathbf{Y}_{t-1} + \mathbf{u}_{s,t} \quad \text{with } s = i, x \tag{3.6}$$

where $\mathbf{A}_{s,0} = (\mathbf{I}_{ks}, -\mathbf{\Lambda}_{s,0})$ and $\mathbf{A}_{s,l} = (\mathbf{\Phi}_{s,l}, \mathbf{\Lambda}_{s,l})$ with $p = max_i(p_i, q_i)$ and $\mathbf{\Phi}_{s,l} = 0$ for $l > p_i$ and $\mathbf{\Lambda}_{s,l} = 0$ for $l > q_i$. For the common factors VARX, where feedback effects are included only with a lag, $\mathbf{\Lambda}_{s=x,0} = \mathbf{0}$. $\mathbf{L_s}$ is a sector specific selection matrix that select the endogenous and star variables for each model. The individual models in Eq. (3.6) can be stacked to deliver the GVAR model:

[2] Acemoglu et al. (2016) use a similar modelling approach using the Leontief inverse of the IO matrix. Here I use a similar approach but I specify the GVAR using the IO martix instead of the Leontief inverse.

$$\mathbf{G}_0\mathbf{Y}_t = \sum_{l=1}^{p} \mathbf{G}_l\mathbf{Y}_{t-1} + \mathbf{u}_t \tag{3.7}$$

where $\mathbf{G} = [(\mathbf{A}_{x,0}\mathbf{L}_X)', (\mathbf{A}_{1,0}\mathbf{L}_1)' \dots (\mathbf{A}_{N,0}L_N)']$ and $\mathbf{G}_l = [(\mathbf{A}_{x,1}\mathbf{L}_0)', (\mathbf{A}_{1,1}\mathbf{L}_1)' \dots (\mathbf{A}_{1,N}\mathbf{L}_N)']$. The vector of errors is $\mathbf{u}_t = [\mathbf{u'}_{x,t}, \mathbf{u'}_{1,t} \dots \mathbf{u'}_{N,t}]$ and the global covariance matrix is $\mathbf{\Sigma}_u = E(\mathbf{u_t u_t}')$. I assume that matrix $\mathbf{\Sigma}_u$ is block diagonal as the contemporaneous correlation across units is captured by the common and the star variable. The latter assumption was also empirically tested with the Bailey et al. (2019) cross-sectional dependence test applied on the median of the residuals distribution.

Finally, the global representation of the model can be written in a VAR(1) formation that is used in the dynamic analysis. With $\mathbf{G}_0$ a non-invertible matrix, I obtained the reduced form global solution by pre-multiplying (3.7) by $\mathbf{G}_0^{-1}$:

$$\mathbf{Y}_t = \sum_{l=1}^{p_i} \mathbf{F}_l\mathbf{Y}_{t-1} + \tilde{\mathbf{u}}_t \tag{3.8}$$

where $\mathbf{F}_l = \mathbf{G}_0^{-1}\mathbf{G}_l$ for $l = 1, 2, ..., p$ and $\tilde{\mathbf{u}}_t = \mathbf{G}_0^{-1}\mathbf{u}_t$ with $\tilde{\mathbf{u}}_t \sim N(0, \Sigma_{\tilde{\mathbf{u}}})$ and $\mathbf{\Sigma}_{\tilde{\mathbf{u}}} = \mathbf{G}^{-1}\mathbf{\Sigma}_u\mathbf{G}^{-1\prime}$.

Overall, the model can capture three distinct transmission channels of the oil shock within and across the different cross-sectional units. First, the model can capture the effects within the aggregate economy unit as the aggregate macroeconomic variables are expected to respond to an exogenous increase in the oil price. Second, the model captures the direct effects of the oil price on each sector through the effect of common variables. Finally, the third channel is the indirect effect of oil prices that can affect each sector through input-output linkages, either by altering the cost or the demand for intermediate inputs. The three channels unfold through matrix $\mathbf{G}_0$ that encloses the contemporaneous correlation among sectors and between each sector and the aggregate economy model.

To identify a shock in a GVAR model, it is necessary to specify a matrix $\mathbf{B_0}$ of structural coefficients that pre-multiplies Eq. (3.7). The reduced form residuals of the global form will be linear combinations of the global vector of the structural shock ϵ_t. Thus, the reduced form residuals are related to the structural shocks by $\mathbf{u}_t = \mathbf{B_0^{-1}}\epsilon_t$, with $\mathbf{\Sigma}_\epsilon$ assumed to be diagonal. The matrix of structural coefficients is a block matrix as follows:

$$\mathbf{B_0^{-1}} = \begin{bmatrix} \mathbf{B}_{x,x} & \mathbf{B}_{x,2} & \dots & \mathbf{B}_{x,N} \\ \mathbf{B}_{1,x} & \mathbf{B}_{1,2} & \dots & \mathbf{B}_{1,N} \\ \dots & \dots & \dots & \dots \\ \mathbf{B}_{N,x} & \mathbf{B}_{N,2} & \dots & \mathbf{B}_{N,N} \end{bmatrix} \tag{3.9}$$

The diagonal blocks rule the contemporaneous correlation of the residuals within each unit, whereas the off-diagonal elements rule the cross-unit correlations. As I am interested in identifying the oil shock within the aggregate economy, it is essential that I identify the upper left block of $\mathbf{B^{-1}}$ and in particular the first column of $\mathbf{B}_{x,x}$ that corresponds to the oil price shock. Once the oil price shock is identified within the aggregate economy unit, the effects at the sectoral level can be calculated, using the coefficients of matrix $\mathbf{G_0}$. For the rest of the blocks, I assumed that $\mathbf{B_{-x,-x}} = \mathbf{0}$. This is equivalent to the assumption that the cross-unit correlation of the residuals is 0 and that the oil shock is propagated across the economy either through the common factors or through IO linkages as proxied by the star variables.

For the identification of the shock, I reliy on the proxy-SVAR method of Stock and Watson (2012) and Mertens and Ravn (2013). Restrictions on the $\mathbf{B}_{x,x}$ are obtained using a proxy for the latent shock. Without loss of generality, I assumed that the shock of interest is ordered first in the vector of structural shocks within the aggregate economy unit $\epsilon_{x,t} = [\epsilon_{x,1t}, \epsilon_{\mathbf{x},\cdot\mathbf{t}}]$ where $\epsilon_{\mathbf{x},\cdot\mathbf{t}}$ is a vector that contains the remaining shock of the unit x. To identify $\epsilon_{x,1t}$, I employ an instrument m_t as described by the following equation:

$$\epsilon_{x,1t} = \beta m_t + \xi_t, \quad \xi_t \sim N(0,1)$$

where $E(\xi_t \epsilon_{x,1t}) = 0$. The identification of the shock is achieved under the assumptions of relevance $\beta \neq 0$ and of exogeneity $E(m_t, \epsilon_{\cdot t}) = 0$. In other words, the instrument must be correlated with the unobserved shock and orthogonal to the rest of the shocks.

To obtain the restrictions for matrix $\mathbf{B}_{x,x}$, one must proceed with the following two steps[3]. First, obtain the reduced form residuals from the VARX model of the aggregate economy unit $\mathbf{u}_{x,t} = [u_{x,t}^{Poil} \quad \mathbf{u}_{x\cdot,t}^{non-oil}]$ where the first element $u_{x,t}^{Poil}$ corresponds to the reduced form residual of oil price equation in the VARX. The second element is a vector containing the rest of the residuals in the model. Second, run a 2SLS regression by regressing the residuals in $\mathbf{u}_{x\cdot,t}^{non-oil}$ on the oil price residual $u_{x,t}^{Poil}$ using m_t as an instrument. The rationale behind the second step is that the oil price residual is a linear combination of multiple structural shocks. By employing an IV regression, it is possible to isolate the variation in the oil price that is the result of news about changes in future oil production. The estimated coefficients of the first and the second stages represents unbiased estimates of the first column of $\mathbf{B}_{x,x}$. However, structural coefficients are identified up to a scale factor, hence it is necessary to impose covariance restrictions.

The instrument used for the identification of the oil shock is the oil surprises measure of Känzig (2021). Känzig identifies changes in oil prices due to oil supply news shocks by

[3] Restrictions will be applied only for the first column of matrix $\mathbf{B}_{x,x}$

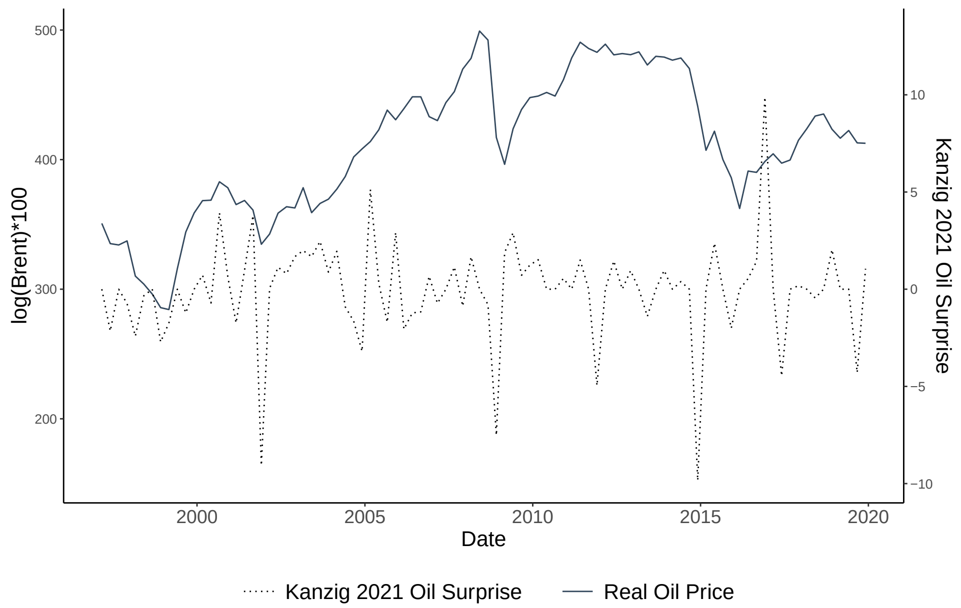
exploiting the variation in oil futures prices around OPEC production announcements. Kanzig's main idea is that by measuring the changes in forward-looking variables, such as the oil futures prices, around the announcements, it is possible to disentangle the impact of news about future oil supply from other effects, most importantly the state of the business cycle. He constructs the instrument as a measure of oil price surprises as follows:

$$Surprise_{t,d}^{H} = F_{t,d}^{h} - F_{t,d-1}^{h}$$

where d and t is the day and the month that OPEC announces their decision for the level of the oil production in the near future. $F_{t,d}^{h}$ is the (log) settlement price of the h-months ahead oil futures contract in month t on day d. Oil surprises are given by the difference between the log price of the future contract on the day of the announcement and the price the day before.

Figure 3.1 shows the real oil price and the instrument for the sample period 1997Q1:2019Q4. The two series show common spikes around dates of key events that led OPEC to revise its production. Such events are the 1997 Asian financial crisis, the financial crisis of 2008, the 2014 oil collapse and the 2016 decision of OPEC to cut down production for the first time after the financial 2008.

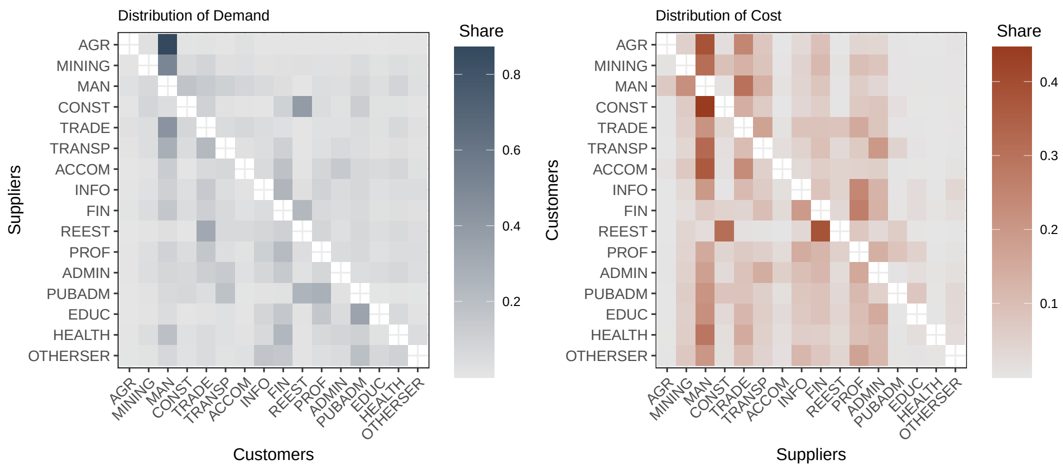
Figure 3.1: Real Oil price - External instrument



Notes: *The plot shows the real Brent oil barrel price in logarithms (solid line - left axis) and the oil surprise instrument of Känzig (2021) (dotted line - right axis) for my sample 1997-2019. The two series show common spikes around dates of key events that led OPEC to revise its production. Such events are the 1997 Asian financial crisis, the financial crisis of 2008, the 2014 oil collapse and the 2016 decision of OPEC to cut down production for the first time after the financial 2008.*

3.2.4 Weight matrices

Figure 3.2: Distribution of Sectoral *Demand and Cost*



Notes: *The plot show the weighting matrices used in the GVAR model. The left matrix illustrates the share of the output of each Supplier (row) sector used as an intermediate input in the production of its Customer (column) sectors. The matrix on the right panel illustrates how the cost of intermediate inputs used in the production of each Customer (row) sector is distributed across its Suppliers (column). The left matrix rules the upstream propagation of shocks and are used for the calculation of* ***output and employment star*** *variables. The right matrix rules the downstream propagation of shocks and is used for the calculation of* ***prices star*** *variables. Matrices are row normalised. Darker colours indicate higher weights.*

An essential component of the specification of the GVAR model is the deterministic weight used for the calculation of the sector-specific star variables. These weights rule the interaction of sectoral models and hence the way the shock is propagated across sectors. Following, Acemoglu et al. (2016) and the extension of Barattieri et al. (2023), I assumed that an oil shock can be propagated to both upstream and downstream industries. However, my analysis differs from previous work in the area, as I take a more specific stance on the mechanism through which the shock is propagated.

In line with previous studies, I assumed that changes in the production of sector i impact all the industries that supply inputs to this sector, through a demand-side effect. For example, a drop in a sector's production due to higher production costs reduces demand for intermediate inputs, thereby impacting its suppliers. Using the definition of Acemoglu et al. (2016) I consider this the "upstream effect".

The oil shock can be propagated to downstream industries through a cost channel. A rise in oil prices can affect the productivity and the production cost of a sectors, driving up the prices of sector's product. Therefore, increasing costs for the customer industries that purchase from this sector. In contrast with previous work, I explicitly allow sectoral variables to be affected by the output prices and the productivity of their suppliers' (downstream) sectors. I call the latter the "downstream effect".

To capture the differences between the upstream and downstream propagation channels, I used two different types of weights. Weight are summarised by the two matrices in 3.2. The two matrices should be read row-wise. The matrix on the left panel illustrates the share of the output of each Supplier (row) sector used as an intermediate input in the production of its Customer (column) sectors. The weights of the left matrix are associated with the cross-sectoral demand channel and the upstream propagation of the shock hence, are used for the calculation of the cross-sectional averages of output and employment for each VARX model.

The matrix on the right panel illustrates how the cost of intermediate inputs used in the production of each Customer (row) sector is distributed across its Suppliers (column). The weights of the right matrix are associated with the cross-sectoral cost channel and rule the downstream effects. The weights of the left matrix are used for the calculation of the cross-sectional averages of sectoral prices and sectoral productivity.

Overall, the rationale behind this weighting scheme is that sectors are affected by the demand for intermediate inputs originating from their customers or the relatively upstream sectors, as indicated by each sector's position in the production network. On the other hand, sectors are affected by the sectoral cost of their suppliers, that is the downstream industries.

Matrices were built with IO tables data, where entries of the IO matrix were averaged over the period 1997–2019. The specification of the GVAR matrices was also row-normalised.

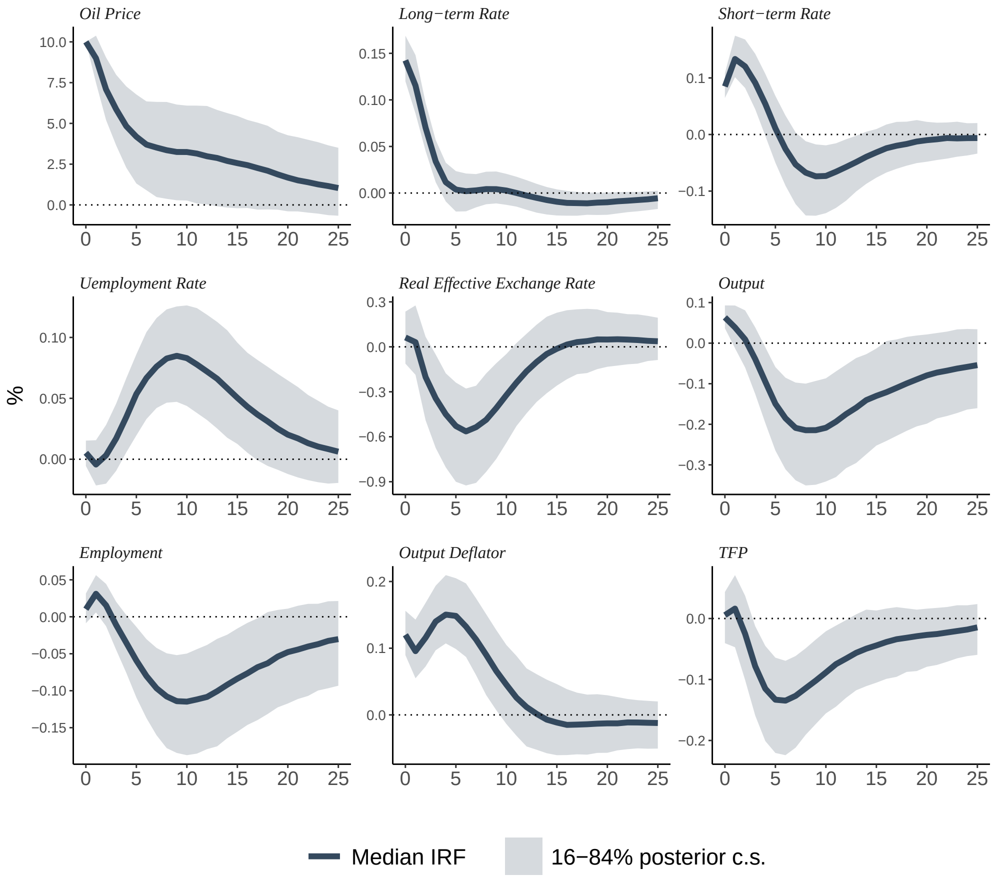
3.3 Results

3.3.1 Aggregate economy

This section presents the results of a VAR estimated using aggregate data. This approach is important for two key reasons. First, to the best of my knowledge, this is the first time that the effect of oil supply news shocks has been explored for the UK economy. Second, the aggregate data estimation provides a baseline framework that can be used to assess the predictions of the multi-sectoral model used in this study.

The specification of the aggregate economy model is similar to the aggregate model described in Eq. (3.5), without any exogenous variables and augmented with the aggregate real output, employment, output deflator and aggregate total factor productivity. The model is estimated with a constant, a linear and a quadratic trend and two lags. The estimation is Bayesian and is similar to the one of the individual VARX model described in Section 3.2.3.

Figure 3.3: Aggregate Economy - Proxy SVAR results



Notes: *The plot shows the dynamic impact of an 10% increase in oil price due to an oil supply news shock. The figure depicts median impulse responses and their 68% central posterior credible set (c.s). All y-axis values are in percentage change. Positive response of the Real Effective Exchange Rate indicate a real appreciation of the £GBP against a basket of foreign currencies.*

Figure 3.3 presents the effects of an oil supply news shock, identified using the external instrument approach. The shock is normalised, so as the oil price response increases on impact by 10%. The solid lines indicate the median IRF and the shaded areas is the 68% of the posterior credible set.

A negative oil supply news shock increases immediately the price of the oil. The oil price response remains in the positive area for five years (entirely positive for quarters) after the shock and then returns to the pre-shock levels. Despite the differences in my sample and data frequency, the shape of the response is similar to Känzig (2021), where the oil price peaks on impact and remains positive for more than 50 months.

The shock has a negative impact on the real macroeconomic indicators. The unemployment rate remains largely unaffected on impact, but gradually rises, reaching its peak 0.08% three years after the shock. Consistently, employment drops, reaching -0.12% at the same three-year mark.[4] GDP increases by 0.1% on impact, but turns negative three quarters after the shock, plunging at -0.21% at horizon 8 and remaining in the negative area up to 15 quarters after the shock.

The economic downturn can be explained by two factors. First, by a negative supply effect. After a 10% increase in the oil price, the GDP deflator jumps to 0.13% on impact and peaks at 0.15% six quarters after the shock. The 0.15% rise is in line with the previous prediction. Higher production cost decreases productivity by -0.15% a year after the shock.

On the other hand, the demand side also plays an important role in the transmission of the shock. Higher inflation pushes interest rates upwards. The 1-Year rate peaks on impact at 0.15% (15 basis points) while the 10-Year rate at 0.12% (12 basis points). The short term rate response turns to 0 a year after the shock. The response of the long term rates turns negative and then returns to the pre-shock level, tracking closely the slowdown of output and the lower inflation. The interest rate responses indicate that monetary policy might play an important role in the transmission of the oil shock. Monetary tightening in response to higher prices and expectations for higher future inflation, reduces aggregate demand and pushes down further output. Besides, the demand effect can work through lower households' discretionary income. Higher oil prices have found to decrease consumers available income leading to lower private consumption. Interestingly, despite the monetary tightening, the oil shock leads to a depreciation of the British pound against a basket of foreign currencies. The real effective exchange rate plunges at -0.55% six quarters after the shock. This result shows that domestic prices are more sensitive to the global oil shock than in prices in the rest of the countries. The depreciation of the currency can produce some boosting effects for exports.

Overall, the oil shock has a negative impact on economic activity. However some positive effects are observed for output the first three quarters. The transitory positive effect, also highlighted by Cashin et al. (2014); Mohaddes and Pesaran (2016); Känzig (2021), has been observed in cases of oil-exporting countries that experience short-term benefits from the international oil price surge. In the following sections, I establish that these benefits primarily originate from highly exporting sectors like Manufacturing, Transportation and the Financial sector. Manufacturing plays an important role. First, is the UK's largest exporter, therefore it profits from a short-term growth in exports. Second, the presence of inventories of inputs and/or tradable goods helps absorb cost shocks and maintain supply and low prices, at least for a short period of time. However, as part of a robustness exercise, I demonstrate that the beneficial effects of the oil shock are likely linked to the UK's status as a net oil exporter.

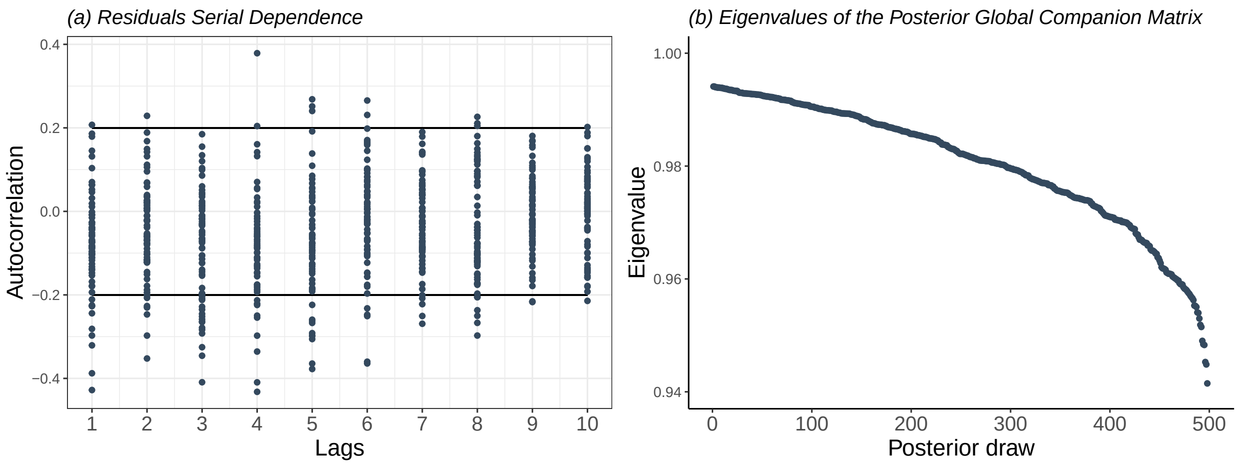
[4] Employment is included in the specification, as it is also used in the multi-sectoral analysis

Specifically, I compare the baseline model with a one that is estimated in a post-2005 sample, when the UK had become a net oil importer. The results indicate that in many sectors, the positive impact on production vanishes once the UK is no longer a net oil exporter.

3.3.2 The multi-sectoral model results

3.3.3 Aggregate VAR vs GVAR and Model Diagnostics

Figure 3.4: Multi-sectoral model diagnostic checks.



Notes: *Panel (a) shows the serial dependence of the residuals of all variables of the model. Panel (b) shows the eigenvalues of the Global companion matrix obtained for each posterior distribution.*

This section presents the results of the baseline multi-sectoral model. Prior to discussing the IRF analysis, I provide some diagnostic checks to assess the serial correlation and the stability of the model. Additionally, to confirm that the multi-sectoral model can produce credible estimates, I compare its predictions with the results obtained from the VAR estimated with aggregate data in section 3.3.1.

Panel (a) of Figure 3.4 illustrates the autocorrelation function of the residuals for all the variables in the model[5]. The majority of the residuals show no effects of serial correlation, indicating that despite the parsimonious specification, the model can efficiently account for the persistence in the data. Panel (b) illustrates the maximum eigenvalue of the global companion matrix obtained for each posterior draw. The maximum eigenvalues for each draw is less than a unit, indicating that the model can capture the complex interaction of the variables and at the same time is stable, resulting in the die out of shock after some horizons. Additionally, residuals

[5]Serial correlation was calculated using the median of the posterior distribution of the residuals of each individual VARX model

were tested for (weak) cross-sectional dependence using the tests of Pesaran (2015); Bailey et al. (2019). The cross-sectional dependence hypothesis was rejected at a 10% confidence level, indicating that the common factors and the star variables account effectively for the cross-sectional dependence of the residuals. The test was applied on the mean (pv = 0.064) and median (pv=0.062) of the posterior distribution of the residuals.

To demonstrate the alignment between the results of the two models, I compared the IRF of the aggregate data VAR, as presented in Figure 3.3, with the aggregate response obtained from the multi-sectoral model. The aggregate IRFs were calculated as the sum of the individual sectoral responses, weighted by the relative share of each sector in terms of total output (or total employment for the employment variable). Figure 3.5 shows the IRFs of the two models. The solid line represents the median VAR responses and the dotted-dashed lines represent the weighted sum of the individual sectoral responses.

The upper panels *(a)* and *(b)* show the median IRFs of output and employment, whereas the bottom panels *(c)* and *(d)* show the responses of the TFP and prices. The GVAR model can replicate the shape of the VAR responses accurately, both in terms of magnitude and timing. The similarity between model responses enabled me to estimate sector-specific responses with a certain degree of confidence.

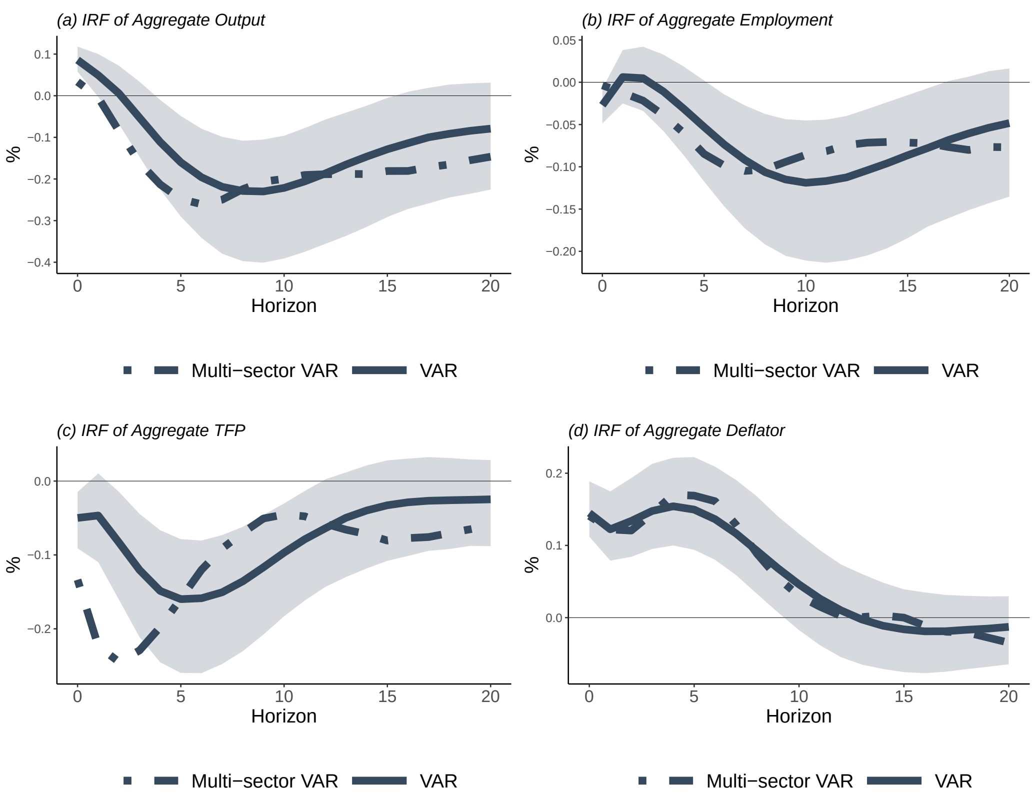
3.3.4 Impulse response functions analysis

This section presents the results of the IRF analysis. I directly proceeded to present the sector-level results, considering that the responses of the aggregate economy variables are almost identical to the aggregate VAR responses presented in Figure 3.3 and are omitted for the economy of space. Figure 3.6 illustrates the sectoral output responses to a 10% increase in oil price, due to an oil supply news shock. Figure Figure 3.7 plots the corresponding responses of sectoral prices.[6] Despite the extensive volume of results, I attempted to provide the key insights into the sectoral effects of the shock and its propagation across the sectors.

The oil shock affects sectoral variables through both supply and demand side forces. Supply reductions can occur due to higher production costs, particularly in the industries where oil is intensively used as production input. Negative demand effects may result from a series of reasons: A decrease in consumers' discretionary income, a lower demand from the external sector, an increased uncertainty about future oil prices, or even a monetary policy tightening in anticipation of higher prices following the oil shock. On the other hand, it is possible that some sectors receive positive demand and supply effects. For example, increasing oil cost can lead to a more productive allocation of inputs and higher output. Additionally, sectors producing

[6]The full dynamic responses of sectoral variables are presented in Appendix C.2 in the appendix.

Figure 3.5: VAR vs Multi-sector-VAR predictions.



Notes: *This graph contrast the IRF of the VAR model estimated with aggregate data and the aggregated responses of the multi-sector GVAR model. The solid line represents the median VAR responses and the dotted-dashed lines represent the weighted sum of the individual sectoral responses.*

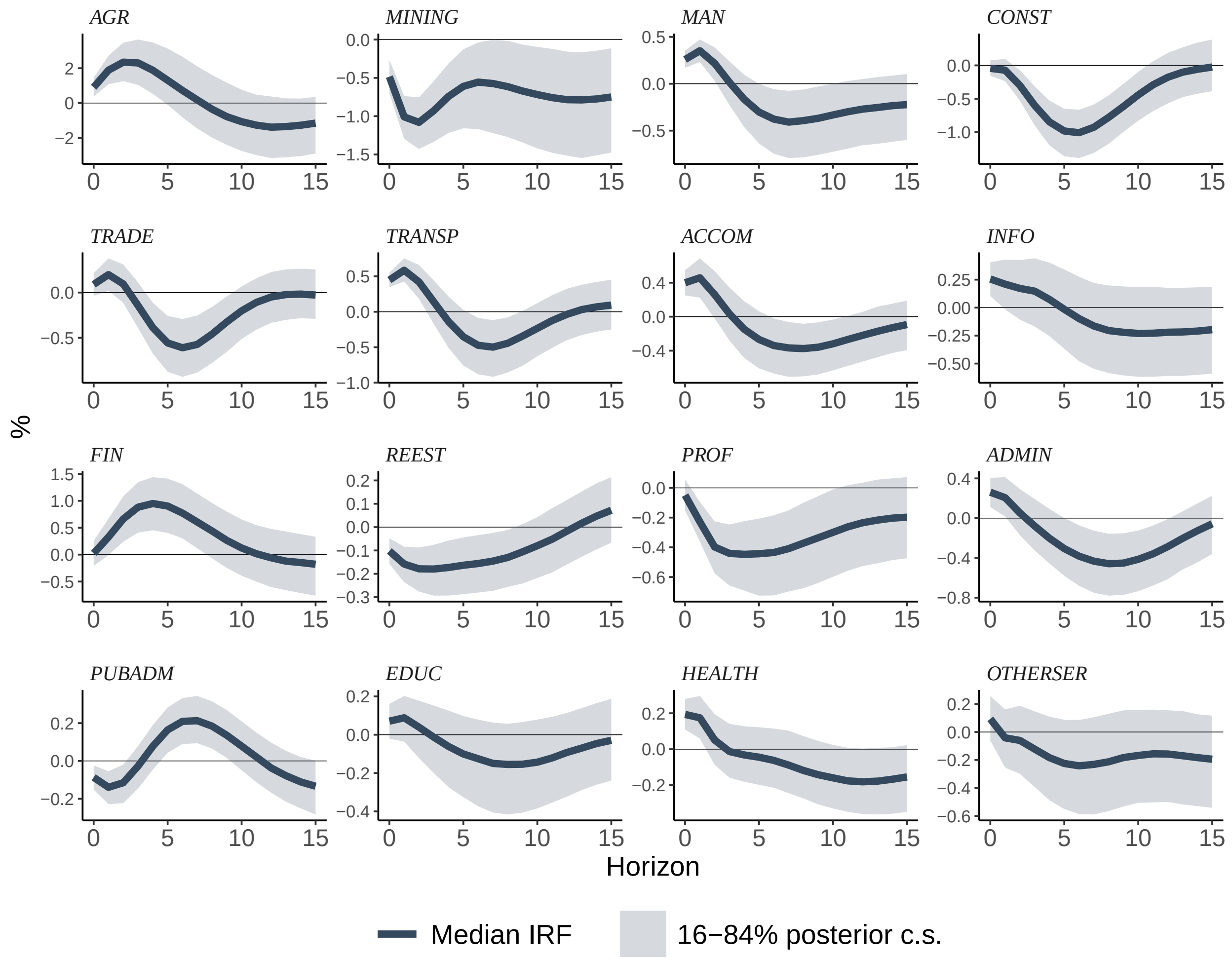
energy-efficient products may witness an uptick in demand during periods of elevated energy costs.

Ultimately, sectors encounter the immediate impacts of a surge in oil prices, as well as the indirect repercussions stemming from other affected industries. A hit industry can generate (positive or negative) spillovers, that propagate across the supply chain.

Supply and demand channels can operate simultaneously. Results indicate the channel that dominates in each case. In the spirit of Lee and Ni (2002) and Jo et al. (2019), the prevailing effect can be inferred by looking at the directions that the sectoral output and the price are moving towards. When the sectoral output and the price move in opposite directions, the prevailing effect is on the supply side. When the two variables move in the same direction, then the demand effect dominates.

For the three sectors of Mining, Energy & Water, Manufacturing and Construction, the oil effects work through a negative supply channel. The increasing cost leads to lower sectoral production. From the IRF in Figure 3.6 the responses of sectoral production are negative and they are accompanied by a rise in sectoral price level, as shown in Figure 3.7.

Figure 3.6: Sectoral output IRF.

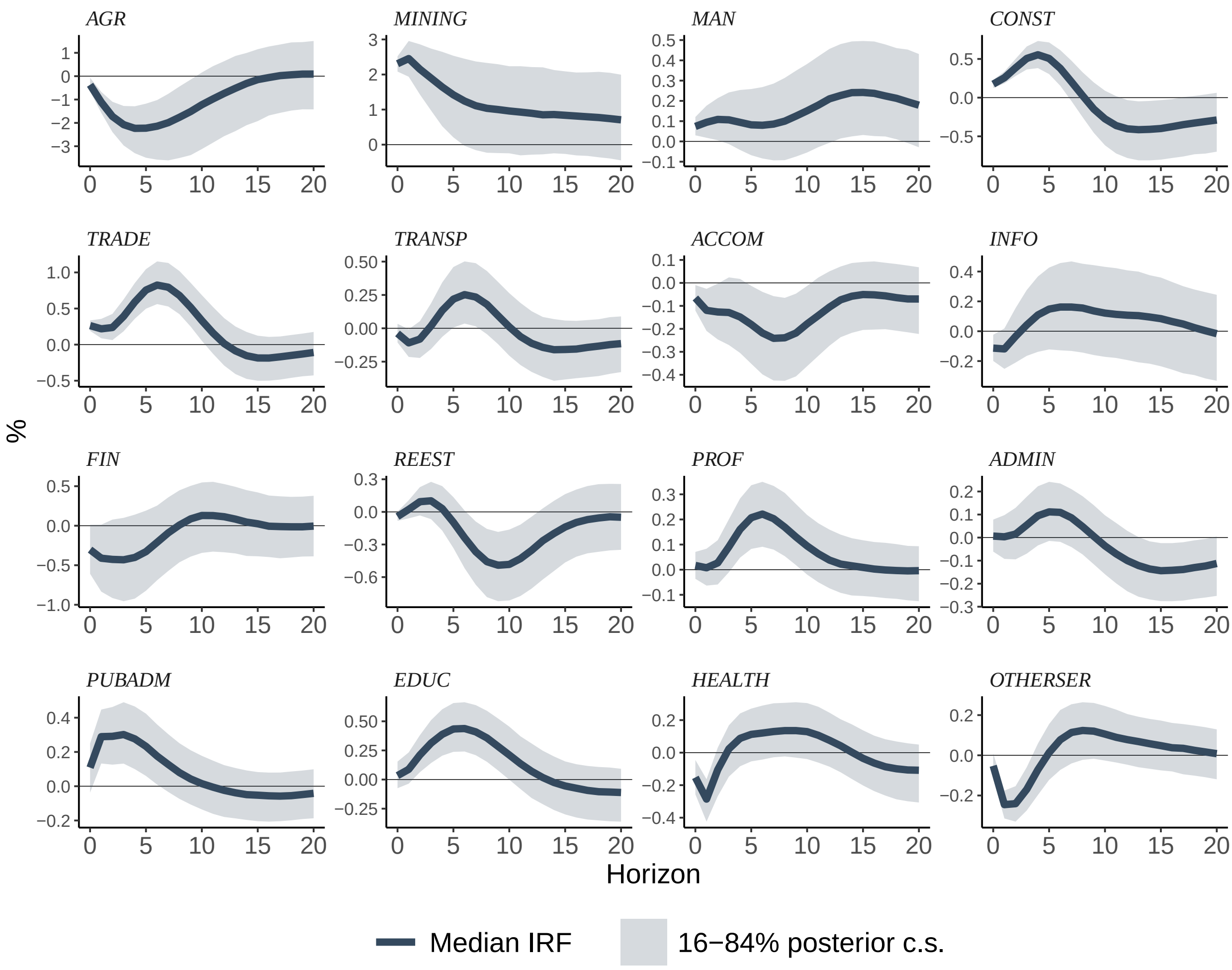


Notes: *The plot shows the sectoral output responses to a 10% increase in oil price due to an oil supply news shock. The solid line is the median impulse response. The grey area shows the 68% central posterior credible set*

However, the case is slightly different for the Manufacturing sector. The manufacturing output response is positive for the first three quarters. The increase can be attributed to the two following factors; First, in contrast to Mining, Energy & Water, and Construction, Manufacturing a significant exporting industry and benefits form the higher export demand.[7] Second, as highlighted in Jo et al. (2019), the existing inventories can work as an initial shock absorber by sustaining the sectoral costs and thus confine sectoral supply. However, when the inventories are depleted, the higher cost effect kicks in, resulting in lower supply and higher

[7] As shown on Figure C.4 exports of Manufacturing increase for the first 4 quarters.

Figure 3.7: Sectoral prices IRF.



Notes: *The plot shows the sectoral prices responses to a 10% increase in oil price due to an oil supply news shock. The solid line is the median impulse response. The grey area shows the 68% central posterior credible set*

prices. Indeed, as shown in Figure 3.7, initially manufacturing prices present a slight increase, but they substantially rise at later horizons.

From the third columns of the matrices in Figure 3.2, it becomes evident that Manufacturing plays an pivotal role in the production network. First, it is a significant buyer of intermediate inputs. Hence, the positive response of the output in the Manufacturing sector entails significant spillover effects for the rest of the industries. Second, manufacturing goods make up a significant share of the total input cost in the remaining sectors. The weak price response in Manufacturing keeps down the cost in the rest of the sectors.

The oil shock has quite heterogeneous effects on service-based sectors. The dominant effect varies depending on the specific industry and can be on the demand or on the supply side.

In some cases, the effect is a mix of supply and demand forces. For example, Trade and Professional Services are industries dominated by a negative supply effect. In Real Estate, Administration and Other Services, a negative demand effect prevails.

In other sectors, such as Transportation, both supply and demand forces are observed. Transportation output initially increases. This result can arise due to to the oil exporting activities of the firms in this sector and due to the close connection with Manufacturing . Price remains unresponsive for four quarters. At a later horizon, a negative supply shock prevails, resulting in lower production and an increase in price.

Another non-typical yet interesting result is the strong positive effect observed in the case of the Financial sector. The effect is not very straightforward to interpret[8]. It is uncertain whether the effect is driven by demand or supply, as the price response is negative but the effect is unclear. The positive output response can be attributed to an increase in demand for insurance services, a higher investment in financial products linked to oil, or non-interest revenues of banks (see Hesse and Poghosyan (2016), Killins and Mollick (2020)). Exports demand can amplify the effects, given the sector's strong export orientation.[9] The slightly negative response of price remains puzzling as someone would expect that a positive demand shock would push sectoral prices up. However, the financial sector experiences a strong productivity improvement (see Figure C.1) that reduces costs and can counter-balance the increase in prices. [10] In any case, the rise in output can generate positive spillovers for other industries, considering that the Financial sector is closely associated with a number of service-based sectors.

The effects on the Agricultural sector exhibit the traits of a strong positive supply shock. This can be explained by the lag between the decision making for production, preceding the oil shock, and the actual production in this specific sector. Indeed, at horizons, the response of output turns negative. Finally, Public Administration, Education and Health depend heavily on public spending and as sectors, are less exposed to short-run market fluctuations. However, oil is intensively used by Public Administration and the cost effect is clearly reflected on the response of the price in that sector.

Figure 3.8 shows the sectoral IRF for the remaining variables in the model. Each bar represents the cumulative sum of the median IRF over an 8-quarter horizon, weighted by the

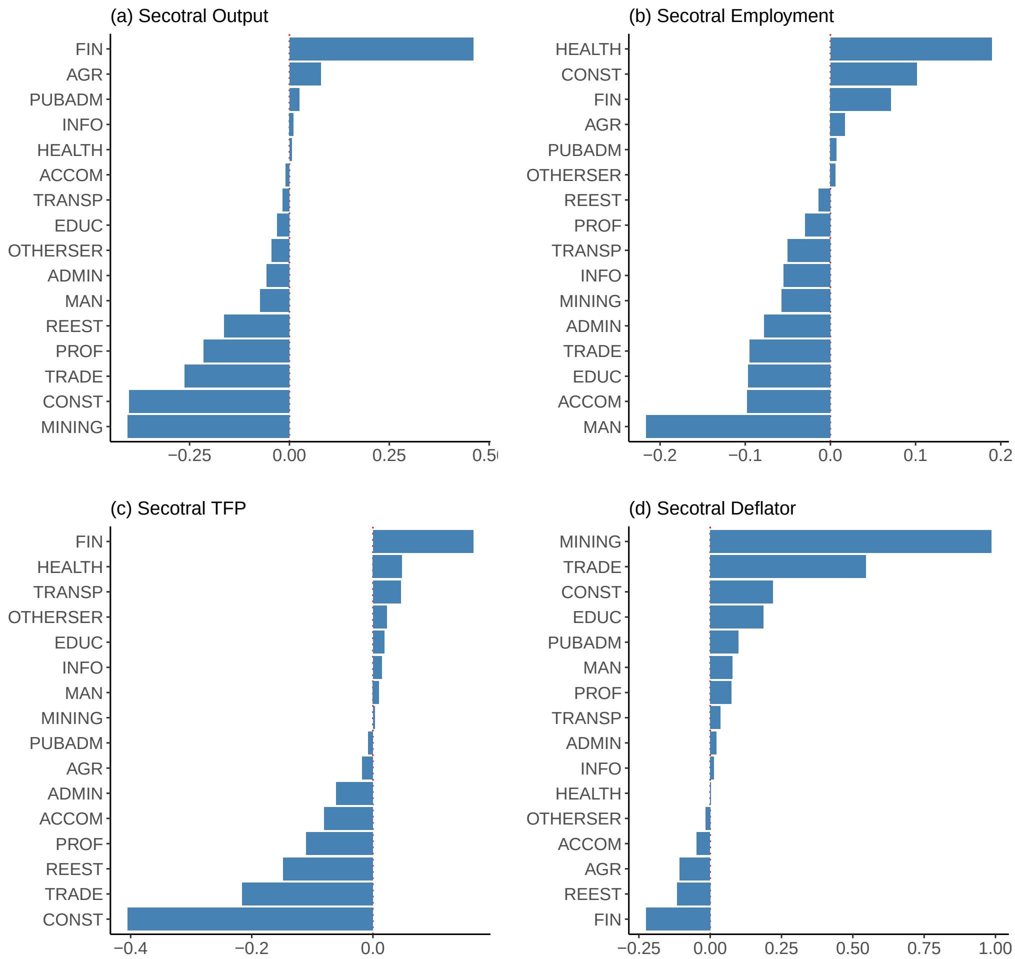
[8] In the following sections, a robustness analysis is provided, where the shock is identified using an alternative instrument. Oil future price revisions are purged from OPEC's decisions that reflect fluctuations in global demand. With the new instrument the positive effect on the Financial sector is of lower magnitude and non-significant.

[9] The financial sector exports more than 8% of its product.

[10] Coyle and Mei (2023) show that productivity of the financial sector had been growing by 3% per year from 1998 to 2008, before slowing down by 1.2% per year from 2009-2019.

relative size of each sector. In this way the sum of the individual cumulative responses is equivalent to the cumulative response of the aggregate variable. Such a representation offers greater value from a policy perspective, as it provides a more accurate view of the relative magnitude of the shock and reveals the sector that bring in the biggest impact on the total economy.

Figure 3.8: 8-quarter cumulative sum of the median IRF.



Notes: *The plot shows the sectoral responses to a 10% increase in oil price due to an oil supply news shock. Bars represents the cumulative sum of the median IRF over an 8-quarter horizon, weighted by the relative size of each sector.*

As shown in panel (a), Mining, Energy & Water and Construction are the sectors with the most significant output loss of 0.4% each. Other significantly affected sectors are Trade, Professional Services and Real Estate. On the other hand, Financial Services is the most benefited sector.

Panel (b) illustrates the responses of employment. Manufacturing bears the most substantial employment burden, while Accommodation, Education, Transportation, and Administration also experience significant decreases. Conversely, employment sees a notable increase in Health, Construction, and Finance. The rise of employment in the Construction sector is rather unexpected, as the sector experiences a negative supply effect. The increase can be rationalised by the substitution of capital with labour that aims to mitigate the increasing capital cost induced by higher oil prices. The rise in employment in some sectors reveals that the oil shock can trigger some sectoral shifts and a process of intersectoral labour reallocation (Davis and Haltiwanger (1992), Keane and Prasad (1996)).

Panel (c) illustrates the responses of sectoral productivity. The size and the sign of the responses follow the ratio of the responses of output over employment. Construction incurs the most substantial productivity costs. Trade and Real Estate undergo notable declines, whereas the Financial sector sees significant productivity gains. However, it is crucial to note that many of these productivity changes are caused by demand-side fluctuations and may not necessarily indicate shifts in technology.

Lastly, panel (d) presents the outcomes for sectoral prices. The Mining, Energy & Water sector emerges as the most significant contributor to total inflation, while the Trade prices also rise substantially. There are only a few sectors where prices fall, but the change is negligible.

3.3.5 The role of the production network - a counterfactual exercise

This section investigates the role of the production network in amplifying or mitigating the effects of a fiscal shock. In the baseline model, the shock affects each sector directly and is further propagated to other sectors through the production network. The extend to which sectors affect each other depends on the structure of the production network. To uncover how intersectoral trade influences the overall size of the shock, I conducted a counterfactual IRF analysis. Specifically, I imposed restrict the coefficients of the star variables to in the baseline model to be zero and I recalculated the IRF. The restrictions are equivalent to a model where each sector can receive the direct effects from the aggregate economy unit but coefficients that rule the sectoral interaction are set to zero.

To show the counterfactual effect, I contrasted the aggregated individual sector responses from the baseline model and the counterfactual responses. Figure 3.9 depicts the two responses. The solid line represents the aggregated sectoral output responses of the baseline model and the dashed line represents the counterfactual responses.

The analysis showed that input-output linkages act as an amplifier for the oil shock. This result corroborates the finding of Caraiani (2022) that network effects amplify the negative impact of an oil supply news shock in the United States. In the early horizons when interactions

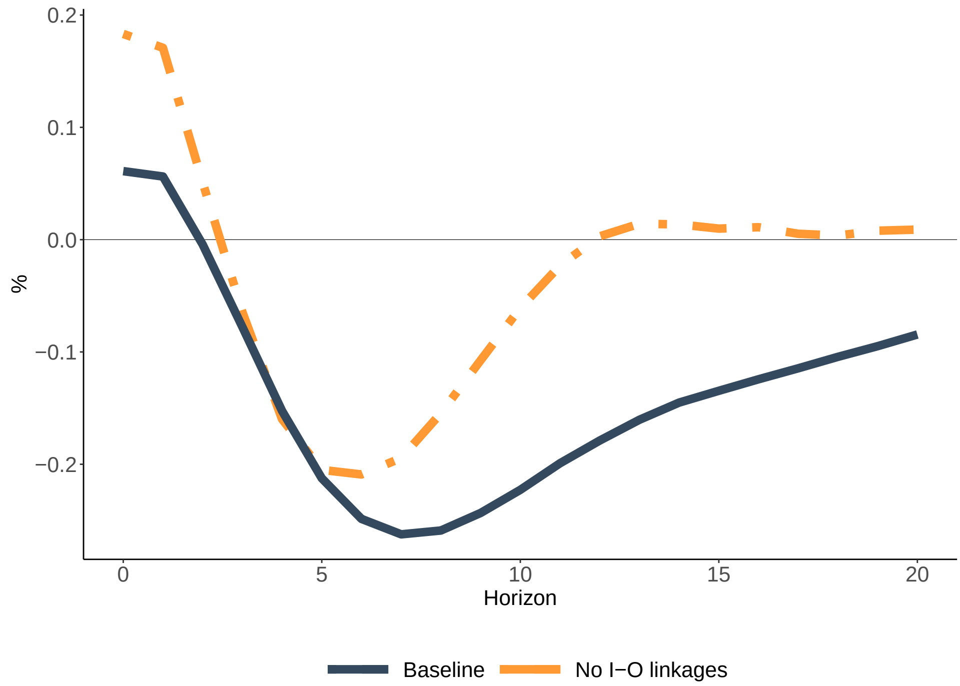


Figure 3.9: Aggregate Output IRF.

Notes: *The figure shows the IRFs of aggregate output to a 10% increase in oil price, due to an oil supply shock. The solid line represents the aggregated sectoral output responses of the baseline model. The dashed line represents the counterfactual aggregated sectoral output from a model where foreign variables coefficients are restrict to zero.*

across sectors are shut down, the counterfactual response is more positive than the baseline one. In later horizons, the counterfactual response is less negative. This implies that a significant fluctuation of the aggregate output originates from the intersectoral connections.

3.3.6 Extension and robustness

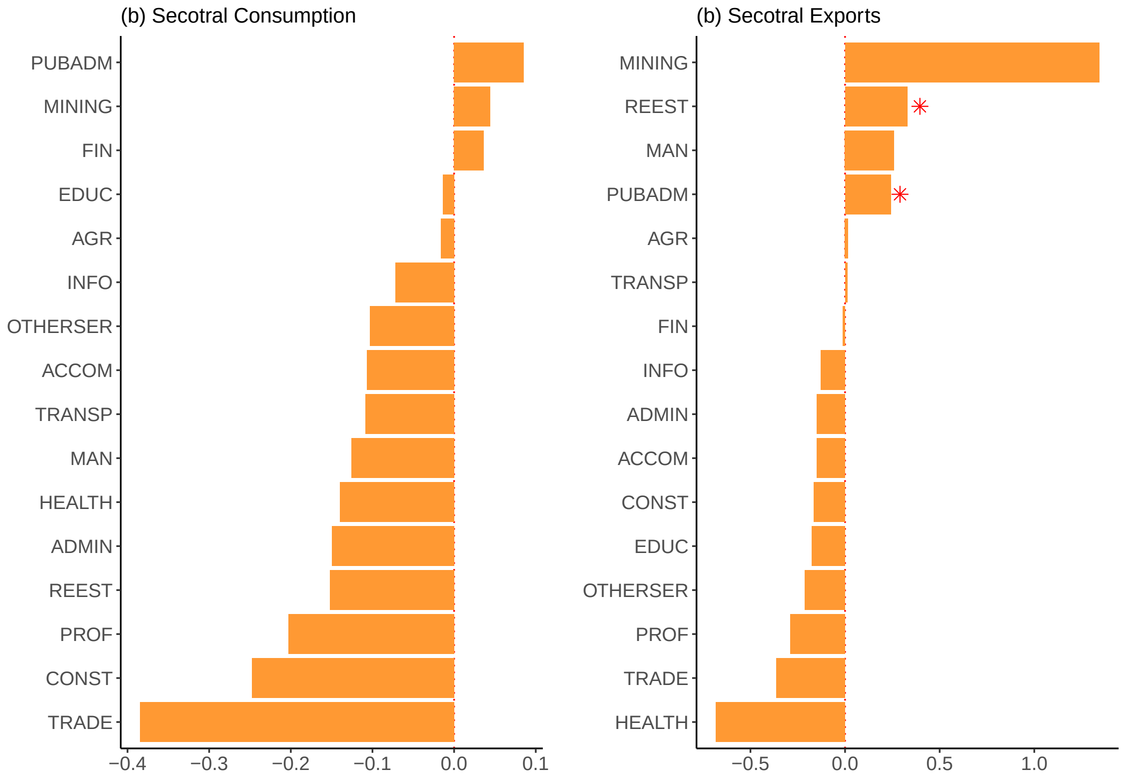
A multi-sectoral model augmented with sectoral consumption and exports

As indicated by the IRF results, the oil shock impacts many industries via a demand-side mechanism. Besides, there is evidence that oil-exporting countries may benefit from a rise in oil prices, at least in the short run. This section attempts to uncover the oil effects on real sectoral consumption and real sectoral exports.

I estimated a multi-sector model where individual VARX are augmented with real sectoral consumption and exports. The overall structure of the model, the identification and the estimation methods are identical to the baseline model.

The two additional variables were calculated as synthetic measures, using the aggregate

Figure 3.10: 8-quarters cumulative sum of the median IRF.



Notes: *The figure shows the IRFs of real sectoral consumption and real sectoral exports to a 10% increase in oil price, due to an oil supply shock. Bars show the weighted 8-quarter cumulative IRF for each sector. Red asterisk indicates non-significance.*

exports and consumption data and the relative sectoral distribution of the two measures. Aggregate data is reported in quarterly frequency in national accounts, whereas the relative sectoral distribution was calculated based on Input-Output tables provided annually. The synthetic variables are not included in the baseline estimation to avoid contaminating it with extra noise.

Figure 3.10 presents the weighted 8-quarter cumulative IRF for each sector[11]. Panel (a) shows the sectoral consumption results. The oil effect has a negative impact on private consumption for thirteen of the sectors. There are three sectors that an increase in consumption is observed; Public Administration, Finance and Mining, Energy & Water. The results are in favour of studies that support that the consumer expenditure can be directly affected by energy price changes, as consumers have less funds available for spending, after covering their energy bills. The effect can also derive from uncertainty about future energy prices and/or precautionary savings (Edelstein and Kilian (2009), Bernanke (1983)). In the case of Public

[11]The complete set of responses is presented in Figure C.3 and Figure C.4 in the appendix

Administration, the increase in consumption can reflect a higher demand of services related to the provision of state-owned goods, such as state-owned housing or commuting, that increase during periods of high energy costs.

Panel (b) provides the results for sectoral exports Exports drop for most of the sectors. However, in the case of Mining, Energy & Water, the response of the exports is positive, aligning with the findings of Mohaddes and Pesaran (2016). This finding applies equally to the Manufacturing sector.

The positive export responses can explain the positive effect on the manufacturing output. It is important to note that manufacturing is an important exporter, with more than 20% of sectoral output being exported. Therefore the increase in exports demand can explain the increase in manufacturing output observed for the 3 quarters after the shock. On the other had less than 5% of the Mining, Energy & Water output is exported. Thus, I do not expect the increase in exports to cover the negative supply effects.

The Real Estate and Public Administration responses are positive, however the effect lacks significance at all horizons.

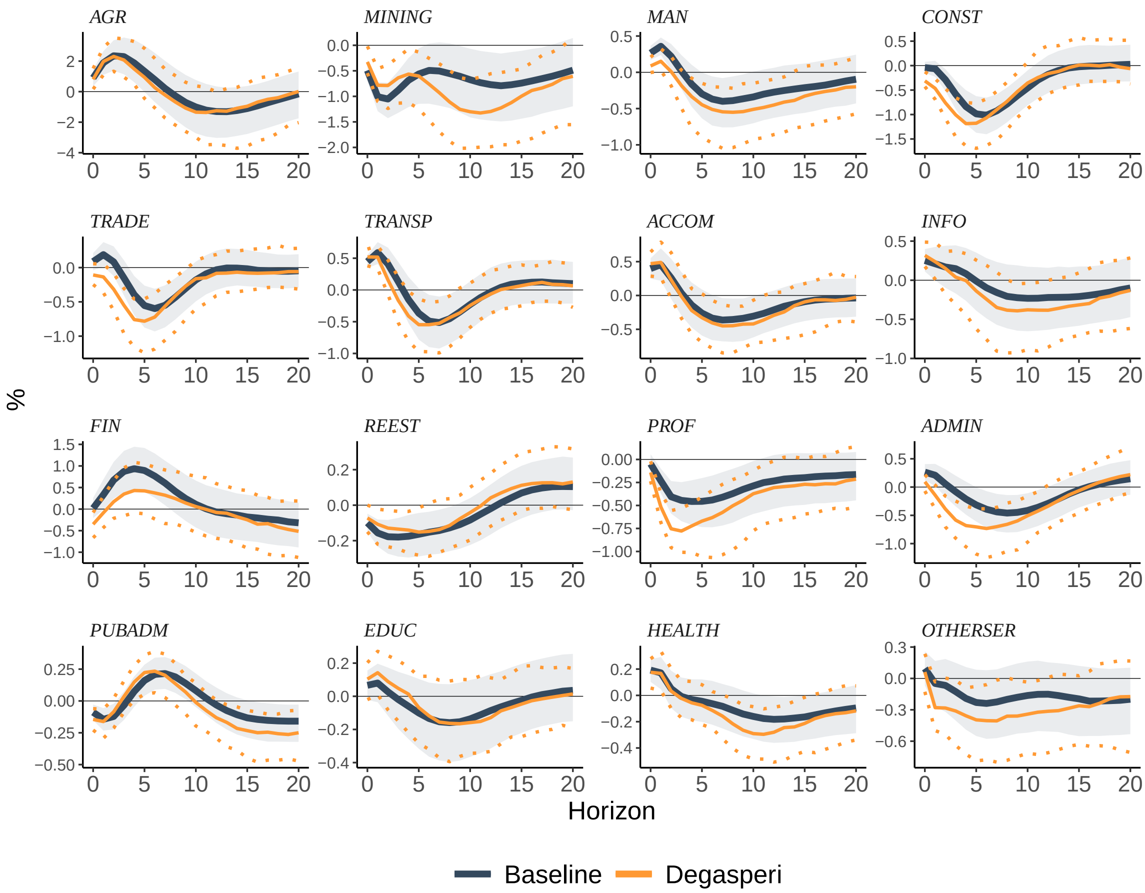
Identification with an alternative instrument

Degasperi (2023) indicates that OPEC announcements are not unrelated to markets' expectations for oil demand. As a consequence, the oil futures revisions capture not only changes in expected oil supply, but also changes in expected oil demand. Therefore, the instrument used in the baseline estimation, violates the exclusion assumption that is necessary for the identification of the shock.

Following the proposed method of Degasperi, I disentangled the supply and demand components of the instrument by exploiting the co-movement of the high frequency data of oil futures with the stock prices, an approach resembling the poor's man identification of monetary policy shocks by Jarociński and Karadi (2020). Particularly, aiming to identify an oil supply news shock, I reconstructed the instrument by keeping the futures revisions that are negatively correlated with the stock market returns and discarding the rest. The revisions and the dates are provided by Kanzig, while for stock prices I used the S&P 500 returns.

Figure 3.11 and Figure 3.12 compare the responses of output and prices from the baseline model and the alternative instrument. The alternative instrument results are qualitatively very similar to the baseline identification. However, some important differences are that with the alternative instrument, output response of many industries, such as Mining, Energy & Water, Manufacturing, Construction, and Trade, the median response is significantly more negative.

Figure 3.11: Sectoral output IRF.

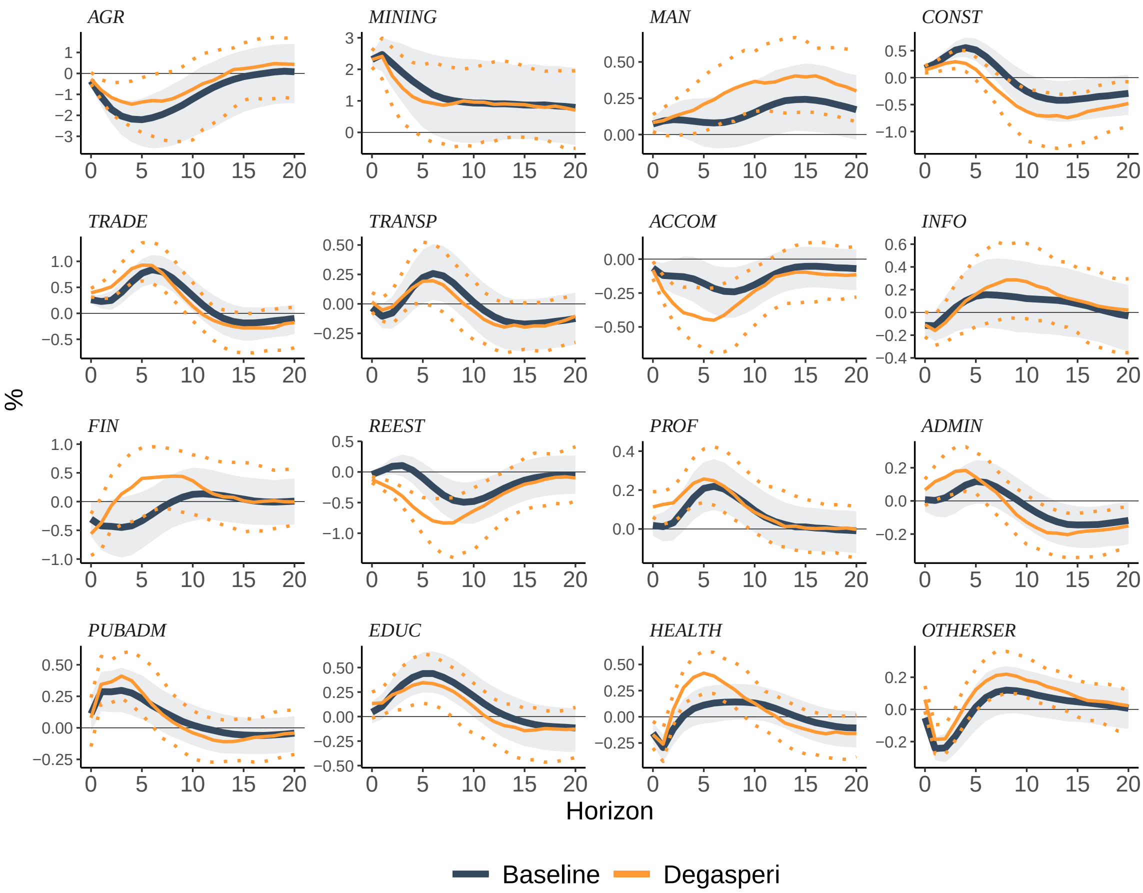


Notes: *The figure shows the IRFs of sectoral outputs to a 10% increase in oil price, due to an oil supply shock. The blue line is the median impulse responses from the baseline model. The orange line is the median IRF using the alternative instrument. The grey are and the yellow dotted lines show the 68% central posterior credible set.*

Another significant difference is observed in the case of Finance, where the response of output is lower compared to the baseline model and is not significantly different than zero. This suggests that the robust positive effect observed in the baseline identification is an overestimation driven by demand expectations, rather than expectations regarding future oil supply.

Certain differences are observed for the price responses. While the responses generally align qualitatively with the baseline model, they exhibit larger magnitudes in certain sectors under the alternative identification. For instance, in Manufacturing, prices rise more, whereas in Real Estate and Accommodation, they drop more significantly. In Construction, the price increase is short-lived and is followed by a notable price decline, indicating that a negative demand effect may dominate in later periods.

Figure 3.12: Sectoral prices IRF.



Notes: *The figure shows the IRFs of sectoral output deflators to a 10% increase in oil price, due to an oil supply shock. The blue line is the median impulse responses from the baseline model. The orange line is the median IRF using the alternative instrument. The grey are and the yellow dotted lines show the 68% central posterior credible set.*

Other robustness checks

Finally, I consider a number of robustness checks to test the stability of the results. First, I estimate a number of alternative specification. First, an alternative model with only 1 lag. Second, a model where the macro-block is augmented with the the US and the EU GDP so as to control for global demand. Third a model where feedback effects affect the macro block contemporaneously. Results are presented in the Appendix C.6.

3.4 Conclusion

This chapter studied the effects of an aggregate oil supply news shock on sectoral output, sectoral employment, sectoral price and sectoral Total Factor Productivity for a 16-sector disaggregation of the UK economy. I estimate the effects of the oil shock at the sector-level, using a Bayesian GVAR model with a sectoral dimension and a macroeconomic block that account for the aggregate fluctuations in the economy. My analysis assumed that the oil price, that is determined internationally, can affect directly the different sectors of the UK economy, but also that the oil shock propagates across sectors through input-output linkages. The identification of the oil price shock was based on a proxy-SVAR approach and the high frequency instruments of Känzig (2021) and Degasperi (2023).

Analysis reveals several key insights. The oil shock has a negative impact on real macroeconomic variables, leading to an output decline and a rise in unemployment. These adverse effects are driven by both supply and demand channels. On the supply side, productivity and employment experience significant downturns. On the demand side, rising oil prices generate inflationary pressures that lead to monetary tightening, ultimately reducing aggregate demand.

Sectoral analysis reveals substantial heterogeneity in the transmission of the shock, with sectors like Mining, Energy & Water, Construction, and Trade primarily facing supply-side effects, while others such as Real Estate, Administration, and Other Services are more affected by demand-side pressures.

Notably, there are case, such as for Manufacturing, Transportation and Finance, where sectors experience positive demand effects. I show that these positive effects primarily originate from highly exporting activity in these sectors. However, such effects are temporary and are soon dominated by negative demand and supply effects.

Finally, I show that Input-Output linkages play a critical role in amplifying the negative effects of the oil shock across the economy, highlighting the interconnected nature of sectoral dynamics.

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Appendix A

Appendix to Chapter 1

A.1 Estimation

The baseline model was estimated with two lags for the endogenous and one lag for the foreign variables. The estimation was Bayesian. Specifically, I employed an Normal Inverse Wishart prior with dummy variables as in Bańbura et al. (2010). Figure A.1 shows the serial correlation of the residuals and the maximum eigenvalues of the companion matrix for each posterior distribution. The model can effectively account for serial correlation and stability is achieved.

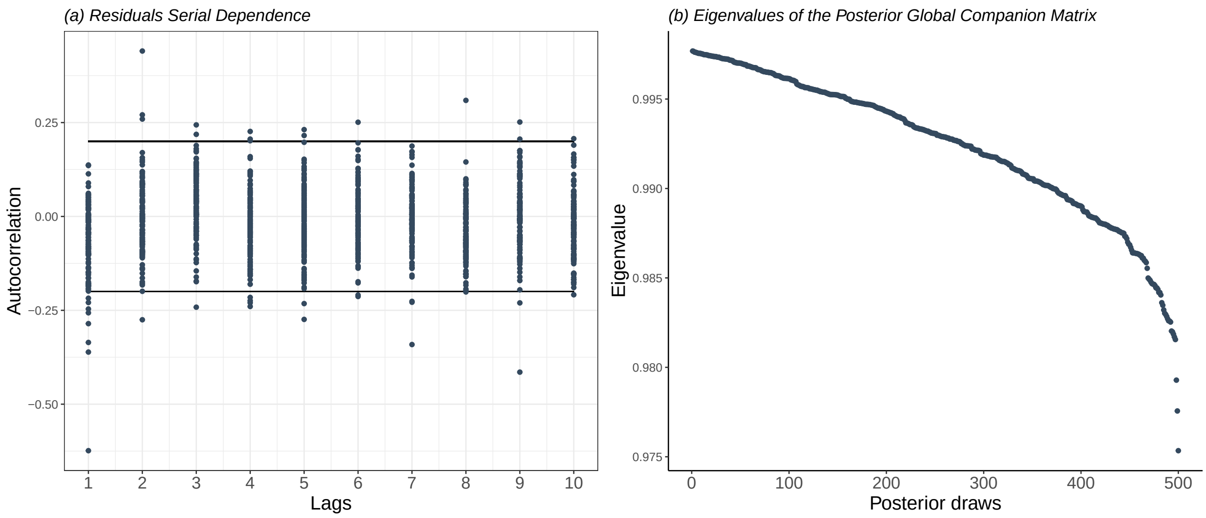


Figure A.1: Diagnostic check GVAR

Notes: *The plot on left panel shows the serial correlation of the residual for all the variables in the model. Residuals are serially uncorrelated indicating that the model captures most of the persistence in the data. The plot on the right panel shows the maximum eigenvalue of the global companion matrix representation of the model. Albeit large, the absolute values of all the eigenvalues stand below unity. This confirms that the model captures well the complex dynamics and interactions among variables, and at the same that it is dynamically stable, so that shocks tend to die out with some inertia.*

A.2 Data

Table A.1: Country availability - Data Sources

Abbreviation	Countries	gdp_t	$cons_t$	$ltir_t$	rer_t	exp_t	imp_t
US	USA	OECD	OECD	OECD	IMF	IMF	IMF
AU	Australia	OECD	OECD	OECD	IMF	IMF	IMF
BE	Belgium	OECD	OECD	OECD	IMF	IMF	IMF
CA	Canada	OECD	OECD	OECD	IMF	IMF	IMF
CH	Switzerland	OECD	OECD	OECD	IMF	IMF	IMF
DE	Germany	OECD	OECD	OECD	IMF	IMF	IMF
DK	Denmark	OECD	OECD		IMF	IMF	IMF
ES	Spain	OECD	OECD	OECD	IMF	IMF	IMF
FR	France	OECD	OECD	OECD	IMF	IMF	IMF
GB	United Kingdom	OECD	OECD	OECD	IMF	IMF	IMF
IE	Ireland	OECD	OECD		IMF	IMF	IMF
IT	Italy	OECD	OECD	OECD	IMF	IMF	IMF
JP	Japan	OECD	OECD	OECD	IMF	IMF	IMF
KR	Korea	OECD	OECD	OECD	IMF	IMF	IMF
MX	Mexico	OECD	OECD		IMF	IMF	IMF
NL	Netherlands	OECD	OECD	OECD	IMF	IMF	IMF
NO	Norway	OECD	OECD	OECD	IMF	IMF	IMF
PT	Portugal	OECD	OECD		IMF	IMF	IMF
SE	Sweden	OECD	OECD	OECD	IMF	IMF	IMF

Notes: *US Government spending and US Tax revenues where collected from the BEA database, following the exact definitions of Blanchard and Perotti (2002)*

Table A.2: Country weights matrix

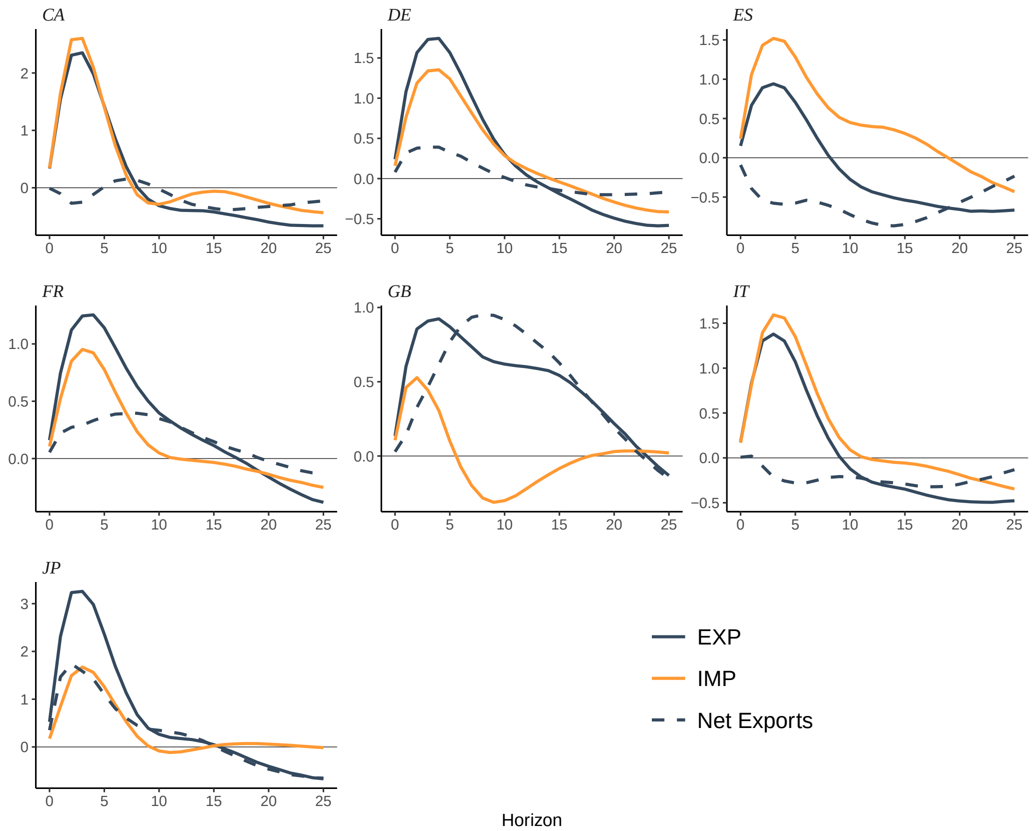
	US	DE	GB	AU	BE	CA	CH	DK	ES	FR	IE	IT	SE	JP	KR	MX	NL	NO	PT
US		0.08	0.06	0.01	0.03	0.25	0.02	0.01	0.01	0.03	0.02	0.03	0.01	0.09	0.05	0.25	0.03	0.00	0.00
DE	0.13		0.09	0.01	0.09	0.01	0.07	0.02	0.06	0.13	0.02	0.09	0.03	0.03	0.02	0.01	0.17	0.02	0.01
GB	0.18	0.17		0.02	0.07	0.03	0.06	0.01	0.05	0.09	0.06	0.05	0.02	0.03	0.01	0.01	0.11	0.03	0.01
AU	0.20	0.07	0.09		0.02	0.02	0.02	0.01	0.01	0.02	0.01	0.03	0.01	0.31	0.14	0.01	0.03	0.00	0.00
BE	0.10	0.21	0.08	0.00		0.01	0.02	0.01	0.03	0.16	0.03	0.06	0.02	0.02	0.01	0.01	0.21	0.01	0.01
CA	0.82	0.02	0.03	0.00	0.01		0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.02	0.01	0.03	0.01	0.00	0.00
CH	0.16	0.29	0.11	0.01	0.03	0.01		0.01	0.03	0.10	0.02	0.12	0.01	0.03	0.01	0.01	0.04	0.00	0.00
DK	0.10	0.26	0.07	0.01	0.04	0.01	0.01		0.03	0.05	0.01	0.04	0.16	0.02	0.01	0.00	0.10	0.08	0.01
ES	0.07	0.19	0.08	0.00	0.05	0.01	0.03	0.01		0.21	0.01	0.12	0.01	0.01	0.01	0.02	0.07	0.01	0.09
FR	0.10	0.23	0.08	0.00	0.12	0.01	0.05	0.01	0.11		0.01	0.12	0.01	0.02	0.01	0.01	0.09	0.01	0.02
IE	0.29	0.11	0.22	0.00	0.09	0.01	0.03	0.01	0.02	0.05		0.03	0.01	0.03	0.01	0.01	0.07	0.00	0.00
IT	0.12	0.23	0.07	0.01	0.06	0.01	0.07	0.01	0.09	0.16	0.01		0.02	0.02	0.02	0.01	0.07	0.01	0.01
SE	0.08	0.21	0.07	0.01	0.07	0.01	0.02	0.11	0.03	0.06	0.01	0.05		0.02	0.01	0.00	0.12	0.12	0.01
JP	0.40	0.08	0.04	0.10	0.02	0.03	0.02	0.01	0.01	0.03	0.01	0.02	0.01		0.14	0.03	0.03	0.00	0.00
KR	0.38	0.08	0.03	0.07	0.01	0.03	0.01	0.00	0.02	0.03	0.00	0.03	0.01	0.22		0.05	0.03	0.01	0.00
MX	0.85	0.03	0.01	0.00	0.00	0.03	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.02	0.02		0.01	0.00	0.00
NL	0.10	0.31	0.10	0.01	0.15	0.01	0.02	0.02	0.04	0.09	0.02	0.05	0.03	0.02	0.01	0.01		0.02	0.01
NO	0.06	0.17	0.17	0.00	0.04	0.02	0.01	0.08	0.03	0.06	0.01	0.02	0.17	0.02	0.02	0.00	0.12		0.01
PT	0.04	0.17	0.05	0.00	0.04	0.01	0.02	0.01	0.35	0.14	0.01	0.07	0.01	0.01	0.01	0.00	0.07	0.01	

Notes: *This table shows the weight matrix used for the construction of the foreign variables and the solution of the global model. Trade weight were collected from the IMF - Direction of trade database. Data were collected annually from 2000 to 2018 and were averaged over time.*

For a full description of the countries' abbreviation see Table A.1.

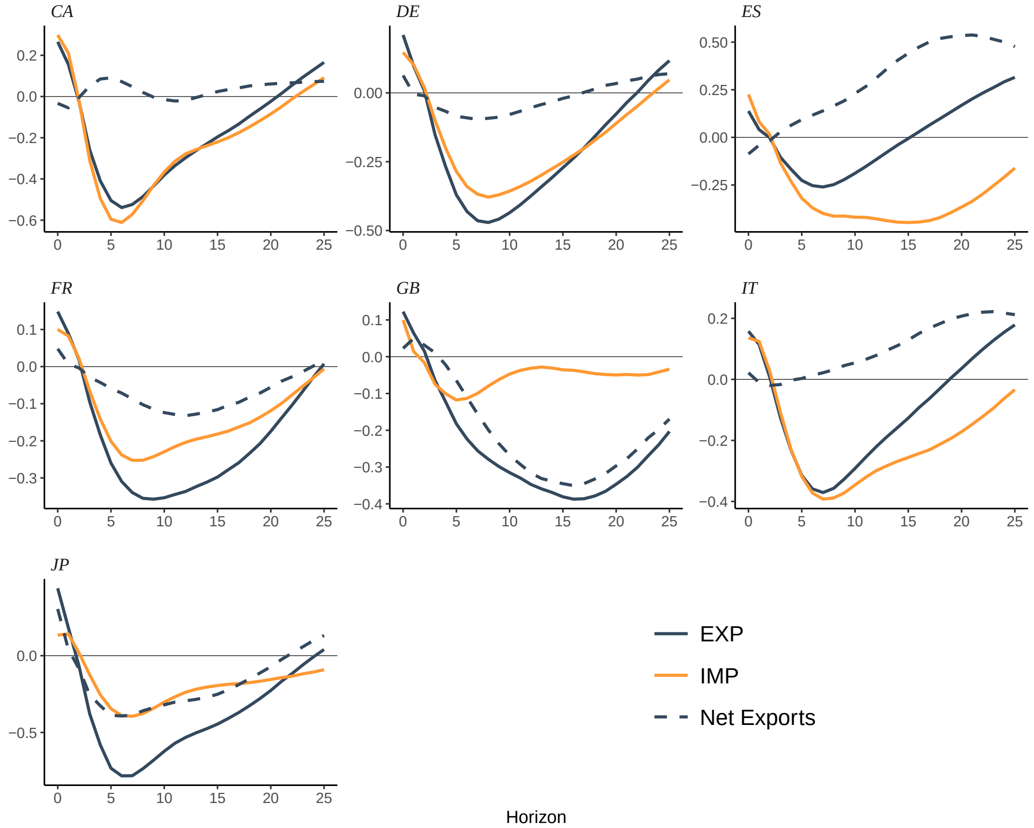
A.3 Response of the Advanced Economies to a the US News Fiscal shock

Figure A.2: Responses of the G7 net trade variables to the US Fiscal News shock



Notes: *The plot shows the responses of the trade variables –Exports (Blue line) and Imports (Orange line)– to a government spending* ***News*** *shock. The dash line shows the Net trade response calculated as the difference between the response of Exports and Imports. The shock has been normalised, in order for the US government spending response to peak at 1%. The figure depicts the median impulse responses and their 68% central posterior credible set.Positive response of the rer indicate a real appreciation of the $USD against a basket of foreign currencies*

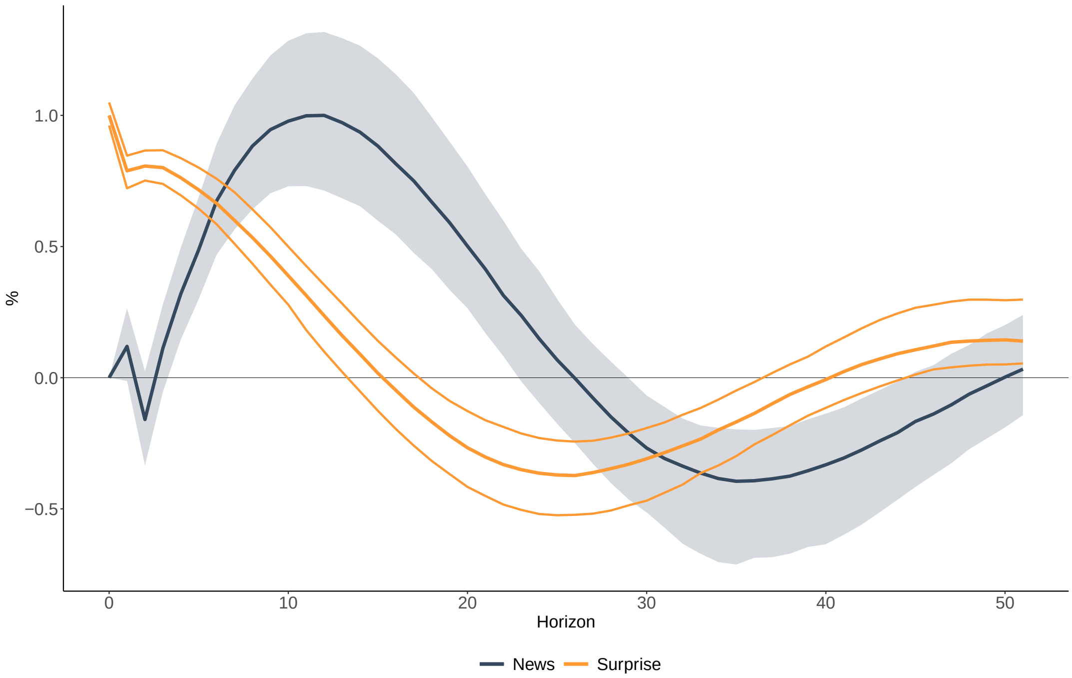
Figure A.3: Responses of the G7 net trade variables to a US Surprise Fiscal shock



Notes: *The plot shows the responses of the trade variables –Exports (Blue line) and Imports (Orange line)– to a government spending* ***Surprise shock****. The dash line shows the Net trade response calculated as the difference between the response of Exports and Imports. The shock has been normalised, in order for the US government spending response to peak at 1%. The figure depicts the median impulse responses and their 68% central posterior credible set.Positive response of the rer indicate a real appreciation of the $USD against a basket of foreign currencies*

A.4 Spending reversals

Figure A.4: Spending reversals in the news and the surprise shock

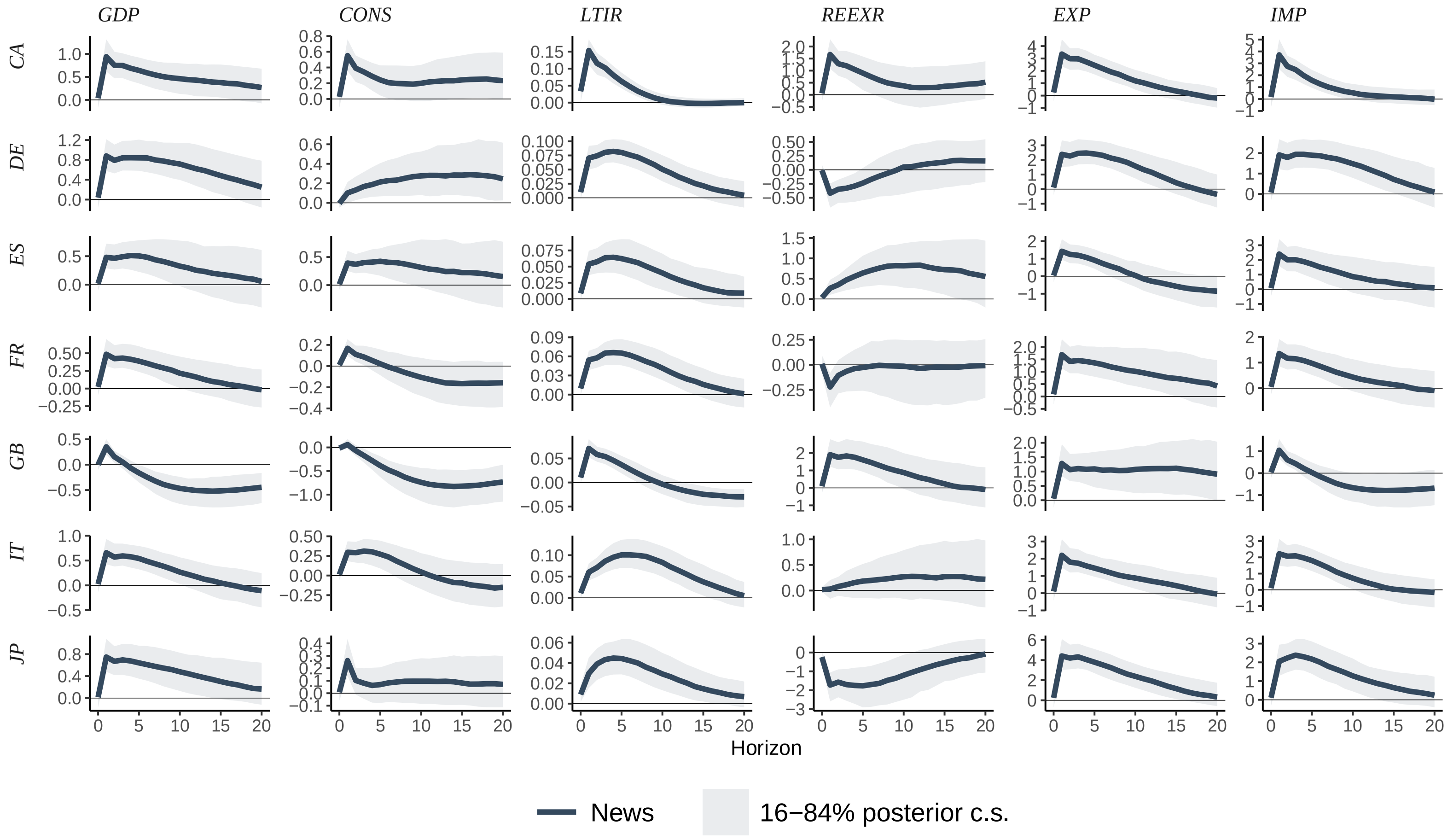


Notes: *The plot shows the US government spending responses to a News and a Surprise shock. The plot presents the results of the baseline model for longer horizons, showing that spending reversals are present for both shocks. The shock has been normalised, in order for the government spending responses to peak at 1%. The figure depicts the median impulse responses and their 68% central posterior credible set.Positive response of the rer indicate a real appreciation of the $USD against a basket of foreign currencies*

A.5 Robustness checks

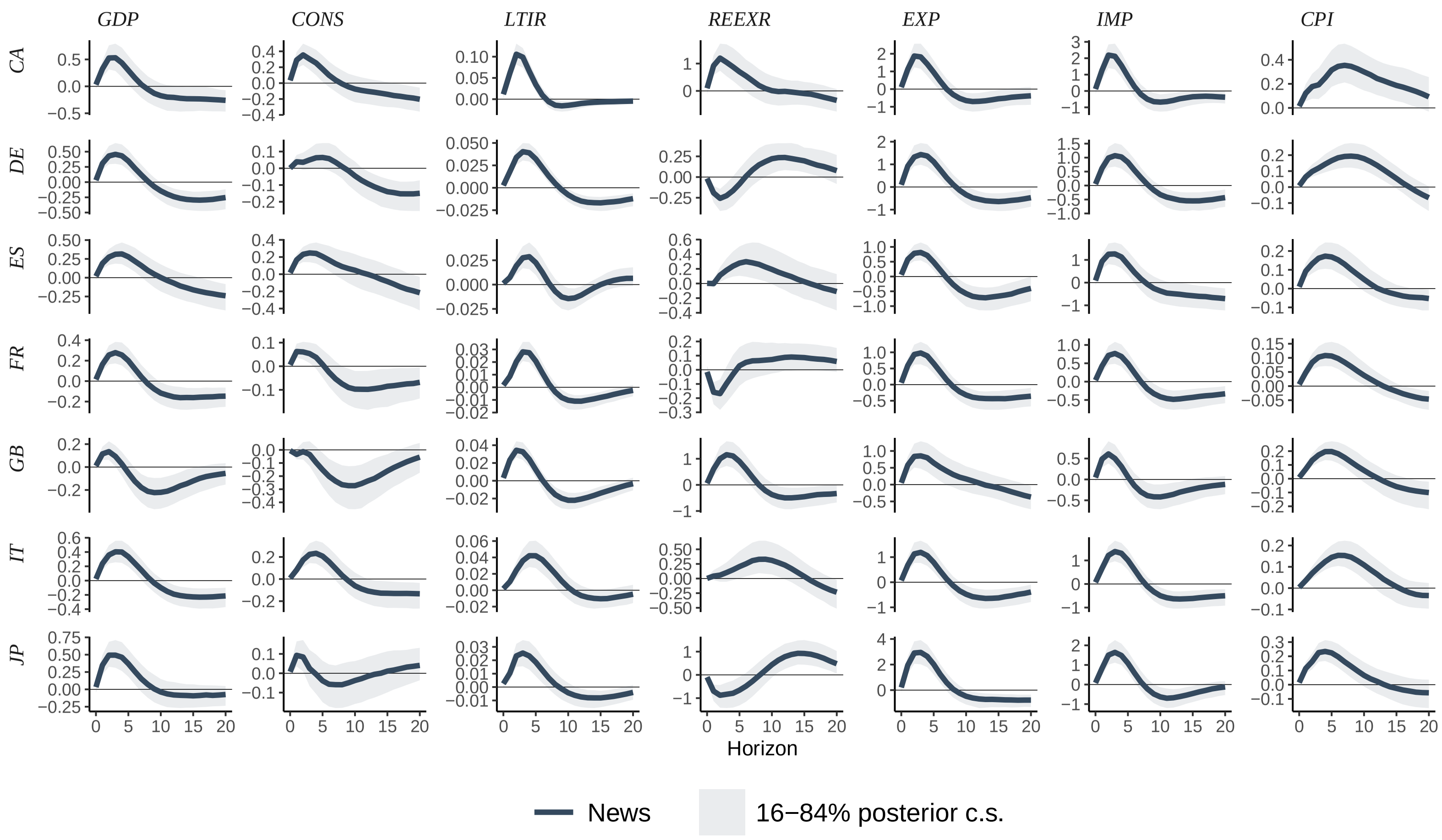
Graphs below shows the results for a number of robustness checks. The robustness of the model is tested against a number of alternative specifications. Particularly, I re-estimate the model with different number of lags and additional or alternative variables. I consider a model where the US is a dominant unit. For the economy of space I report only the results for the news shock, but the results remain robust also for the surprise shock.

Figure A.5: Estimation with only 1 lag for the endogenous



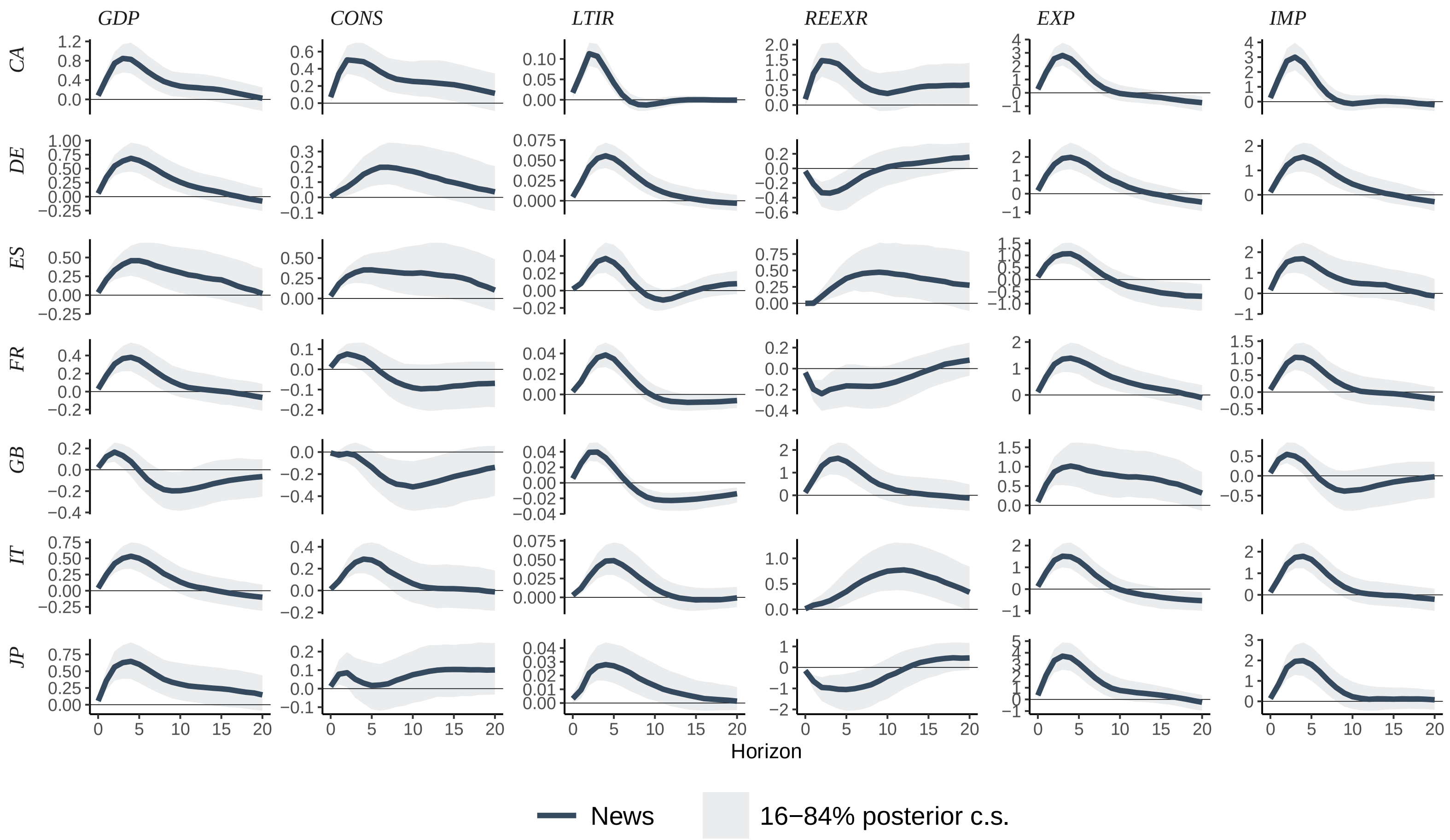
Notes: *The plot shows the international effects of a government spending News shock on the G7 countries. The plot presents the results of a model similar to the baseline, with each individual model estimated using only one lag for the endogenous variables. The shock has been normalised, in order for the government spending response to peak at 1%. The figure depicts the median impulse responses and their 68% central posterior credible set.Positive response of the rer indicate a real appreciation of the $USD against a basket of foreign currencies*

Figure A.6: The baseline model augmented with CPI



Notes: *The plot shows the international effects of a government spending News shock on the G7 countries.The plot presents the results of a model similar to the baseline, but with each individual model augmented by the Consumer Price Index (CPI). The shock has been normalised, in order for the government spending response to peak at 1%. The figure depicts the median impulse responses and their 68% central posterior credible set.Positive response of the rer indicate a real appreciation of the $USD against a basket of foreign currencies*

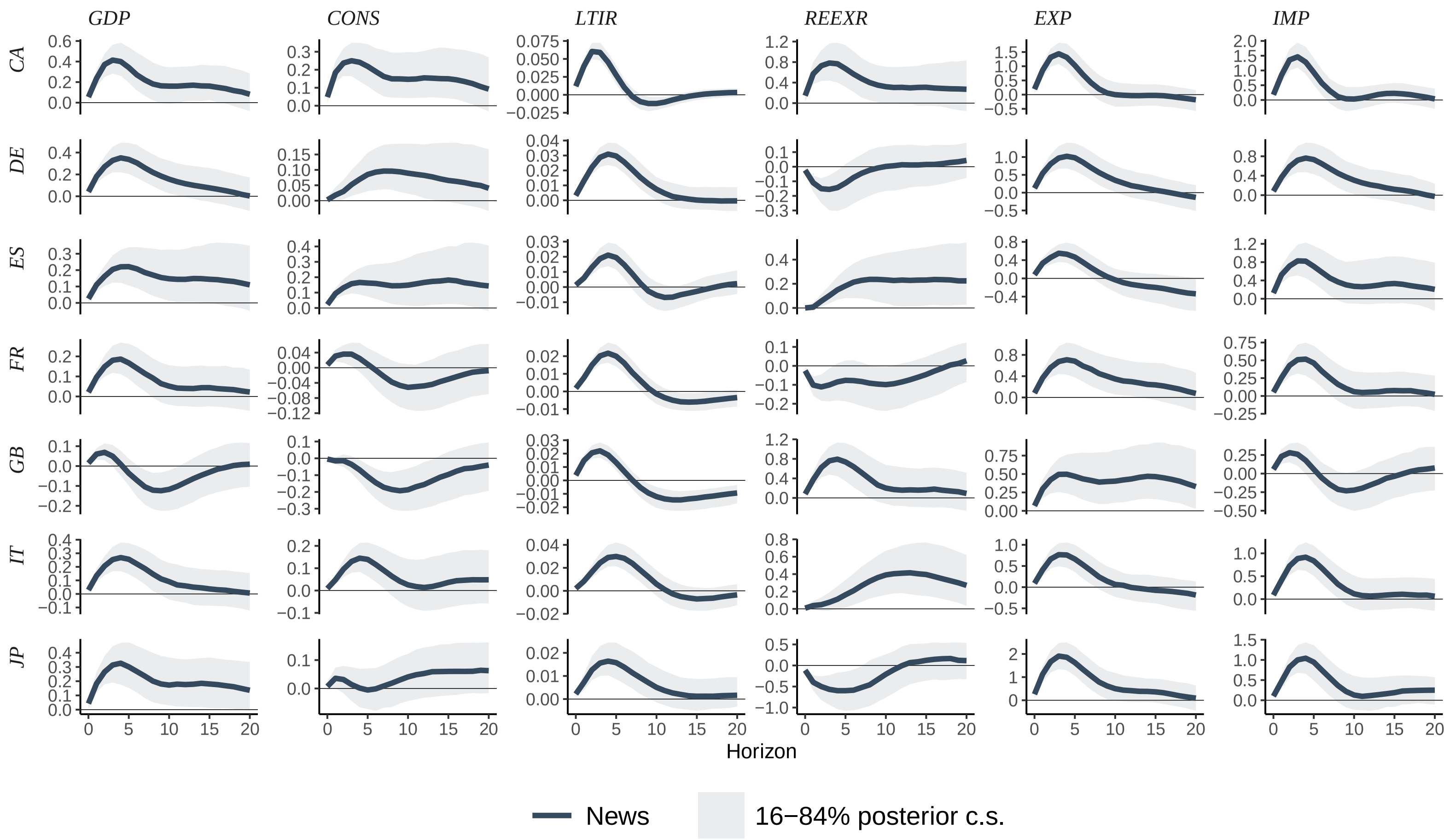
Figure A.7: The US as a dominant unit



Notes: *The plot shows the international effects of a government spending News shock on the G7 countries. The plot presents the results of a model similar to the baseline, but with the US considered a Dominant unit*[a]*. The shock has been normalised, in order for the government spending response to peak at 1%. The figure depicts the median impulse responses and their 68% central posterior credible set.Positive response of the rer indicate a real appreciation of the $USD against a basket of foreign currencies*

[a]Dominant Unit: No foreign variables enter the US model contemporaneously.

Figure A.8: Alternative fiscal expectations proxy



Notes: *The plot shows the international effects of a government spending News shock on the G7 countries. The plot presents the results of a model similar to the baseline, but an alternative proxy of fiscal news has been used in the US model.*[a]*. The shock has been normalised, in order for the government spending response to peak at 1%. The figure depicts the median impulse responses and their 68% central posterior credible set.Positive response of the rer indicate a real appreciation of the $USD against a basket of foreign currencies*

[a] I identify the fiscal news shock using the cumulative sum of government spending forecasts(see Forni and Gambetti (2016) specification #2).

Appendix B

Appendix to Chapter 2

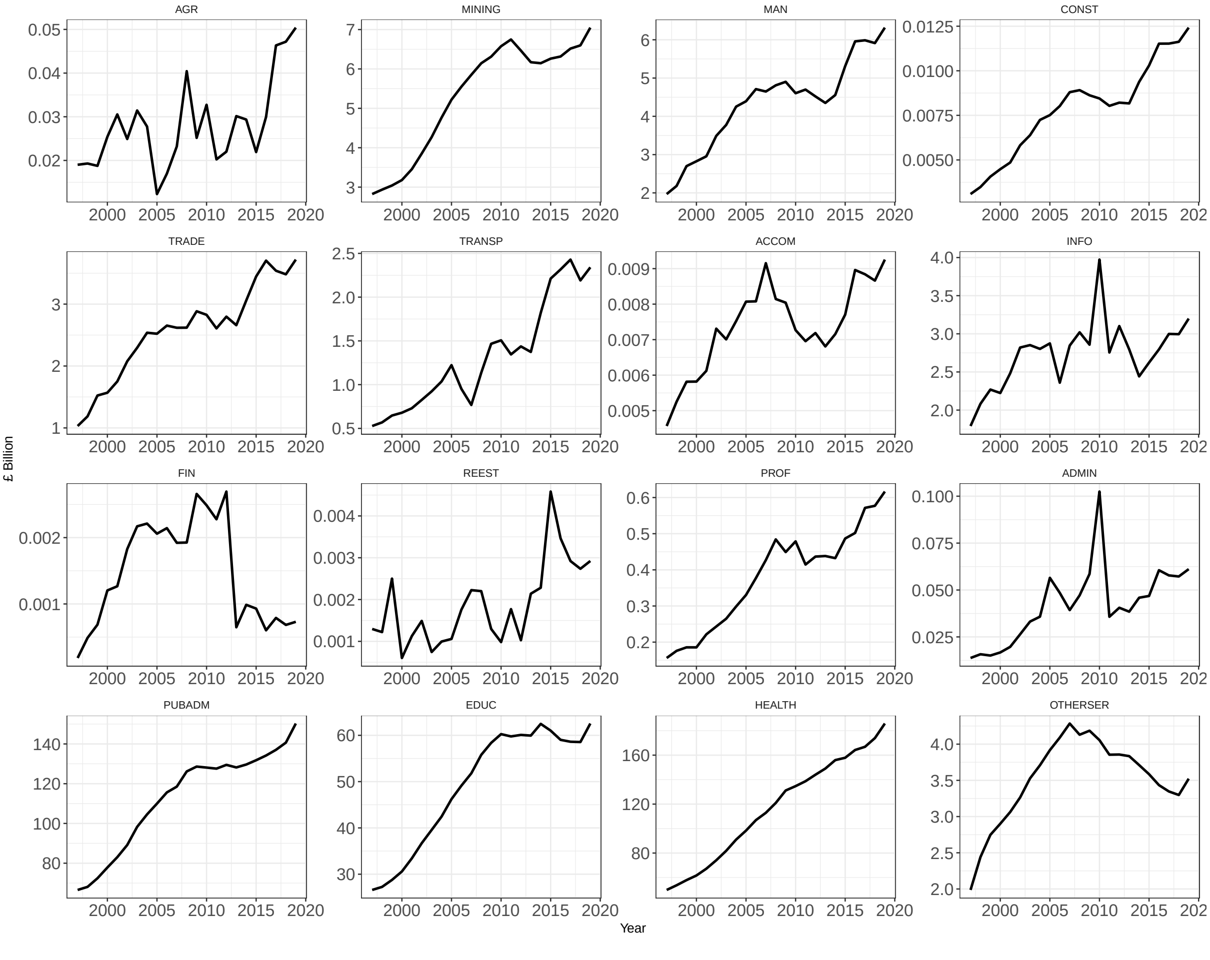
B.1 Descriptive

Table B.1: Sectoral disaggregation

Abbreviation	Sector	Abbreviation	Sector
Agriculture	*AGR*	Financial	*FIN*
Mining, Energy & Water	*MINING*	Real Estate	*REEST*
Manufacturing	*MAN*	Professional Services	*PROF*
Construction	*CONST*	Administration	*ADMIN*
Trade	*TRADE*	Public Admin & Defence	*PUBADM*
Transportation	*TRANSP*	Education	*EDUC*
Accommodation	*ACCOM*	Health	*HEALTH*
Information	*INFO*	Other Services	*OTHERSER*

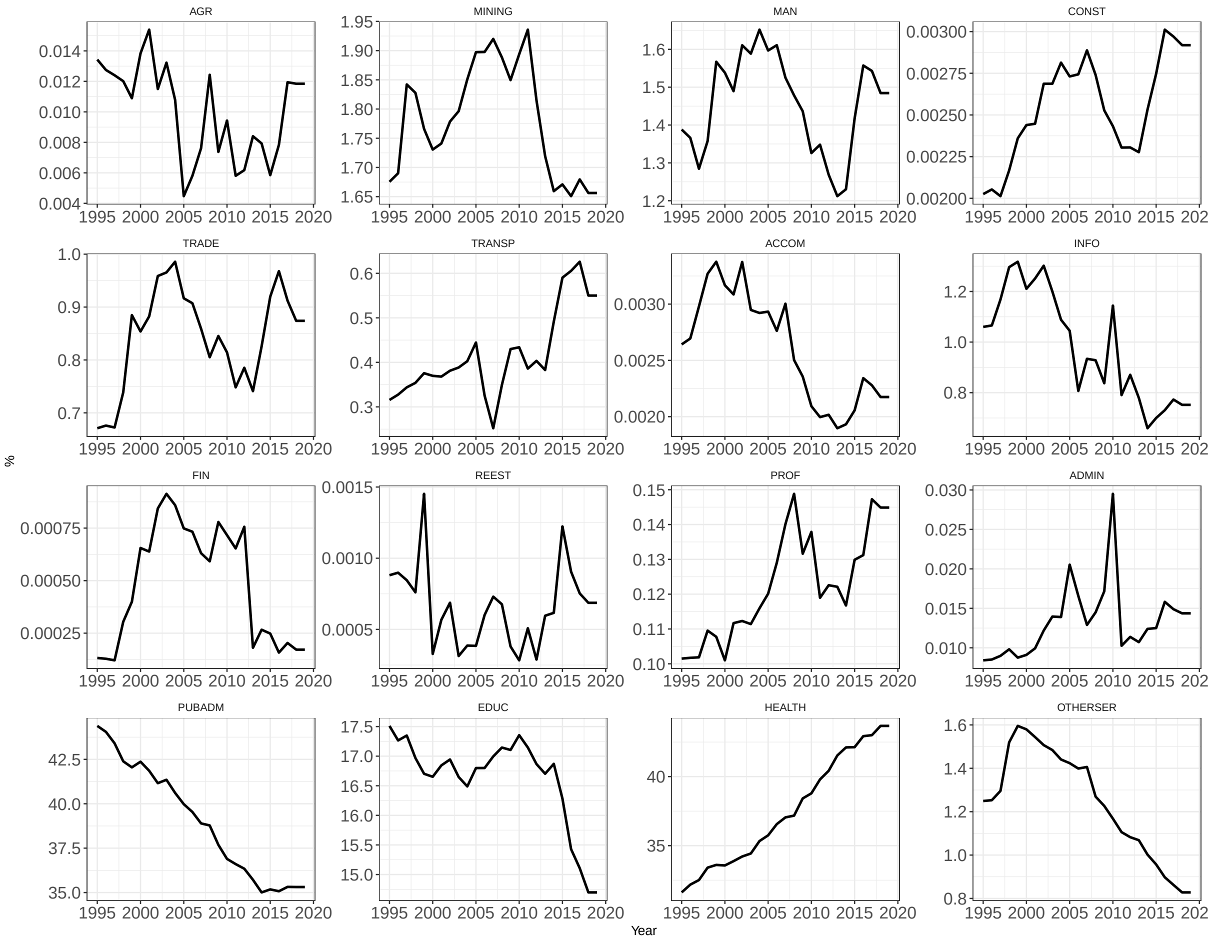
Notes: *The table summarises the names of the sectors and the abbreviations used throughout the chapter. The full disaggregation of sectors is given in Appendix D*

Figure B.1: Sectoral government spending - absolute number



Notes: *The graph shows the Sectoral Government spending in absolute numbers and in annual frequency as reported in Input-Output tables.*

Figure B.2: Sectoral government spending - shares



Notes: *The graph shows the Sectoral Government spending as a share of the aggregate government spending in annual frequency as reported in Input-Output tables.*

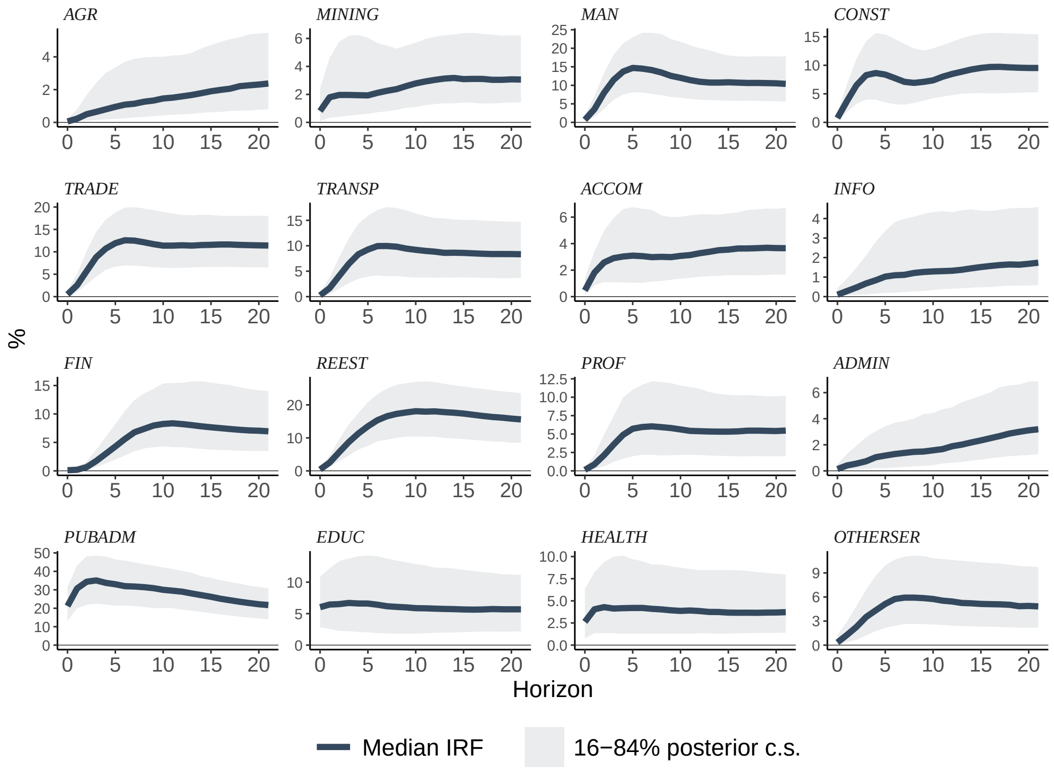
Table B.2: Sectoral contribution to the cumulative output response

Sector	Horizon 0	Horizon 1	Horizon 4	Horizon 8
AGR	1.26	1.59	1.53	1.50
MINING	-18.75	-14.89	-7.37	-3.67
MAN	13.15	15.99	17.52	17.84
CONST	11.65	14.40	14.05	9.49
TRADE	17.77	20.93	22.73	21.12
TRANSP	4.51	5.90	7.23	7.47
ACCOM	5.49	5.49	3.62	2.56
INFO	1.02	1.33	1.72	2.08
FIN	-11.01	-2.61	11.14	20.18
REEST	-7.34	-9.35	-10.56	-12.32
PROF	4.90	6.33	7.55	7.93
ADMIN	3.79	3.54	2.62	2.42
PUBADM	26.81	18.21	9.43	7.75
EDUC	27.42	16.10	7.67	5.86
HEALTH	20.28	14.28	7.17	5.55
OTHERSER	-0.95	2.77	3.95	4.24

The table shoes the percentage contribution of each sector to the cumulative output response for horizons 0,1,4 and 8. This figures were used for the calculation of the sectoral multipliers in Section 2.6.3.

B.2 Forecast Error Variance Decomposition

Figure B.3: Forecast Error Variance Decomposition



Notes: *The plot shows the sectoral output Forecast Error Variance decomposition results of the baseline model. The solid line indicate the median contribution of the fiscal shock to the Forecast Error Variance of the sectoral output. The grey area indicates the 68% central posterior credible set.*

In this section, I present the results of the sectoral output Forecast Error Variance Decomposition. Results show that the government spending shock accounts for a substantial proportion of sectoral output fluctuations. Focusing on the three sectors that receive the most public funding, government spending shocks explain 35% of the variance in the Public Administration and Defence sector's output one year after the shock. This influence remains significant over time, contributing around 20% in the long run. For the Education and Health sectors, the contribution of government spending is smaller, approximately 6% and 4%, respectively. The government spending shock significantly impacts the output forecast error variance in other sectors too. For example the fiscal shock impacts more than 10% of the forecast error variance of Manufacturing, Trade, Transportation and Real Estate. All these sector together account for more than 40% of the total production. Therefore, I can conclude that in my model the government spending shock can explain a large part of the variance of output.

B.3 Robustness check

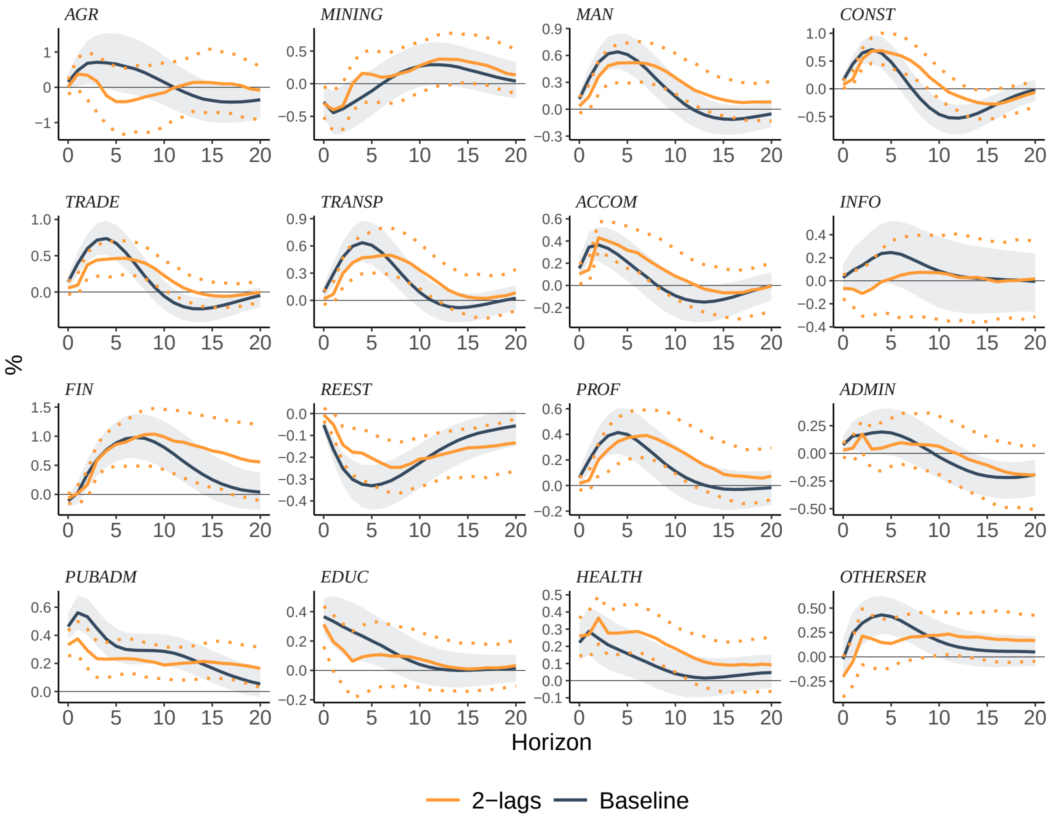
This section presents a number of robustness checks. The robustness of the model is tested against a number of alternative specifications.

First, I estimate individual VARX models using 2 lags for the endogenous variables. Figure B.4 shows that results are qualitatively very similar to the baseline model. Some differences are observed for the Agricultural and the Information sector, but given the small size of these sectors multipliers are not change significantly.

Second, I re-estimate the model in a sample that excludes the post Brexit period. Figure B.5 shows that results remain qualitatively very similar to the baseline model. Some differences in the magnitude of the responses are observed in the Accommodation, the Real estate and the Education sectors. Specifically, the responses of this sectors seem to react more when the Post-Brexit sample is included. This indicates a possible regime change an should be investigated further.

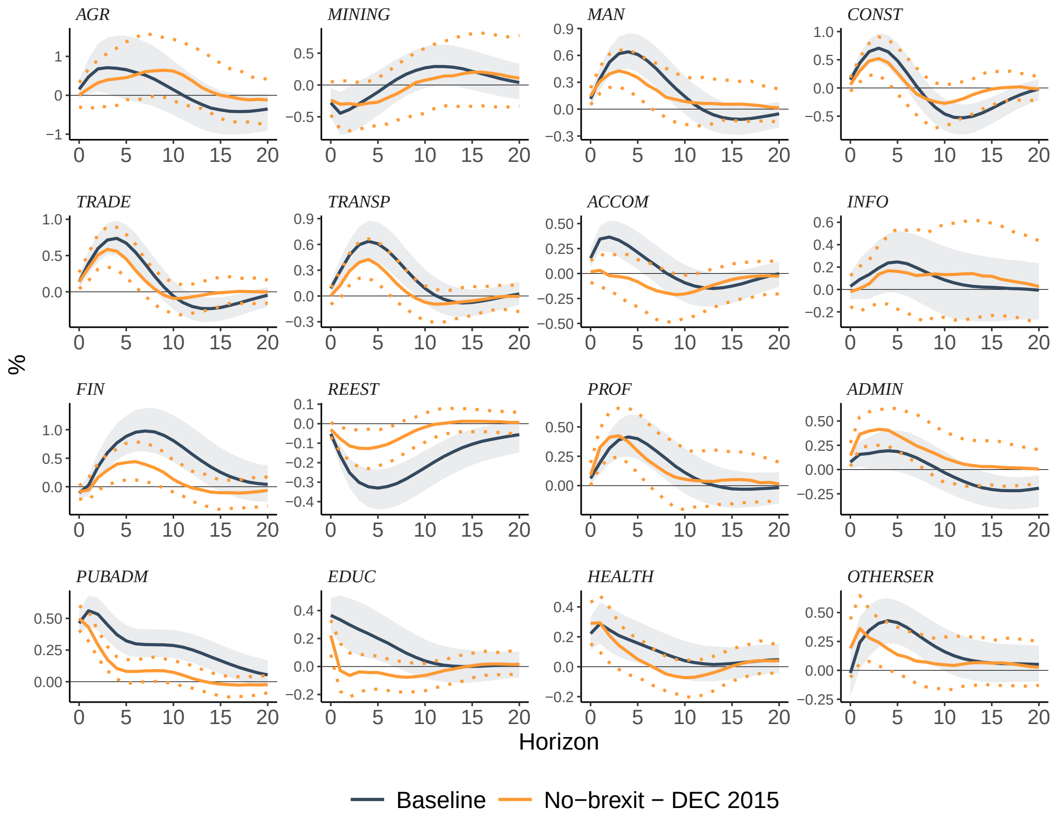
Finally, I augment sectoral VARXs with a measure of sectoral producer price index. Figure B.6 shows that IRFs are very close to the baseline model after accounting for sectoral prices changes.

Figure B.4: Baseline vs 2 lags



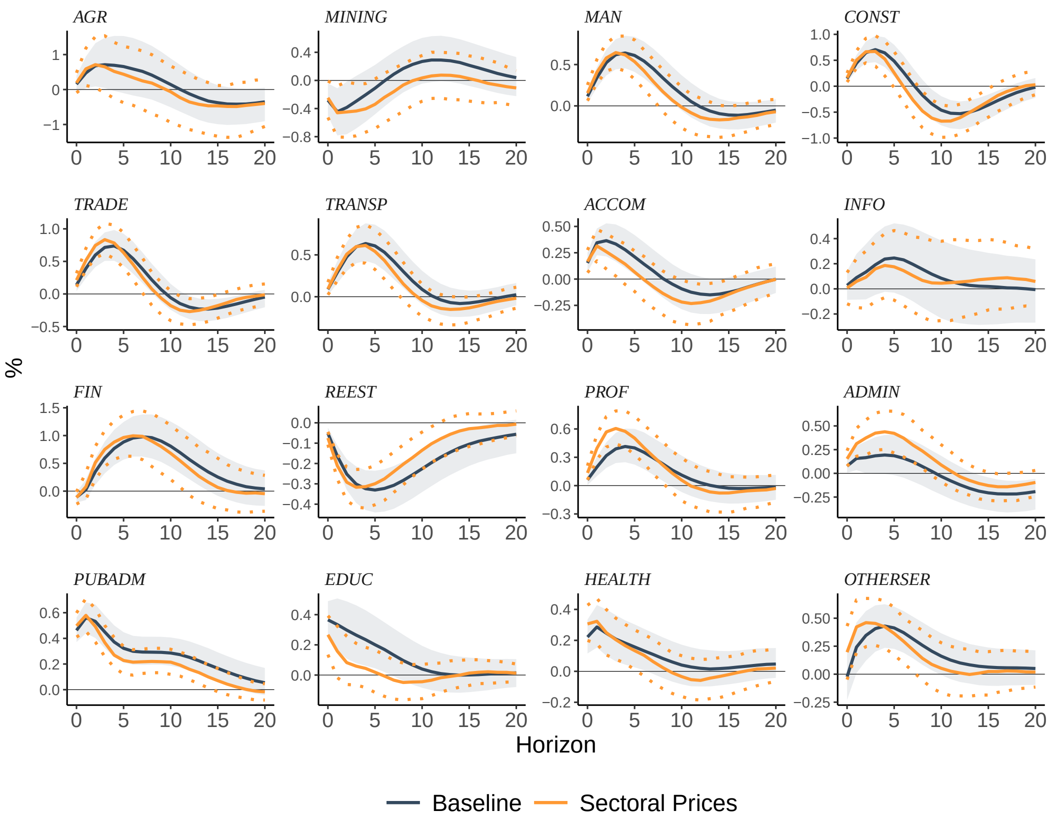
Notes: *The plot shows the IRFs to a 1% Unexpected Government spending shock. The figure depicts median impulse response and the 68% central posterior credible set. The blue line (grey area) shows the Sectoral responses of the baseline model. The orange lines show the responses of a model estimated with 2 lags for the endogenous variables.*

Figure B.5: Baseline vs Pre-Brexit sample (1997-2015Q4)



Notes: *The plot shows the IRFs to a 1% Unexpected Government spending shock. The figure depicts median impulse response and the 68% central posterior credible set. The blue line (grey area) shows the Sectoral responses of the baseline model. The orange lines show the responses of a model estimated in the pre-brexit sample.*

Figure B.6: Baseline vs Sectoral Prices



Notes: *The plot shows the IRFs to a 1% Unexpected Government spending shock. The figure depicts median impulse response and the 68% central posterior credible set. The blue line (grey area) shows the Sectoral responses of the baseline model. The orange lines show the responses of a model where sectoral price index is included in sectoral models.*

Appendix C

Appendix to Chapter 3

C.1 Sectoral Disaggregation

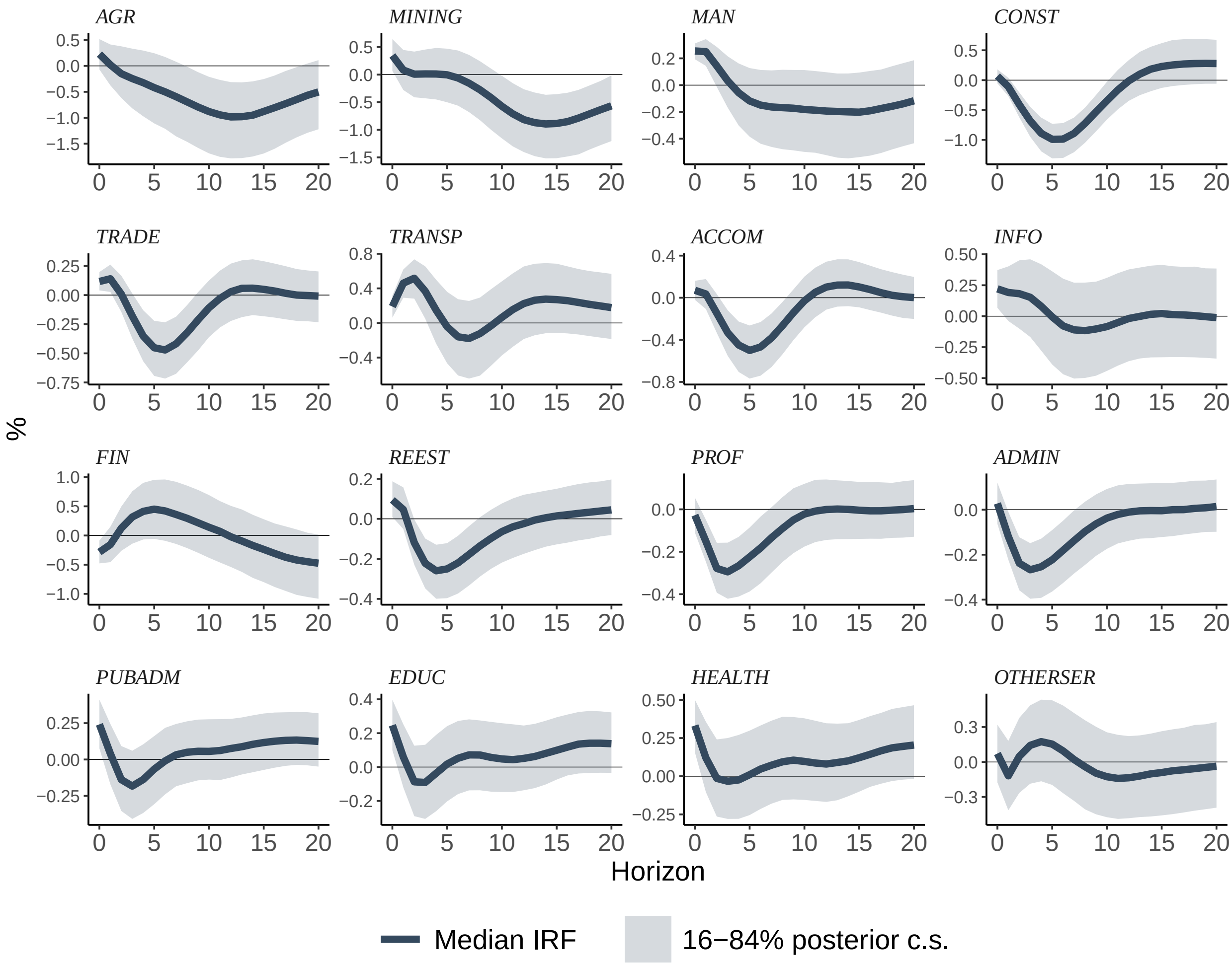
Table C.1: Sectoral disaggregation

Abbreviation	Sector	Abbreviation	Sector
Agriculture	*AGR*	Financial	*FIN*
Mining, Energy & Water	*MINING*	Real Estate	*REEST*
Manufacturing	*MAN*	Professional Services	*PROF*
Construction	*CONST*	Administration	*ADMIN*
Trade	*TRADE*	Public Admin & Defence	*PUBADM*
Transportation	*TRANSP*	Education	*EDUC*
Accommodation	*ACCOM*	Health	*HEALTH*
Information	*INFO*	Other Services	*OTHERSER*

Notes: *The table summarises the names of the sectors and the abbreviations used throughout the chapter. The full disaggregation of sectors is given in Appendix D*

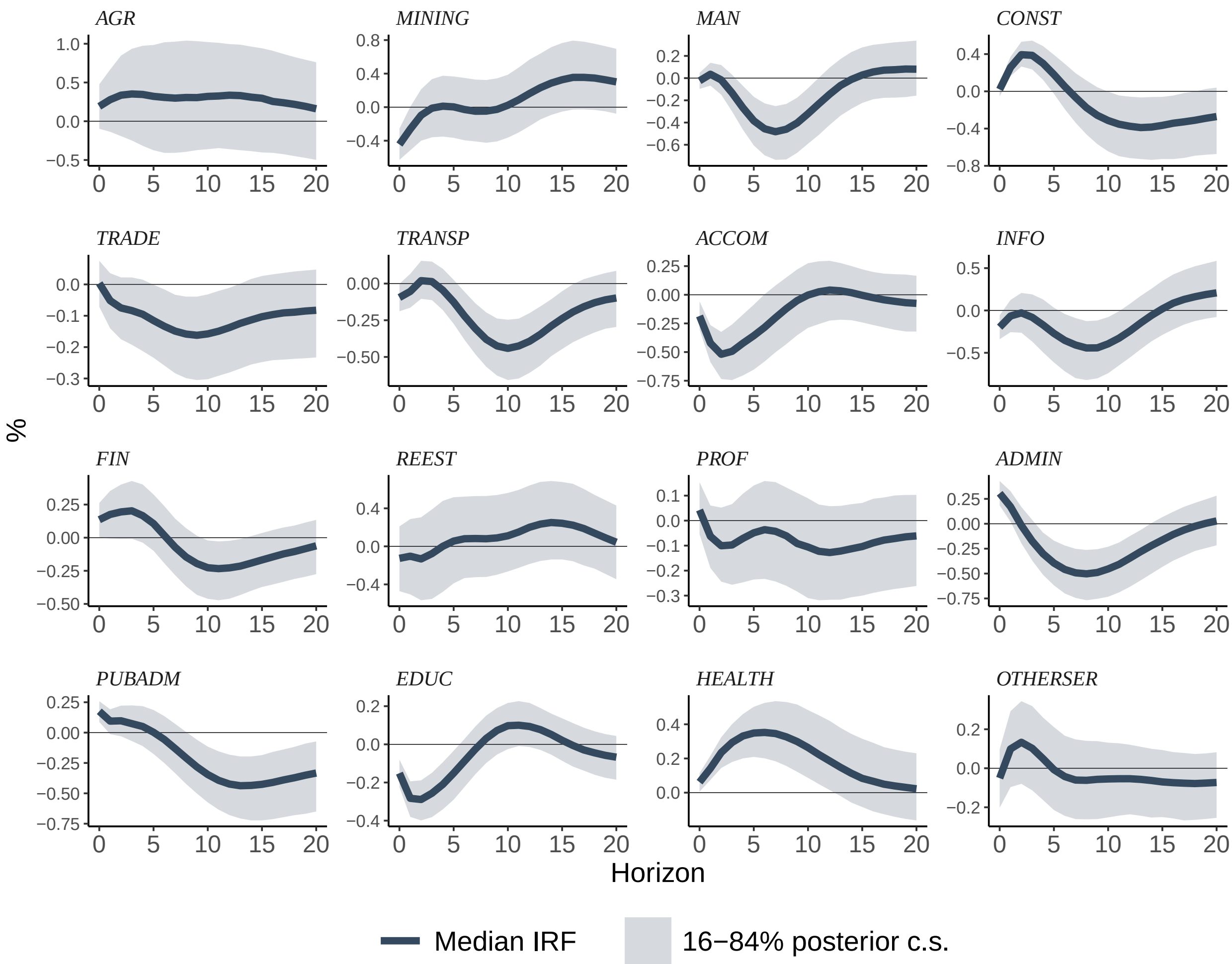
C.2 Full set of Sectoral IRFs - Baseline model

Figure C.1: *Sectoral Total Factor Productivity IRFs*



Notes: *The plot shows the sectoral Total Factor Productivity responses to a 10% increase in oil price due to an oil supply news shock. The figure depicts median impulse responses (solid line) and the 68% central posterior credible set (grey area)*

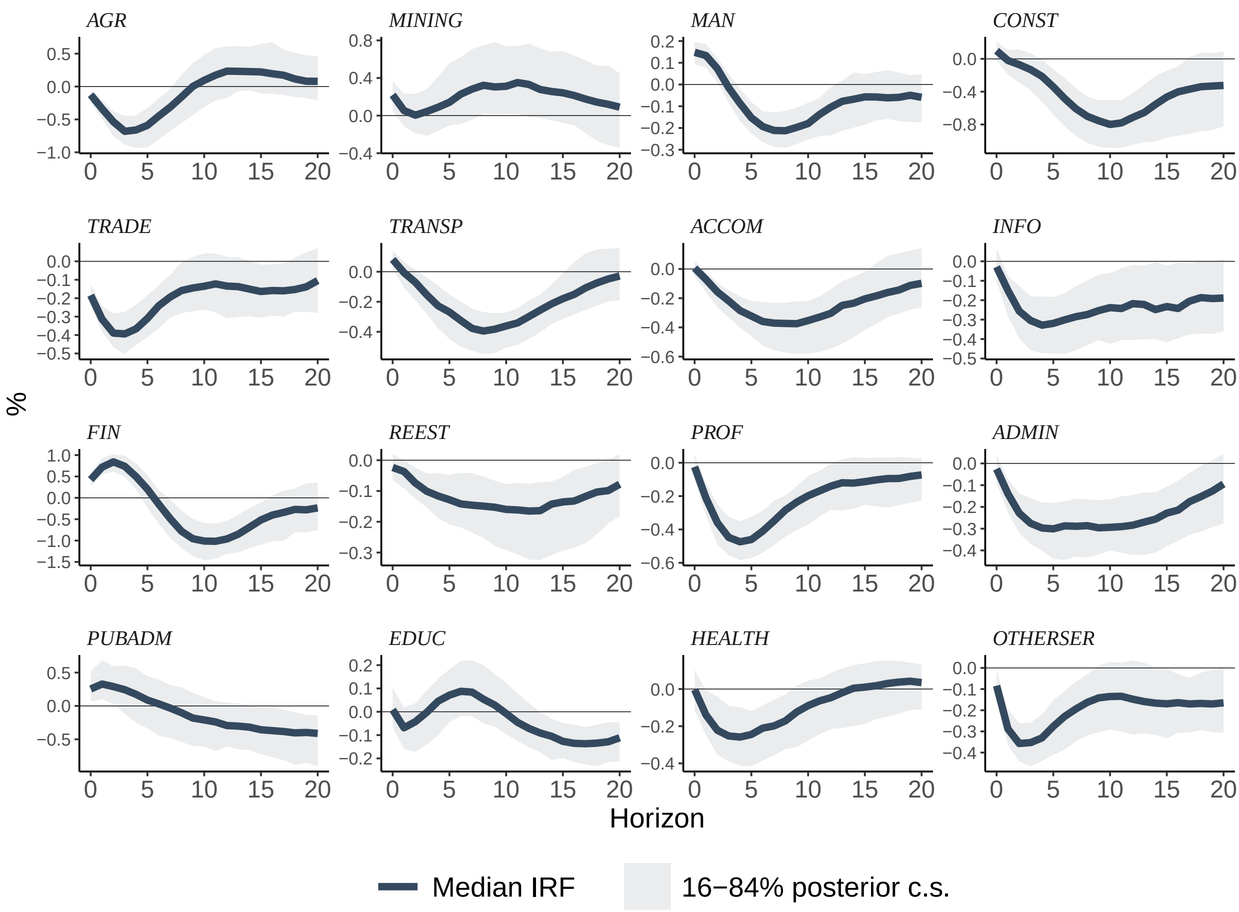
Figure C.2: *Sectoral Employment IRFs*



Notes: *The plot shows the sectoral employment responses to a 10% increase in oil price due to an oil supply news shock. The figure depicts median impulse responses (solid line) and the 68% central posterior credible set (grey area)*

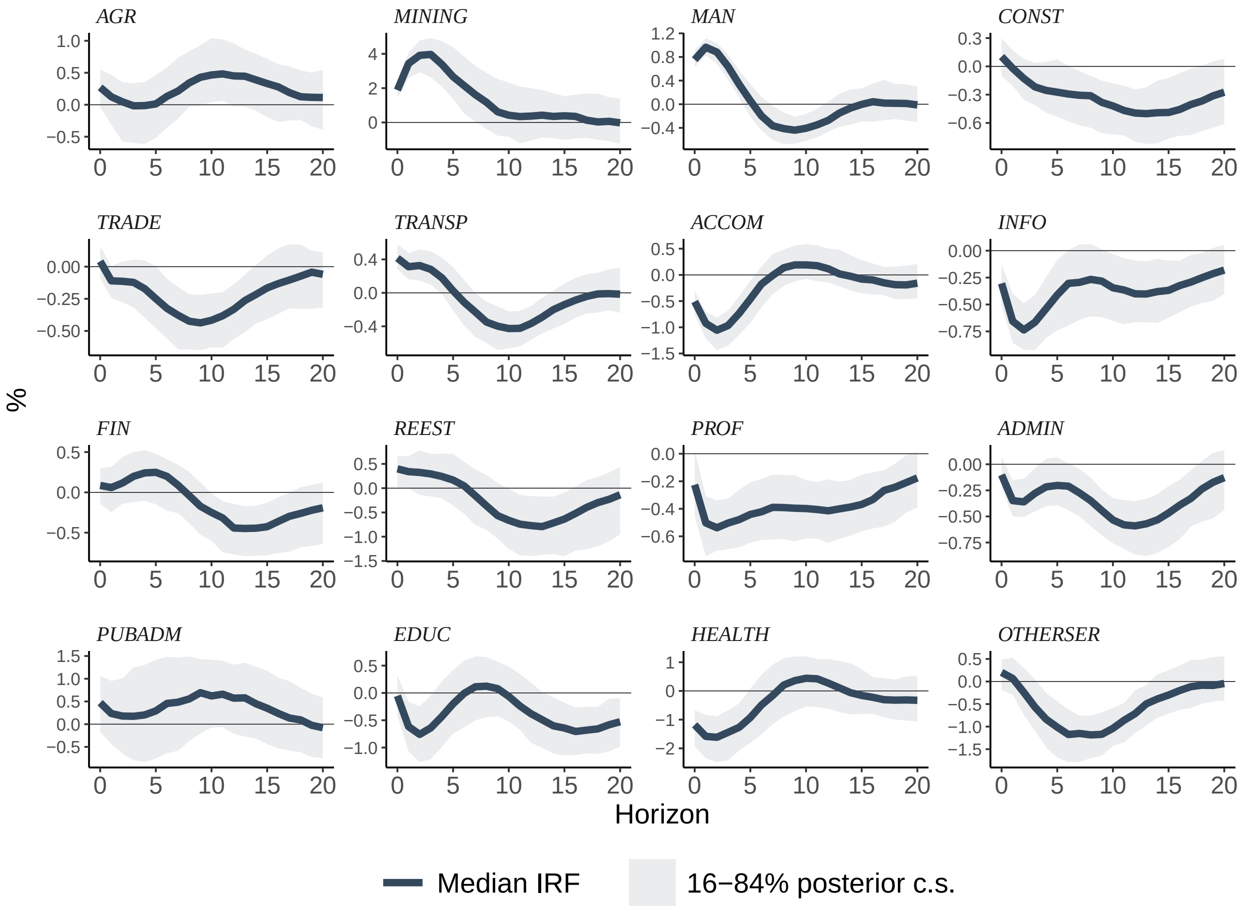
C.3 Full set of Sectoral IRFs -Synthetic Consumption & Exports

Figure C.3: Sectoral Consumption IRF.



Notes: *The plot shows the sectoral consumption responses to a 10% increase due to an oil supply news shock. The blue line is the median impulse responses from the baseline model. The grey area and the yellow dotted lines show the 68% central posterior credible set.*

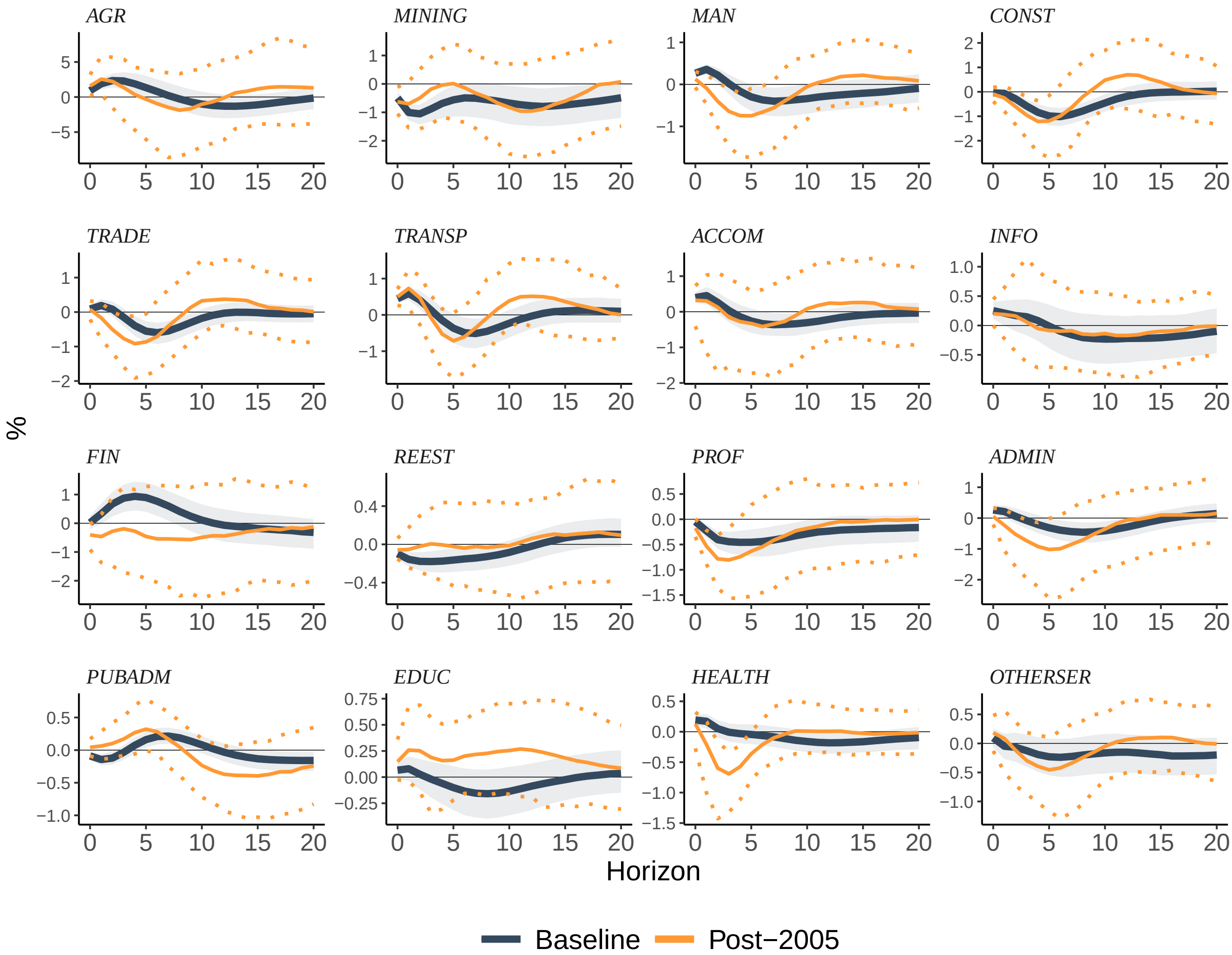
Figure C.4: Sectoral Exports IRF.



Notes: *The plot shows the sectoral exports responses to a 10% increase due to an oil supply news shock. The blue line is the median impulse responses from the baseline model. The grey area and the yellow dotted lines show the 68% central posterior credible set.*

C.4 The UK as a Net importer

Figure C.5: *Sectoral Output - Net oil importer regime*



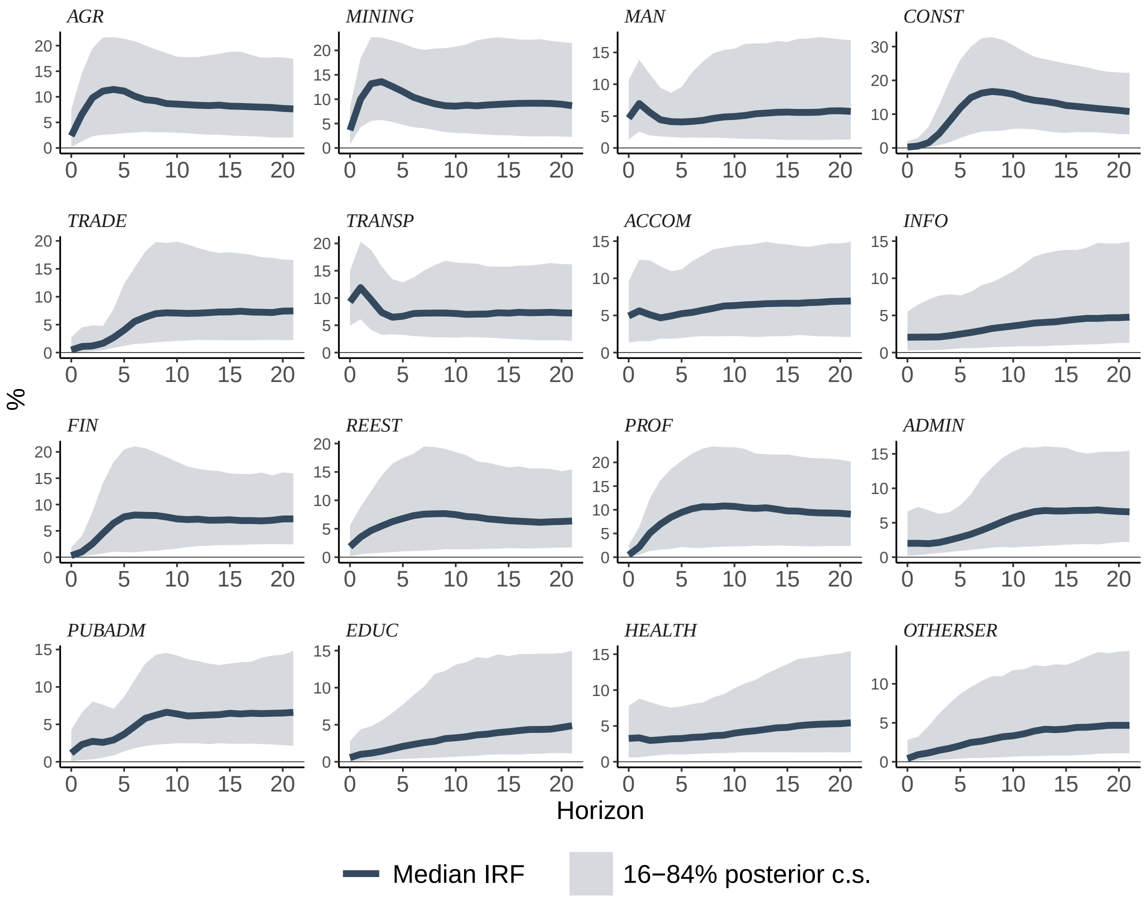
Notes: *The plot shows the sectoral output responses to a 10% increase due to an oil supply news shock. The blue line is the median impulse responses from the baseline model. The orange line is the median IRF from a model estimated in a post 2005 sample for which the UK was a net oil importer. The grey area and the yellow dotted lines show the 68% central posterior credible set.*

A key factor that could impact the results is the UK's status as a net oil exporter. The baseline model is estimated using data from 1997Q1 to 2019Q4, a period during which the UK transitioned from being a net oil exporter (1997-2005) to a net importer (2005-2019), raising concerns about a potential regime switch. To address this, I re-estimate the model using data that focus on the second period (Net importer). Results show that the oil effect is stronger compared to the baseline model. For many sectors, particularly those which production rely heavily on oil (Mining, Manufacturing, Construction), the response of the production is more negative compared to the baseline results. However, the responses are less accurately estimated. Overall, this is an important finding, as a potential break can explain the counter-intuitive positive response of some sectoral output responses when I don't account for the two regimes.

The estimation of the model in the first half of the sample was not possible because of the small number of observations.

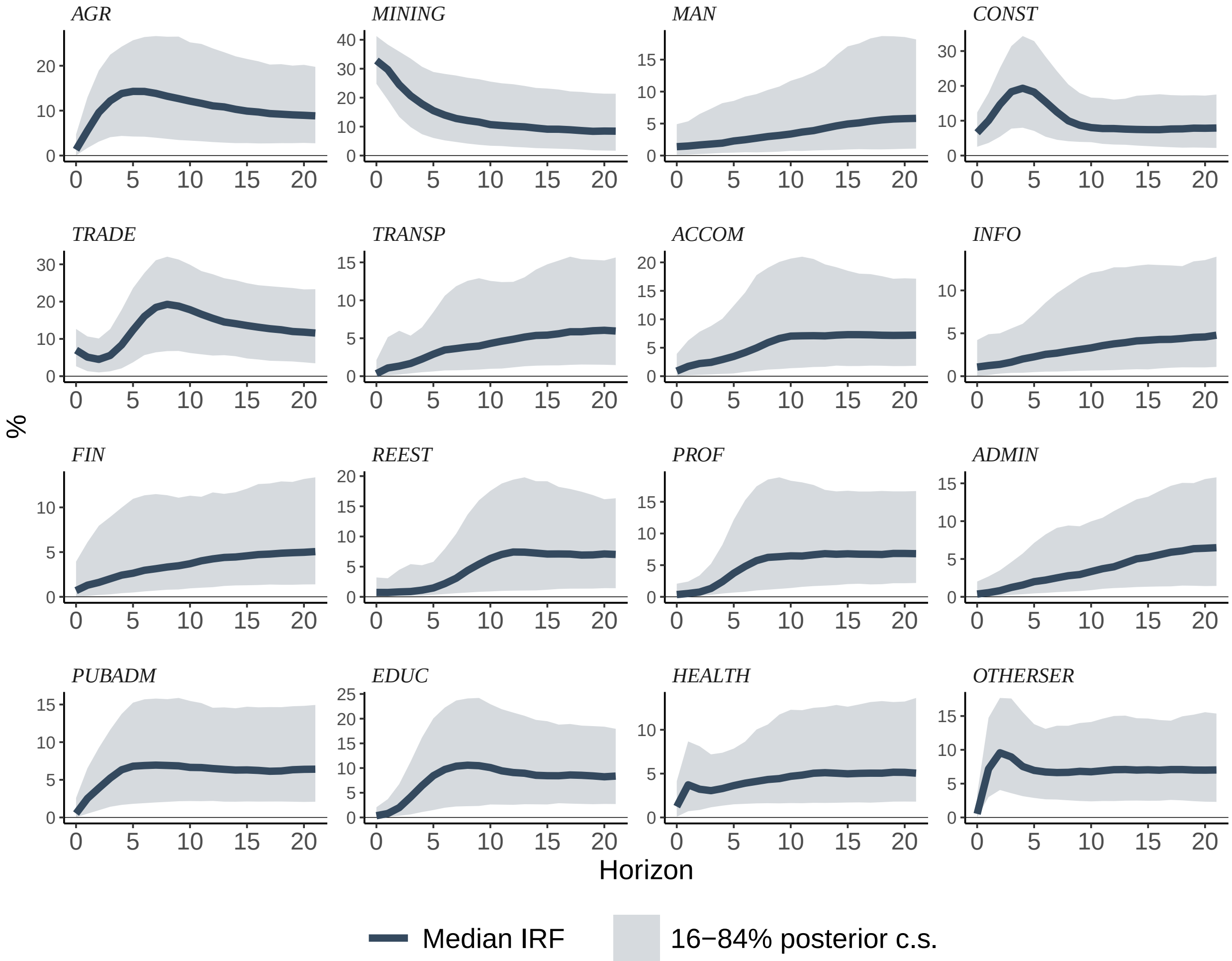
C.5 Are oil supply news shocks an important driver of the sectoral production and prices

Figure C.6: Forecast Error Variance Decomposition - Sectoral Output



Notes: *The plot shows the sectoral output Forecast Error Variance Decomposition results of the baseline model. The solid line indicate the median contribution of the oil shock to the Forecast Error Variance of the sectoral output. The grey area indicates the 68% central posterior credible set.*

Figure C.7: Forecast Error Variance Decomposition - Sectoral Prices



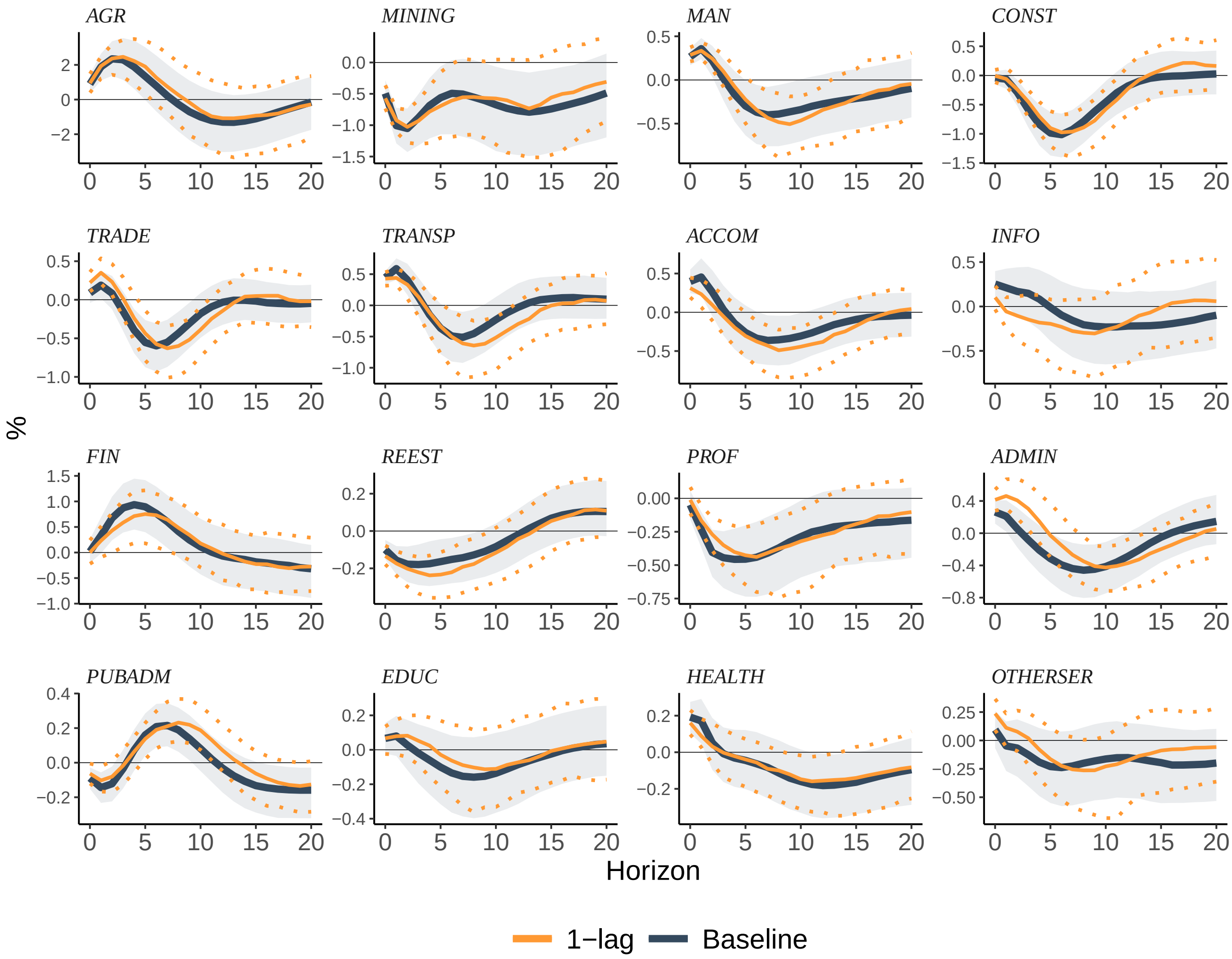
Notes: *The plot shows the sectoral output Forecast Error Variance Decomposition results of the baseline model. The solid line indicate the median contribution of the fiscal shock to the Forecast Error Variance of the sectoral prices. The grey area indicates the 68% central posterior credible set.*

Figure C.6 and Figure C.7 present the results of the sectoral output and sectoral output deflator Forecast Error Variance Decomposition (FEVD). Results show that the oil shock accounts for a substantial proportion of sectoral output variance particularly in sectors which production depends strongly on oil. For example, the shock explains around 15% of the forecast error variance of Mining, Energy & Water and Construction sector. The contribution is high in the short term and remains around 10% uo to five years after the shock. The oil shock contributes 10% to Transportation, the Financial and the Professional Services sectors' output forecast error variance. For the rest of the sector the contribution is close to 5%.

From Figure C.7, the oil shock explains significantly the variance of the sectoral prices in a number of sector. For example more contributes initially more than 30% to the variance of Mining, Energy & Water but the effect becomes weaker over time falling to 10% 4 years after the shock. The oil shock explains a significant part of the price fluctuations also in Construction (20%) and Trade (20%). In the rest of the sector the contribution varies between 5% and 10%.

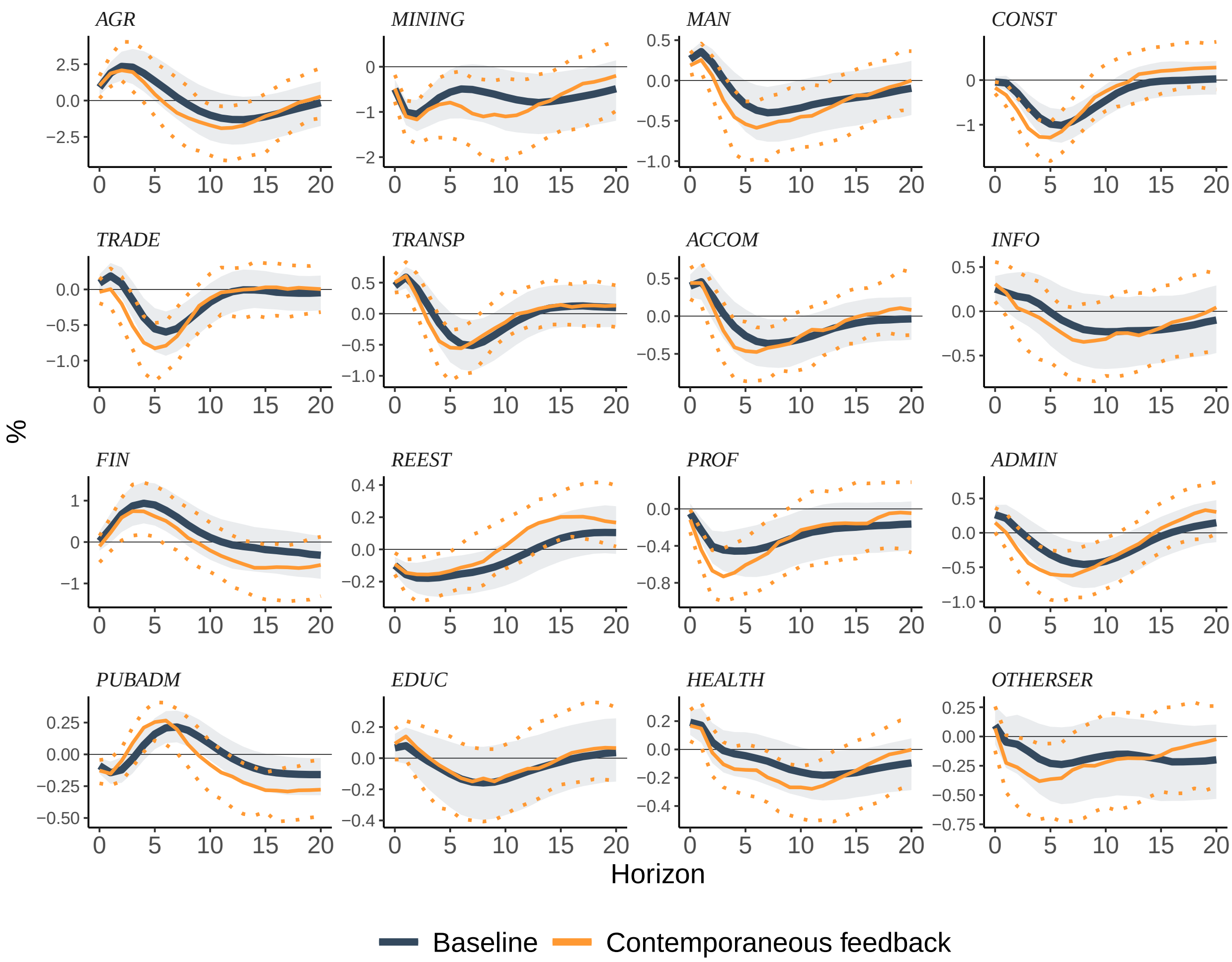
C.6 Estimation with alternative specification

Figure C.8: Sectoral output - 1 lag



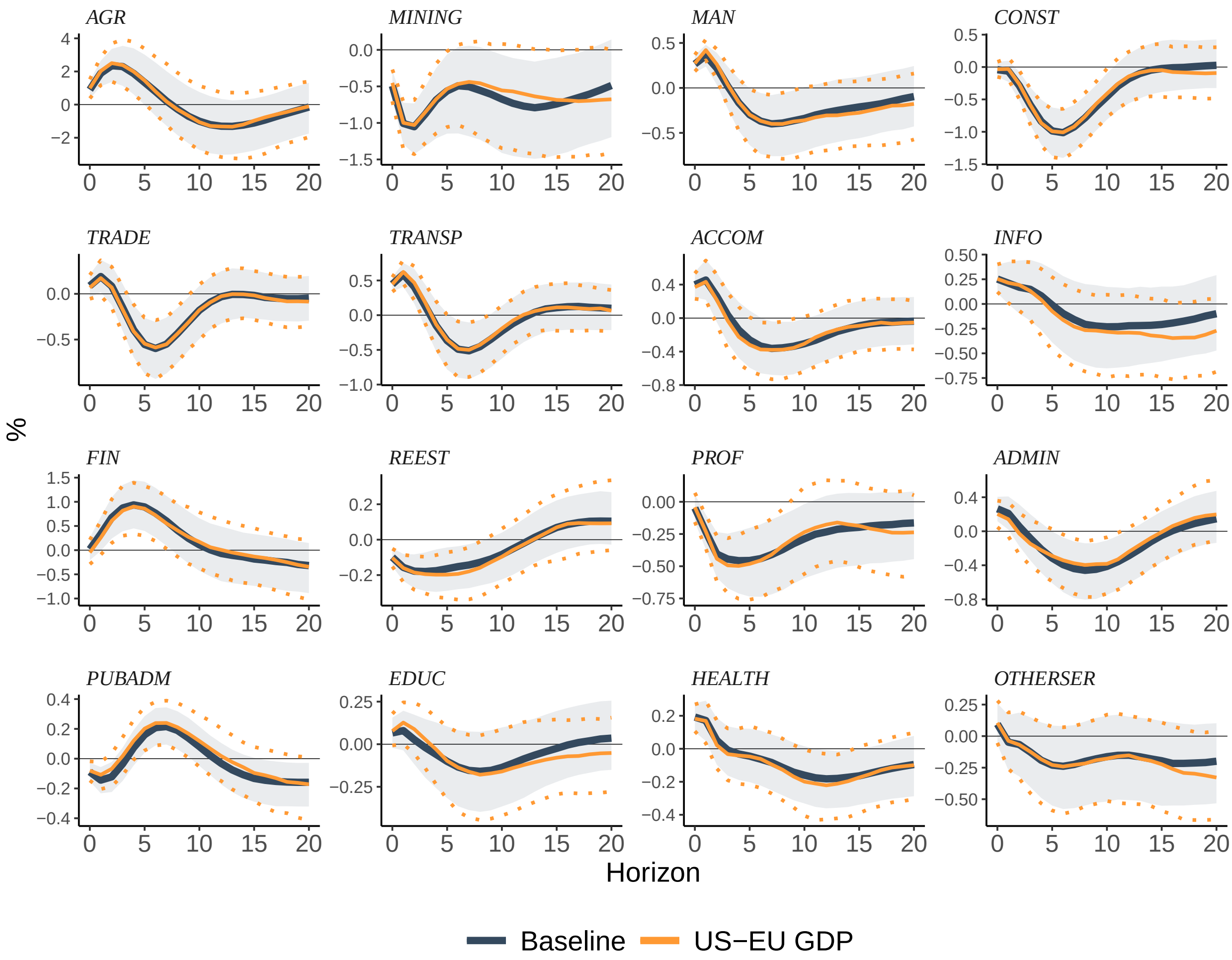
Notes: *The plot shows the sectoral output responses to a 10% increase due to an oil supply news shock. The blue line is the median impulse responses from the baseline model. The orange line is the median IRF from a model estimated with 1 lag for the endogenous and 1 lag for the exogenous variables. The grey area and the orange dotted lines show the 68% central posterior credible set.*

Figure C.9: Sectoral output - Contemporaneous Feedback Effects.



Notes: *The plot shows the sectoral output responses to a 10% increase due to an oil supply news shock. The blue line is the median impulse responses from the baseline model. The orange line is the median IRF from a model where the aggregate economy (common factors) VARX was estimated with contemporaneous feedback effects. The grey area and the orange dotted lines show the 68% central posterior credible set.*

Figure C.10: Sectoral output - EU and US output.



Notes: *The plot shows the sectoral output responses to a 10% increase due to an oil supply news shock. The blue line is the median impulse responses from the baseline model. The orange line is the median IRF from a model where the aggregate economy (common factors) VARX was augmented with the EU and US GDP. The grey area and the orange dotted lines show the 68% central posterior credible set.*

Appendix D

Sectoral Disaggregation

Table D.1: Low-level Sectoral Disaggregation - ONS

Sectoral Disaggregation - ONS

Section A: AGRICULTURE, FORESTRY AND FISHING
Division 01: Crop and animal production, hunting and related service activities
Division 02: Forestry and logging
Division 03: Fishing and aquaculture
Section B: MINING AND QUARRYING
Division 05: Mining of coal and lignite
Division 06: Extraction of crude petroleum and natural gas
Division 07: Mining of metal ores
Division 08: Other mining and quarrying
Division 09: Mining support service activities
Section C: MANUFACTURING
Division 10: Manufacture of food products
Division 11: Manufacture of beverages
Division 12: Manufacture of tobacco products
Division 13: Manufacture of textiles
Division 14: Manufacture of wearing apparel
Division 15: Manufacture of leather and related products
Division 16: Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
Division 17: Manufacture of paper and paper products
Division 18: Printing and reproduction of recorded media
Division 19: Manufacture of coke and refined petroleum products
Division 20: Manufacture of chemicals and chemical products
Division 21: Manufacture of basic pharmaceutical products and pharmaceutical preparations

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Table D.1 – continued from previous page

Division 22: Manufacture of rubber and plastic products
Division 23: Manufacture of other non-metallic mineral products
Division 24: Manufacture of basic metals
Division 25: Manufacture of fabricated metal products, except machinery and equipment
Division 26: Manufacture of computer, electronic and optical products
Division 27: Manufacture of electrical equipment
Division 28: Manufacture of machinery and equipment n.e.c.
Division 29: Manufacture of motor vehicles, trailers and semi-trailers
Division 30: Manufacture of other transport equipment
Division 31: Manufacture of furniture
Division 32: Other manufacturing
Division 33: Repair and installation of machinery and equipment
Section D: ELECTRICITY, GAS, STEAM AND AIR CONDITIONING SUPPLY
Division 35: Electricity, gas, steam and air conditioning supply
Section E: WATER SUPPLY; SEWERAGE, WASTE MANAGEMENT AND REMEDIATION ACTIVITIES
Division 36: Water collection, treatment and supply
Division 37: Sewerage
Division 38: Waste collection, treatment and disposal activities; materials recovery
Division 39: Remediation activities and other waste management services
Section F: CONSTRUCTION
Division 41: Construction of buildings
Division 42: Civil engineering
Division 43: Specialised construction activities
Section G: WHOLESALE AND RETAIL TRADE; REPAIR OF MOTOR VEHICLES AND MOTORCYCLES

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Table D.1 – continued from previous page

Division 45: Wholesale and retail trade and repair of motor vehicles and motorcycles
Division 46: Wholesale trade, except of motor vehicles and motorcycles
Division 47: Retail trade, except of motor vehicles and motorcycles
Section H: TRANSPORTATION AND STORAGE
Division 49: Land transport and transport via pipelines
Division 50: Water transport
Division 51: Air transport
Division 52: Warehousing and support activities for transportation
Division 53: Postal and courier activities
Section I: ACCOMMODATION AND FOOD SERVICE ACTIVITIES
Division 55: Accommodation
Division 56: Food and beverage service activities
Section J: INFORMATION AND COMMUNICATION
Division 58: Publishing activities
Division 59: Motion picture, video and television programme production, sound recording and music publishing activities
Division 60: Programming and broadcasting activities
Division 61: Telecommunications
Division 62: Computer programming, consultancy and related activities
Division 63: Information service activities
Section K: FINANCIAL AND INSURANCE ACTIVITIES
Division 64: Financial service activities, except insurance and pension funding
Division 65: Insurance, reinsurance and pension funding, except compulsory social security
Division 66: Activities auxiliary to financial services and insurance activities

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Table D.1 – continued from previous page

Section L: REAL ESTATE ACTIVITIES
Division 68: Real estate activities
Section M: PROFESSIONAL, SCIENTIFIC AND TECHNICAL ACTIVITIES
Division 69: Legal and accounting activities
Division 70: Activities of head offices; management consultancy activities
Division 71: Architectural and engineering activities; technical testing and analysis
Division 72: Scientific research and development
Division 73: Advertising and market research
Division 74: Other professional, scientific and technical activities
Division 75: Veterinary activities
Section N: ADMINISTRATIVE AND SUPPORT SERVICE ACTIVITIES
Division 77: Rental and leasing activities
Division 78: Employment activities
Division 79: Travel agency, tour operator and other reservation service and related activities
Division 80: Security and investigation activities
Division 81: Services to buildings and landscape activities
Division 82: Office administrative, office support and other business support activities
Section O: PUBLIC ADMINISTRATION AND DEFENCE; COMPULSORY SOCIAL SECURITY
Division 84: Public administration and defence; compulsory social security
Section P: EDUCATION
Division 85: Education
Section Q: HUMAN HEALTH AND SOCIAL WORK ACTIVITIES
Division 86: Human health activities
Division 87: Residential care activities

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Table D.1 – continued from previous page

Division 88: Social work activities without accommodation
Section R: ARTS, ENTERTAINMENT AND RECREATION
Division 90: Creative, arts and entertainment activities
Division 91: Libraries, archives, museums and other cultural activities
Division 92: Gambling and betting activities
Division 93: Sports activities and amusement and recreation activities
Section S: OTHER SERVICE ACTIVITIES
Division 94: Activities of membership organisations
Division 95: Repair of computers and personal and household goods
Division 96: Other personal service activities
Section T: ACTIVITIES OF HOUSEHOLDS AS EMPLOYERS; UNDIFFERENTIATED GOODS- AND SERVICES-PRODUCING ACTIVITIES OF HOUSEHOLDS FOR OWN USE
Division 97: Activities of households as employers of domestic personnel
Division 98: Undifferentiated goods- and services-producing activities of private households for own use
Section U: ACTIVITIES OF EXTRATERRITORIAL ORGANISATIONS AND BODIES
Division 99: Activities of extraterritorial organisations and bodies