# Industry effects of unconventional monetary policy, within and across countries ☆

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## ABSTRACT

While conventional monetary policy causes differential impacts on industry output, how unconventional monetary policy affects industries across countries is as of yet unknown. This paper characterizes the effects of unconventional monetary policy on domestic industry output and spillover effects on foreign industry output between the US, the UK, and Japan. I set up a Bayesian global vector autoregressive model and identify monetary policy shocks using a sign restrictions identification. I find that the effects on output have substantial heterogeneity both within a country and across countries, however, the pattern of the industry-level output responses within a country and across countries are similar to each other. Regression analysis indicates that industries with lower working capital and larger firm size are associated with a large industry output response to unconventional policy, indicating the relevance of the interest rate channel and portfolio balance channel. Overall, unconventional policy can be used as another tool in the policymakers' toolbox with similar industry impacts as conventional policy but with somewhat different transmission mechanisms.

## 1. Introduction

Unconventional monetary policy (henceforth unconventional policy) stimulates the economy mainly through quantitative easing (QE) and forward guidance. Unconventional policy was implemented during the financial crisis when the monetary policy rates reached the zero lower bound (ZLB).[1] Although the policy targets of central banks are aggregate variables, investigating the effects across industries provides new insights. First, industry analysis may discover differential impacts of unconventional policy, which are masked with aggregation. Second, cross-country analysis allows an investigation of the potential asymmetric industry responses within and across countries. Third, by associating the industry effects of unconventional policy with the financial structure of the industry, we can learn more about the monetary policy transmission mechanisms. The steadily declining natural rate of interest (Holston et al., 2017) implies a high likelihood of re-entering the ZLB. To illustrate,

the recent COVID-19 pandemic and the corresponding economic slowdown led to advanced economies re-entering the ZLB.[2] Thus, unconventional policy through the lens of industry analysis remains relevant.

In this paper, I first examine the impacts of unconventional monetary policy on different industries within the US, the UK, and Japan. Throughout the paper, I identify unconventional policy shocks using sign restrictions (e.g. Gambacorta et al., 2014) to capture the large-scale asset purchases of the central banks. To test the robustness of my findings, I also employ the proxy vector autoregression (proxy VAR) identification method (e.g. Caldara and Herbst, 2019), which uses high-frequency data to capture the forward guidance policy of the central banks. Additionally, I use the shadow rate, another commonly used measure of unconventional monetary policy shock (e.g. Krippner, 2013), within the sign restriction framework to identify unconventional policy shocks. Finally, I examine the spillover effects of unconventional policy at the industry level in these countries using the benchmark sign restrictions identification method.

This paper contributes to our knowledge on several fronts. First, it provides the differential impacts of unconventional policy on industry output. Conventional policy causes heterogeneous impacts on different groups such as industries (e.g. Dale and Haldane, 1995 and Ganley and Salmon, 1997), households (e.g. Kaplan et al., 2018 and Ampudia et al., 2018), and regions (e.g. Carlino and DeFina, 1998 and Arnold and Vrugt, 2002). In spite of the large volume of focus on the aggregate effects (e.g. Gambacorta et al., 2014 and Boeckx et al., 2017) and the financial market effects (e.g. Gagnon et al., 2011 and Krishnamurthy and Vissing-Jorgensen, 2011), the distributional impacts of unconventional policy in the literature is scarce[3]. This paper fills this gap in the literature and estimates the effects of unconventional policy on industry output.

Second, this paper investigates the industry-level spillover effects. In prior literature, the spillover effects of the US monetary policy have been widely explored in order to understand the transmission mechanisms of the US monetary policy to foreign economies (e.g. Bhattarai et al., 2021; Bowman et al., 2015; and Tillmann, 2016). US monetary policy has been found to have strong spillover effects on emerging market economies, especially financial variables such as exchange rates and capital flows. However, the large focus on the aggregate variables limits the investigation of the differential impacts of the spillover effects within a foreign country. To the best of my knowledge, this is the first investigation of heterogeneous impacts of the spillover effects within a country.

Third, this paper explores the transmission mechanisms of unconventional policy. One of the advantages of an industry analysis is to evaluate the potential transmission mechanisms: the connection between the financial structures and output response for each industry infers the transmission mechanisms (Dedola and Lippi, 2005 and Peersman and Smets, 2005). Given the ZLB, the traditional interest rate channel may be irrelevant for unconventional policy and some alternative channels may play a role. I investigate the transmission mechanisms of unconventional policy through industry analysis and compare it to the prior findings during the conventional policy periods.

I use a structural Bayesian global vector autoregressive (GVAR) model to take into account the cross-industry interactions.[4] The estimation includes monthly series of industry output from the 17 industries as well as the price level, central bank total assets, stock market implied volatility, and exchange rate for each country. I estimate the period from 2008M1 through 2015M12 where the unconventional policy was implemented for those three countries. I then assess the dynamic impacts of policy shocks on industry output by generating impulse response functions (henceforth response functions).

I find that industries respond heterogeneously within a country to unconventional policy shocks. For example, in the US the magnitude varies from 0.03% in petroleum and coal product to 0.54% in motor and transportation, in response to a 1% increase in the central bank total assets under the sign restriction. I find that the industries in the durable goods manufacturing are responsive to unconventional policy, while industries in the non-durable goods manufacturing respond weakly. This pattern is observed for all of the countries investigated and is similar to the pattern of responses to conventional policy found in the literature (e.g. Peersman and Smets, 2005 and Dedola and Lippi, 2005).

I also find that industries with lower working capital and larger firm size on average respond strongly to unconventional policy. Working capital represents liquidity of an industry. When monetary policy alters the borrowing cost of capital through affecting the expected real interest rate, industries with lower working capital respond strongly to the policy. Also, the central bank's long-term asset purchases alter the market participants' portfolio allocations towards corporate bonds, which might benefit large firms. These observations imply the existence of the traditional interest rate channel and the portfolio balance channel. The portfolio balance channel is often discussed during the unconventional policy periods. Thus, despite that the pattern of the industry-level output responses is similar between conventional and unconventional policies, the transmission mechanisms are somewhat different.

Furthermore, the spillover exercise also reveals that the industries in a foreign country respond heterogeneously. However, the industry-level output responses across countries are very similar to the responses within a country, despite foreign currency appreciation. This finding is confirmed for all of the combinations of the bilateral country pairs (i.e. the US- the UK, the US- Japan, and so on).

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[2] An exception to this is Japan, which has stayed in the ZLB since the financial crisis.

[3] An exception includes Goto, 2020 in which the author estimates the impacts of US unconventional policy on industry output in the manufacturing sector. In contrast, this paper adds a cross-country dimension.

[4] The model used in this study enables the explicit inclusion of cross-industry interactions, which is achieved through the incorporation of an input–output (IO) table. Theoretically, the inclusion of the IO matrix in a multisector model can improve the ability to generate observed comovement of sectoral output in response to monetary policy shocks. See Sudo (2012) and Bouakez et al. (2009).

The rest of this paper is organized as follows: Section 2 specifies the methodology (including data, the model, identification, and estimation), Section 3 reports the main results, Section 4 explores transmission mechanisms through regression analysis, Section 5 investigates the industry level spillover effects, and finally Section 6 concludes.

## 2. Methodology

In this paper, I use a global VAR (GVAR) model and apply the sign restrictions in Gambacorta et al. (2014) to identify an unconventional policy shock, generate response functions, and evaluate the industry impacts. Section 2.1 describes the data, Section 2.2 depicts the models, Section 2.3 explains the identifications, and Section 2.4 illustrates the estimation.

### 2.1. Data

I analyze the following countries: the US, the UK, and Japan, since they have all experienced ZLBs and implemented unconventional policies. I exclude countries in the EU area.[5] The data is of a monthly frequency. The data covers 2008M1 to 2015M12 capturing the periods of unconventional policies and near-zero policy rates at the same time. In the model, I include the industrial production index as industry output, the consumer price index as the price level, central bank total assets, stock market implied volatility, and the broad effective exchange rate index as the exchange rate.

The following is a complete list of the industries examined for all of the countries in this paper: food, beverage, and tobacco; textile mills product; apparel and leather product; wood product; paper; printing activities; petroleum and coal product; chemical; plastic and rubber product; nonmetallic mineral product; primary metal; fabricated metal product; machinery; computer and electronic product; electrical equipment etc; motor and transportation; and furniture and related product. More details on the industry definitions are available on Table B.6. in the Appendix.

I use an input–output (IO) table to construct the GVAR model. Specifically, I use the IO table for generating the weights of how an industry is related to the remaining industries. For the IO table, I use the 2012 data for the US and Japan and the 2017 data for the UK. The data for the US, the UK, and Japan are retrieved from the Bureau of Economic Analysis, the Office for National Statistics, and the Ministry of Economy, Trade and Industry, respectively.

### 2.2. The empirical model

A GVAR model (Pesaran et al., 2004) is a panel expression of vector autoregression (VAR) models. This GVAR specification follows Burriel and Galesi (2018), whose framework is an extension of Pesaran et al. (2004). This model simultaneously allows industry dynamics and the cross-sectional interaction of the industries. Additionally, this model incorporates the IO table as the external information on the degree of the industry interactions.

For each industry $i$, I model an ARX($p_i, q_i$):

$$y_{i,t} = c_i + \sum_{j=1}^{p_i} A_{i,j} y_{i,t-j} + \sum_{j=0}^{q_i} B_{i,j} y_{i,t-j}^* + \sum_{j=0}^{q_i} C_{i,j} x_{t-j} + u_{i,t} \quad (1)$$

where $c_i$ is an intercept; $A_{i,j}, B_{i,j}$, and $C_{i,j}$ are coefficient matrices; $u_{i,t}$ is white noise with nonsingular covariance matrix $\Sigma_{i,i}$; $y_{i,t}$ is output of industry $i$ at time $t$; and $y_{i,t}^*$ is a weighted average of output of industries $\forall k \neq i$:

$$y_{i,t}^* = \sum_{k \neq i} w_{i,k} y_{k,t} \qquad \sum_{k \neq i} w_{i,k} = 1 \quad (2)$$

where $w_{i,k}$ measures the weight of industry $k$ for industry $i$. Traditionally, bilateral trade flow is used (e.g. Vansteenkiste and Hiebert, 2011 and Galesi and Lombardi, 2009), because GVAR models assess interactions of countries. However, I use an IO table for the weight, since the focus of this paper is on industry-level interactions.[6]

The vector $x_t$ is a common variable. $x_t$ includes the price level, central bank total assets, stock market implied volatility, and exchange rate. $x_t$ is the same across industries and has the following VARX ($p_x, q_x$) specification:

$$x_t = c_x + \sum_{j=1}^{p_x} D_j x_{t-j} + \sum_{j=0}^{q_x} F_j \tilde{y}_{t-j} + u_{xt} \quad (3)$$

where $c_x$ is a vector of intercepts; $D_j$ and $F_j$ are coefficient matrices; $u_{xt}$ is white noise with nonsingular covariance matrix $\Sigma_{x,x}$; and $\tilde{y}_t = \sum_i w_i^* y_{i,t}$ and $w_i^*$ is real gross value added share of industry $i$.

I individually estimate Eqs. (1) and (3). In what follows, I stack Eqs. (1) and (3). Straightforward algebra leads to a structural GVAR model:

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[5] The countries in the EU area are susceptible to spillover effects from the other countries governed by the European Central Bank, and also it is difficult to choose a representative country for the EU area as there are several major economies.

[6] Holly and Petrella (2012) and Vansteenkiste (2007) use an IO table for the construction.

$$H_0 Z_t = h_0 + \sum_{j=1}^{p} H_j Z_{t-j} + e_t \tag{4}$$

where $Z_t = (y_{1,t}, \ldots, y_{17,t}, x_t\prime)\prime$. Assuming that $H_0$ is invertible. Then, I obtain the reduced form global VAR $(p)$ model:

$$Z_t = k_0 + \sum_{j=1}^{p} K_j Z_{t-j} + v_t \qquad v_t \sim \mathcal{N}(0, \Omega) \tag{5}$$

The variables enter the model without taking the first differences. I estimate the models in levels without explicitly imposing any cointegrating relationships of the variables and keep the long-run relationships implicit. The level specification is standard in the literature (e.g. Gambacorta et al., 2014; Boeckx et al., 2017; and Christiano et al., 1999) and generates more robust response functions than other alternatives (e.g. Gospodinov et al., 2013).

### 2.3. Identification

Under the ZLB, the monetary policy rates are no longer a reasonable monetary policy instrument and quantitative easing is an important tool of unconventional policies. I apply the sign restriction (e.g. Gambacorta et al., 2014; Boeckx et al., 2017 and Bhattarai et al., 2021) to capture this aspect. The identification is a mixture of zero and sign restrictions that are summarized in Table 1. The zero restriction states that a shock to central bank total assets does not have contemporaneous impacts on industry output and the price level. The zero restriction is imposed to separate the unconventional policy shock from other contemporaneous shocks such as demand and supply shocks.

Imposing the zero restriction is not sufficient to extract an exogenous unconventional policy shock from the endogenous increase in the central bank total assets. The central banks are widely thought to endogenously respond to financial turmoil and economic uncertainty with unconventional policy. That is, a higher financial market distress increases central bank total assets. This aspect of an increase in central bank assets cannot be regarded as an exogenous shock. By exploiting the sign restriction, I disregard the response function that leads to an increase in total assets and stock market volatility.

An exogenous component of the policy is a shock to central bank total assets that decreases (or keeps steady) the stock market volatility. I call this as an unconventional policy shock. This is consistent with the findings in the literature that unconventional policy reduces financial market uncertainty, volatility, and risk (e.g. Hattori et al., 2016; Krishnamurthy and Vissing-Jorgensen, 2011; Gagnon et al., 2011; Mallick et al., 2017; and many others). The mixture of the zero and sign restrictions are imposed on the impact period. Further, I impose the same sign restriction for one period after the shock to be consistent with Gambacorta et al. (2014). In order to generate the mixture of the sign and zero restrictions, I adopt the Givens rotation matrix as in Gambacorta et al. (2014). A complete description of the identification is in Appendix A.1.

### 2.4. Estimation

Following convention, I estimate Eqs. (1) and (3) individually and recover the reduced form GVAR in Eq. (5). I estimate each equation using the Stochastic Search Variable Selection (SSVS) prior proposed in George et al. (2008). This prior is based on the independent normal and inverse-Wishart prior, and has a hierarchical structure for the coefficients prior. SSVS prior chooses promising subsets of parameters that are identified while the irrelevant parameters are designed to shrink towards zeros.

For each equation, I set the coefficient prior to the first own lag of each variable to be 1 and the remaining parameters to be zeros. I draw 2,000 samples from the posterior distribution after a 10,000 burn-in. For each sample draw, I draw 50 Givens rotation matrix for the sign restrictions. A detailed explanation of the Bayesian estimation is in Appendix A.2.

Based on the Bayesian Information Criterion, all countries select $p_i = q_i = p_x = q_x = 1$. However, to minimize the post-estimation serial correlation in the reduced form residuals, I set the lag length at $p_i = q_i = p_x = q_x = 2$ for Japan and the US and $p_i = q_i = p_x = q_x = 4$ for the UK, as determined by the Box-Ljung test. The autocorrelation functions of all variables in the three countries are presented in Fig. 1. The majority of variables are within the insignificant bands. The selected lag length, which is relatively small for monthly frequency data, is consistent with previous studies that utilize large-scale VAR models. For instance, one lag was used in Feldkircher and Huber (2016) and two lags in Gambacorta et al. (2014).

## 3. Results

I first provide the identified shocks in Section 3.1. Next, in Section 3.2, I demonstrate that the responses of the industry-level output are heterogeneous. In Section 3.3, I compare the results within each country and compare them with previous studies. I then investigate the contributions of individual industry effects and spillover effects from other industries by decomposing the total effects in Section 3.4. Lastly, in Section 3.5, I present the results under the proxy VAR and shadow rate monetary policy shocks to test the robustness of the findings.

**Table 1**
Sign restrictions of impulse response functions.

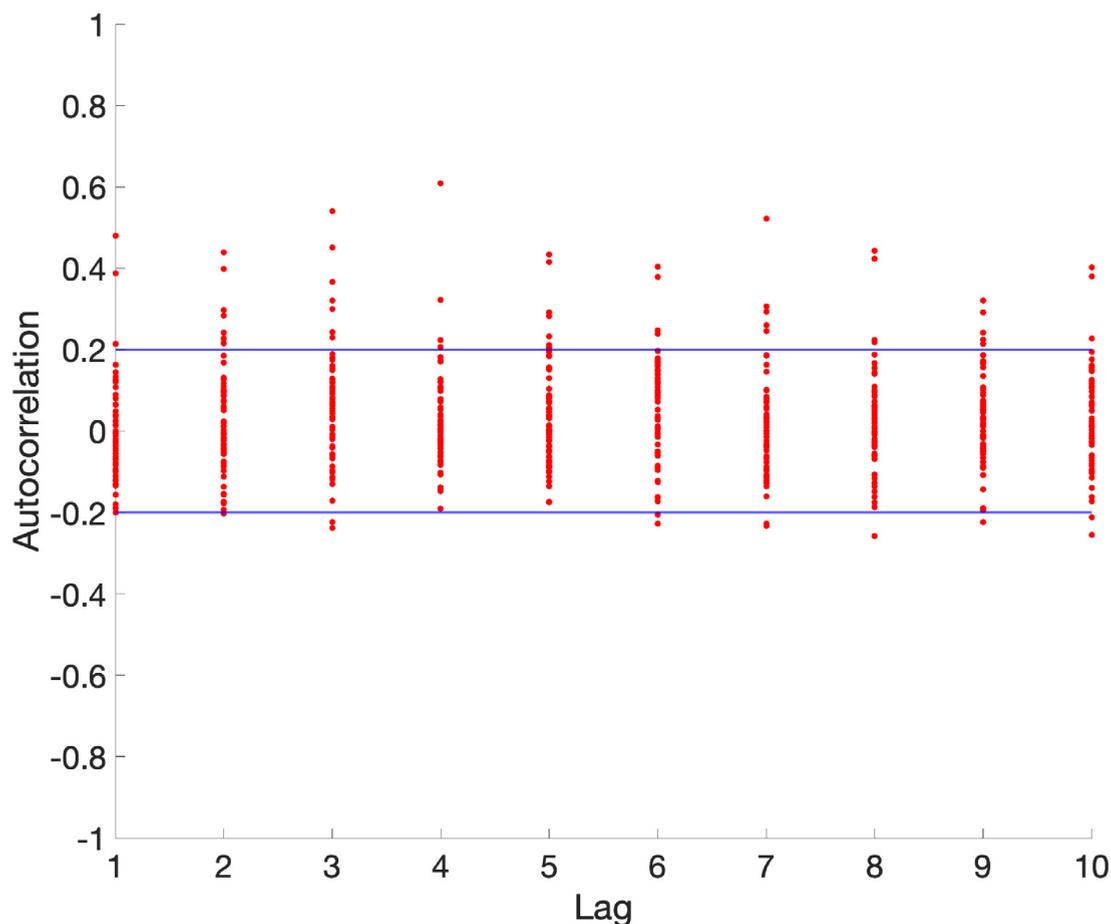|  | at period = 0 | at period = 1 |
|---|---|---|
| Industry output$_1$ | 0 | * |
| ⋮ | ⋮ | ⋮ |
| Industry output$_{17}$ | 0 | * |
| Consumer price index | 0 | * |
| Central bank total assets | + | + |
| Stock market volatility | − | − |
| Exchange rate | * | * |



**Fig. 1.** The autocorrelation function. Note: The autocorrelation functions of the reduced form residuals for all of the variables of the three countries.

### 3.1. The identified shocks

I present the time series figures of the identified unconventional policy shocks and examine the shocks along with the actions taken by these central banks. Fig. 2 presents the median identified shocks for all three countries. The identified shocks are normalized so that the mean and standard deviation of the shocks are zero and one, respectively.

The identified shocks capture some unexpected components of the actions by the central banks indicated in the figure. However, the identified shocks do not simply comove with the rise in central bank total assets. For example, in the US, the onset of QE1 by the Federal Reserve comes with positive spikes. Nonetheless, the spikes during QE3 are modest, despite that the central bank total assets persistently rise during the period, indicating that there are extensive endogenous and expected components. Similar observations are made of the identified shock for the UK and Japan. The highest spikes occur near the beginning of the sample period when market participants have never experienced or expected such a large magnitude of easing. However, at the end of the sample, the identified shocks behave erratic in spite of the ballooning of the bal-
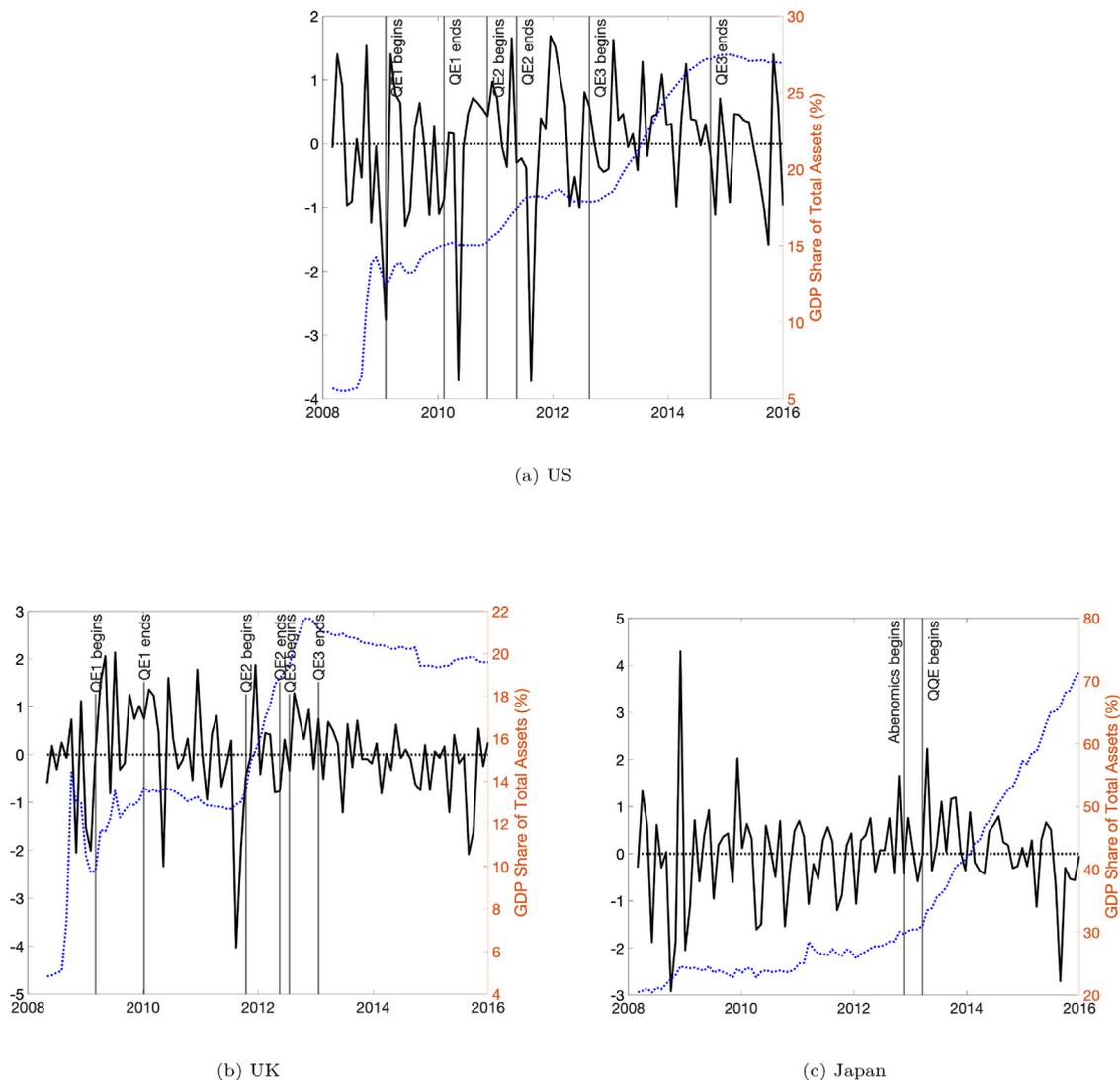
(a) US



(b) UK



(c) Japan

**Fig. 2.** The identified shocks. Note: The identified shocks from the sign restrictions. The solid curves represent the median of the identified shocks from the structural GVAR model. The dotted curve represents the share of central bank total assets of real GDP. I normalized the scale of the shocks so that the mean (as well as the sum) of the shock and the standard deviation of the shock are zero and one, respectively.

ance sheets of those central banks. Overall, the identified shocks seem to successfully draw surprising components of the actions by the central bank earlier in the sample but not in the middle or later on in the sample.

For all three countries, the surprise increase in central bank total assets comes with a decrease in stock market implied volatility, leads to a depreciation of the currency, and an increase in the price level. This is consistent with the findings in the literature (such as Gambacorta et al., 2014; Bhattarai et al., 2021; Boeckx et al., 2017, and many others).

### 3.2. Industry results

The industry response functions reveal heterogeneous responses to unconventional policy shocks. Fig. 3 shows the selected industry response functions for each country.[7] For each country, I list the two most responsive industries and the least responsive industry. Compared to the industry average response function, the top two industries respond stronger and the least responsive industry responds weaker. To comprehensively compare the industry-level impacts across industries, Table 2 summarizes unconventional policy elasticity of output: the maximum percentage change in output in response to 1% increase in central bank total assets.[8]

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[7] All of the response functions for each country are reported in the online Appendix.
[8] Under each elasticity, I listed the 64% credible band in parenthesis analogous to standard errors.
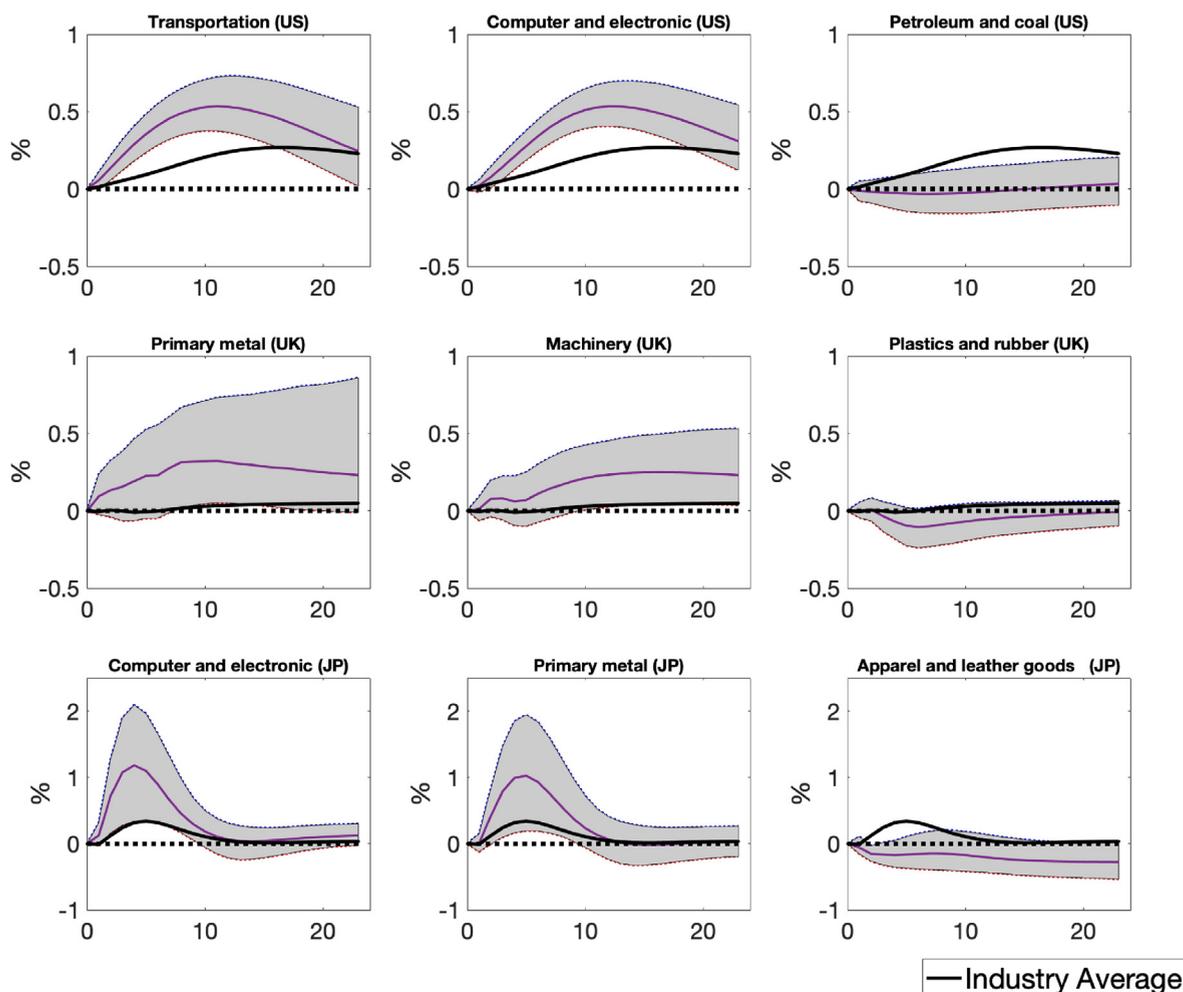
**Fig. 3.** Selected industry response functions. Note: The median, 16th, and 84th Bayesian percentiles are reported. Monthly horizon. The 1st row shows the results for the US, the 2nd row shows the results for the UK, and the 3rd row shows the results for Japan. For each country the two most responsive industries and the least responsive industry are selected.

The elasticity varies from 0.03% to 0.54% in the US, 0.01% to 0.16% in the UK, and −0.06% to 1.18% in Japan.[9] The finding indicates that the same policy affects industries disproportionately. The industry that shows the strongest elasticity is motor and transportation in the US, primary metal in the UK, and computer and electronic product in Japan: the most affected industry is different for each country.

I find that the durable goods producing industries respond strongly and non-durable goods producing industries respond weakly. I rank the elasticity for each country to examine which industry is responsive to the policy. The top five most responsive industries vary across countries, however, there are some commonalities. The motor and transportation industry is within the top five most responsive industries for all of the countries. Also, computer and electronic, primary metal, machinery, and nonmetallic mineral industries are within the top five most responsive industries for two of the countries. The industries listed above are all durable goods producing industries. In fact, there are only two industries that are within the top five and that are not durable goods producing industries across the three countries. With regards to five least responsive industries, I find that printing and related; food, beverage, and tobacco; petroleum and coal; and apparel and leather goods are within the five least responsive industries for two of the countries. Overall, I find that the responsiveness of the industries to the policy are similar across these investigated countries.

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**Table 2**
Unconventional policy elasticity of output.

| Country Industry | US | UK | Japan | Country | US | UK | Japan |
|---|---|---|---|---|---|---|---|
| Food, beverage, and tobacco | 0.088 | 0.059 | 0.009 | Nonmetallic mineral product | 0.404 | 0.041 | 0.611 |
| | (0.016,0.198) | (0.010,0.131) | (−0.061, 0.089) | | (0.237, 0.630) | (−0.060, 0.171) | (0.068, 1.202) |
| Textile mills product | 0.371 | 0.015 | 0.180 | Primary metal | 0.308 | 0.322 | 1.027 |
| | (0.148, 0.667) | (−0.154, 0.201) | (−0.043, 0.474) | | (0.039, 0.574) | (0.052, 0.731) | (0.196, 1.942) |
| Apparel and leather product | 0.424 | 0.027 | −0.059 | Fabricated metal product | 0.266 | 0.065 | 0.154 |
| | (0.089, 0.928) | (−0.043, 0.104) | (−0.152, 0.106) | | (0.098, 0.458) | (0.003, 0.158) | (−0.087, 0.467) |
| Wood product | 0.372 | 0.097 | 0.142 | Machinery | 0.311 | 0.249 | 0.799 |
| | (0.203, 0.573) | (−0.031, 0.219) | (−0.044, 0.407) | | (0.095, 0.560) | (0.043, 0.493) | (0.257, 1.490) |
| Paper | 0.086 | 0.054 | 0.227 | Computer and electronic product | 0.535 | 0.072 | 1.183 |
| | (−0.042, 0.209) | (−0.007, 0.117) | (−0.003, 0.503) | | (0.408, 0.690) | (−0.014, 0.156) | (0.341, 2.090) |
| Printing activities | 0.125 | 0.067 | 0.010 | Electrical equipment etc | 0.234 | 0.066 | 0.517 |
| | (0.003, 0.278) | (−0.047, 0.193) | (−0.039, 0.065) | | (0.095, 0.402) | (−0.037, 0.188) | (0.134, 0.992) |
| Petroleum and coal product | 0.034 | 0.087 | −0.003 | Motor and transportation | 0.535 | 0.164 | 0.695 |
| | (−0.102, 0.204) | (−0.070, 0.343) | (−0.134, 0.183) | | (0.376, 0.724) | (0.024, 0.328) | (−0.125, 1.865) |
| Chemical | 0.260 | 0.014 | 0.203 | Furniture and related product | 0.380 | 0.023 | 0.155 |
| | (0.079, 0.564) | (−0.035, 0.065) | (−0.005, 0.472) | | (0.208, 0.608) | (−0.048, 0.106) | (−0.022, 0.425) |
| Plastic and rubber product | 0.237 | 0.008 | 0.385 | | | | |
| | (0.054, 0.409) | (−0.063, 0.083) | (−0.019, 0.905) | Industry average | 0.292 | 0.084 | 0.367 |
| | | | | Industry median | 0.308 | 0.065 | 0.203 |

Note: Lower and upper values of credible band in parenthesis. Credible band is an interval within which the estimate falls with the probability given. Elasticity is the maximum median impulse response function consistent with a 1% increase in central bank total asset. For example, for the food, beverage, and tobacco industry in the US, a 1% increase in central bank total assets increases the output by 0.088%. Credible bands are also transformed by the same amount as the elasticity is scaled.

## 3.3. Cross-country analysis

The literature of conventional policy uncovers heterogeneous industry effects. However, these analyses typically limit their attention to a single country. Only a few studies have compared the industry effects across countries of conventional policy, and to my knowledge, there are no previous studies of the industry effects across countries of unconventional policy. In what follows, I briefly compare the pattern obtained in Section 3.2 across these three countries. I also examine to what extent the pattern is similar to that in the literature of conventional policy.

Almost all of the responsive industries in the previous section are known to be durable goods producing industries (motor and transportation, computer and electronic, primary metal, machinery, and Nonmetallic mineral) and they are interest rate sensitive. Alternatively, the common least responsive industries across the countries (printing and related; food, beverage, and tobacco; petroleum and coal; and apparel and leather goods) are all known to be non-durable goods producing industries and they are not interest rate sensitive. Despite that under the ZLB the interest rate movement is minimal, I find that the elasticity of the durable goods producing industries is strong.

One possibility is signaling theory (e.g. Bauer and Rudebusch, 2014 and Bhattarai et al., 2015): a central bank's promise to keep the policy rate lower towards the future, lowers the expected short-term real interest rates. This creates an incentive for capital intensive firms to invest in projects that involve money borrowing and also creates an incentive for consumers to make purchases of durable goods. Alternatively, changes in the long-term asset yields from unconventional policy influences the interest sensitive industries strongly.

A few studies investigate the industry impacts of conventional policy using multiple countries. Peersman and Smets (2005) investigate seven euro area countries using quarterly data that covers the period of 1980 to 1998. They find that transport equipment and fabricated metal are responsive to the policy while food, beverage, and tobacco and non-

metallic mineral products are not responsive to the policy. Dedola and Lippi (2005) study the five OECD countries over the period of 1975 to 1997 using monthly frequency data. They find that motor vehicle, primary metal, machine and equipment, and nonmetallic mineral product are responsive while food, beverage, and tobacco; paper; and printing respond poorly. The pattern of industry responses found in Dedola and Lippi (2005) and Peersman and Smets (2005) are overall consistent with the findings in this paper. This indicates that the industry impacts of unconventional policy and conventional policy are similar to each other.

*3.4. Decomposition of effects on output*

One insightful application of GVAR models is to examine the extent to which the effects of unconventional policy shocks are driven by industry-level linkages. To approach this, I employ a decomposition technique in Burriel and Galesi (2018) that separates the observed unconventional policy elasticity of output into direct effects from the industry under consideration and spillover effects from other industries. Specifically, I consider an alternative model in which Eq. 1 excludes the weighted average of output from other industries. This modified equation takes the form:

$$y_{i,t} = c_i + \sum_{j=1}^{p_i} A_{i,j} y_{i,t-j} \sum_{j=0}^{q_i} C_{i,j} x_{t-j} + u_{i,t}$$

With this specification, unconventional policy shocks only affect an industry $i$ through its own lags and common variables. After estimating the response functions using this model, I calculate the spillover effects by taking the difference between the response functions with and without the industry linkage.

Fig. 6 presents a decomposition of the unconventional policy elasticity of output decomposed into direct effects and spillover effects. The findings show significant contributions of the spillover effects to the total effects in both the US and Japan, with the most responsive industries showing an increase in elasticity from 0.38 (direct effect) to 0.53 (direct and spillover effects combined) in the US, and from 0.90 to 1.18 in Japan. Additionally, the spillover effects also amplify the heterogeneity of industry-level output responses across industries. In particular, the range of elasticity increases from 0.41 to 0.50 in the US and 0.97 to 1.24 in Japan, suggesting that the missing industry interaction likely leads to an understatement of the spillover effects of unconventional policy.

In contrast, the UK appears to experience limited benefits from spillover effects, with the elasticity of output of the most responsive industries decreasing from 0.35 (direct effect) to 0.32, and the range of elasticity decreasing from 0.37 to 0.31. While some industries in the UK do benefit from spillover effects, the majority of industries respond to the policy mainly through direct effects.

One possible explanation for this phenomenon is the role of the IO tables. Specifically, the IO tables indicate that non-metallic mineral and food, beverage, and tobacco industries have strong ties to other industries. Although the response functions of food, beverage, and tobacco industries are weak across all countries, the response function of nonmetallic mineral industry is particularly weak in the UK, which may explain the diminished spillover effects observed in this country. Overall, accounting for industry interactions is crucial to accurately characterize the industry-level effects of unconventional policy. However, it is important to note that this analysis excludes non-manufacturing sectors, thus the spillover effects could still be underestimated.

*3.5. Robustness*

*3.5.1. Proxy VAR*
The sign restriction captures the quantitative easing component of unconventional policy. Another important aspect of unconventional policy is announcement effects from the forward guidance. Also, an imposition of the usual flat prior is indeed informative under sign restriction (e.g. Baumeister and Hamilton, 2015 and Baumeister and Hamilton, 2019). To complement the shortcoming of the sign restriction, I use proxy VAR or external instrument (e.g. Stock and Watson, 2012 and Mertens and Ravn, 2013) incorporating high-frequency data. I apply the approach in Caldara and Herbst (2019). This method takes proxy or external instrument, $m_t$ and links it to the structural monetary policy shock $e_{MP,t}$:

$$m_t = \beta e_{MP,t} + \sigma_v v_t, \qquad v_t \sim \mathcal{N}(0,1) \text{ and } v_t \perp e_t$$

where $v_t$ is an iid measurement error. Similar to the instrument variables method, the proxy satisfies the following "relevance" condition:

$$\rho \equiv \text{corr}(m_t, e_{MP,t})^2 = \frac{\beta^2}{\beta^2 + \sigma_v^2}$$

and the "exogeneity" condition:

$$E\left[m_t e'_{NMP,t}\right] = \mathbf{0}$$

where $e_{NMP,t}$ is a vector of structural shocks excluding $e_{MP,t}$. These two assumptions imply that the proxy needs to be correlated with the structural unconventional policy shock but are orthogonal to other structural shocks.

For the proxy, I use the change in the tick-by-tick financial variables. I use the change in 10-year Treasury note futures between 15 min before and 105 min after the announcement in the US, the change in 10-year long guilt futures between 15 min before and 15 min after the announcements in the UK, and the change in 10-year government bond futures between 10 min before and 20 min after the announcements in Japan.[10] Unfortunately, due to the data limitation, the window sizes and timings around the announcements are inconsistent across countries. These high frequency variables take zero if there are no announcements in a month and take the summation if there is more than one announcement in a month. Given the narrow intervals, these monetary policy surprises should capture the shocks from the central bank announcements but not other macroeconomic shocks.

I follow the estimation method in Caldara and Herbst (2019) and omit the details for brevity. However, I modify how the response functions are generated. Under the proxy VAR, ensuring exogeneity becomes challenging as the size of the dimension increases. To circumvent the problem, I identify structural shocks *locally*, following the method in Dees et al. (2007), Eickmeier and Ng (2015) and Feldkircher and Huber (2016). This approach reduces the dimensions of exogeneity conditions that must be satisfied and applies identification only to the unit of interest. It is reasonable to assume that the central banks conduct unconventional policy based on the aggregate variables shown in the common VARX in Eq. (3), rather than focusing on the output of each individual industry. However, given that the identification is based on only a fraction of the entire system, it is possible that some of the structural shocks that are outside the locality consideration might be correlated with unconventional policy shocks.

In what follows, I identify an unconventional policy shock from the common VARX equation:

$$Q_x^{-1}x_t = Q_x^{-1}c_x + \sum_{j=1}^{p_x}Q_x^{-1}D_jx_{t-j} + \sum_{j=0}^{q_x}Q_x^{-1}F_j\tilde{y}_{t-j} + Q_x^{-1}u_{xt} \tag{6}$$

where $Q_x^{-1}$ is the product of the Cholesky factor of $\Sigma_{xx}$ and a rotation matrix. Let

$$Q = \begin{bmatrix} 1 & 0 & \dots & 0 & \mathbf{0} \\ 0 & 1 & \ddots & \vdots & \vdots \\ \vdots & \ddots & \ddots & 0 & \vdots \\ 0 & \dots & 0 & 1 & \mathbf{0} \\ \mathbf{0} & \dots & \dots & \mathbf{0} & \mathbf{Q_x} \end{bmatrix}$$

The locally identified global GVAR is obtained by pre-multiplying $Q^{-1}$ in Eq. (4).[11]

The results indicate that the industry response functions are also heterogeneous within a country. Fig. 4 shows the selected industry response functions for each country under proxy VAR.[12] For each country, I list the two most responsive industries and the least responsive industry. As with the case of the sign restrictions, the top two industries respond strongly and the least responsive industry responds weakly. Compared to the sign restrictions, the two most responsive industries and the least responsive industry are somewhat different. The differences between the QE and the announcement effects may potentially explain the finding.

However, the pattern of the industry-level output responses is similar to the pattern found in the sign restrictions. I rank the elasticity for each country to investigate which industry is responsive to the policy. Primary metal, machinery, and motor and transportation industries are in the top five most responsive industries for all countries. Also, computer and electronic is among the top five most responsive industries in two of the countries. These industries are again durable goods producing industries. For all the countries, the five least responsive industries include, food, beverage, and tobacco; printing and related; and petroleum and coal. I also find that chemical is among the five least responsive industries for two of the countries. These industries are all non-durable goods producing industries. The industries listed here are very similar to the industries from the sign restrictions.

### 3.5.2. Shadow rate

Another common approach to capturing unconventional policy is through the use of a shadow rate (such as Wu and Xia, 2016 and Krippner, 2013), which is an implied latent interest rate derived from a term structure model. The shadow rate allows for assessing the monetary policy stance and quantitative analysis during the ZLB. In this study, I use the shadow rate measures from Krippner (2013), since the shadow rate in Japan is not available in Wu and Xia (2016). I utilize the shadow rate as an alternative measure in the sign restriction identification scheme. I replace the central bank total assets and stock market implied volatility with the shadow rate. In addition to the zero restrictions that are imposed on industry output and

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[10] The data in the US is retrieved from Rogers et al. (2018), the data in the UK is retrieved from Cieslak and Schrimpf (2019), and the data in Japan is retrieved from Kubota and Shintani (2022).

[11] Under the specification, unconventional policy shocks are generated from the system of 10-year government bond yield, CPI, excess bond premium, and exchange rates as well as the weighted industry output.

[12] All of the response functions for each country and the elasticity table are reported in the online Appendix.
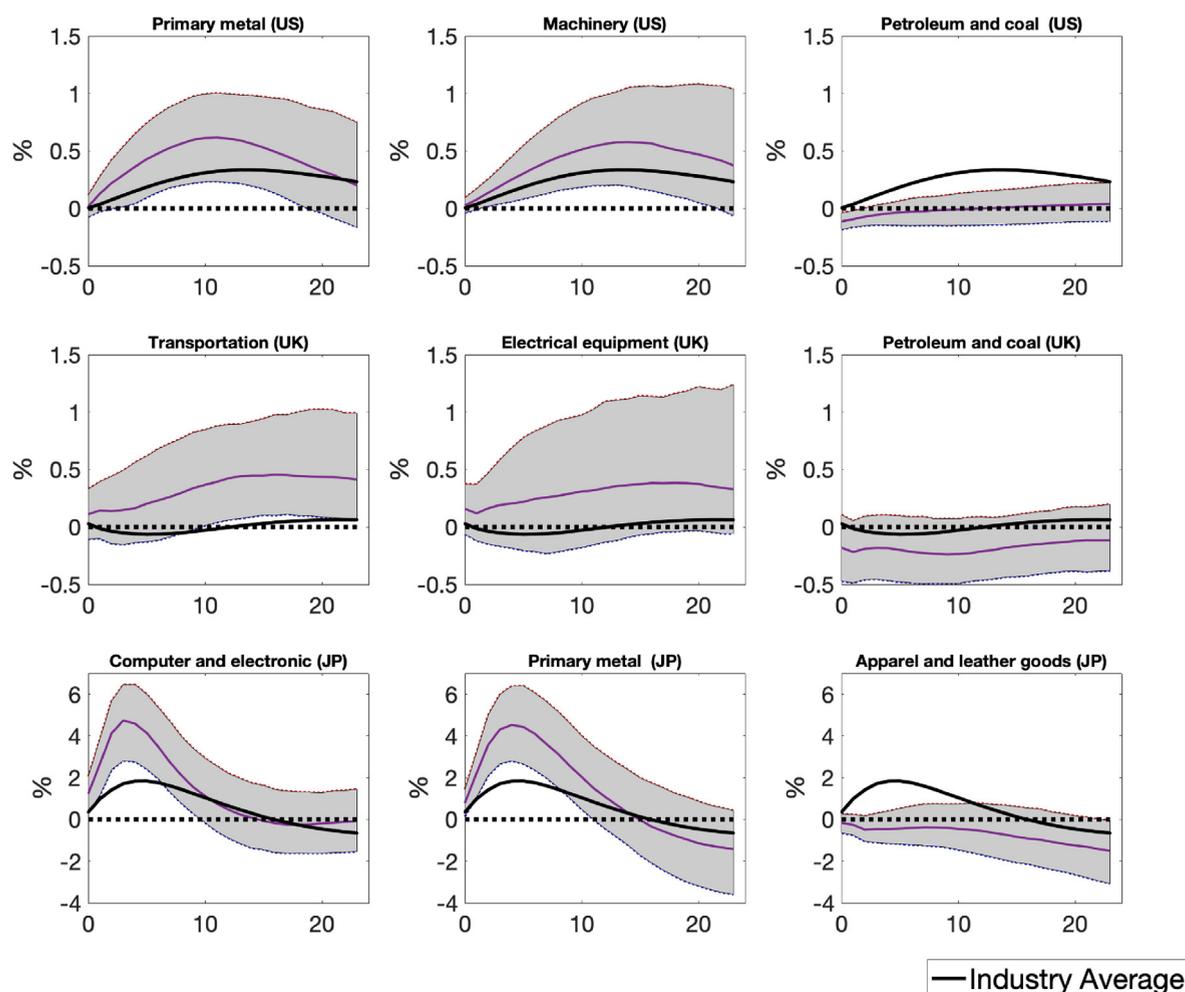
**Fig. 4.** Selected industry response functions (Proxy VAR). Note: The median, 16th, and 84th Bayesian percentiles are reported. Monthly horizon. The 1st row shows the results for the US, the 2nd row shows the results for the UK, and the 3rd row shows the results for Japan. For each country, the two most responsive industries and the least responsive industry are selected. All of the impulse response functions are generated by a 5 basis point decline in the yields of respective 10-year government bond futures.

the consumer price index, I impose a sign restriction so that a negative shock to the shadow rate depreciates the domestic exchange rate.

The results again indicate that the industry response functions are also heterogeneous within a country. Fig. 5 shows the selected industry response functions for each country under this identification.[13] I find that primary metal, machinery, and motor and transportation industries are among the top five most responsive industries for all of the countries. Computer and electronic is among the top five most responsive industries in two of the countries. These industries are again durable goods producing industries. For two of the countries, the five least responsive industries include, food, beverage, and tobacco; paper; printing and related; and petroleum and coal. Again, these industries are all non-durable goods producing industries. The pattern of the industry-level output responses is similar to the pattern found in both the benchmark identification and the proxy VAR. Overall, I find that the industries that are responsive to the policy are similar and robust across the identifications.[14]

## 4. Implication of transmission channels

In the previous section, I find that the industry impacts of unconventional policy are heterogeneous and that durable goods producing industries tend to respond strongly. In this section, I seek to understand the transmission mechanisms

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[13] All of the response functions for each country and the elasticity table are reported in the online Appendix.
[14] I find similar findings for the following alternative identifications: 1) benchmark identification but changing the sign restriction effective periods, 2) benchmark identification with long-term interest rate and imposing additional sign restriction that unconventional policy lowers the long-term interest rate, and 3) benchmark identification but changing the order of the industries being estimated. The results are all available in the online Appendix.
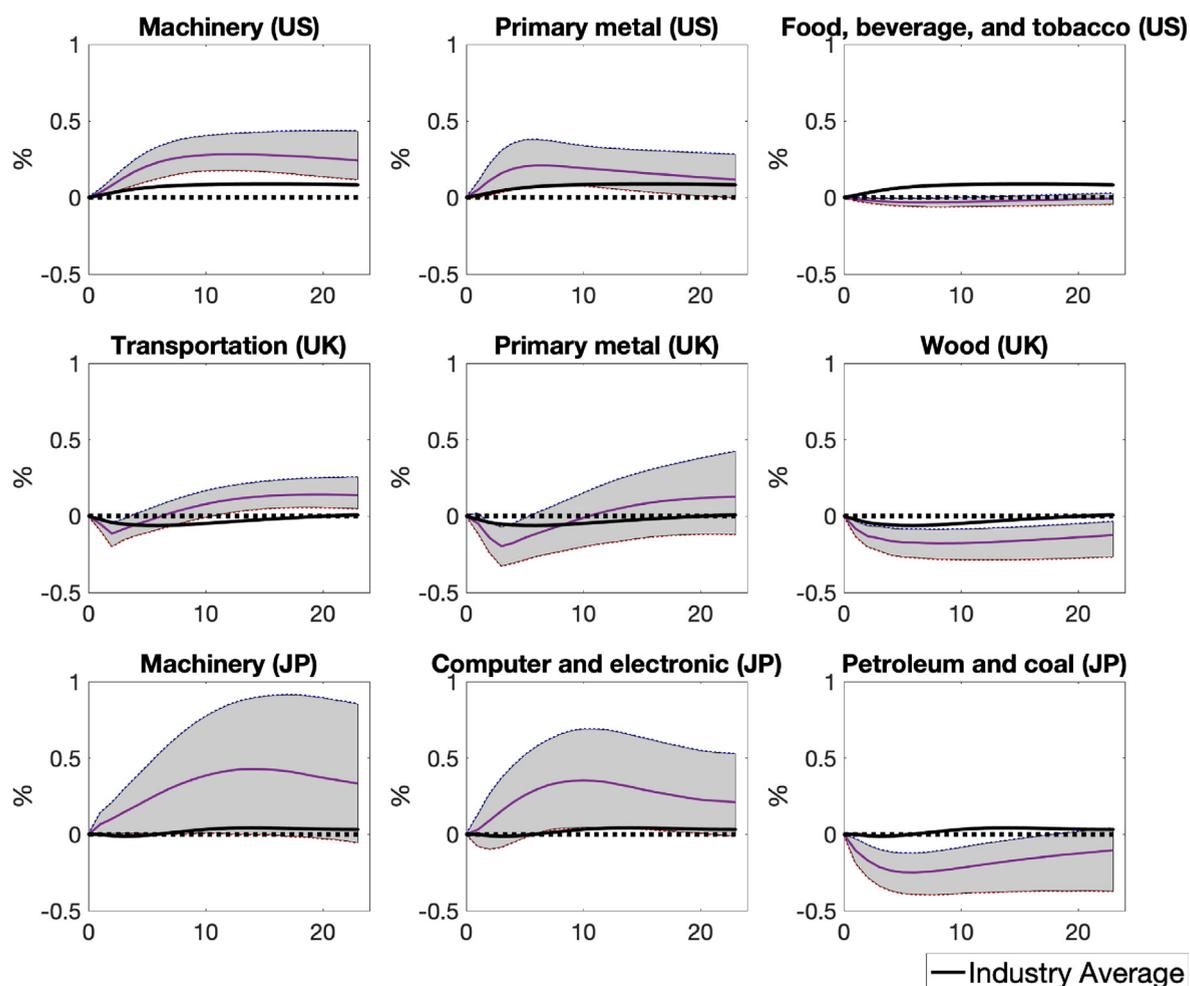
**Fig. 5.** Selected industry response functions (Shadow Rate Measure). Note: The median, 16th, and 84th Bayesian percentiles are reported. Monthly horizon. The 1st row shows the results for the US, the 2nd row shows the results for the UK, and the 3rd row shows the results for Japan. For each country, the two most responsive industries and the least responsive industry are selected. All of the impulse response functions are generated by a 5 basis point decline in shadow rate measured by Krippner (2013).

of unconventional policy by running simple regressions: I regress the industry level elasticity in Table 2 on industry characteristics. By doing this, I specifically focus on whether or not the transmission mechanisms vary between conventional and unconventional policies.

### 4.1. Industry characteristics

To construct the industry characteristics for each industry, I use the Compustat database. The Compustat database contains annual frequency firm-level information of the balance sheets and income statements. Since the Compustat database covers only publicly traded companies, the industry characteristics that are constructed in this paper are not a comprehensive representation of the characteristics of industries from all firms. For each country, the database provides the Standard Industrial Classification (SIC) code. I define each industry based on the SIC on Table B.6 in the Appendix.

I construct the following four variables which represent industry characteristics from the Compustat database: firm size, debt to equity (D\E) ratio, working capital, and short-term debt. I construct these variables based on Dedola and Lippi (2005):

- Firm Size  = Log of the number of Employees
- D\E ratio = $\frac{\text{Total Liabilities}}{\text{Shareholders' Equity}}$
- Working Capital = $\frac{\text{Current Assets} - \text{Current Liabilities}}{\text{Total Assets}}$
- Short-Term Debt = $\frac{\text{Current Liabilities}}{\text{Total Liabilities}}$
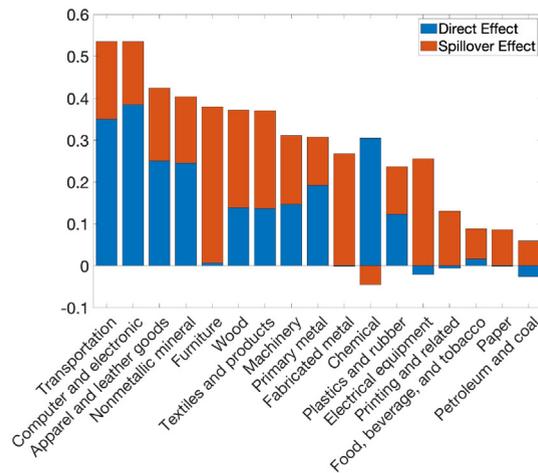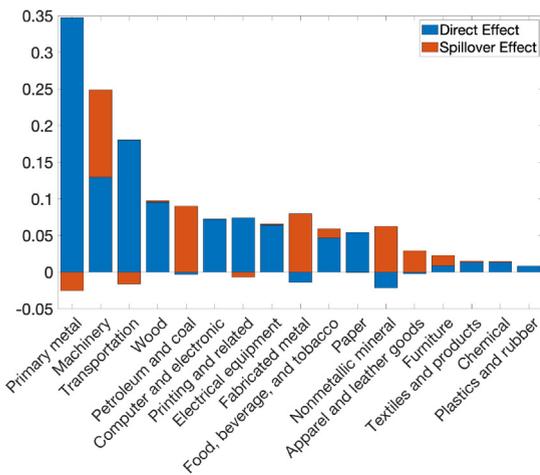
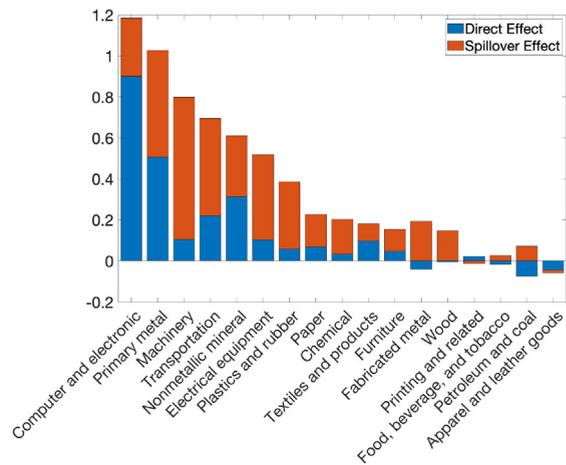**Fig. 6.** Decomposition of the maximum response functions. Note: The maximum median impulse response functions that are consistent with a 1% increase in central bank total asset.

I construct the above variables over the sample period used in this paper. The variables are constructed in the following order: I deflate the nominal variables using the GDP deflator, for each firm and each year I construct the variables of interest, for each firm I take the average of each variable over the sample period, I allocate firms into industries based on the SIC, and for each industry I take the average and median of the above variables.

Firm size and D\E ratio represents borrowing capacity and proxy for a credit channel. An industry with larger firms or firms with a high D\E ratio tends to possess more borrowing capacities. In the literature, the negative relationship between firm size and monetary policy elasticity is well investigated (e.g. Gertler and Gilchrist, 1994; Ehrmann and Fratzscher, 2004; and Fisher, 1999). Also, large firms have access to both direct and indirect finance. On the other hand, small firms are restricted to only indirect finance. Conventional policy is likely to help small firms or firms with a low D\E ratio increase their production.

Working capital and short-term debt represents the liquidity and financing needs, respectively. Both are proxies for the interest rate channel: a change in the nominal interest rate alters the real interest rate and the user cost of capital, which alters production decisions. When the industry has a lower working capital and higher short-term debt, I expect these industries to respond strongly. Given that the policy rates are attached to the ZLB for most of the sample periods, it is of interest to know the significance of the interest rate channel. These channels are introduced as if they work independently. However, as in Bernanke and Gertler (1995), the channels are interrelated and hard to disentangle.

If we were to assume that the unconventional policy transmission mechanisms are the same as conventional policy transmission mechanisms, then industries that have smaller firm size, a lower D\E ratio, lower working capital, and higher short-term debt would be expected to respond strongly to the policy.

### 4.2. Regression results

I estimate a pooled OLS (cross-industry and cross-country) with robust standard errors by following Dedola and Lippi (2005) who perform similar analysis for conventional monetary policy shocks. They obtain the industry impacts of conventional policy for the US, the UK, Germany, Italy, and France by estimating a VAR model for each industry in each country. I have a total of three different dependent variables for each industry: the maximum median response, the cumulative response, and the end of the period (24th) response.

Table 3 reports the results. The results show that working capital is significantly negative and firm size is (mildly) significantly positive. The other variables are insignificant but show expected signs. This suggests that the interest rate channel plays a role, despite that the policy rates are attached to the ZLB. This implies the expected real interest rate still affects the production decisions of the industries. Again, this can be potentially explained by signaling theory (e.g. Bauer and Rudebusch, 2014 and Bhattarai et al., 2015). Alternatively, the changes in the long-term asset yields from unconventional policy stimulate the interest sensitive industries strongly.

Surprisingly, firm size has positive signs. This differs from the traditional view of credit channel. A possible explanation to this is that credit channel exists but unconventional policy also provides portfolio balance channel: the central banks purchase long-term securities, which forces market participants to change their portfolio towards some assets that have similar characteristics to long-term securities such as corporate bonds. This approach helps large firms capitalize through direct finance. Even though the traditional credit channel may exist, industries with large firms respond strongly to the policy.

Through this regression exercise, the impacts of unconventional policy seem to be related to the traditional interest rate channel. However, this analysis also indicates the possible existence of the portfolio balance channel of unconventional policy. This finding differs from Dedola and Lippi (2005) who investigated during a conventional policy period.

### 4.3. Comparison to the economic theory

In this section, I contrast the regression results obtained in this study with those of previous research on monetary theory. Despite recent advancements in heterogenous agent models, there is limited research on unconventional policy. Notable exceptions include Sims et al. (2022) and Cui and Sterk (2021); however, they focus on household heterogeneity rather than that of firms or industries. Due to the limitation, I compare this analysis to the monetary theory of conventional policy with firm heterogeneity.

Several studies have employed heterogeneous firms models to investigate the channels through which monetary policy generates heterogeneous responses, including those conducted by Ottonello and Winberry (2020), Jeenas (2019), and Deng and Fang (2022). Ottonello and Winberry (2020) attribute the heterogeneous capital accumulation to default risk and set up a default risk embedded New Keynesian model, in which firms decide the optimal capital stocks by equating the marginal benefit and marginal cost curves. An expansionary monetary policy stimulates capital accumulation for both low-risk and risky firms by increasing expected returns to capital, improving the net worth of risky firms, and reducing credit spread. The aggregate effects depend on the distribution of firms, and the quantitative analysis reveals that the former channel dominates the latter, showing that capital accumulation is smaller for riskier firms. The leverage ratio is a suitable proxy for default risk, and the negative coefficient found in the regression analysis is aligned with the transmission mechanisms.

In their study, Jeenas (2019) demonstrate the important role of liquidity, specifically the assets held in cash, in explaining the heterogeneous investment decision of firms. The authors introduce a general equilibrium model with financial frictions and heterogeneous firms that have the option to seek long-term debt financing subject to fixed issuance costs. These fixed costs generate an endogenous disconnect of firms from the borrowing costs currently observed in the debt market. When a monetary tightening policy is implemented, high-liquidity firms can buffer the falls in cash flow because they can reduce dividends and sustain investment growth. However, for low-liquidity firms, they cannot sustain the capital stock to serve as collateral and therefore must cut back on some investment. The measure of liquidity used in this study resembles the working capital ratio employed in the regression exercise, and the negative coefficient found in the analysis is consistent with this view.

In addition, recent research by Deng and Fang (2022) shows that firms with more long-term debt are less responsive to monetary policy shocks. They develop a model with heterogeneous firms that can issue both short and long-term debts, facing idiosyncratic productivity shocks that can lead to default and can invest through internal and external finance. The existence of productivity shocks makes long-term debt insurance more costly. An expansionary monetary policy increases investment by 1) raising the stochastic discount factor of firms and 2) lowering the cost of external finance. However, the second channel becomes weaker if firms hold long-term debts. The negative relationship between long-term debt and the effectiveness of monetary policy could be akin to the positive coefficients of short-term debt in the regression analysis. Overall, the findings of the regression analysis under the unconventional policy in the previous section are in line with recent developments in conventional monetary theory with firm heterogeneity.

**Table 3**
Regression results.

| | Maximum Response | Cumurative Response | 24th Period Response |
|---|---|---|---|
| Explanatory variable | | | |
| Firm size (credit channel) | 0.0504* | 0.698* | 0.0309** |
| | (0.0256) | (0.359) | (0.0147) |
| Working capital (interest rate channel) | -0.0674** | -1.320** | -0.0574** |
| | (0.0328) | (0.524) | (0.0243) |
| Debt to equity ratio (credit channel) | -0.0593 | -0.577 | -0.0295 |
| | (0.0664) | (0.731) | (0.0242) |
| Short-term debt (interest rate channel) | 0.189 | 1.864 | 0.0385 |
| | (0.246) | (4.242) | (0.141) |
| Durable dummy | 0.257*** | 3.270*** | 0.0956*** |
| | (0.0595) | (0.695) | (0.0256) |
| Country dummy | | | |
| US | -0.288 | -3.365 | -0.0592 |
| | (0.263) | (4.170) | (0.155) |
| UK | -0.445 | -6.261 | -0.196 |
| | (0.267) | (4.257) | (0.153) |
| UJ | -0.181 | -4.669 | -0.219 |
| | (0.273) | (4.353) | (0.157) |
| N | 51 | 51 | 51 |
| Adj. R-sq | 0.653 | 0.613 | 0.704 |

Note: Pooled OLS (cross-industry and cross-country). Robust standard errors in parentheses, * $p<0.10$, ** $p<0.05$, *** $p<0.01$. The durable dummy takes one if industries are wood product, nonmetallic mineral product, primary metal, fabricated metal product, machinery, computer and electronic product, electrical equipment etc, motor and transportation, and furniture and related product and 0 otherwise.

*4.4. Decomposition of the regression results*

In a preceding section, I decomposed the effects of unconventional policy at the industry level into two categories: direct effects and spillover effects. In this section, I extend the regression analysis to examine the relationship between these two components of elasticity and various industry characteristics. To accomplish this, I replace the dependent variables in the previous regression with the elasticity of direct and spillover effects. Table 4 presents the results of this modified regression analysis, with the first two columns displaying the corresponding regression results from the previous section.

The analysis reveals several noteworthy results. Firstly, I find that working capital is significant for direct effects but insignificant for spillover effects. Moreover, the coefficients for direct effects are stronger than those for total effects, indicating that the interest rate channel is industry-specific and that spillover effects do not propagate this channel.

Secondly, the coefficients for firm size and durable dummy decline compared to the total effects. In fact, the coefficients for firm size become insignificant when the total effects are split into direct and spillover effects. The regression table on spillover effects is mostly insignificant, likely due to the fact that spillover effects are closely related to industry linkage from the IO table discussed in Section 3.4. Overall, this analysis highlights the importance of considering industry-level interactions and suggests that the effects of those channels are likely underestimated when only direct effects are considered.

**5. Extension: spillover effects**

So far, this paper has limited its attention to the industry effects of unconventional policy within a country. I now investigate the industry effects of unconventional policy *across* countries. Specifically, I estimate the spillover effects of unconventional policies on industry-level output between countries. Although this exercise is a purely empirical-driven extension, it is of interest to what extent within and across-country effects vary. Especially, in monetary theory, spillover effects of monetary policy affect (aggregate) foreign output through different channels compared to the domestic output. For example Ammer et al. (2016) introduces three channels: exchange rate channel, domestic demand channel, and financial Spillovers channel.

In the empirical literature, the spillover effects of monetary policy conducted by advanced economies (typically in the US) are well established. Bhattarai et al. (2021) investigate the QE effects of the Federal Reserve on emerging market economies using a panel VAR approach. Tillmann (2016) utilizes a Qual VAR model to investigate the announcement effects of the Federal Reserve on emerging market economies. Both papers find strong impacts on the financial variables of emerging market economies. Dekle and Hamada (2015) investigate the spillover effects of unconventional policy in Japan to the US using a standard two-country VAR and find that the expansionary policy by the Bank of Japan leads to an increase in output in the US. Overall, the literature of spillover effects of monetary policy focuses on the aggregate impacts of the foreign economies but not the heterogeneous impacts within a country.

**Table 4**
Regression results (decomposition).

| | Maximum Response Both Effect | Cumulative Response Both Effect | Maximum Response Direct Effect | Cumulative Response Direct Effect | Maximum Response Spillover Effect | Cumulative Response Spillover Effect |
|---|---|---|---|---|---|---|
| Explanatory variable | | | | | | |
| Firm size (credit channel) | 0.0504* | 0.698* | 0.0238 | 0.590 | 0.0265 | 0.108 |
| | (0.0256) | (0.359) | (0.0193) | (0.380) | (0.0173) | (0.203) |
| Working capital (interest rate channel) | -0.0674** | -1.320** | -0.0846** | -1.776*** | 0.0172 | 0.456 |
| | (0.0328) | (0.524) | (0.0317) | (0.542) | (0.0260) | (0.449) |
| Debt to equity ratio (credit channel) | -0.0593 | -0.577 | -0.0158 | -0.0995 | -0.0436 | -0.478 |
| | (0.0664) | (0.731) | (0.0489) | (0.677) | (0.0325) | (0.406) |
| Short-term debt (interest rate channel) | 0.189 | 1.864 | 0.221 | 3.115 | -0.0323 | -1.251 |
| | (0.246) | (4.242) | (0.237) | (4.589) | (0.141) | (2.081) |
| Durable dummy | 0.257*** | 3.270*** | 0.128*** | 2.005*** | 0.129*** | 1.265*** |
| | (0.0595) | (0.695) | (0.0436) | (0.674) | (0.0355) | (0.421) |
| Country dummy | | | | | | |
| US | -0.288 | -3.365 | -0.222 | -5.439 | -0.0652 | 2.074 |
| | (0.263) | (4.170) | (0.213) | (4.363) | (0.187) | (2.251) |
| UK | -0.445 | -6.261 | -0.285 | -6.512 | -0.160 | 0.251 |
| | (0.267) | (4.257) | (0.228) | (4.494) | (0.176) | (2.192) |
| UJ | -0.181 | -4.669 | -0.220 | -7.036 | 0.0390 | 2.367 |
| | (0.273) | (4.353) | (0.236) | (4.729) | (0.184) | (2.281) |
| N | 51 | 51 | 51 | 51 | 51 | 51 |
| Adj. R-sq | 0.653 | 0.613 | 0.334 | 0.185 | 0.677 | 0.677 |

Note: Pooled OLS (cross-industry and cross-country). Robust standard errors in parentheses, * $p<0.10$, ** $p<0.05$, *** $p<0.01$. The durable dummy takes one if industries are wood product, nonmetallic mineral product, primary metal, fabricated metal product, machinery, computer and electronic product, electrical equipment etc, motor and transportation, and furniture and related product and 0 otherwise.

In what follows, I estimate the same GVAR model as before, however, I include variables in two countries (e.g. the US and the UK).[15] The variables included in the model are the industry output, the price level, central bank total assets, stock market implied volatility, and the exchange rate for both countries.

Although the US and Japan generally satisfy a large open economy assumption, it is questionable whether the UK satisfies such an assumption. Rather, the UK is often regarded as a small open economy. In this paper, I only investigate the industry-level spillover effects of unconventional policy from the US and Japan. Thus, we have a total of four combinations for this analysis. Notably, Home US - Foreign UK, Home US - Foreign Japan, Home Japan - Foreign US, and Home Japan - Foreign UK.

I order the variables so that the zero restriction is only imposed on industry output and the price level for both countries but not on the fast-moving variables such as central bank total assets, stock market implied volatility, and exchange rate for both countries. Given the assumption, central bank total assets, stock market implied volatility, and exchange rate for both countries can contemporaneously respond to Home unconventional policy shocks. The sign restriction that I impose is on Table 5.

In the previous section, I use an IO table to construct a weight of industry interactions. In this section, I construct the measures of the industry interactions assuming that the on-diagonal matrix is IO tables from each country and off-diagonal matrices are zero matrices:

$$ \text{IOtable} = \begin{bmatrix} \text{IO}^* & \mathbf{0} \\ \mathbf{0} & \text{IO} \end{bmatrix} $$

That is, the industry interactions are stronger within a country than across countries.[16]

The spillover exercise also reveals that the industry-level output responses are heterogeneous. Fig. 7 reports the selected industry response functions for each combination of countries.[17] For each combination, I re-list the two most responsive industries and the least responsive industry from the benchmark results (within a country). Similar to the within-response function, the two most responsive industries respond strongly and the least responsive industry responds weakly. The elasticity varies from −0.07% in petroleum and coal to 0.41% in primary metal for the US to the UK, −0.00% in apparel and leather goods to 0.67% in computer and electronic for the US to Japan, −0.02% in petroleum and coal to 0.41% in primary metal for Japan to the

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[15] I take this approach to avoid the computational burden of a model that includes all three countries.

[16] I examine the OECD Inter-Country Input–Output (ICIO) Tables as a potential measure. However, the industry-level interactions across countries is negligibly small.

[17] All of the response functions for each combination of countries are reported in the online Appendix.

**Table 5**
Sign restrictions (spillover effects) of impulse response functions.

|  | at period $= 0$ | at period $= 1$ |
|---|---|---|
| Industry output$^*_1$ | 0 | * |
| $\vdots$ | $\vdots$ | $\vdots$ |
| Industry output$^*_{17}$ | 0 | * |
| Consumer price index* | 0 | * |
| Industry output$_1$ | 0 | * |
| $\vdots$ | $\vdots$ | $\vdots$ |
| Industry output$_{17}$ | 0 | * |
| Consumer price index | 0 | * |
| Central bank total assets | + | + |
| Stock market volatility | − | − |
| Exchange rate | * | * |
| Central bank total assets* | * | * |
| Stock market volatility* | * | * |
| Exchange rate* | * | * |

Note: * is next to foreign variables.
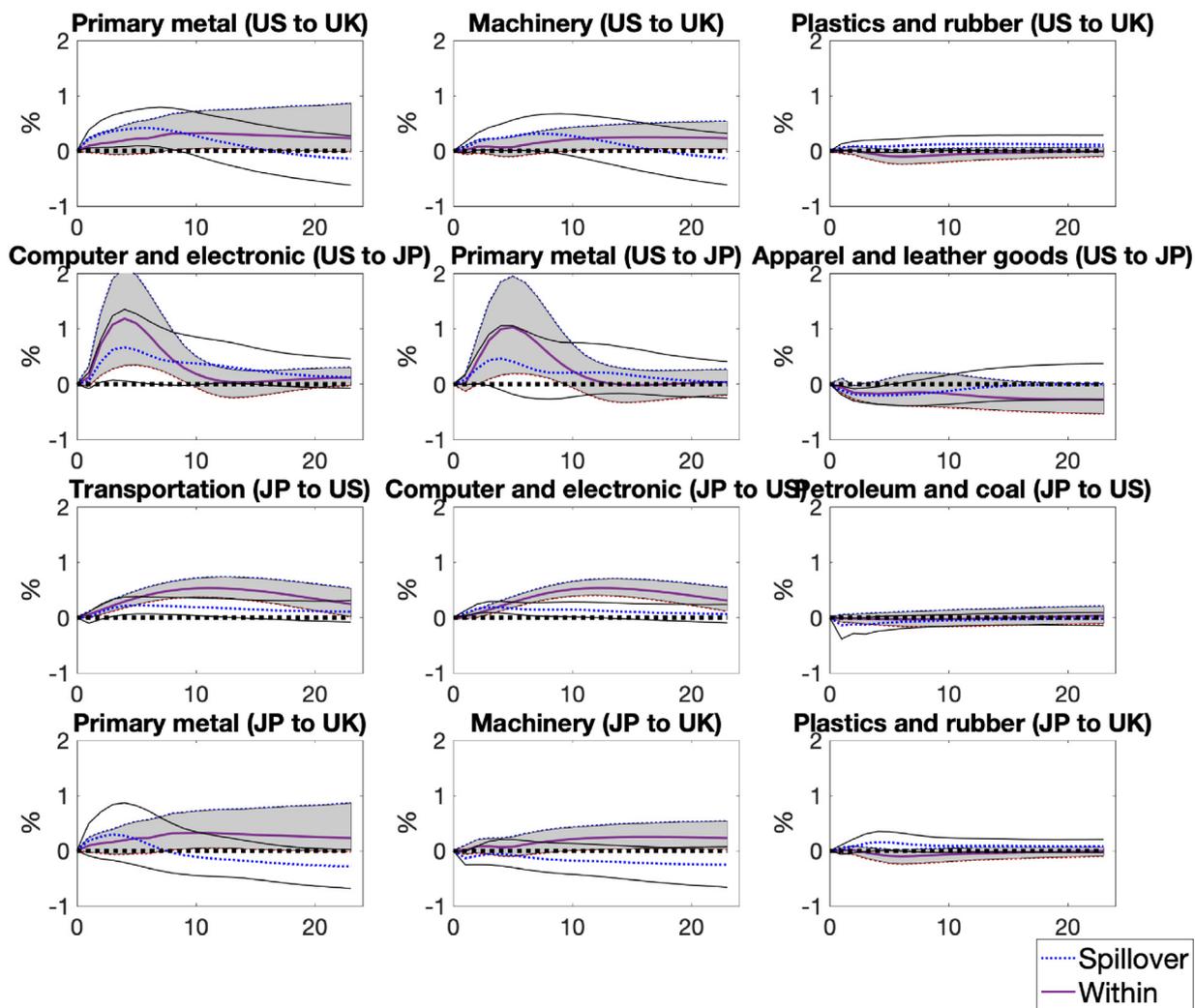


**Fig. 7.** Selected industry response functions (spillover). Note: The median, 16th, and 84th Bayesian percentiles are reported. Monthly horizon. The 1st row shows the results for the US to UK, the 2nd row shows the results for the US to Japan, the 3rd row shows the results for Japan to US, and the 4th row shows the results for Japan to UK. For each combination, the two most responsive industries and the least responsive industry are selected.

US, and −0.13% in petroleum and coal to 0.40% in motor and transportation for Japan to the UK. The finding indicates that the spillover effects are heterogeneous.

The industry-level output responses are generally similar to the findings in the previous section: the most responsive industries are all durable goods producing industries and the least responsive industries are non-durable goods producing industries. Further, I rank the elasticity for each combination to know which industry is responsive to the policy. The primary metal industry is within the top five most responsive industries for all combinations. Also, motor and transportation, non-metallic mineral, machinery, computer and electronic, furniture, and wood are within the top five most responsive industries for two or more combinations. Repeatedly, those industries are durable goods producing industries. For all of the combinations, the five least responsive industries include, petroleum and coal and printing and related. Also, food, beverage, and tobacco; apparel and leather goods; and textiles and products are within the five least responsive industries for two or more combinations. These responsive industries are all non-durable goods producing industries. The findings are very comparable to the within-country effects found in Section 3.2.

Despite the similarity of the within-country effects and the spillover effects, there are some small differences, possibly due to the appreciation of the Foreign currency.[18] In the US, computer and electronic has a large percent of firms that are exposed to international trade (e.g. Bernard et al., 2007. On the contrary, in the UK, nonmetallic mineral industry has a small percentage of firms that are exposed to international trade (e.g. Warwick, 2010). The relative responsiveness of the computer and electronic in the US decreases while the relative responsiveness of the nonmetallic mineral industry increases in the UK. This finding can be potentially explained by how much the industries are exposed to the appreciation of the currency due to the spillover effects. Overall, I confirm that the industry-level output responses are similar between within country and across countries.

## 6. Conclusion

This paper explores the industry impacts of unconventional policy for the US, the UK, and Japan. Using a structural Bayesian GVAR model, I investigate the differential effects of unconventional policy, potential industry-level asymmetric effects within and across countries, and monetary policy transmission mechanisms. I first find that unconventional policy stimulates industries heterogeneously both within a country and across countries. Specifically, unconventional policy strongly stimulates the durable goods industries. Second, I find that the pattern of the industry-level output responses is similar both within a country and across countries, and the pattern is similar to that of conventional policy in the literature. Third, I find that lower working capital and larger firm size is associated with higher industry output responses, implying the relevance of the interest rate channel and portfolio balance channel.

This paper assumes that the responses of unconventional policy are symmetric. However, it is likely that tightening and easing have different industry-level output responses and transmission mechanisms both within and across countries. This would be an interesting topic for future research.

## Appendix A. Mathematical Appendix

*A.1. Appendix: complete description of identification*

The reduced form variance–covariance matrix, $\Omega$, can be expressed as:

$$\Omega = BB' = BIB' = BQQ'B' \tag{A.1}$$

where $B$ is a lower triangle matrix obtained by the Cholesky decomposition and $Q$ is a Givens rotation matrix defined as:

$$Q = \begin{bmatrix} & 0 & 0 & 0 \\ I & \vdots & \vdots & \vdots \\ & 0 & 0 & 0 \\ 0\ldots0 & cos(\theta) & -sin(\theta) & 0 \\ 0\ldots0 & sin(\theta) & cos(\theta) & 0 \\ 0\ldots0 & 0 & 0 & 1 \end{bmatrix} \tag{A.2}$$

where $\theta \in [0, 2\pi]$. The above definition can generate the relationship between reduced form error and structural form error terms:

---

[18] I find that unconventional policy leads to a depreciation of the Home currency, a decline in the Home stock market volatility, an appreciation of the Foreign currency, an increase in the Foreign total assets, and a decline in the Foreign stock market volatility (not reported).

$$
\underbrace{\begin{bmatrix} u_{\text{Industryoutput}_1} \\ \vdots \\ u_{\text{Industryoutput}_{17}} \\ u_{\text{pricelevel}} \\ u_{\text{TotalAssets}} \\ u_{\text{Volatility}} \\ u_{\text{Exchangerate}} \end{bmatrix}}_{\substack{\text{Reducedformerror} \\ u_t}} = \begin{bmatrix} * & \dots & * & * & 0 & 0 & 0 \\ \vdots & \ddots & \vdots & \vdots & \vdots & \vdots & \vdots \\ * & \dots & * & * & 0 & 0 & 0 \\ * & \dots & * & * & 0 & 0 & 0 \\ * & \dots & * & * & + & * & 0 \\ * & \dots & * & * & -/0 & * & 0 \\ * & \dots & * & * & * & * & * \end{bmatrix} \underbrace{\begin{bmatrix} \epsilon_{\text{Industryoutput}_1} \\ \vdots \\ \epsilon_{\text{Industryoutput}_{18}} \\ \epsilon_{\text{pricelevel}} \\ \epsilon_{\text{TotalAssets}} \\ \epsilon_{\text{Volatility}} \\ \epsilon_{\text{Exchangerate}} \end{bmatrix}}_{\substack{\text{Structuralerror} \\ \epsilon_t}}
\tag{A.3}
$$

*A.2. Appendix: complete description of Bayesian estimation*

I have the following industry-level (V) ARX:

$$
y_{i,t} = c_i + \sum_{j=1}^{p_i} A_{i,j} y_{i,t-j} + \sum_{j=0}^{q_i} B_{i,j} y_{i,t-j}^* + \sum_{j=0}^{q_i} C_{i,j} x_{t-j} + u_{i,t}
$$

Let $\Psi_i = (c_i, A_{i,1}, \dots, A_{i,pi}, B_{i,0}, \dots, B_{i,qi}, C_{i,0}, \dots, C_{i,qi})$ and I denote the prior mean to be $\underline{\Psi_i}$. The elements of $\underline{\Psi_i}$ take 1 if the parameter is associated with the first own lag and 0 otherwise. The prior covariance matrix, defined as $V_{\Psi_i}$, is a diagonal matrix. The elements in $V_{\Psi_i}$ take values based on hyperparameters. I set the prior variance of the intercept to be 100. I also set the prior variance associated with the $i$-th variable's own lag $l$ to be $\lambda_1^2/l^2$. I further set the prior variance of the $l$ th lag of variable $j$ where $j \neq i$ to be $\left(\frac{\sigma_i * \lambda_2}{\sigma_j * l}\right)^2$, where $\sigma_j$ is the univariate OLS estimate of the standard deviation. Lastly, I set the prior variance of the exogenous variable, $k$, to be $\left(\frac{\sigma_i * \lambda_3}{\sigma_k * (l+1)}\right)^2$. Here I set $\lambda_1 = \lambda_2 = 0.2$ and $\lambda_3 = 0.1$

The elements of the prior coefficients, $\psi_{i,jk}$, follow weighted Gaussian distributions:

$$
\psi_{i,jk} | \gamma_{i,jk} \sim \left(1 - \gamma_{i,jk}\right) \mathcal{N}\left(\underline{\psi_{i,jk}}, \kappa_{0,i,jk}\right) + \gamma_{i,jk} \mathcal{N}\left(\underline{\psi_{i,jk}}, \kappa_{1,i,jk}\right).
$$

Let $\kappa_{1,i,jk} = 10$ and $\kappa_{0,i,jk}$ to be the corresponding element of the Minnesota prior covariance matrix, $V_{\Psi_i}$.

As for $\Sigma_{i,i}$, I assume the inverse-Wishart prior:

$$
\Sigma_{i,i} \sim \mathcal{IW}\left(S_{i,*}, n_i\right)
$$

where $S_{i,*} = I$, and $n$ is the number of variables in the system plus 2.

Now the posterior distributions are:

$$
\Psi_i | \mathbf{y_i}, \mathbf{Z_i}, \gamma_i, \Sigma_{i,i} \sim \mathcal{N}\left(\bar{\Psi}_i, K_{\Psi_i}^{-1}\right)
$$

where

- $\mathbf{y_i} = vec(Y)$ and $Y_i = [y_{i,1}, \dots, y_{i,T}]$
- $\mathbf{Z}_{i,t} = Z_{i,t} \otimes I$ and $Z_i = [Z_{i,0}, \dots, Z_{i,T-1}]$ with
  $Z_{i,t-1} = \left(1, y'_{i,t-1}, \dots, y'_{i,t-pi}, y^{*\prime}_{i,t}, \dots, y^{*\prime}_{i,t-qi}, x'_t, \dots, x'_{t-qi}\right)'$
- $\gamma_i$ is a vector of $\gamma_{i,jk}$
- $K_{\Psi_i} = W_i^{-1} + Z_i Z_i' \otimes \Sigma_{i,i}^{-1}$ where $W_i$ is diagonal with diagonal elements $\left(1 - \gamma_{i,jk}\right) \kappa_{0,i,jk} + \gamma_{i,jk} \kappa_{1,i,jk}$
- $\overline{\Psi}_i = K_{\Psi_i}^{-1}\left(W_i^{-1} vec\left(\underset{\cdot}{\Psi}_i\right) + \left(Z_i \otimes \Sigma_{i,i}^{-1}\right)\mathbf{y_i}\right)$,

$$
\Sigma_{i,i} | \mathbf{y_i}, \mathbf{Z_i}, \Psi_i \sim \mathcal{IW}(S_i, \tau_i)
$$

where

- $S_i = S_{i*} + \sum_{t=1}^{T}\left(y_{i,t} - \mathbf{Z}_{i,t} vec(\Psi_i)\right)\left(y_{i,t} - \mathbf{Z}_{i,t} vec(\Psi_i)\right)$
- $\tau_i = n_i + T$ ,

and

$$Prob\left(\gamma_{i,jk} = 1 | \psi_{i,jk}\right) = \frac{q_{i,jk}\phi\left(\psi_{i,jk}; 0, \kappa_{1,i,jk}\right)}{q_{i,jk}\phi\left(\psi_{i,jk}; 0, \kappa_{1,i,jk}\right) + \left(1 - q_{i,jk}\right)\phi\left(\psi_{i,jk}; 0, \kappa_{0,i,jk}\right)}$$

where

- $Prob\left(\gamma_{i,jk} = 1 | \psi_{i,jk}\right) \propto q_{i,jk}\phi\left(\psi_{i,jk}; 0, \kappa_{1,i,jk}\right)$
- $Prob\left(\gamma_{i,jk} = 0 | \psi_{i,jk}\right) \propto \left(1 - q_{i,jk}\right)\phi\left(\psi_{i,jk}; 0, \kappa_{0,i,jk}\right)$
- $\phi\left(\cdot; \mu, \sigma^2\right)$ denotes the density function of the normal distribution.
- $q_{i,jk} = 0.5$

I also impose an analogous specification for the common VARX equation.

Then, a burn-in sample of 10,000 draw is discarded and then the following steps are taken to generate response functions.

**Step 1:** Draw parameters $\Psi_i$, $\Psi_x$, $\Sigma_{i,i}$ and $\Sigma_{x,x}$.

**Step 2:** Recover the reduced form GVAR model and compute the Cholesky decomposition of $\Omega$.

**Step 3:** For each parameter draw of $\Psi_i$, $\Psi_x$, $\Sigma_{i,i}$ and $\Sigma_{x,x}$, draw $N$ random Given's rotation matrix, $Q^{i \in N}$ and calculate the $N$ response functions.

**Step 4:** If the response function satisfies the sign restriction on Table 1 in Section 2.3, keep it. Otherwise, discard the response function.

**Step 5:** Repeat steps 1, 2, 3, and 4 M times.

Here N = 50 and M = 2,000. All of the successful response functions are sorted in descending order and the upper 84% and bottom 16% are reported as the Bayesian credible band. This credible band represents the statistical significance as well as modeling uncertainty since sign restrictions from structural VAR models are not unique.

## Appendix B. Appendix: Tables

(see Table B.6).

**Table B.6**
Industry definition.

| Country | US | UK | Japan | |
| Codes | NAICS | UK SIC | JSIC | SIC |
| --- | --- | --- | --- | --- |
| Industries | | | | |
| Food, beverage, and tobacco | 311–312 | C10-12 | E09-10 | 2000, 2100 |
| Textile mills product | 313–314 | C13 | E11 | 2200 |
| Apparel and leather product | 315–316 | C14-15 | E20 | 2300, 3100 |
| Wood product | 321 | C16 | E12 | 2400 |
| Paper | 322 | C17 | E14 | 2600 |
| Printing activities | 323 | C18 | E15 | 2700 |
| Petroleum and coal product | 324 | C19 | E17 | 2900 |
| Chemical | 325 | C20-21 | E16 | 2800 |
| Plastic and rubber product | 326 | C22 | E18-19 | 3000 |
| Nonmetallic mineral product | 327 | C23 | E21 | 3200 |
| Primary metal | 331 | C24 | E22,E24 | 3300 |
| Fabricated metal product | 332 | C25 | E23 | 3400 |
| Machinery | 333 | C28 | E25-26 | 3500–3569, 3580–3599 |
| Computer and electronic product | 334 | C26 | E27,E30 | 3570–3579 |
| Electrical equipment etc | 335 | C27 | E28-29 | 3600 |
| Motor and transportation | 336 | C29-30 | E31 | 3700 |
| Furniture and related product | 337 | C31 | E13 | 2500 |

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