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 policy makers' tool box with similar industry impacts as conventional policy but with somewhat different transmission mechanisms.

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Keywords: Unconventional monetary policy; Industry output; Monetary policy transmission mechanisms; Spillover effects

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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 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 characterize the impacts of unconventional policy across industries within a country for the US, the UK, and Japan. Throughout the paper, I identify unconventional policy shocks using sign restrictions (e.g. Gambacorta et al., 2014). This identification intends to capture the large scale asset purchases of the central banks. For a robustness check, I also use proxy vector autoregression (proxy VAR) identification (e.g. Caldara and Herbst, 2019) which is based on a use of high frequency data and intends to capture the forward guidance policy of the central banks. This paper also characterizes the industry level spillover effects of unconventional policy across these countries using the benchmark sign restrictions identification.

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

[1] Unconventional policy was first implemented in Japan prior to the financial crisis.

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

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 has been widely explored in order to understand the transmission mechanisms of the US monetary policy to foreign economies (e.g. Bhattarai et al., 2021a; Bowman et al., 2015; and Tillmann, 2016). US monetary policy has been found to have strong spillover effects on emerging market economies, especially the 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. 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 the industries respond heterogeneously within a country to the unconventional policy shocks. For example, in the US the magnitude varies from -0.01% in paper to 0.44% 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 is responsive to unconventional policy, while industries in the non-durable goods manufacturing respond weakly. This

[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.

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 the 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 are 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).

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.[4] 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 industrial production index as industry output, the consumer price index as the price level, central bank total assets, stock market implied volatility, and broad effective exchange rate index as 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 in Appendix 5.

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 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):

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

[4]The countries in the EU area are susceptive 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.

where c_i is an intercept; $A_{i,j}$, $B_{i,j}$, and $C_{i,j}$ are coefficient matrix; $u_{i,t}$ 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 $\forall k \neq i$:

$$y^*_{i,t} = \sum_{k \neq i} w_{i,k} y_{k,t} \qquad \sum_{k \neq i} w_{i,k} = 1 \tag{2}$$

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.[5]

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:

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

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

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

where $Z_t = (y_{1,t}, \ldots, y_{17,t}, x'_t)'$. Assuming that H_0 is invertible. Then, I obtain the reduced form global VAR (p) model:

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

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

[5] Holly and Petrella (2012) and Vansteenkiste (2007) use an IO table for the construction of a foreign variable.

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., 2021b) to capture this aspect. The identification is a mixture of zero and sign restrictions. Table 1 summarizes the zero and sign restrictions that I impose. 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 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 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 equations (1) and (3) individually and recover the reduced form GVAR in equation (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 of 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. Due to the low sample size, I impose $p_i = q_i = p_x = q_x = 3$ for the lag length.[6] Although results are qualitatively similar across the different number of lags.

3 Results

I first provide the identified shocks in Section 3.1. Next, in Section 3.2, I show that the industry level output responses are heterogeneous. In Section 3.3, I briefly compare the within country results across countries and with existing studies and, in Section 3.4, I report the results under the proxy VAR identification.

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. Figure 1 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 and QE2 by the Federal Reserve come with positive spikes. Nonetheless, the spikes during QE3 are modest, despite that the central bank

[6] In the UK, I impose $p_i = q_i = p_x = q_x = 4$ to ensure that the identified shocks are stationary.

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 balance 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., 2021b; Boeckx et al., 2017, and many others).

3.2 Industry Results

The industry response functions reveal heterogeneous responses to unconventional policy shocks. Figure 2 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]

The elasticity varies from -0.01% to 0.44% in the US, 0.01% to 0.30% in the UK, and -0.04% to 1.38% 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 know which industry is responsive to the policy. The top five most responsive industries vary across countries, however,

[7]All of the response functions for each country are reported in online Appendix.

[8]Under each elasticity, I listed the 32% credible band in parenthesis analogous to standard errors.

[9]Exploring the cross-country differences of the effectiveness of unconventional policy would be an interesting topic of research but is out of the scope of this paper.

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; wood; primary metal; machinery; and nonmetallic mineral industries are within the top five most responsive industries for two countries. The industries listed above are all durable good producing industries. In fact, there is only one industry across the three countries' top five most responsive industries that is not a durable good producing industry, apparel and leather product in the US. 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 countries. Overall, I find that the responsiveness of the industries to the policy are similar across these investigated countries.

3.3 Cross-Country Analysis

The literature of industry effects 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; wood; 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, 2013 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 incentive for capital intensive firms to invest in projects that involve money borrowing and also creates 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 in 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 Robustness

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 compliment 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 $e_{MP,t}$:

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

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

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

and the "exogeneity" condition:

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

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 bond futures between 15 minutes before and 105 minutes after the announcement in the US, the change in 3-month Sterling futures between 10 minutes before and 20 minutes after the announcements in the UK, and the change in 10-year government bond futures between 10 minutes before and 20 minutes after the announcements in Japan.[10] Unfortunately, due to the data limitation, the financial instruments and window sizes between the announcements are not consistent across countries. These high frequency variables take zero if there are no announcements in a month and take the summation if there are 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 exogenity becomes challenging as the size of system increases. To circumvent the problem, I identify the model *locally* (e.g. Dees et al., 2007 and Feldkircher and Huber, 2016).[11] That is, I identify an unconventional policy shock from the common VARX equation:

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

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

[10] The data in the US is retrieved from Rogers et al. (2018), the data in the UK is retrieved from Cesa-Bianchi et al. (2020), and the data in Japan is retrieved from Kubota and Shintani (2022).

[11] Unfortunately, the response functions in the UK do not become significant, even though the median response functions are qualitatively similar to the results in sign restriction. This is likely that the maturity of 3-month Sterling futures is low and struggles to capture unconventional policy shocks.

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

The locally identified global GVAR is obtained by pre-multiply Q^{-1} in equation (4).[12]

The results indicate that the industry response functions are also heterogeneous within a country. Figure 3 shows the selected industry response functions for each country under proxy VAR.[13] 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 and the least responsive industries are somewhat different. The differences between the QE and the announcement effects might potentially explain the differences.

However, the pattern of the industry level output responses are similar to the pattern found in the sign restrictions. I rank the elasticity for each country to know 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 of the countries. Also, computer and electronic is within the top five most responsive industries for two countries. These industries are again durable good producing industries. With regards to five least responsive industries, I find that chemical; food, beverage, and tobacco; petroleum and coal; and apparel and leather goods; and plastics and rubber industries are within the five least responsive industries for two countries. These industries are all non-durable good producing industries. The industries listed here are very similar to the industries from the sign restrictions. Overall, I find that the industries that are responsive to the policy are similar between both of the identifications.[14]

[12]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.

[13]All of the response functions for each country and the elasticity table are reported in 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 online Appendix.

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 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 5 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 = $\dfrac{\text{Total Liabilities}}{\text{Shareholders' Equity}}$
- Working Capital = $\dfrac{\text{Current Assets- Current Liabilities}}{\text{Total Assets}}$
- Short-Term Debt = $\dfrac{\text{Current Liabilities}}{\text{Total Liabilities}}$

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 always 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. This can be again potentially explained by signaling theory (e.g. Bauer and Rudebusch, 2013 and Bhattarai et al., 2015). Alternatively, the changes in the long term asset yields from unconventional policy stimulates 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.

5 Extension: Spillover Effects

So far, this paper has limited its attention to the industry effects of unconventional policy within a country. I will 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.

In the literature, the spillover effects of monetary policy conducted by advanced economies (typically in the US) are well established. Bhattarai et al. (2021a) investigate the QE effects of the Federal Reserve on the 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 the emerging market economies. Both papers find strong impacts on the financial variables of the 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 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.

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 4.[16]

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:

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

That is, the industry interactions are stronger within a country than across countries.[17]

The spillover exercise also reveals that the industry level output responses are heterogeneous. Figure 4 reports the selected industry response functions for each combination of countries.[18] For

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

[16] Given the high dimension of GVAR, proxy VAR fails to provide significant results. Thus, we only use sign restriction for this analysis.

[17] I look at the OECD Inter-Country Input-Output (ICIO) Tables `https://www.oecd.org/sti/ind/inter-country-input-output-tables.htm` as a potential measure. However, the industry level interactions across countries is negligibly small.

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

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 -0.02% in petroleum and coal to 0.44% in nonmetallic mineral for the US to the UK, -0.04% in apparel and leather goods to 0.60% in machinery for the UK to Japan, -0.04% in petroleum and coal to 0.53% in primary metal for Japan to US, and -0.12% in petroleum and coal to 0.71% 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. Primary metal; and motor and transportation industries are within the top five most responsive industries for all of the combinations. Also, Nonmetallic mineral is within the top five most responsive industries for three combinations. Repeatedly, those industries are durable good producing industries. Regarding the least responsive industries, I find that petroleum and coal is within the five least responsive industries for all of the combinations. Also, food, beverage, and tobacco; printing and related; and chemical are within the five least responsive industries for three combinations. These responsive industries are all non-durable goods producing industries. The findings are very comparable to the within country effects found in the Section 3.2.

Despite the similarity of the within country effects and spillover effects, there are some small differences, possibly due to the appreciation of the Foreign currency.[19] 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 percent of firms that are exposed to the 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

[19] 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).

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 nonlinearity 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.

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7 Tables

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	*	*

Table 2: Unconventional Policy Elasticity of Output

Country Industry	US	UK	Japan	Country	US	UK	Japan
Food, beverage, and tobacco	0.057	0.057	0.011	Nonmetallic mineral product	0.334	0.040	0.686
	(0.001 , 0.139)	(0.008 , 0.132)	(-0.076 , 0.093)		(0.210 , 0.500)	(-0.056 , 0.174)	(0.173 , 1.199)
Textile mills product	0.300	0.015	0.214	Primary metal	0.319	0.304	1.097
	(0.096 , 0.538)	(-0.148 , 0.199)	(-0.014 , 0.475)		(0.079 , 0.562)	(0.051 , 0.691)	(0.314 , 1.876)
Apparel and leather product	0.393	0.026	-0.040	Fabricated metal product	0.229	0.067	0.151
	(0.067 , 0.880)	(-0.038 , 0.108)	(-0.171 , 0.135)		(0.075 , 0.383)	(0.002 , 0.161)	(-0.097 , 0.431)
Wood product	0.351	0.092	0.145	Machinery	0.247	0.250	0.868
	(0.215 , 0.525)	(-0.029 , 0.216)	(-0.062 , 0.376)		(-0.001 , 0.499)	(0.049 , 0.509)	(0.338 , 1.455)
Paper	-0.007	0.048	0.178	Computer and electronic product	0.419	0.070	1.377
	(-0.104 , 0.086)	(-0.011 , 0.109)	(-0.044 , 0.422)		(0.327 , 0.533)	(-0.013 , 0.150)	(0.527 , 2.224)
Printing activities	0.062	0.070	0.017	Electrical equipment etc	0.192	0.058	0.547
	(-0.048 , 0.194)	(-0.048 , 0.199)	(-0.047 , 0.087)		(0.073 , 0.325)	(-0.052 , 0.170)	(0.164 , 0.958)
Petroleum and coal product	0.012	0.084	-0.036	Motor and transportation	0.441	0.172	0.586
	(-0.124 , 0.169)	(-0.076 , 0.321)	(-0.185 , 0.142)		(0.315 , 0.591)	(0.032 , 0.334)	(-0.426 , 1.697)
Chemical	0.214	0.013	0.215	Furniture and related product	0.329	0.021	0.250
	(0.054 , 0.433)	(-0.036 , 0.064)	(-0.016 , 0.471)		(0.194 , 0.520)	(-0.049 , 0.102)	(0.014 , 0.559)
Plastic and rubber product	0.214	0.008	0.399				
	(0.056 , 0.365)	(-0.059 , 0.079)	(-0.037 , 0.861)				
				Industry average	0.242	0.082	0.392
				Industry median	0.247	0.058	0.215

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 0.057%. Credible bands are also transformed by the same amount as the elasticity is scaled.

Table 3: Regression Results

	Maximum Response	Cumurative Response	24th Period Response
Explanatory variable			
Firm size (credit channel)	0.0518**	0.773**	0.0339**
	(0.0244)	(0.351)	(0.0140)
Working capital (interest rate channel)	-0.0667**	-1.394***	-0.0578**
	(0.0327)	(0.489)	(0.0232)
Debt to equity ratio (credit channel)	-0.0864	-0.789	-0.0376
	(0.0659)	(0.779)	(0.0247)
Short-term debt (interest rate channel)	0.129	0.421	0.0528
	(0.256)	(3.866)	(0.149)
Durable dummy	0.271***	3.529***	0.113***
	(0.0634)	(0.740)	(0.0267)
Country dummy			
US	-0.301	-3.946	-0.129
	(0.257)	(3.883)	(0.151)
UK	-0.398	-5.754	-0.229
	(0.268)	(3.995)	(0.152)
UJ	-0.105	-3.462	-0.222
	(0.273)	(4.022)	(0.154)
N	51	51	51
Adj. R-sq	0.610	0.577	0.637

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.

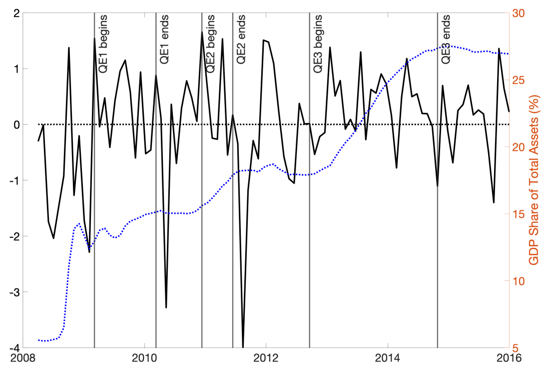
Table 4: Sign restrictions (Spillover Effects) of impulse response functions

	at period = 0	at period = 1
Industry output*$_1$	0	*
⋮	⋮	⋮
Industry output*$_{17}$	0	*
Consumer price index*	0	*
Industry output$_1$	0	*
⋮	⋮	⋮
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*	*	*

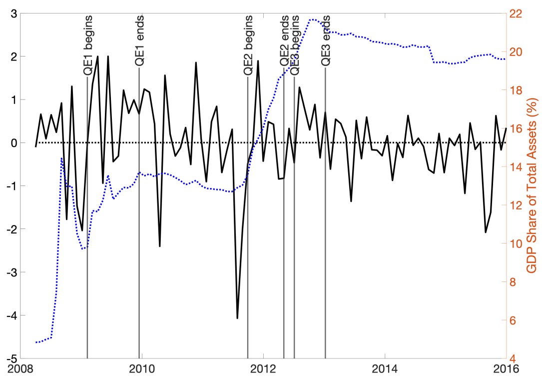
Note: * is next to foreign variables.

8 Figures

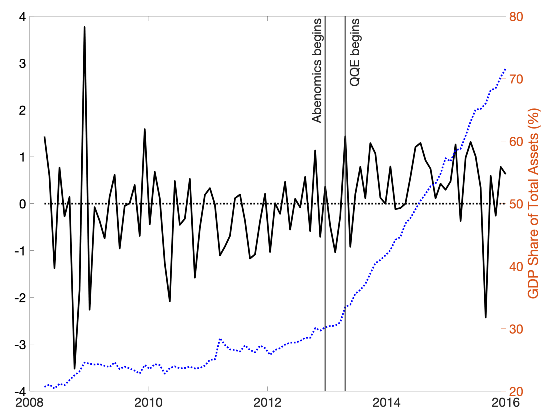
Figure 1: The Identified Shocks



(a) US



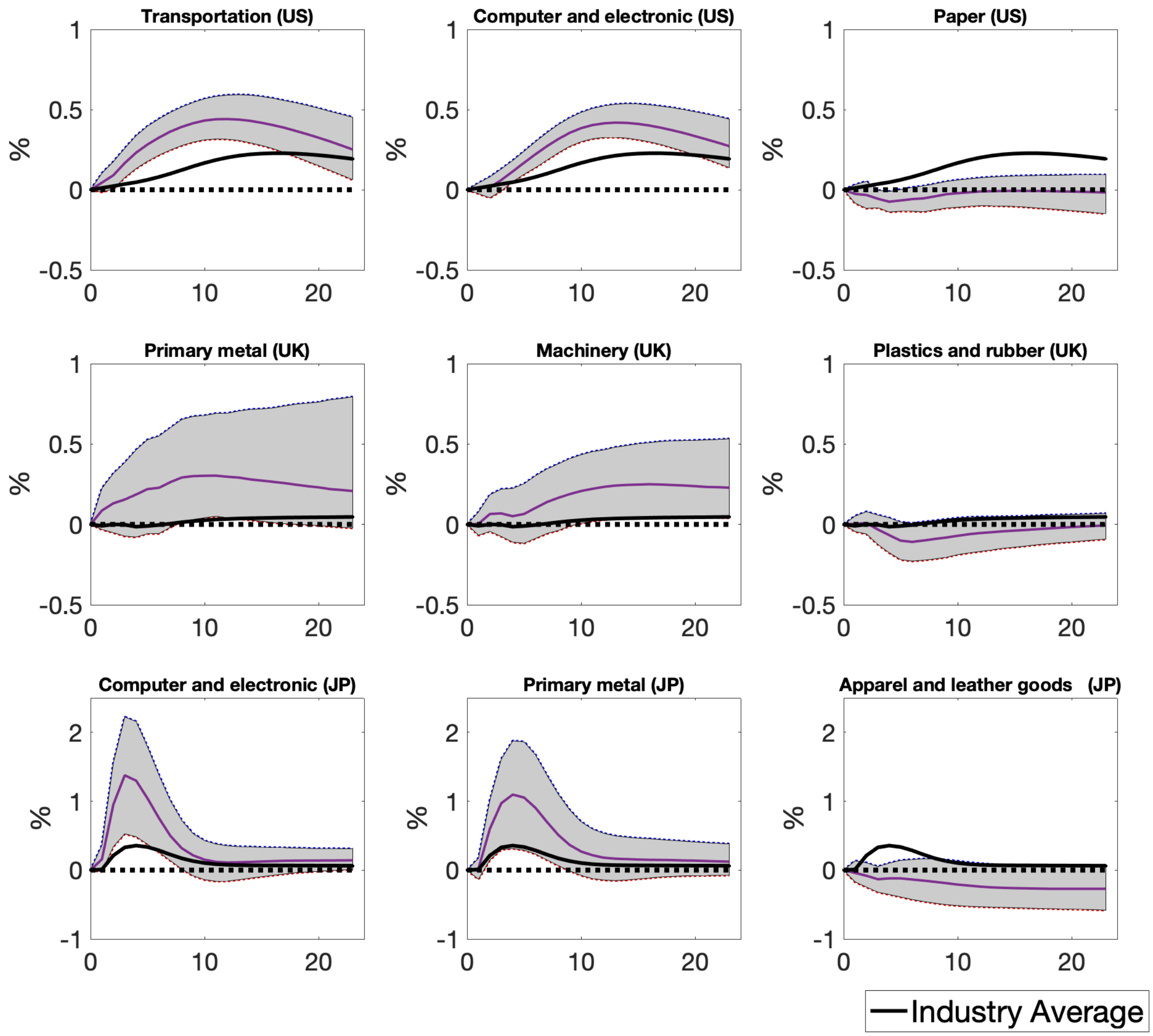
(b) UK



(c) Japan

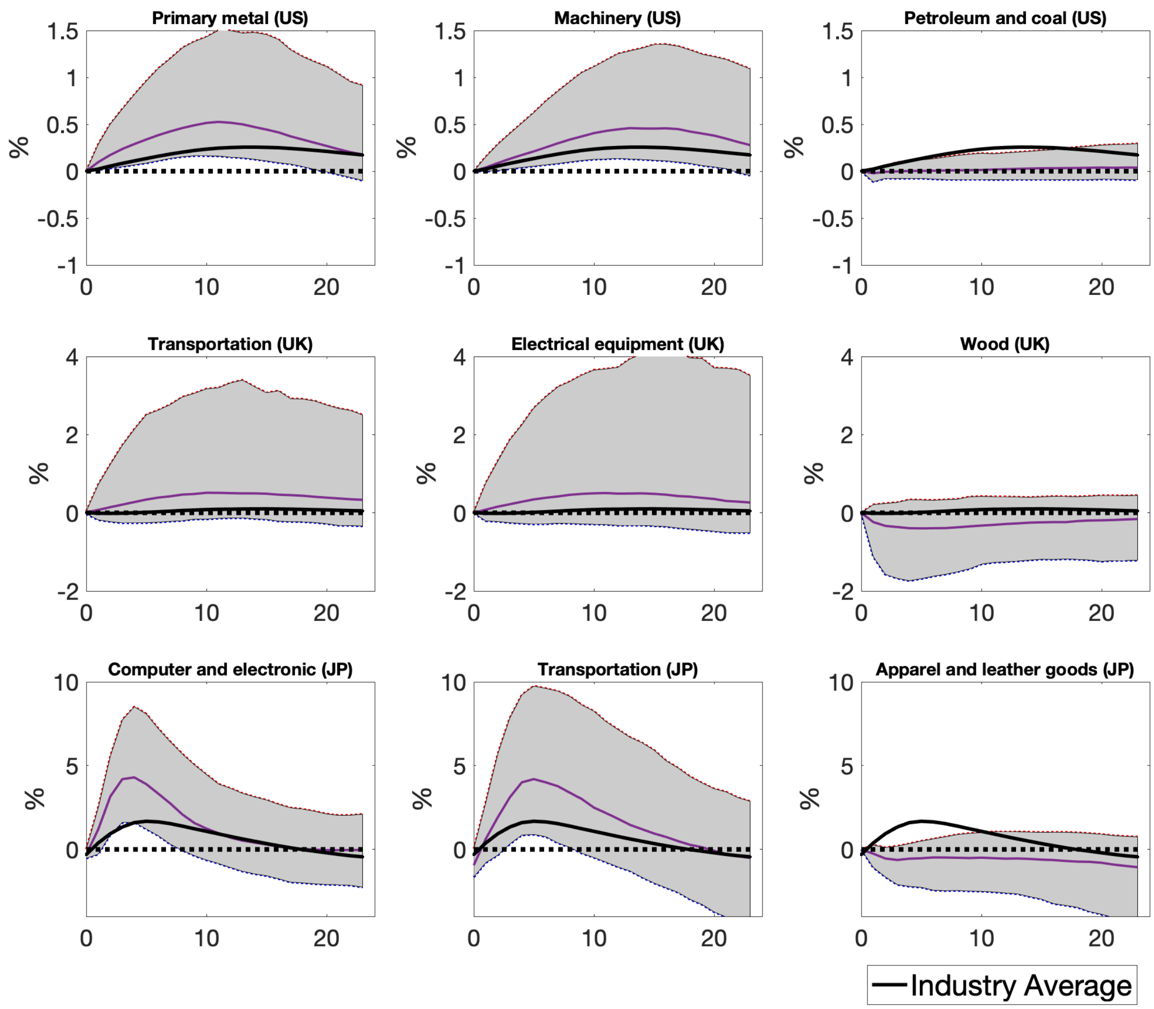
Note: The identified shocks from the sign restrictions. The solid curves represent the median of the identified shocks from the structural GVAR model. The dotted curve represents the share of central bank total assets of real GDP. I normalized the scale of the shocks so that the mean (as well as the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

Figure 2: Selected Industry Response Functions



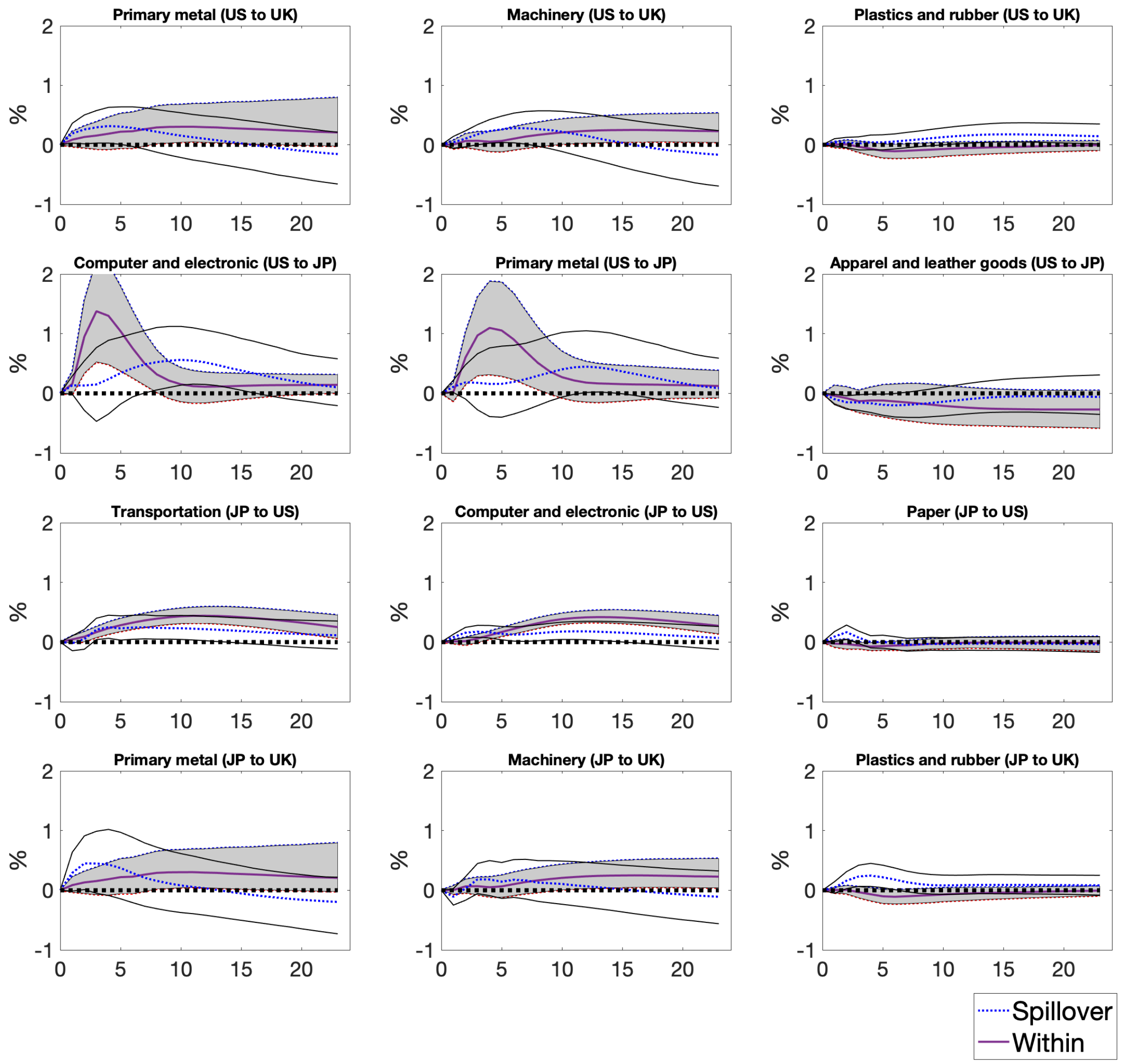
Note: The Median, 16th, and 84th Bayesian percentiles are reported. Monthly horizon. The 1st row shows the results for the US, the 2nd row shows the results for the UK, and the 3rd row shows the results for Japan. For each country the two most responsive and the least responsive industries are selected.

Figure 3: 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 and the least responsive industries are selected. All of the impulse response functions are multiplied by -1.

Figure 4: Selected Industry Response Functions (Spillover)



Note: The Median, 16$^{\text{th}}$, and 84$^{\text{th}}$ 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 and the least responsive industries from within a country are selected.

A Mathematical Appendix

A.1 Appendix: Complete Description of Identification

The reduced form variance-covariance matrix, Ω, can be expressed as:

$$\Omega = BB' = BIB' = BQQ'B' \tag{7}$$

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

$$Q = \begin{bmatrix} & 0 & 0 & 0 \\ I & \vdots & \vdots & \vdots \\ & 0 & 0 & 0 \\ 0\dots0 & cos(\theta) & -sin(\theta) & 0 \\ 0\dots0 & sin(\theta) & cos(\theta) & 0 \\ 0\dots0 & 0 & 0 & 1 \end{bmatrix} \tag{8}$$

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

$$\underbrace{\begin{bmatrix} u_{\text{Industry output}_1} \\ \vdots \\ u_{\text{Industry output}_{17}} \\ u_{\text{price level}} \\ u_{\text{Total Assets}} \\ u_{\text{Volatility}} \\ u_{\text{Exchange rate}} \end{bmatrix}}_{\substack{\text{Reduced form error} \\ u_t}} = \begin{bmatrix} * & \dots & * & * & 0 & 0 & 0 \\ \vdots & \ddots & \vdots & \vdots & \vdots & \vdots & \vdots \\ * & \dots & * & * & 0 & 0 & 0 \\ * & \dots & * & * & 0 & 0 & 0 \\ * & \dots & * & * & + & * & 0 \\ * & \dots & * & * & -/0 & * & 0 \\ * & \dots & * & * & * & * & * \end{bmatrix} \underbrace{\begin{bmatrix} \epsilon_{\text{Industry output}_1} \\ \vdots \\ \epsilon_{\text{Industry output}_{18}} \\ \epsilon_{\text{price level}} \\ \epsilon_{\text{Total Assets}} \\ \epsilon_{\text{Volatility}} \\ \epsilon_{\text{Exchange rate}} \end{bmatrix}}_{\substack{\text{Structural error} \\ \epsilon_t}} \tag{9}$$

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_{Ψ_i}, is a diagonal matrix. The elements in V_{Ψ_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 λ_1^2/l^2. I further set the prior variance of the l th lag of variable j where $j \neq i$ to be $(\frac{\sigma_i * \lambda_2}{\sigma_j * l})^2$, where σ_j is the univariate OLS estimate of the standard deviation. Lastly, I set the prior variance of the exogenous variable, k, to be $(\frac{\sigma_i * \lambda_3}{\sigma_k * (l+1)})^2$. 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:

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

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

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

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

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

Now the posterior distributions are:

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

where

- $\mathbf{y_i} = vec(Y) \quad \text{and} \quad Y_i = [y_{i,1}, \cdots, y_{i,T}]$
- $\mathbf{Z}_{i,t} = Z_{i,t} \otimes I$ and $Z_i = [Z_{i,0}, \cdots, Z_{i,T-1}]$ with $Z_{i,t-1} = (1, y_{i,t-1}^{'}, \ldots, y_{i,t-pi}^{'}, y_{i,t}^{*'}, \ldots, y_{i,t-qi}^{*'}, x_t^{'}, \ldots, x_{t-qi}^{'})'$
- γ_i is a vector of $\gamma_{i,jk}$
- $K_{\Psi_i} = W_i^{-1} + Z_i Z_i' \otimes \Sigma_{ii}^{-1}$ where W_i is diagonal with diagonal elements $(1-\gamma_{i,jk})\kappa_{0,i,jk} + \gamma_{i,jk}\kappa_{1,i,jk}$
- $\bar{\Psi}_i = K_{\Psi_i}^{-1}(W_i^{-1} vec(\underline{\Psi_i}) + (Z_i \otimes \Sigma_{i,i}^{-1})\mathbf{y_i})$

,

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

where

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

- $\tau_i = n_i + T$

, and

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

where

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

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

- $\phi(\cdot; \mu, \sigma^2)$ 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 Ψ_i, Ψ_x, $\Sigma_{i,i}$ and $\Sigma_{x,x}$

Step 2: Recover the reduced form GVAR model and compute the Cholesky decomposition of Ω.

Step 3: For each parameter draw of Ψ_i, Ψ_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 a 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 restriction from structural VAR models are not unique.

B Appendix: Tables

Table 5: Industry definition

Country Codes	US NAICS	UK UK SIC	Japan 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