# Industry Impacts of Unconventional Monetary Policy*

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**Abstract**

While conventional monetary policy has been shown to create differential impacts on industry output, how unconventional monetary policy affects industries is not yet known. Conducting an industry level analysis provides insights of the relative response of industries, monetary transmission mechanisms, and the role of industry composition on the aggregate impact. This paper studies the effects of unconventional monetary policy on industry output in the United States, the United Kingdom, and Japan, three countries that have recently implemented unconventional monetary policy. I use a structural Bayesian vector autoregressive model with zero and sign restrictions to identify an unconventional monetary policy shock. The effects on output across industries within a country have substantial heterogeneity. For example, industry peak output responses in the United States vary from -0.01% to +0.35% in response to a one standard deviation shock to the central bank total asset. Industries across the three countries have some variation in output response to unconventional monetary policy, however, on average the effects are similar to conventional monetary policy. Furthermore, regression analysis shows that lower working capital is associated with a larger industry output response to unconventional monetary policy. The finding indicates the relevance of the interest rate channel to unconventional monetary policy while the policy rates adhere to the zero lower bound.

**JEL:** E32; E52; G32

**Keywords:** Unconventional monetary policy; Industry ouput; Monetary transmission mechanism

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# 1 Introduction

After the financial crisis, the policy rates of many of the highly advanced economies reached the zero lower bound (ZLB) and they implemented unconventional monetary policy (henceforth unconventional policy). Unconventional policy influences the economy through quantitative easing, credit easing, yield curve control, forward guidance, negative interest rate policy, etc. While the central banks focus on aggregate variables, investigating the effects across industries provide new insights. First, differential impacts across industries directly influences the relative performance of industries. Second, by associating industry effects of unconventional policy with the financial structure of the industry, we can learn more about the monetary policy transmission mechanisms. Third, industry analysis enables the determination of whether the industry composition matters with regards to effects on the aggregate. While implementing unconventional policy is often regarded as an extreme circumstance, due to the steadily decline of the natural rate of interest (Holston et al., 2017a), re-occurrence of the ZLB is likely and therefore this analysis remains relevant.

In this paper I estimate the impacts of unconventional policy on industry-level output in the US, the UK, and Japan: these three countries have all experienced near zero policy rates and have implemented unconventional policy in recent years. This paper also investigates whether the pattern of industry output responses from these countries are similar to the literature of conventional monetary policy (henceforth conventional policy).

This paper provides several contributions to the literature. First, it provides differential impacts of unconventional policy on industry output. In conventional policy literature, it has been shown that conventional policy creates differential impacts on industry output (Dale and Haldane, 1995; Ganley and Salmon, 1997; Alam and Waheed, 2006; and many others), on regional output (Carlino and DeFina, 1998 and Arnold and Vrugt, 2002), and on household consumption (Kaplan et al., 2018 and Ampudia et al., 2018). The literature of unconventional policy focuses on the financial market effects (Gagnon et al., 2011; Krishnamurthy and Vissing-Jorgensen, 2011; Neely, 2015) and aggregate effects (Gambacorta et al., 2014; Boeckx et al., 2017; Bhattarai et al., 2015a; and many others), however, the differential impacts of unconventional policy in the literature is scarce. This paper fills this gap in the literature and examines the effects of unconventional policy on industry output.

Second, comparing across multiple countries reveals the similarities in the industry-level output responses. Previous studies focus on a single country to assess the industry output effects of conventional policy (Dale and Haldane, 1995; Carlino and DeFina, 1998; Ganley and Salmon, 1997; and many others). This observation is also true for other macroeconomic topics such as fiscal policy (Bénétrix and Lane, 2010 and Monacelli and Perotti, 2008) and news shock (Vukotić, 2019). It may be misleading to generalize a finding from a single country analysis as countries differ by a variety of aspects such as types of policies, periods of ZLB, industry composition, etc. This paper adds a cross-country dimension to those studies to examine the relevance of country characteristics.

Third, I provide the implications of monetary transmission mechanisms of unconventional policy. One of the advantages of estimating the effects of monetary policy on industry output is to provide monetary transmission mechanisms: estimating the effects make it possible to associate the effect of the monetary policy with the industry characteristics of financial structure (Dedola and Lippi, 2005 and Peersman and Smets, 2005). I apply this approach to understand the transmission mechanisms, specifically to observe to what extent the monetary transmission mechanims between unconventional and conventional policies are similar.

I use a structural Bayesian vector autoregressive (VAR) model with zero and sign restrictions as in Gambacorta et al. (2014) to identify an unconventional policy shock. Given the shock, I generate impulse response functions (henceforth response functions). I use monthly industry output data for the UK and Japan and quarterly output data for the US to individually estimate the model for each country and each industry. To confirm the industry level estimates, I construct a weighted response function from the industry response functions with a weight being GDP share of the industry. The weighted response functions are approximately the same as the national-level response functions, indicating that the single industry esimation is reasonable since industry comovements and spillover effects are sufficiently small.

I find that the industry-level output responses are different within a country. For example, in the US the magnitude varies from -0.01% in healthcare to 0.35% in mining, in response to a one standard deviation shock to the central bank total asset[1]. Generally, production industry, such as manufacturing and construction, is responsive due to the production structure relying heavily on investment and thus the inflow of funds help to stimulate the industry. On the other hand, industries that are tied to government or producing staple goods respond weakly. The response of industries in service vary because the financial structure differ by industry. The effect on real estate industry is not strong in the US despite that the Federal reserve purchased mortgage backed securities to support the industry. It could be possible that the macroprudential policy after the crisis might limit the activity of the industry. In addition, I generate several counterfactual weighted response functions to investigate the hypothetical aggeregate impacts by altering the industry compositions. The aggregate impact declines as the share of the service sector of an economy increases because the policy tends to stimulate the production sector more than the service sector.

Next, the observed industry-level output responses moderately vary across those three countries. However, I find that, on average, manufacturing, construction, and trade are the most re-

[1]In the UK the magnitude varies from -0.04% in finance to 0.24% in construction and in Japan the magnitude varies from -0.02% in arts, entertainment, and recreation to 0.39% in manufacturing

sponsive. Those three industries are also the most responsive to conventional policy (Dale and Haldane, 1995; Ganley and Salmon, 1997; and Ibrahim, 2005) which suggests that industry impacts of unconventional policy are qualitatively similar to conventional policy. Furthermore, I find that lower industry working capital is associated with a larger output response to unconventional policy. This observation implies the existence of the traditional interest rate channel, which contributes to the similarity of unconventional and conventional policies.

In robustness analysis, I estimate a structural Bayesian global vector autoregressive (GVAR) model (Burriel and Galesi, 2018) for the UK and Japan[2] to take into account the fact that industries are interrelated. The results from the joint estimation and single industry estimation are generally comparable to each other.

The rest of this paper is organized as follows: Section 2 describes the datasets that are used, Section 3 outlines the methodology (including the model, identification, and estimation), Section 4 presents the main results, Section 5 conducts regression analyses, Section 6 checks robustness, and finally Section 7 concludes.

## 2 Data

I analyze the following countries: the US, the UK, and Japan. These three countries are suitable for this analysis. They have all experienced ZLBs, implemented unconventional policies, and are relatively closed economies and therefore are less likely to have spillover effects from other countries[3]. In addition, the US has been the center of intensive research on unconventional policy since the onset of the financial crisis, the UK has a large variety of industry-level datasets available, and Japan has experienced prolonged ZLB and is the pioneer of large-scale asset purchasing.

Based on data availability, the US is of quarterly frequency while the Japanese and UK data are of monthly frequency. The datasets cover 2008Q1-2017Q4 for the US, 2008M1-2018M6 for the UK, and 2003M1-2018M2 for Japan. I chose these ranges based on when these central banks operated unconventional policy and when the policy rates are generally below 1 and near zero, representing the ZLB.

The VAR framework consists of the following four endogenous variables: industry output ($IO$), consumer price index ($CPI$), central bank total assets ($AT$)[4], and stock market implied volatility ($VOL$). These variables, excluding VOL, are seasonally adjusted.

[2] The US was not included in this analysis because the sample size is small with quarterly series.

[3] For that reason, countries in the EU area are excluded.

[4] $AT$ for the UK does not contain other foreign currency assets from 2014M10 onward. Thus it may underestimate the effects. Despite this limitation, it is better to have a larger sample size than to exclude these periods to have a more accurate measure of AT.

The industry output data for the US is real value added and is obtained from the Bureau of Economic Analysis. The UK data is monthly GDP and Japanese output data is quantity indices and are retrieved from the Office of National Statistics and the Ministry of Economy, Trade and Industry, respectively. Since the Japanese dataset is not commonly used[5], a brief description follows. The series is quantity index and is made to systematically understand the production activities of the various industries in Japan. The series is of monthly frequency and is available with relatively short time lags[6]. The base year is 2010 which takes the value of 100. For each industry, main products that represent the industry are chosen and the index represents the transitions of quantitative fluctuations of those selected products within the industry. The selected products cover a relatively large share of the industry. For example, for Indices of industry Production the selected products are chosen so that they account for 90% of the aggregate values of the industry.

I plot industry output of the three countries by industry on Figures 1 and 2. Data are normalized so that the first period of 2010 is 100. In general, the US and the UK has a higher trend than Japan. This represents the lower GDP growth rate in Japan, though, some industries in Japan do have similar trends as the US and the UK. Also for a motivational purpose, I plotted the composition of industries in GDP for the respective sample years for each country in the online Appendix. I also plot the aggregate output, consumer price index, central bank total asset, and stock market implied volatility in Figure 3[7].

To combat the financial crisis, these countries implemented unconventional policies and increased their total assets in an unprecedented degree: all of the central banks more than quadrupled their size of assets. These substantial increases in central bank total assets are correlated with the increase in aggregate output and consumer price index, though Japan does not exhibit as much of a rise in these variables. In this paper I investigate whether unconventional policy contributes to these rises in aggregate output and whether there exists any heterogeneity in industry output.

There are several limitations of the datasets. First, unlike the US and UK datasets that provide comprehensive coverage of 16 industries, the industries in the Japanese datasets are not perfectly comprehensive since agriculture is excluded. Additionally, the education industry in Japan does not include public components. Second, unlike the UK and Japanese data, the frequency of the US data is quarterly which is not as suitable for the analysis of monetary policy as the monthly frequency as used in Gambacorta et al. (2014) and Bhattarai et al. (2015a)[8]. The quarterly data and limited ZLB period provide a small sample period of 40 in the US, while the Japanese data covers a

[5]However, it was used in Du et al. (2010) and Shintani (2005)

[6]Datasets are available within a one and half month lag. A revision is done approximately a month after the first release only.

[7]I use CBOE volatility index for the US, FTSE 100 volatility index for the UK, and Nikkei volatility index for Japan.

[8]They use the interpolation method (Chow and Lin, 1971) to generate a monthly GDP. However, in order to implement this method, relevant monthly frequency data for each industry's output is required.

large sample period of 182 because of the prolonged ZLB periods in Japan. Third, even though the UK and Japanese data have a bigger sample size, the coverage of the industries is limited due to the nature of monthly data. That is, the series does not capture the entire, but rather, a highlighted movement of the individual industries. Finally, the industry definitions do not match perfectly across countries, since each country provides output data based on their own definitions of industries. I attempt to match industry definitions across countries as much as possible, however, caution still needs to be taken.

Lastly, the following is the complete set of industries examined in this paper: agriculture (excluding Japan); mining; utilities; construction; manufacturing (durable goods and non-durable goods); trade (sum of wholesale and retail trade); transportation; information; finance; real estate; professional service; education; healthcare; arts, entertainment, and recreation; accommodation and food; and other services. More details of the industry definitions are available in the online Appendix.

# 3 Methodology

Structural VAR models have been widely used for studying impacts of monetary policy since Christiano et al. (1999). In this paper, I also use the structural VAR model but follow the identification methodology in Gambacorta et al. (2014) to identify an unconventional policy shock, generate response functions, and assess the industry effects. Section 3.1 describes the model, Section 3.2 states the identification, and Section 3.3 depicts the estimation.

## 3.1 The Empirical Model

I estimate the following VAR ($p$) model for each industry and for each country:

$$y_t = \nu + \sum_{i=1}^{p} A_i y_{t-i} + u_t \qquad\qquad t = 1, .., T \tag{1}$$

where $p$ is the number of lags, $y_t$ is a column vector of endogenous variables, $\nu$ is a column vector of intercept terms, $A_i$s are coefficient matrices, and $u_t$ is white noise with nonsingular covariance matrix $\Sigma_u$. In this paper, $y_t$ consists of the following variables: log of industry output ($IO_t$), log of consumer price index ($CPI_t$), log of central bank total assets ($AT_t$), and level of stock market implied volatility ($VOL_t$).

Output variables are not first differenced by following the standard monetary policy literature (for example, Gambacorta et al., 2014; Boeckx et al., 2017; Christiano et al., 1999; Ibrahim, 2005; and many others). However, there are some studies in which the authors take the first-difference of the output (for example Arnold and Vrugt, 2002; Carlino and DeFina, 1998).

To understand the behavior of the variables that I use, I perform unit root and stationarity tests. Detailed descriptions and results are available in the online Appendix. I find that for each industry output, test results tend to contradict each other. When test results are consistent, the implication is usually I(1) or non-stationary. It is known that the ADF test suffers power (Cochrane, 1991) and the KPSS test, when the sample is large, has a large size problem (Caner and Kilian, 2001). Since many variables have mixed results, there is a possibility that some of the series are actually I(0). Thus, taking the difference of these series may lead to a misspecification, even though there is an economic meaning (growth rates). When I compared the effects of monetary policy across industries, if some series are first differenced and others are in levels, it is difficult to precisely compare cross industry effects. If I include the variables in levels for all of the series, I can avoid this problem. However, a caveat is that under level specification, a monetary policy shock may lead to a permanent effect. Given these diverse test results, it is safe to use level in the specification and I implicitly keep the long-run relationship of these variables in the VAR.

These 4 variables are intended to capture the minimal dynamics of macroeconomics and to identify an unconventional policy shock. As is standard in the monetary policy literature, industry output and CPI are in the system to ensure the macroeconomic and industry dynamics. While industry output itself may not necessarily summarize the entire aggregate dynamics and the reaction function may be different for each industry, I add aggregate output excluding the industry in the system in the robustness check to examine whether or not the results change radically.

Central bank total assets are included as a monetary policy instrument, due to the fact that short-term nominal interest rate is no longer an instrument under the ZLB. Central bank total asset is a general measure of unconventional policy and can compare the effects of monetary policy across countries of different states and situations. However, this obviously has some shortfalls. First it does not differentiate the policies. For example, the Federal Reserve's QE1 is mainly to purchase the mortgage-backed securities and agency securities, but the policies after QE2 are to purchase the long-term securities. Those differences are not captured and are expressed as a mere increase in total assets. Thus the results cannot discern how and by how much each specific policy affected the output.

Second, it cannot cover the policies which intend to change the composition of the central bank total assets. For example, Operation Twist by the Federal Reserve is not captured in this framework. This policy is to purchase the long-term securities and sell the short-term securities by the same amount. The net increase in the assets is zero and thus the effect is not represented in the instrument.

Third, it cannot explicitly include the forward guidance component. While this identification is coming from the literature of event study showing that unconventional policy has an effect on mitigating financial market distress, the frequency in the VAR framework in this paper is significantly lower than those event studies.

Finally, stock market implied volatility is in the framework to represent financial market turmoil. The variable is used to disentangle the exogenous innovation to central bank total assets from the endogenous response to financial market distress. Details of the identification is discussed in the next section.

### 3.2 Identification

I follow the identification in Gambacorta et al. (2014). The identification is a mixture of zero and sign restrictions. The following equation summarizes the identification by showing the relationship of the reduced form error and structural error terms of the VAR model (I omit the time subscript):

$$\underbrace{\begin{bmatrix} u_{IO} \\ u_{CPI} \\ u_{AT} \\ u_{VOL} \end{bmatrix}}_{\substack{\text{Reduced form error} \\ u_t}} = \begin{bmatrix} * & * & 0 & 0 \\ * & * & 0 & 0 \\ * & * & + & + \\ * & * & -/0 & + \end{bmatrix} \underbrace{\begin{bmatrix} \epsilon_{SO} \\ \epsilon_{CPI} \\ \epsilon_{AT} \\ \epsilon_{VOL} \end{bmatrix}}_{\substack{\text{Structural error} \\ \epsilon_t}} \tag{2}$$

where the components of $\epsilon_t$ are uncorrelated and have unit variance, $\Sigma_\epsilon = I_4$. The zero restriction states that a shock to the central bank total assets does not have a contemporaneous impact on industry output and price. In other words, unconventional policy has at most a lagged impact on output and price. This zero restriction is a standard assumption in structural VAR analysis. This assumption enables the separation of an unconventional policy shock from other contemporaneous shocks, such as demand or supply shocks.

To identify an unconventional policy shock, I apply a short-run sign restriction. An unconventional policy shock is essentially an increase in central bank total assets. However, a mere increase contains some endogenous components. To separate these components from an increase in central bank total assets, stock market implied volatility plays a role as a financial market distress measure. The endogenous component is a shock to stock market volatility that increases the central bank total assets. The central banks endogenously respond to financial turmoil and economic uncertainty by unconventional policy. This component is a reverse causality of unconventional policy: a higher financial market distress increases the central bank total assets.

On the contrary, an exogenous component is a shock to the central bank total assets that decreases (or keeps steady) the stock market volatility. This notion is consistent with the literature that unconventional policy reduces the financial uncertainty (for example, Baumeister and Benati, 2012; Mallick et al., 2017) and improves the financial market condition (for example, Gagnon et al., 2011; Krishnamurthy and Vissing-Jorgensen, 2011). I then only take the latter component of an increase in central bank total assets and call it as an unconventional policy shock. Without the stock market implied volatility term, one could not differentiate these two distinct effects. Lastly, shocks to central bank assets and stock market volatility increase their own variables.

In order to generate the mixture of the sign and zero restrictions, I adapt the Givens rotation matrix as in Gambacorta et al. (2014). The complete description of the identification is in Appendix A.1. The mixture of the zero and sign restriction is imposed on the impact period for all of the countries. As in Gambacorta et al. (2014), I also impose the same sign restriction the next period after the shock except for the US, since the US data is quarterly unlike the monthly frequency used in Gambacorta et al. (2014). If I were to impose the same sign restriction, it would imply that the sign restriction is effective for three months (a quarter). This assumption may not be realistic. Thus I impose the restriction only in the impact period for the US. However, I relax this assumption in the robustness check to examine how the results are affected. The following table summarizes the restrictions that are imposed[9].

Table 1: Sign Restrictions of Impulse Response Functions

| | All countries at period = 0 | US at period = 1 | UK and Japan at period = 1 |
|---|---|---|---|
| Industry Output | 0 | * | * |
| Consumer Price Index | 0 | * | * |
| Central Bank Total Asset | >0 | * | >0 |
| Stock Market Implied Volatility | ≤0 | * | ≤0 |

### 3.3 Estimation

I estimate Bayesian VAR and generate response functions using the Independent Gaussian-inverse Wishart prior. This prior is more flexible than other Bayesian priors and is useful for estimating models with small sample sizes by setting tight parameter distributions. However, it is computationally more demanding than other Bayesian methods and requires a Markov Chain Monte Carlo (MCMC) algorithm. The estimation includes 2 lags of endogenous variables by following Gambacorta et al. (2014). I follow the Bayesian method of Kilian and Lütkepohl (2017) and Koop

[9]The complementary restriction (a shock to VOL increases AT and own variable) also are imposed so that the shock is fully identified. The importance of a fully identified sign restriction for inference is mentioned in Kilian and Lütkepohl (2017)

et al. (2010). One of the gains of estimating Bayesian VAR is to circumvent problems with over-parameterization, especially with the US data that is used. Another gain of estimating Bayesian VAR is to overcome the problems of the frequentest approach of the broader confidence bands and uninformative response functions (Kilian and Lütkepohl, 2017). A detailed explanation of the Bayesian estimation and how I generated response functions are in Appendix A.2.

# 4 Results

In this section, I first provide the national results in Section 4.1 which I then compare to the existing literature. Next, in Section 4.2 I show that the industry responsive functions approximately sum up to the national response function and that the industry results are heterogeneous within a country in. In Section 4.3, I briefly show that the industry output responses from those three countries are on average similar to the responsiveness of conventional policy. Finally, in Section 4.4, I generate counterfactual response functions to show that the impacts on aggregate depends on industry composition.

## 4.1 National Results

Figure 4 shows the response functions from a one standard deviation shock to the central bank total assets on aggregate output, CPI, central bank total asset, and stock market implied volatility for each country from the corresponding sample periods. The 68% Bayesian credible bands[10] are reported as is standard in the literature. The results show that for all of these countries, unconventional policy has a statistically positive impact on both aggregate output and CPI. Central bank total asset (the identified shock) is positive and stock market volatility is negative at the first period and slowly revert back to zero: these observations are in line with the literature of empirical unconventional policy (such as Gambacorta et al., 2014; Bhattarai et al., 2015a; Boeckx et al., 2017, and many others). Figure 4 shows that the effects on aggregate output and price are long lasting for all of the countries and stay significantly positive until the last period.

Now, I investigate whether the results are in line with the studies in the empirical literature of unconventional policy. The following table summarizes the results as well as the results from other studies. The table reports the maximum value of the median response function of output and price from a one standard deviation shock to the central bank total assets. The one standard deviation shock is a 2.86% increase in central bank total asset in the US. This is equivalent to an increase of approximately \$100 billion. To interpret the size of the shock better, the size of QE1 is \$1.75 trillion, QE2 is \$600 billion, and QE3 is \$40 billion per month.

[10] Credible band is an interval within which the estimate falls with the probablity given

Table 2: Comparison of National Effects Across Unconventional Policy Studies

| Authors | Country | Estimate | | | Sample periods |
|---|---|---|---|---|---|
| | | GDP in % | CPI in % | 1 stanard deviation shock in % | |
| This paper | US | 0.16 | 0.11 | 2.86 | 2008-2017 |
| | UK | 0.12 | 0.09 | 2.23 | 2008-2018 |
| | Japan | 0.23 | 0.07 | 1.80 | 2003-2018 |
| Gambacorta et al. (2014) | US | 0.10 | 0.06 | 2.70 | 2008-2011 |
| | UK | 0.12 | 0.01 | 4.50 | 2008-2011 |
| | Japan | 0.10 | 0.02 | 1.20 | 2008-2011 |
| | EU | 0.10 | 0.08 | 2.40 | 2008-2011 |
| Bhattarai et al. (2015a) | US | 0.40 | 0.10 | 2.00 | 2008-2014 |
| Boeckx et al. (2017) | EU | 0.10 | 0.10 | 1.50 | 2007-2014 |
| Burriel and Galesi (2018) | EU | 0.08 | 0.03 | 1.00 | 2007-2015 |
| Schenkelberg and Watzka (2013) | Japan | 0.40 | 0.05 | 7.00 | 1995-2010 |
| Peersman (2011) | EU | 0.40 | 0.07 | 1.75 | 1999-2009 |
| Average | | 0.20 | 0.06 | 2.67 | |
| Median | | 0.10 | 0.06 | 2.00 | |

The results of output in this paper are comparable to other studies, however, the results of price are a bit higher, though statistically insignificant. While there are several similarities of the methodologies to these studies, such as identification (Gambacorta et al., 2014) and estimation (Boeckx et al., 2017), generally the responses to the shock are slightly larger than those studies. The main difference is that these studies did not generally include the periods after 2012: there were a few large increases in central bank total assets after 2012. It could that the impacts of unconventional policy are nonlinear. I also compare the national results in this paper to several conventional policy studies in the online Appendix.

While the estimation method, identification, countries, and sample periods are different, the results are overall comparable to the results of those studies, especially with regard to output, which is the focus of this paper.

### 4.2 Industry Results

First, I plot the weighted response functions and national response functions on Figure 5 to ensure that the industry results approximately sum up to the national results[11]. One of the purposes of this paper is to uncover the heterogeneous responses to the unconventional policy shock. If the industry response functions sum up to the national response function, it is credible to argue the validity of the industry response functions, since the output comovements across industries and the role of spillover are sufficiently small. The weighted response functions are calculated by

[11]For this calculation, I include the response function from government since the national response function includes it.

following:

$$WIRF_p = \sum_{i=1}^{I} weight_i * MIRF_{ip} \tag{3}$$

where $WIRF_p$ represents the weighted response function at period $p \in 24$[12], $MIRF_{ip}$ represents the median response functions for industry $i$ at period $p \in 24$, and $I$ is the total number of industries. Each industry response function is the average response from the entire sample periods. Thus, I calculate the weighted response function using weight from the sample period average. I calculate the weight for the US and the UK the following way. First, I calculate the average gross value added (GVA) of the sample periods for each industry. Then, I sum up the average GVA across industries and I denote it as total GVA. Finally, I calculate the weight as the average GVA of individual industries over total GVA. Japanese data provides the weight from the GDP share and so I used the weight for the calculation of the weighted response functions. In Figure 5, for each country, the bold line represents the national response function and the dotted line represents the weighted response function. I also reported the credible bands of the national response functions.

For each country, the weighted response function is similar to the national response function but not identical. For example, during the second half of the entire period, the weighted response function for the US is lower than the national response function. The weighted response function for the UK is consistently lower than the respective national response function. The Japanese weighted response function is slightly higher than the national response function.

The potential explanations of these deviations are estimation uncertainty, statistical measurement error between aggregate output and sum of the industry output, and/or missing industry comovement or spillover effects due to the separate industry level estimation. While there are some deviations, for each country the deviation is not large and is generally within the credible band. Therefore, the weighted response functions overall match the national results.

The first three columns of Figure 6 show the selected industry response functions for each country. I report the four industries with the highest median responses. I report the 16% and 84% credible bands. I find that 15 out of 17 (88%) industries in the US, 13 out of 17 (76%) industries in the UK, and 8 out of 15 (53%) industries in Japan are statistically significant and positive. The number of industries which are significantly positive is similar between the US and the UK; Japan, however, differs from these two countries.

To compare the impacts of unconventional policy across industries, Table 3 shows the unconventional policy elasticity of output: the percentage change in median peak response function to a one percent increase in central bank total asset. Under each elasticity, I listed the 32% credible band in parenthesis analogous to standard errors.

[12] I plot the response function over a 24 period horizon

Table 3: Monetary Policy Elasticity of Output

| Country | US | UK | Japan | Country | US | UK | Japan |
|---|---|---|---|---|---|---|---|
| Industry | | Elasticity | | Industry | | Elasticity | |
| Aggregate | 0.06 | 0.05 | 0.13 | Information | 0.10 | 0.09 | 0.04 |
| | (0.02) | (0.02) | (0.07) | | (0.03) | (0.06) | (0.04) |
| Agriculture | 0.04 | 0.06 | | Finance | 0.28 | -0.04 | 0.16 |
| | (0.01) | (0.07) | | | (0.11) | (0.04) | (0.05) |
| Mining | 0.35 | -0.11 | 0.00 | Real estate | 0.07 | 0.02 | 0.01 |
| | (0.19) | (0.05) | (0.10) | | (0.01) | (0.01) | (0.01) |
| Utilities | 0.18 | 0.10 | 0.02 | Professional service | 0.09 | 0.12 | 0.02 |
| | (0.03) | (0.04) | (0.04) | | (0.03) | (0.04) | (0.04) |
| Construction | 0.05 | 0.24 | 0.08 | Education | 0.03 | 0.01 | 0.09 |
| | (0.04) | (0.08) | (0.06) | | (0.01) | (0.00) | (0.06) |
| Manufacturing | 0.06 | 0.07 | 0.39 | Healthcare | -0.01 | 0.03 | 0.01 |
| | (0.03) | (0.04) | (0.25) | | (0.06) | (0.03) | (0.01) |
| Durable goods | 0.16 | 0.17 | 0.52 | Arts, entertainment, and recreation | 0.10 | -0.01 | -0.02 |
| | (0.04) | (0.06) | (0.33) | | (0.04) | (0.03) | (0.03) |
| Non-durable goods | 0.00 | -0.01 | 0.17 | Accommodation | 0.12 | 0.02 | 0.04 |
| | (0.04) | (0.02) | (0.12) | | (0.03) | (0.03) | (0.03) |
| Trade | 0.09 | 0.08 | 0.19 | Other services | 0.02 | 0.08 | 0.24 |
| | (0.02) | (0.03) | (0.09) | | (0.02) | (0.01) | (0.08) |
| Transportation | 0.08 | 0.07 | 0.10 | | | | |
| | (0.02) | (0.01) | (0.03) | | | | |
| | | | | Industry average | 0.10 | 0.06 | 0.12 |
| | | | | Industry median | 0.09 | 0.07 | 0.06 |

Note: credible bands (32%) in parenthesis. Credible band is an interval within which the estimate falls with the probablity given. Elasticity is the maximum median impulse response function consistent with a 1% increase in central bank total asset. For example, in the US for the aggregate, a 1% increase in central bank total asset increases the aggregate output by 0.06%. Credible bands are also transformed by the same amount as the elasticity is scaled.

The aggregate elasticity in Japan is twice as large as in the US or the UK, though, Japan has a broader credible band. When it comes to industries, the results uncover the differential responses to the unconventional policy shock. The elasticity varies from -0.01 to 0.28 in the US, -0.11 to 0.24 in the UK, and -0.02 to 0.39 in Japan, indicating that the same policy creates industries that are expanding and industries that are contracting. This implies that there are winners and losers. The industries that show the strongest elasticity are mining in the US, construction in the UK, and manufacturing in Japan. The most affected industry is different for each country.

In order to know which industry is more responsive to the shock than the national average, I look for industries whose credible band is above the industry median elasticity[13]. Mining, utilities, finance, and accommodation and food respond stronger than the industry median in the US; construction, professional, and other service respond stronger than the industry median in

[13] It is important to compare with the median elasticity, not the national elasticity. The Japanese national elasticity is higher than the US and the UK, however, this is coming from the manufacturing industry whose elasticity is exceptionally large and composition in GDP is around 20%. If one industry has a very large or small elasticity with non-negligible GDP share, the national elasticity tends to be skewed and may not be suitable for a central tendency measure.

the UK; and manufacturing, trade, transportation, finance, education, and other service respond stronger than the industry median in Japan. The industries mentioned above include construction, manufacturing, and trade: industries that are very responsive to conventional policy shock in the literature (for example, Ganley and Salmon, 1997). Industries responsive to unconventional policy shock tend to vary by countries,

As mentioned in Section 1, the financial market has been given a large amount of attention in the literature since stimulating the financial market is one of the main goals of unconventional policy. In the UK, the effect on the finance industry is negative, which is surprising (this result is observed using both GVA and monthly GDP in the UK). However, the response functions for the US and Japan indicate that unconventional policy has significantly positive effects on the finance industry. Additionally, the credible band of finance industry is greater than the industry median in the US and Japan as well. This observation is consistent with the literature (such as Krishnamurthy and Vissing-Jorgensen, 2011 and Neely, 2015).

Interest rate sensitive industries are usually responsive to conventional policy and durable goods manufacturing industry is known to be the most interest rate sensitive industry. Despite that under ZLB the interest rate channel is blocked, I find that elasticity of durable goods manufacturing is greater than the industry median for all of the countries. One possibility is that signaling theory, (such as Bauer and Rudebusch, 2013 and Bhattarai et al., 2015b) a central bank's promise to keep the interest 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. Thus this signaling channel may cause the effect of unconventional policy to be similar to that of conventional policy.

#### 4.2.1 Discussion of Industry Response

***Production Sector (Mining, Utilities, and Manufacturing)***

Production sector is generally responsive to unconventional policy. Notably, mining industry responds very strongly in the US, however, this is not observed in the UK or Japan[14]. Unlike the other two countries, the United States experienced a boom of natural gas and oil. It is likely that this exogenous component is not excluded by the identification and thus the results show that the mining industry has the strongest effect. Utilities industry provides basic amenities to consumers and firms. While the industry plays a role as a staple good producer and is insensitive to business cycles, the effect of unconventional policy is rather high. This industry is heavily capital intense due to the requirement for infrastructure investment and the industry relies on the inflow of funds

[14]The joint estimation in Section 6 alters the response in the UK and the industry is stimulated by other industries.

to manage debts, invest, and upgrade the infrastructure. Therefore, it is not surprising that utilities respond strongly to the policy. Manufacturing industry is relatively sensitive to monetary policy as it partly consists of durable goods manufacturing and the industry itself is generally capital intensive. The industry requires a large inflow of funds and the response of the durable goods manufacturing to unconventional policy is extremely strong.

***Construction and Real Estate Industries***

The Federal reserve implemented mortgage backed security (MBS) purchases mainly during QE1. It is intuitive to think that construction and real estate industries would get a direct benefit from the policy and would respond strongly. The construction industry is generally one of the most responsive industries to monetary policy as the industry heavily relies on large investment projects, which is found in the high elasticity in the UK and Japan. However, the response is rather modest. One possibility is extremely slow employment recovery. In the aftermath of the financial crisis, many labor forces of the industry exited the market. After 4 years labor forces began to reenter the market, however, the recovery of employment was very slow. This constraint of labor availability in the construction industry held back the possibility of growth. With regards to the real estate industry, the MBS purchase saved the housing market, however, the housing crash also caused the regulation of mortgage contracts. There are more hurdles for consumers to be qualified for a mortgage. Thus, the positive influence of the policy might be offset by the effect of the macroprudential policy. Additionally, real estate industry is interest rate sensitive as the mortgage rate ties to the monetary policy rate. However, under the ZLB period, mortgage rate fluctuates. It is possible that the identified unconventional policy shock may not coincide with the movement of the mortgage rate[15] and thus the responses of real estate output is not well captured.

***Industries Linked to Public Sector or Producing Stable Goods***

Agriculture produces staple goods and has responses that are below the national average. However, it responds significantly positive in the US and the UK. It is possible that the portfolio balance channel[16] pushed the industry activity as agriculture industry generally has a larger firm size than other industries. Education and healthcare are industries that are tied to the public sector. Therefore, the industry is not cyclical and not sensitive to the impact of monetary policy.

[15]For the next revision, I plan to investigate this.

[16]The central bank purchases reduce the supply of long-term security. Public investors shift their portfolio toward other assets whose characteristics (risk or maturities) are similar. This reduces the yields of these assets as well. Thus, large firms are able to issue bonds to direct finance easier.

*Service Sector*

The output response of industries in service vary because the financial structure differ by industry. Trade consists of retail trade, which handles final goods sales, and wholesale, which plays an intermediary role in the economy. Similar to manufacturing, the trade industry deals with durable goods and thus it tends to be responsive to the policy. Transportation and information industries are capital intensive as the transportation industry operates airplane, rails, trucks, ships, etc, and information industry requires a large investment in infrastructure. Thus, these industries are generally responsive to the inflow of funds. Finance industry is responsive because the central bank is included in the industry and their liquidity level is generally lower than other industries, which implies that the inflow of funds yields a strong response. Professional service is a high skilled and growing industry in advanced economies. Since the financial structure of the industry is rather average, it is possible that the identified shock cannot exclude increase in output coming from the exogeneous boom component. Leisure industry (food, accommodation, art entertainment, and recreation) is labor-intensive. Generally, it is not responsive to the policy in the UK or Japan. In the US, however, the responses are strong. It could be that the industry is benefited by the portfolio balance channel because the industry in the US has a large firm size.

## 4.3 Cross-Country Analysis

The literature of industry studies in conventional policy uncovers heterogeneous industry effects. However, these analyses typically limit their attention to a single country and have not compared the industry effects across countries[17]. In this section, I briefly compare the pattern obtained in Section 4.2 across the US, the UK, and Japan and observe to what extent the pattern is similar to conventional policy.

The observed pattern of industry responses show some similarities across countries. There are six industries that have significantly positive impacts for all of the countries. These six industries are construction, manufacturing[18], trade, transportation, education[19] and other services. Thus, this implies that there are some similar patterns of heterogeneity. Some of these industries belong to the production sector, such as construction and manufacturing which tend to be interest rate sensitive. Despite that the interest rate channel is blocked due to the ZLB, the effect on the industries still exist. Industries that are not responsive to the policy are industries that have a strong link to the public sector. Those industries include education and healthcare.

[17]However, Dedola and Lippi (2005) and Peersman and Smets (2005) did explore the industry impact of monetary policy across countries.

[18]Durable goods manufacturing is significant as well

[19]Education responds positively but the cumulative impact is not positive

However, when it comes to relative responsiveness to the national median, cross country effects are not so similar. For example, accommodation and food is significantly stronger than the industry median only in the US, construction and professional service are significantly stronger than the industry median only in the UK, and manufacturing and trade are significantly stronger than the industry median only in Japan. Though, industries that respond relatively weakly are similar: such as real estate, healthcare, and government.

To qualitatively compare to the literature of conventional policy (for example Ganley and Salmon, 1997 and Ibrahim, 2005), I generate industry mean response functions, a simple average of response functions for each period within an industry across countries. Frequencies of response functions in the US and in the UK and Japan are different, however, they can show a tendency of which industries, on average, strongly respond to the policy. The fourth column of Figure 6 shows the results of the top 4 most responsive industries. The red line represents the average of the median response functions and the average of credible bands are attached. The figure shows that construction, manufacturing, and trade are stronger than the overall average[20] and they are the top 3 most responsive industries. This suggests that, on average, responsive industries between unconventional policy and conventional policy are similar. Additionally, industries that have a link to the public sector did not respond well on average (except for utilities). These industries generally do not comove with business cycle (Berman and Pfleeger, 1997). While monetary policy is typically not a large source of business cycles (Gambacorta et al., 2014), unconventional policy affects these industries in a similar manner.

Based on the cross-country analysis, I find that the pattern of heterogeneity is not very similar. However, based on the industry average from the investigated countries, the observed differential impacts are similar to the literature of conventional policy.

### 4.4 Counterfactual Analysis

The effectiveness of monetary policy may vary as the industry composition changes. In this section, I change the industry composition and examine the impact on the aggregate as a counterfactual analysis by exploiting the industry-level analysis. In the previous section, I showed that the weighted response function is approximately equal to the national response function. Thus, in this section, by treating the counterfactual weighted response function as the hypothetical national effect, I change the industry composition of the economy and observe the impact on the aggregate.

In this analysis, I change the composition of the production sector (which consists of agriculture, mining, utilities, construction, and manufacturing) and the service sector (which consists of

[20]Contrary to the national response functions, this average is not a weighted average. Thus, it is less likely to be biased by a specific industry that responds very strongly with a large GDP share.

everything else). Since I only change the composition of these two sectors, within the sector, the change of the size of each industry is the same (i.e. if the production sector increased by 50%, all of the industries within the production sector also increase by 50%). I impose 3 different counterfactual compositions in this analysis: the production sector share makes up 0%, 10%, and 50% of an economy. Currently, the composition of the production sector is around 25%[21]. I set up 0% for an extreme case where the economy is a complete service economy, 10% for a realistic future service economy of the three countries, and 50% for the case of a developing country.

Figure 7 shows the counterfactual weighted response functions for the US, the UK, and Japan. While the results in the US are very similar across the different weights, the results in the UK and Japan reveal that the higher the share of the production sector the stronger the aggregate effect. It is intuitive as the production sector consists of industries that are investment intensive. Thus, being that countries become more service sector oriented as they develop, the effectiveness of the policy declines due to development. The US has similar results across different weights because of the unusual lower responses of manufacturing and construction as well as the higher responses of leisure industry.

Another finding is that even though the effect on the aggregate is weaker as the composition of industries moves towards the service sector, the effect lasts longer. This is possible as production sector plays an intermediary role while the service sector plays a final sales role[22]. When an economy is highly production based, the economy expands in the earlier phase after the shock. However, when an economy is highly service sector based, the economy expands in the later phase after the shock.

There are several limitations of this analysis. First, the counterfactual results are based on the sample period used in this paper and the implied results can be completely different with the different sample periods and/or economic states and conditions. Second, there is no guarantee that industries within in the sector increase at the same rate. This is a very strong assumption that is imposed for the sake of simplicity. Third, economic development changes the financial and production structures of industries and thus the analysis may not be suitable to represent developing countries. Fourth, the different policies may change the effects in different directions.

## 5 Implication of Transmission Channels

In the previous section, I find that industry impacts are heterogeneous. In this section I seek to understand the transmission mechanisms of unconventional policy by running simple regressions.

[21] The production sector share in the US and UK is 21% and Japan is 29%(it is high due to agriculture and government not being included in the data).

[22] wholesale and finance are exceptions.

In specific, I regress the industry elasticity on several industry characteristics. The elasticity comes from the median response functions from the previous chapter. Explanatory variables are constructed from the Mergent Online by FTSE Russell which is a firm-level database that covers annual balance sheets and income statements information for public and private companies for both domestic and international companies. The database contains the information of 743,242 companies in the US, 106,678 companies in the UK, and 152,686 companies in Japan. Explanatory variables are constructed from the periods used in the VAR analysis.

However, there are limitations of this dataset. First, since the dataset only contains NAIC and SIC for the industry definition, I need to use the US industry definition to classify the UK and Japanese companies to the respective industries. Second, many of the UK and Japanese companies do not contain the information of NAIC, which loses many observations. Third, the balance sheet and income statement information are generally only available of public firms. Therefore, explanatory variables constructed from these financial statements are less accurate than explanatory variables such as firm size. The numbers of firms that contain the financial statements and NAIC are 125,033 in the US, 3,020 in the UK, and 5989 in Japan, which produces less accurate constructions of the variables for the UK and Japan.

Following Dedola and Lippi (2005), the explanatory variables are: firm size ( = number of employees / number of firms), leverage ( = total liabilities / shareholders equity), interest burden ( = interest payment / operating profit), working capital (= [current assets current liabilities] / total assets ), and short-term debt (= current liabilities / total liabilities). These explanatory variables are meant to be proxies for traditional transmission mechanisms.

The industry-level explanatory 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 the variables over the sample period, and for each industry I take the median of the variable[23].

Firm size and leverage are proxies for borrowing capacity of an industry and represent credit channel. An industry with larger firms or higher leverage firms, on average, tend to possess more borrowing capacities than other industries with smaller firms or lower leverage firms. In the literature, the connection between firm size and monetary policy elasticity is closely investigated empirically (Gertler and Gilchrist, 1994 and Ehrmann and Fratzscher, 2004) and theoretically (Fisher, 1999). Also, large firms access direct finance in addition to indirect finance, while small firms do not always have that option. Since credit supply helps small or low leverage firms increase their production, these firms tend to respond to the policy strongly.

[23] I chose median over mean because there are some outliers and they distort the overall averages of some variables in some industries, and the variables do not necessarily have to be normally distributed.

Interest Burden is a proxy for the cost channel of monetary policy. This theory originates to explain the price puzzle of monetary policy: when interest rate is higher due to tightening, it raises the firms' marginal cost of production, which raises the price of output as well. The literature also supports this view of monetary policy (Barth III and Ramey, 2001 and Gaiotti and Secchi, 2006). Along with this view, I use interest burden. An industry with a higher interest burden responds to the shock strongly.

Lastly, working capital and short-term debt are proxies for channels on the supply side, mainly traditional interest rate channel: change in the nominal interest rate alters the real interest rate and user cost of capital, which alters the production decisions. Working capital represents liquidity and short-term debt represents financing need of an industry. These two variables are constructed using current liabilities. Since a change in nominal interest rate affects the current liabilities, these two variables are affected by the change in policy rate. Thus, industries with lower working capital and higher short-term debt are expected to respond strongly. Since the policy rates are attached to the ZLB during unconventional policy periods, it is of interest to know to what extent interest rate channel plays a role.

These channels are introduced as if they work independently. However, as in Bernanke and Gertler (1995), these channels are interrelated and hard to disentangle. For example, interest burden is a proxy for the cost channel, a change in interest rate affects the user cost of capital which also contains an element of the interest rate channel.

If I assume that unconventional policy transmission mechanisms are the same as conventional policy transmission mechanisms, industries that have smaller firm size, lower leverage, higher interest burden, lower working capital, and higher short-term debt are expected to respond to the policy strongly.

I estimate pooled OLS (cross-section and cross-country) with robust standard errors by following Dedola and Lippi (2005). They estimate the industry impacts of conventional policy for the US, the UK, Germany, Italy, and France using a VAR model. The industries they investigated are within manufacturing. They also estimate the effects of monetary tightening instead of easing unlike this paper[24]. Therefore the results obtained in this paper cannot be directly compared to theirs. Among these five variables they find that firm size, leverage, and working capital are significant.

I have the following four different dependent variables: (1) maximum and (2) $24^{\text{th}}$ period median elasticity from the benchmark VAR and (3) maximum, and (4) $24^{\text{th}}$ period median elasticity from 5-variable VAR (the details of this can be found in Section 6.1.1). I include country and industry dummy variables for all of the regressions.

[24]However, the specification of the VAR model is not nonlinear and does not differentiate the impacts differences between easing and tightening. Thus, the impacts are symmetric.

Table 4: Regression Results

| Explanatory variable | Dependent variable | | | |
|---|---|---|---|---|
| | (1) Maximum Output Response from Benchmark | (2) $24^{th}$ Period Output Response from Benchmark | (3) Maximum Output Response from Joint Estimation | (4) $24^{th}$ Period Output Response from Joint Estimation |
| Working capital (interest rate channel) | -0.69*** | -0.35*** | -0.56*** | -0.30*** |
| | (0.24) | (0.10) | (0.19) | (0.09) |
| Leverage (credit channel) | 0.73 | 1.00*** | 0.51 | 0.67*** |
| | (0.59) | (0.21) | (0.47) | (0.16) |
| Firm size (credit channel) | 0.22 | 0.13 | 0.40 | 0.18 |
| | (0.38) | (0.19) | (0.34) | (0.18) |
| Interest burden (cost channel) | 0.47 | -0.05 | 0.31 | -0.20 |
| | (0.29) | (0.23) | (0.31) | (0.19) |
| Short-term debt (interest rate channel) | 0.02 | -0.01 | 0.03 | 0.02 |
| | (0.17) | (0.08) | (0.14) | (0.06) |
| Country dummy | | | | |
| US | 0.10 | 0.03 | 0.08 | 0.01 |
| | (0.07) | (0.03) | (0.08) | (0.03) |
| UK | -0.03 | 0.00 | -0.04 | -0.02 |
| | (0.10) | (0.05) | (0.11) | (0.04) |
| JP | 0.03 | 0.01 | 0.01 | -0.02 |
| | (0.13) | (0.06) | (0.13) | (0.05) |
| Industry dummy | Yes | Yes | Yes | Yes |
| N | 49 | 49 | 49 | 49 |
| adj. R-sq | 0.44 | 0.45 | 0.58 | 0.59 |

Note: pooled OLS (cross-industry and cross-country). Robust standard errors in parentheses. $*p < 0.10 **p < 0.05 ***p < 0.01$.

The second column shows the effects of transmission measures on maximum elasticity. The results show that only working capital is significant with the expected sign. Interest burden and short-term debt have the expected sign, however, they are not significant. Interestingly enough, credit channel measures of firm size and leverage have the opposite sign. The third through fifth columns show the results when the dependent variables are different. For each specification, working capital is significant with the expected sign, interest burden and short-term debt are insignificant, and credit channel measures are, again, the opposite sign. Also, leverage is significant with the opposite sign when the $24^{th}$ period elasticity is used.

Based on the results, it seems that the interest rate channel plays a role, even though the policy rate is attached to the ZLB. This implies that real or expected interest rate still affects the production decisions of firms. Again, this can be possibly explained by signaling theory (Bauer and Rudebusch, 2013 and Bhattarai et al., 2015b). Cost channel is generally insignificant, which is also observed in Dedola and Lippi (2005). The surprising result is that both credit channel measures have positive signs and leverage is sometimes significant, which disagrees with the traditional view of credit channel.

There are two potential explanations of this. First, credit channel may have an asymmetric reaction depending on tightening and easing (Gertler and Gilchrist (1994)). Contractionary policy makes small firms face borrowing constraints and their production falls dramatically. However, monetary easing might have a homogeneous impact on small and large firms. Therefore, firm size does not matter for easing, however this observation is not seen in Dedola and Lippi (2005). The second possibility is that traditional credit channel exists but unconventional policy also provides an additional monetary transmission mechanism which is the portfolio balance channel: the central banks purchase long-term securities, which forces investors to change their portfolio. Those investors shift their holdings towards some assets that have similar characteristics to long-term securities, such as corporate bonds. This approach helps large firms or highly leverage firms to acquire additional funding easier through direct finance. Even though the traditional credit view might still exist, large or high leverage firms also responded strongly to the policy due to the portfolio balance channel. Therefore, the regression results cannot show the insignificant results of credit view.

Through this regression analysis, the impacts of unconventional policy seem to be related to the traditional interest rate channel. However, this analysis does not reject the possibility that unconventional policy has an additional channel through which large firms benefit. This might be the reason that construction industry, whose firm size is smaller in general, is not more responsive than other industries in the US and Japan.

# 6 Robustness Analysis

In this section I conduct two types robustness analyses. In Section 6.1, I investigate the industry impacts of unconventional policy by estimating multiple industries jointly, in Section 6.2, I estimate the model with different identifications, and in Section 6.3, I estimate the effects of unconventional policy during non-ZLB periods.

## 6.1 Joint Consideration

The first set of robustness analyses carries out joint estimations. In Section 6.1.1, I consider a small scale joint estimation and in Section 6.1.2, I seek an explicit joint estimation with a global VAR model.

### 6.1.1 Including Aggregate Output Excluding the Industry

The structural VAR model for monetary policy analysis is based upon the three equations New Keynesian model. The model is a system of aggregate variables. Omitting the aggregate dynamics may lead to a biased estimation. In spite of the underline assumption, there are many papers investigating the industry effect of monetary policy without controlling aggregate output. I estimate the model including aggregate output (or GDP)[25] excluding the industry, defined as $GDPex_t$ in the endogenous vector, $y_t$, so that the system is able to capture not only the dynamics of the industry but also the dynamics of the aggregate output and the output of the other industries. By including aggregate output excluding the industry into the system, the endogenous vector, $y_t$, consists of five variables. I add log of $GDPex_t$ after industry output, so that the endogenous vector, $y_t$, is now:

$$y_t = \begin{bmatrix} ln(IO_t) \\ ln(GDPex_t) \\ ln(CPI_t) \\ ln(AT_t) \\ VOL_t \end{bmatrix} \tag{4}$$

The inclusion of the variable generates the additional zero restriction for the identification: a shock to the central bank total assets has at most a lagged impact on aggregate output excluding the industry. This additional zero restriction is reasonable since I impose the same identification on the industry output. The inclusion of the variable and the identification are used in Ibrahim (2005) in the same manner. Aside from the additional identification, I estimate the model the same way as in Section 3.3. The number of lag, $p$, is the same as before ($p$=2).

Figure 8 highlights the selected industry response functions where aggregate dynamics are controlled. For each industry, the solid line represents median response function from the benchmark (Section 3.3) VAR model while the dotted line represents the median response function from the new specification (Benchmark VAR with $GDPex_t$).

Even though I controlled the overall dynamics of the economy, there is not many qualitative differences of the industry response functions between the benchmark VAR and benchmark VAR with aggregate output excluding the industry. The results imply that the single industry VAR is generally sufficient enough to generate its own response function. Exceptions to this are the agriculture and mining industries for these countries. Their results were dramatically changed by the inclusion of the variable. These industries account for very small shares in GDP. Thus it is likely that not including the aggregate information causes the system to be misspecified.

Although there are some disparities, industry impacts of unconventional policy were not largely affected by the inclusion of aggregate output excluding the industry.

[25] I did not choose this as a benchmark as the benchmark model is more parsimonious and the weighted response functions approximately sum up to the national response functions and the comevement and spillover between industries are sufficiently small.

### 6.1.2 Global VAR Model

In the previous section, I estimated the VAR model with GDP excluding the industry to deal with the potential problem of treating each industry independently and found that the inclusion of GDP excluding the industry does not change the results overall. However, there is still a potential misspecification when some industries crucially depend on another industry. For example, if the trade industry is crucially dependent on manufacturing, estimating the model for trade industry with GDP excluding the industry may lose the relationship between these two industries by the aggregation of manufacturing with the other industries. In this case, the obtained results above may still be misspecified.

In this section, I estimate a global VAR (GVAR) model to take into account the industry interactions to circumvent this problem. I estimate the model only for the UK and Japan[26]. A GVAR model is a panel expression of VARs (Pesaran et al., 2004). A general form of a GVAR model is:

$$y_{i,t} = v_i + A_i Y_{i,t-1} + W(L) y^*_{i,t} + u_{i,t}$$

where $W(L)$ represents a matrix polynomial in the lag operator and $Y_{i,t-1}$ includes all of the $y_{i,t-1}$s and lags of all of the industries. $y^*_{i,t}$ is a foreign variable capturing information from the other industries:

$$y^*_{i,t} = \sum_{\substack{j=1 \\ j \neq i}}^{I} \omega_{i,j} y_{j,t}$$

where $\omega_{i,j}$ is the weight on $j$ in the model for $i$. A typical weight used in the literature is bilateral trade flow.

I setup a GVAR model following Burriel and Galesi (2018) whose framework is an extension of Pesaran et al. (2004). A detailed explanation of the GVAR estimation is in Appendix A.2.

I use an IO table for constructing the weight of the foreign variable. For the IO table I use the newest data available at this time: 2016 data for the UK retrieved from the Office for National Statistics and 2015 data for Japan retrieved from the Ministry of Economy, Trade and Industry.

Figure 9 shows the selected industry response functions from a one standard deviation shock to the central bank total assets using the GVAR model. For each industry, the solid line represents the median response function from the benchmark VAR model (Section 3.3) while the dotted line represents the median response function from the new specification (GVAR model). 64 % credible bands from both specifications are reported.

For the UK, response functions from the GVAR are overall qualitatively similar to the benchmark response functions. When the benchmark response function responds positively, so does the

[26] Due to the limited sample size, I am not able to estimate the model for the US.

response function from the GVAR. Generally, response functions from the GVAR model follow the benchmark response functions for the first few periods and then they start deviating. It seems that industry interactions are in place. A notable industry is mining. For the first few periods the response follows the benchmark response function then it changes to the opposite direction. Since mining industry is behaving in a similar manner as in the previous section, estimating this industry itself seems misspecified. In addition, trade, education and health, and leisure (sum of accommodation and food and arts, recreation, and entertainment) industries also deviate from the credible bands of the benchmark estimation.

For Japan, similar to the observations in the UK, the response functions from GVAR follow the benchmark response functions and both response functions are very similar for the first few periods and then deviate. Generally the results for Japan are closer to the benchmark response functions. As is seen in the UK, the mining industry also responds very differently after the first few periods. This observation is consistent with the previous section and the GVAR results in the UK. This shows that mining industry requires a joint estimation. Trade, finance, education, and other service also deviate from the respective response functions credible bands.

To assess why mining industry deviates dramatically from the benchmark response function, I include the weighting matrices in the online Appendix figures. According to the weighting matrices, mining industry is largely dependent on manufacturing (and utilities in the UK). As manufacturing expands due to the unconventional policy shock, it spills over to mining industry.

Exercises from this section suggest that joint consideration is useful for the industry estimation for both the UK and Japan, while most of the stylized facts of response functions are preserved by the single industry estimation.

## 6.2 Different Identifications

### 6.2.1 Changing the Sign Restriction Effective Periods

In this section, I change the periods that the sign restriction is effective. To study the effect of unconventional policy, accurate identification is a key part and the results should not be radically altered by the choice of the effective periods of sign restriction. Previously, the sign restriction was imposed for the shock period (period = 0) for all of the countries and the first period in the UK and in Japan. To see how sensitive the results are, I impose the restriction until the end of the first quarter after the shock. In other words, I impose the same sign restriction in the shock period as well as the 1st period after the shock in the US and through the 3rd period after the shock in the UK and Japan. The following table summarizes the new identification.

Table 5: Sign Restriction (Robustness) of Impulse Response Function

| | All countries at period = 0 | All countries at period = 1 | US at periods = 2 and 3 | UK and Japan at periods = 2 and 3 |
|---|---|---|---|---|
| Industry Output | 0 | * | * | * |
| Consumer Price Index | 0 | * | * | * |
| Central Bank Total Asset | >0 | >0 | * | >0 |
| Stock Market Implied Volatility | ≤0 | ≤0 | * | ≤0 |

Figure 10 shows the results for the the aggregate and durable goods manufacturing. The results are not largely affected by the new specification. Rather two results are almost identical. Therefore, imposing the sign restriction on Table 1 in Section 3.2 is sufficient to generate an ideal unconventional policy shock.

#### 6.2.2 Alternative Identification

An unconventional policy shock needs to be exogenous. Gambacorta et al. (2014) use stock market implied volatility and assume that an unconventional policy shock reduces stock market implied volatility, since unconventional policy is known to mitigate financial market distress and economic uncertainty in the literature. In Section 3.2, I also state that endogenous part of an increase in central bank total assets is when stock market implied volatility increases (mainly contemporal reverse causality from the stock market volatility). In this section, I estimate this endogenous part and examine whether this identification struggles with generating clear results.

I estimate the VAR model using the following identification:

$$\underbrace{\begin{bmatrix} u_{IO} \\ u_{CPI} \\ u_{AT} \\ u_{VOL} \end{bmatrix}}_{\substack{\text{Reduced form error} \\ u_t}} = \begin{bmatrix} * & * & 0 & 0 \\ * & * & 0 & 0 \\ * & * & + & + \\ * & * & + & + \end{bmatrix} \underbrace{\begin{bmatrix} \epsilon_{IO} \\ \epsilon_{CPI} \\ \epsilon_{AT} \\ \epsilon_{VOL} \end{bmatrix}}_{\substack{\text{Structural error} \\ \epsilon_t}} \tag{5}$$

That is, the sign of the structural covariance of total asset and stock market volatility is positive. The identified shock captures the effect of an increase in central bank total assets when stock market implied volatility rises. I estimate the VAR model with the identification.

Figure 11 shows the results for the aggregate and durable goods manufacturing. The red line represents median response functions from the benchmark, while the blue line represents median response functions from the alternative identification. Credible bands from both specifications are shown.

The results for the US suggest this identification generates very similar response functions compared to the benchmark identification, which suggests the model struggles differentiating exogenous and endogenous unconventional policy shocks. This finding is not surprising as the frequency of the data is quarterly, and it is difficult to use a financial market variable in a model with quarterly basis. However, results for the UK and Japan are contrary to the benchmark results. The effect on aggregate output is negative for both countries, while this goes to the positive range for Japan. Also, durable goods manufacturing responds negatively. Sine this industry is the most responsive industry to conventional policy and business cycle sensitive, it is counterintuitive that expansionary unconventional policy shock suppresses their activities. It seems that monthly data can extract the exogenous part of the policy shock better[27]. From this section, I obtain support for using the Gambacorta et al. (2014) identification and show that it is important to use monthly series for unconventional policy analysis. Additionally, generalizing findings from quarterly frequency data itself may be misleading.

#### 6.2.3 Unconventional Policy Shock with Long-term Interest Rate

In this section, I use long-term asset yields to identify an unconventional policy shock, which has a taste of the unconventional policies operated in the US and the UK, by following Bhattarai et al. (2015a). The unconventional policies operated in the US and the UK focus on long-term asset purchases. In Section 3.2, I use the identification in Gambacorta et al. (2014), which is a general measure of unconventional policy. For the cross-country analysis it is important to use a general measure of unconventional policy rather than an identification that is specific to certain policies since the Bank of Japan's main purpose of unconventional policy is direct lending to banks. However, in this section, I relax this setting and observe how the use of long-term asset yields change the results from the benchmark identification.

The identification is to include long-term interest rate in the VAR framework. I retrieved 10-year government bond yield from the FRED database for each country. One of the purposes of unconventional policy is to reduce long-term interest rates through the purchase of assets. This identification allows the unconventional policy shock to be more specific to the policy.

[27] When I use monthly GDP data for the US retrieved from the Macroeconomic Advisor, the effect from the exogenous shock is statistically significantly positive, while the effect from the endogenous identification was insignificant (results not attached.)

Now the endogenous vector $y_t$ contains:

$$y_t = \begin{bmatrix} ln(IO_t) \\ ln(CPI_t) \\ LInt_t \\ ln(AT_t) \\ VOL_t \end{bmatrix} \tag{6}$$

where $LInt_t$ is the 10-year government bond yield. I impose an additional sign restriction so that a shock to central bank total asset decreases long-term interest rate. One caveat of this identification is that not all of the central banks aim at reducing long-term asset yields: such as in Japan where the main purpose of the Bank of Japan is the direct lending to banks. Therefore, this identification may not be suitable for Japan. The following is the identification:

$$\underbrace{\begin{bmatrix} u_{IO} \\ u_{CPI} \\ u_{LInt} \\ u_{AT} \\ u_{VOL} \end{bmatrix}}_{\substack{\text{Reduced form error} \\ u_t}} = \begin{bmatrix} * & * & 0 & 0 & 0 \\ * & * & 0 & 0 & 0 \\ * & * & * & - & * \\ * & * & * & + & + \\ * & * & * & -/0 & + \end{bmatrix} \underbrace{\begin{bmatrix} \epsilon_{IO} \\ \epsilon_{CPI} \\ \epsilon_{LInt} \\ \epsilon_{AT} \\ \epsilon_{VOL} \end{bmatrix}}_{\substack{\text{Structural error} \\ \epsilon_t}} \tag{7}$$

Figure 12 shows the results for the aggregate and durable goods manufacturing. The results for other industries are on the online appendix. As before, the red line represents the median response functions from the benchmark identification, while the blue line represents the median response functions from this identification. Credible bands from both specifications are shown.

For the US, the response functions from the benchmark identification and the new identification are qualitatively comparable. Generally, the effects of this identification are slightly smaller than the benchmark results: such as the aggregate, manufacturing, trade, information, real estate, etc. However, some of the industries' responses, such as healthcare or education, are not affected by the choice of identification.

The results for the UK also add additional support of this finding. The effects between the benchmark shock and the new shock are quantitatively and qualitatively even more similar than the results for the US. The aggregate effects are almost identical. While some industries, such as agriculture and construction, have responses that differ from the benchmark, the median response functions from the new identification is within the credible bands of the benchmark. Thus, the benchmark identification seems sufficient for the US and the UK. However, this shock does not seem to work work for Japan. The aggregate and durable goods manufacturing are both insignificant. This finding is consistent with the notion that the unconventional policy in Japan does not purposely seek to reduce the long-term asset yields.

#### 6.2.4 Unconventional Policy Shock with Interest Rate Spread

The main purpose of the Bank of Japan and the European Central Bank is direct lending to banks. The third identification is to capture this behavior following Boeckx et al. (2017). The identification is to include the spread between discount rate (ECB policy rate) and interbank rate. An exogenous shock, which involves direct lending to banks, stimulates the demand for bank reserves which then increases the interbank rate. Meanwhile, the discount rate is unchanged. Thus, an unconventional policy shock decreases the spread between discount rate and interbank rate. They add this identification on top of the Gambacorta et al. (2014) identification. Similar to the previous section, this identification is specific to the bank lending policy rather than a general measure of unconventional policy.

I retrieved interbank rates from FRED for each country and discount rate from the respective central banks. The endogenous vector $y_t$ is:

$$y_t = \begin{bmatrix} ln(IO_t) \\ ln(CPI_t) \\ Spread_t \\ ln(AT_t) \\ VOL_t \\ Policy_t \end{bmatrix} \tag{8}$$

The sign restriction is:

$$\underbrace{\begin{bmatrix} u_{IO} \\ u_{CPI} \\ u_{Spread} \\ u_{AT} \\ u_{VOL} \\ u_{Policy} \end{bmatrix}}_{\substack{\text{Reduced form error} \\ u_t}} = \begin{bmatrix} * & * & 0 & 0 & 0 & 0 \\ * & * & 0 & 0 & 0 & 0 \\ * & * & * & - & * & * \\ * & * & * & + & + & * \\ * & * & * & -/0 & + & * \\ * & * & * & 0 & * & * \end{bmatrix} \underbrace{\begin{bmatrix} \epsilon_{IO} \\ \epsilon_{CPI} \\ \epsilon_{Spread} \\ \epsilon_{AT} \\ \epsilon_{VOL} \\ \epsilon_{Policy} \end{bmatrix}}_{\substack{\text{Structural error} \\ \epsilon_t}} \tag{9}$$

The above identification works in the euro area, since the intention of ECB was to directly lend to banks and discount rate is the policy rate. However, this identification may not work for the countries in this paper. First a central banks policy rate can be interbank rate, which is true in both the US and Japan. Thus, bank lending behavior may not be captured. Second, some central banks do not seek to directly lend to banks. The unconventional policy in the US and the UK are to focus on purchasing long-term assets. Therefore, this identification is not likely to work in any of the countries used in this paper.

Figure 13 shows the results from the aggregate and durable goods manufacturing. The red line represents the median response functions from the benchmark identification, while the blue line represents the median response functions from this identification. Credible bands from the both specifications are shown.

The results for the US show that response functions are insignificant with broad credible bands and are very different from the benchmark results. The identification struggles to generate a clear shock. The results for the UK also suggest that this identification does not work for the country. In the UK, the discount rate is the policy rate and this identification is suitable in this sense. However, the aggregate and almost all of the industries show insignificant effects. Since the direct lending to banks is not a feature of the UK unconventional policy, the shock was not identified well. Lastly, the results for Japan also show that the shock is not identified well. The aggregate and almost all of the industries again show insignificant effects. Since the policy rate is the interbank rate in Japan, the identification is not able to correctly articulate the policy implemented in Japan. Based on the literature of unconventional policy, this shock seems to be suitable for the analysis in the Euro area. However, this identification is not suitable for the countries investigated in this paper.

### 6.3 Does Unconventional Policy Work During Non-ZLB Periods

While unconventional policy has only been used during ZLB periods, it also has the potential to be used during non-ZLB periods in future policy actions. During non-ZLB periods, conventional policy controls short-term nominal interest rates. However, unconventional policy tools such quantitative easing, credit easing, and forward guidance could potentially be used by themselves or combined with conventional policy to stimulate an economy during non-ZLB periods. An increase in the variety of policy options during future non-ZLB periods could be appealing to central banks if they are shown to be effective.

To study the effects of unconventional policy during non-ZLB periods, I identify unconventional policy shocks during non-ZLB periods. However, because I identify shocks using pre-2008 sample periods, there are some caveats. First, a change in the central bank total assets before ZLB periods almost exclusively comes from a change in short-term government security. Thus, effects of purchases of a different type of asset, such as long-term securities or corporate bonds, are not captured. Second, unconventional policy measures do not necessarily decrease the policy rate. Third, the degree of asset purchases between ZLB and non-ZLB periods are significantly different[28].

The sample periods are 1992M1-2007M12 for the US (only aggregate), 2000M1-2007M12 for the UK, and 1993M1-1999M12 for Japan based on data availability. The data are retrieved from the same sources as in Section 2 with exception to monthly GDP in the US which is retrieved from the Macroeconomic Advisers. The data are seasonally adjusted with exception to stock market volatility. The identification and estimation are the same as before.

Table 14 shows the national results. The red line represents the median response functions during the ZLB periods and the blue line represents the median response functions during non-ZLB periods. Since the central bank total assets have completely different magnitudes when they are estimated, I re-scale the non-ZLB response functions so that the shock has the same percent increase in central bank total assets.

Regarding the impacts on output, the effects are insignificant in the US and the UK. In Japan, the effect is significant, however, is smaller during non-ZLB than during ZLB. Regarding price, the effect is positive and stronger during non-ZLB in the US, insignificant in the UK, and negative but moves to the positive range in Japan. Generally, unconventional policy measure does not work well during non-ZLB periods, even though price in the US increases. Prior to 2008, the policy rate plays the main role for monetary policy and affects economic agents expectations and behaviors. Here, the identified shock does not inform us whether the rate increases, decreases, or stays the same. It seems that unconventional policy might not work well unless the policy rate decreases.

For industry results for the UK and Japan, the responses are heterogeneous, which is in line with the industry results of unconventional policy during ZLB periods. Some of the UK results are also in line with the results during ZLB in terms of magnitudes and signs of industries, such as with manufacturing and professional service. However, it is odd that some cyclical industries, such as construction and trade, do not respond positively. The results for Japan show that the effects are different by industries. Similar to the UK, cyclical industries such as construction and trade do not necessarily respond positively.

Based on the overall results, unconventional policy during non-ZLB does not seem effective for the aggregate. The effects are heterogeneous across industries. However, this is questionable since two different interest rate sensitive industries are affected in opposite ways; manufacturing is positively affected while construction is negatively affected.

Given these findings, I also investigate how well unconventional policy works when the policy rate is guaranteed to decrease. To investigate this, I include the respective policy rates (retrieved from FRED) in VAR for each country. I impose an additional sign restriction so that an unconven-

[28] As mentioned before, in the US the identified unconventional policy shock during the ZLB period was equivalent to an increase in central bank total asset of approximately $100 billion. However, the identified unconventional policy shock during non-ZLB periods is equivalent to approximately $5.6 billion. Both are one standard deviation shocks.

tional policy shock decreases the policy rate at the shock period. Although the identified shock decreases the policy rate, it is not an interest rate shock.

Figures in the online appendix show the results when the policy rate is included. Surprisingly, the inclusion of the policy rate does not change the results much. The aggregate response functions are still insignificant (except in Japan). The industry effects are weaker, however, are qualitatively very similar[29]. Thus, the inclusion of policy rate does not seem to change the effect of unconventional policy during non-ZLB periods, at least not during the pre-financial crisis periods.

# 7 Conclusion

This paper estimates the industry impacts of unconventional policy for the US, the UK, and Japan using a structural Bayesian VAR model. The industry response functions reveal some interesting features. First, unconventional policy stimulates industries heterogeneously. Among those responses, I find that unconventional policy strongly stimulates the finance industry, which is stressed in the literature on event studies. Second, industry responses are not very similar across countries, however, heterogeneous impacts of unconventional policy is similar to the heterogeneous impacts of conventional policy on average across countries. Third, higher working capital is associated with higher industry output responses, implying the relevance of the interest rate channel.

Given the potential decline of the natural rate of interest in highly advanced countries (Holston et al., 2017b), it is likely that the ZLB spreads to other countries and requires other central bankers to implement an unconventional policy. The results obtained in this paper provide some bottom line predictions for countries that have not yet experienced ZLB and aid central bankers in creating an unconventional policy. Lastly, this paper did not assess impacts across policies. This would be a great subject for future research.

[29]However, surprisingly, manufacturing industry in Japan responds negatively.

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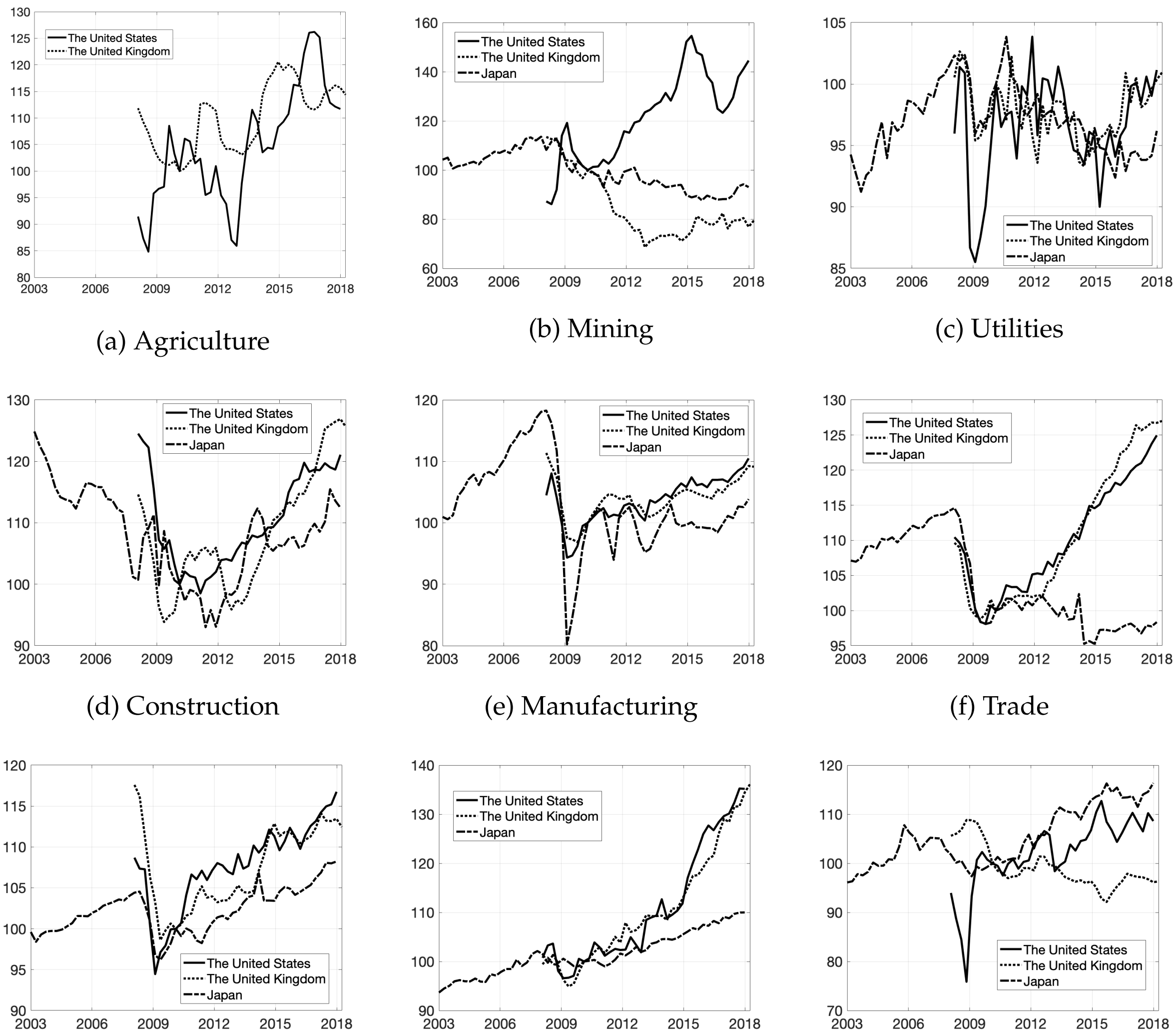
# Figures

Figure 1: Industry Output I




(a) Agriculture (b) Mining (c) Utilities

(d) Construction (e) Manufacturing (f) Trade

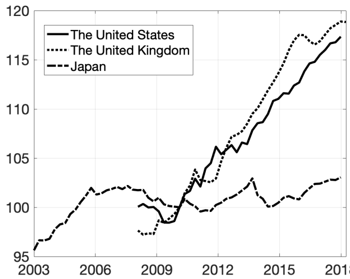
(g) Transportation (h) Information (i) Finance

Sources:

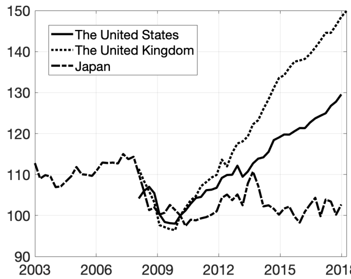
The Bureau of Economic Analysis (US), The Office for National Statistics (UK), and The Ministry of Economy, Trade, and Industry Analysis (Japan)

Note: All of the variables are normalized so that 2010Q1=100.

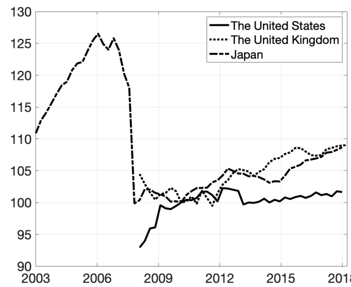
Figure 2: Industry Output II



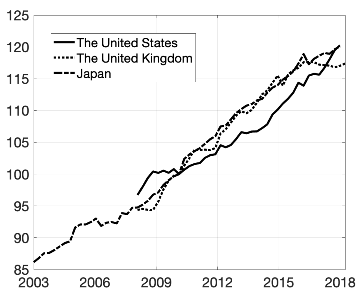

(a) Real Estate



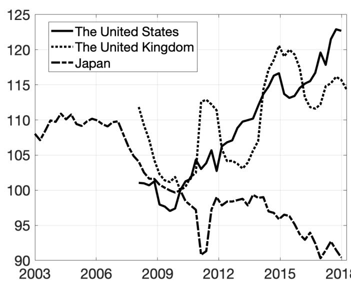

(b) Professional service



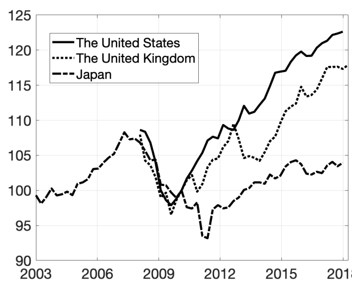

(c) Education



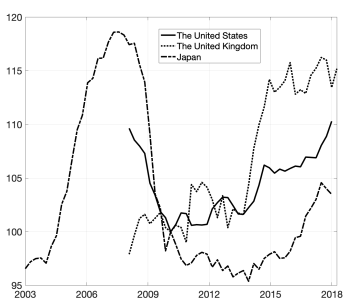

(d) Healthcare




(e) Arts, entertainment, and recreation



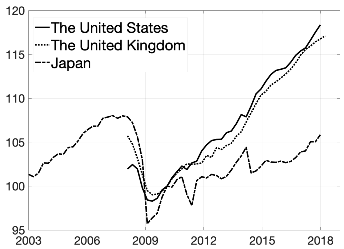

(f) Accommodation and food



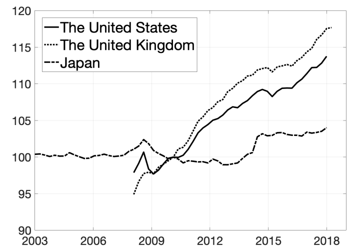

(g) Other services

Sources:
The Bureau of Economic Analysis (US), The Office for National Statistics (UK), and The Ministry of Economy, Trade, and Industry Analysis (Japan)
Note: All of the variables are normalized so that 2010Q1=100.

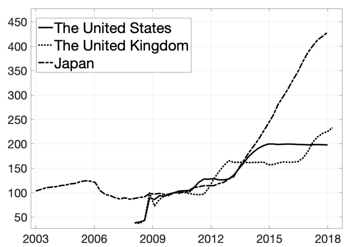
Figure 3: Aggregate Output, Consumer Price Index, Central Bank Total Assets, and Stock Market Implied Volatility



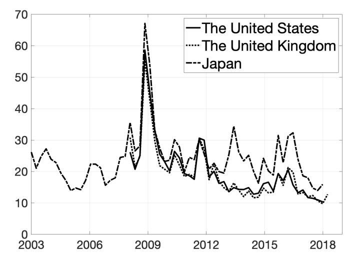

(a) Aggregate Output




(b) Consumer Price Index




(c) Central Bank Total Assets

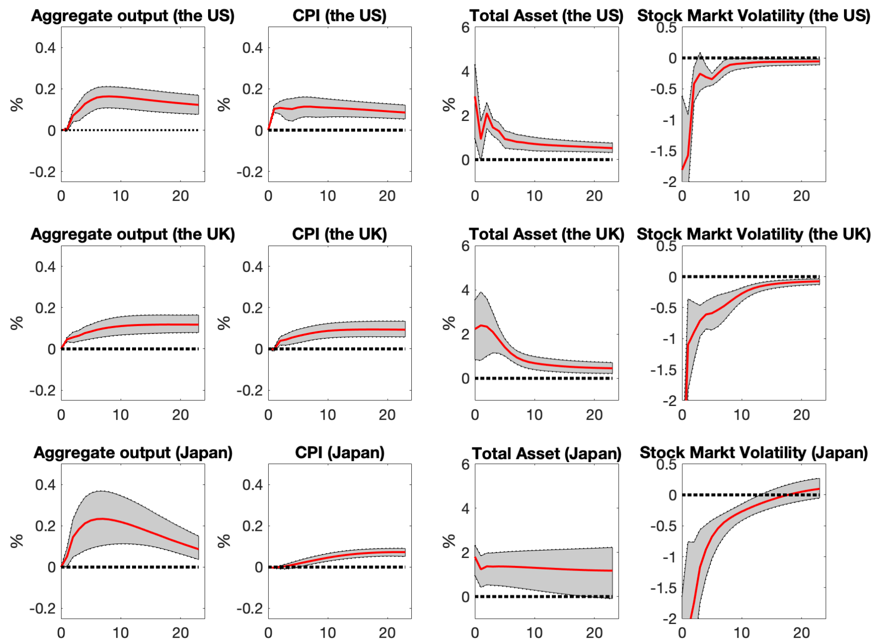



(d) Stock Market Implied Volatility

Sources:
Aggregate Output: the Bureau of Economic Analysis (US), the Office for National Statistics (UK), the Ministry of Economy, Trade, and Industry (Japan).
Consumer Price Index: the Bureau of Labor Statistics (US) and Datastream (UK and Japan).
Central Bank Total Assets: the FRED database (US), Bank of England (UK) and Datastream (Japan).
Stock Market Implied Volatility: the FRED database (US), Datastream (UK and Japan).

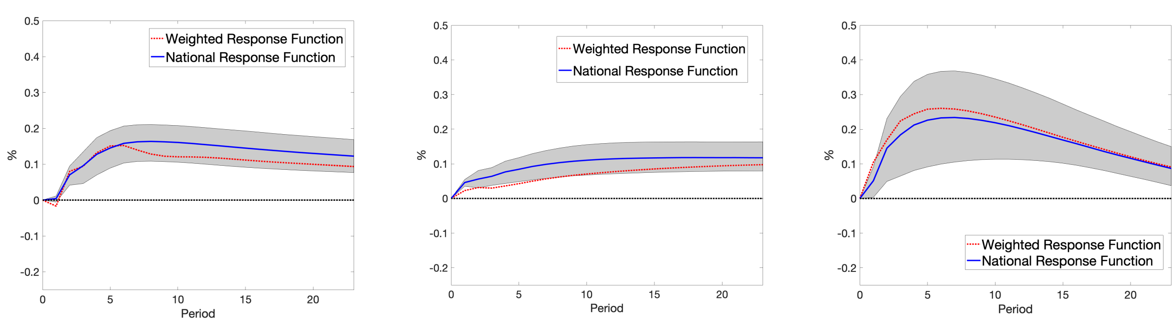
Note: All of the variables except stock market implied volatility are normalized so that 2010Q1=100.

Figure 4: National Impulse Response Functions




Note: The Median, 16th, and 84th Bayesian percentiles. Quarterly horizon (US) and Monthly horizon (UK and Japan).

Figure 5: Weighted Average of Industry Impulse Response Functions



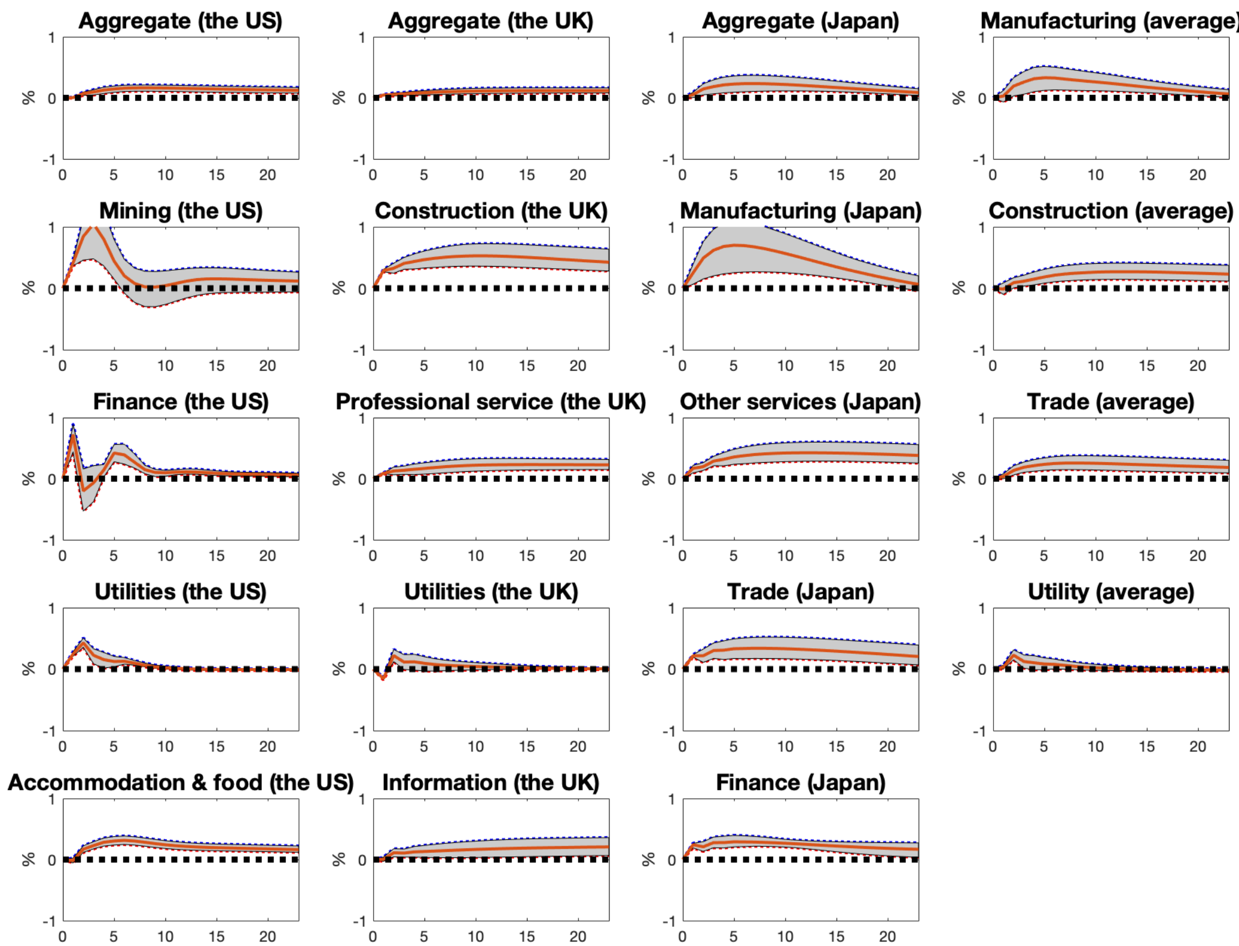

(a) The United States

(b) The United Kingdom

(c) Japan

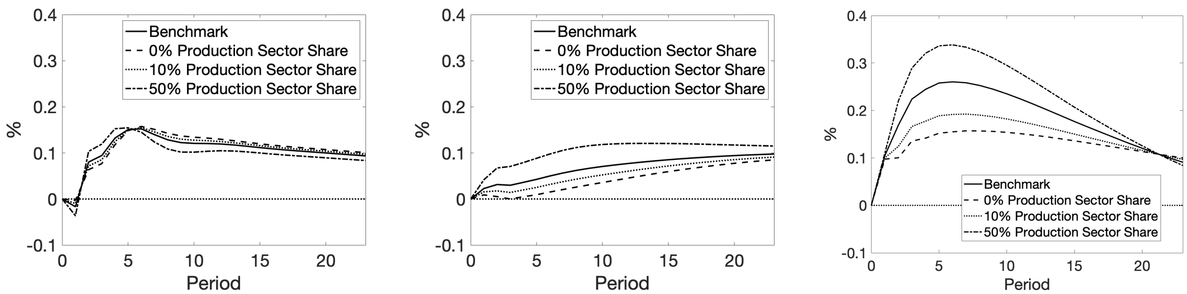
Note: (a) Quarterly horizon. (b), (c) Monthly horizon. The bold lines represent the national impulse response functions and the dotted lines represent the weighted impulse response functions. The credible bands are from the national impulse response functions.

Figure 6: Industry Impulse Response Functions




Note: The 1st column shows the results for the US (quarterly horizon), the 2nd column shows the results for the UK (monthly horizon), the 3rd column shows the results for Japan (monthly horizon), and the 4th column shows the results of the average of the three countries (mixed horizon). Responsive industries are selected. The Median, $16^{th}$, and $84^{th}$ Bayesian percentiles are reported.

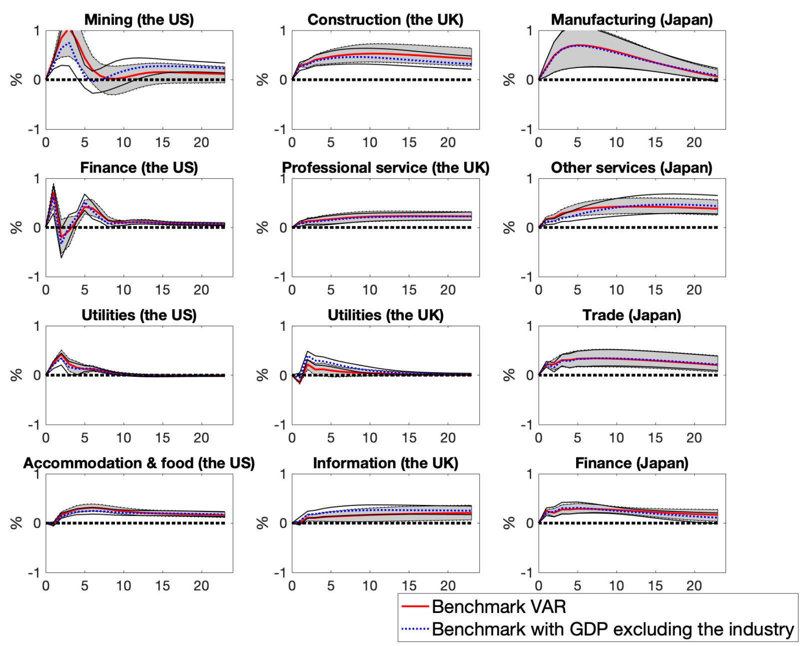
Figure 7: Weighted Impulse Response Functions with Counterfactual Industry Composition




(a) The United States (b) The United Kingdom (c) Japan

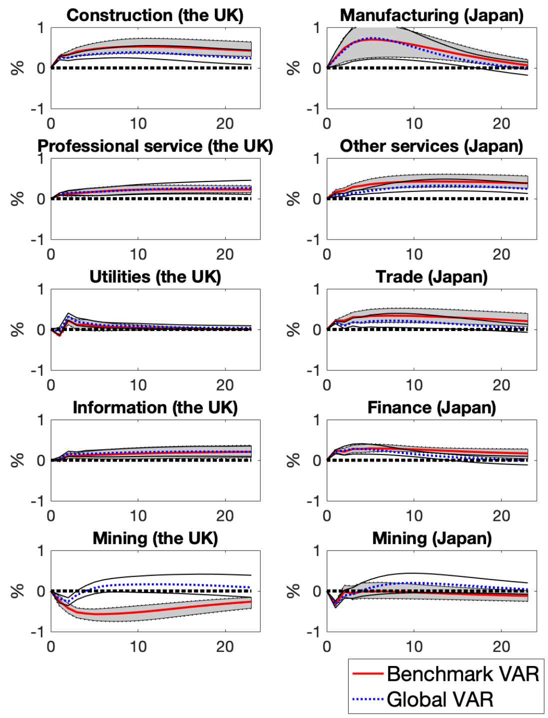
Note: (a) Quarterly horizon. (b), (c) Monthly horizon. Production sector consists of agriculture (except in Japan), mining, utilities, construction, and manufacturing.

Figure 8: Industry Impulse Response Functions with Aggregate Output Excluding the Industry



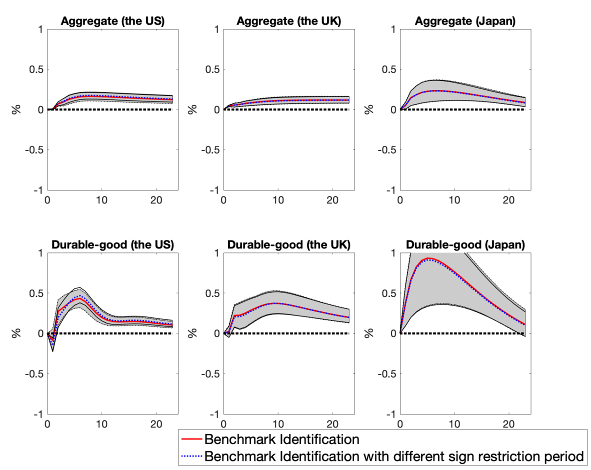

Note: The 1st column shows the results for the US (quarterly horizon), the 2nd column shows the results for the UK (monthly horizon), and the 3rd column shows the results for Japan (monthly horizon). Responsive industries are selected. The Median, $16^{\text{th}}$, and $84^{\text{th}}$ Bayesian percentiles are reported.

Figure 9: Industry Impulse Response Functions with GVAR



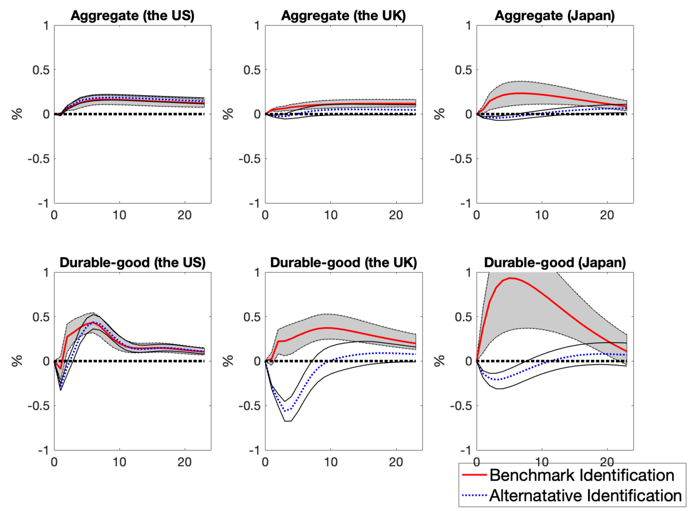

Note: The 1st column shows the results for the UK (monthly horizon) and the 2nd column shows the results for Japan (monthly horizon). Responsive industries are selected. The Median, 16th, and 84th Bayesian percentiles are reported.

Figure 10: Industry Impulse Response Functions with Different Identification Periods



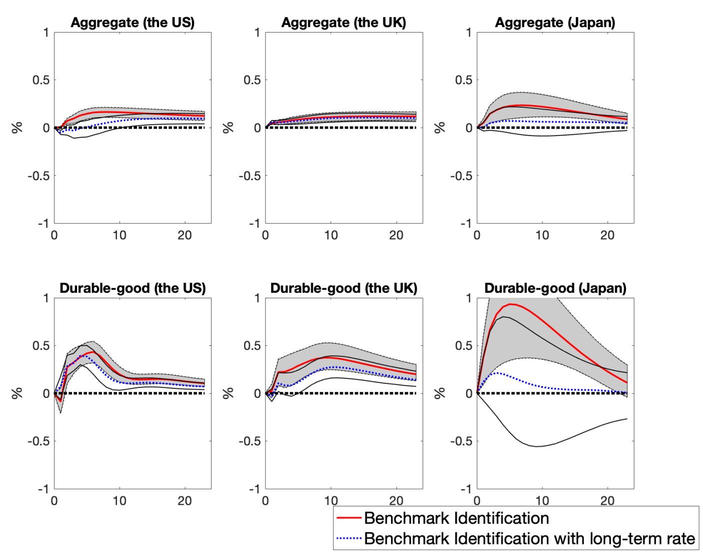

Note: The 1st column shows the results for the US (quarterly horizon), the 2nd column shows the results for the UK (monthly horizon), and the 3rd column shows the results for Japan (monthly horizon). The Median, 16th, and 84th Bayesian percentiles are reported.

Figure 11: Industry Impulse Response Functions with Alternative Identification



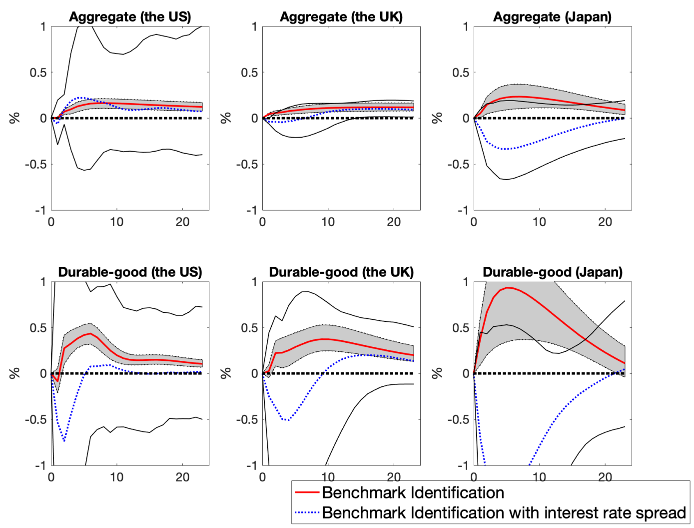

Note: The 1st column shows the results for the US (quarterly horizon), the 2nd column shows the results for the UK (monthly horizon), and the 3rd column shows the results for Japan (monthly horizon). The Median, 16th, and 84th Bayesian percentiles are reported.

Figure 12: Industry Impulse Response Functions with Long-term Interest Rate



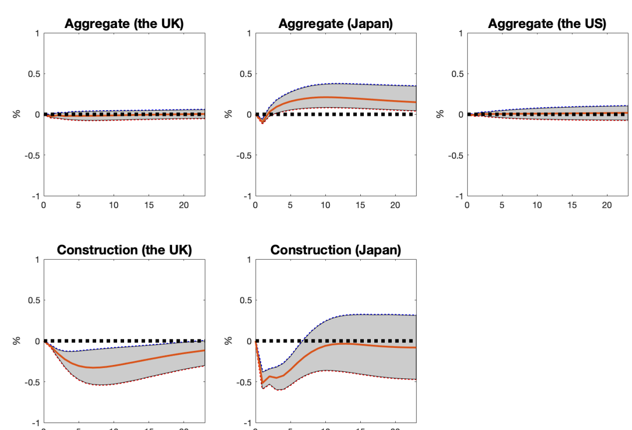

Note: The 1st column shows the results for the US (quarterly horizon), the 2nd column shows the results for the UK (monthly horizon), and the 3rd column shows the results for Japan (monthly horizon). The Median, 16th, and 84th Bayesian percentiles are reported.

Figure 13: Industry Impulse Response Functions with Interest Rate Spread




Note: The 1st column shows the results for the US (quarterly horizon), the 2nd column shows the results for the UK (monthly horizon), and the 3rd column shows the results for Japan (monthly horizon). The Median, 16$^{\text{th}}$, and 84$^{\text{th}}$ Bayesian percentiles are reported.

Figure 14: Industry Impulse Response Functions During Non-Zero Lower Bound




Note: The 1st column shows the results for the UK (monthly horizon), the 2nd column shows the results for Japan (monthly horizon), and the 3rd column shows the results from the US (monthly horizon). The Median, 16$^{\text{th}}$, and 84$^{\text{th}}$ Bayesian percentiles are reported.

# A Appendix

## A.1 Complete Description of Identification

The reduced form variance-covariance matrix, $\Sigma_u$, can be expressed as:

$$\Sigma_u = BB' = BI_4B' = BQQ'B' \tag{10}$$

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

$$Q = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & cos(\theta) & -sin(\theta) \\ 0 & 0 & sin(\theta) & cos(\theta) \end{bmatrix} \tag{11}$$

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

$$\underbrace{\begin{bmatrix} u_{SO} \\ u_{CPI} \\ u_{AT} \\ u_{VOL} \end{bmatrix}}_{\substack{\text{Reduced form error} \\ u_t}} = \underbrace{\begin{bmatrix} * & * & 0 & 0 \\ * & * & 0 & 0 \\ * & * & + & + \\ * & * & -,0 & + \end{bmatrix}}_{BQ} \underbrace{\begin{bmatrix} \epsilon_{SO} \\ \epsilon_{CPI} \\ \epsilon_{AT} \\ \epsilon_{VOL} \end{bmatrix}}_{\substack{\text{Structural error} \\ \epsilon_t}} \tag{2 revisited}$$

## A.2 Complete Description of Bayesian Estimation

First, I impose the priors of $vec(A)$ and $\Sigma_u$ to be independent and they follow the independent Gaussian-inverse Wishart distribution. The joint pdf is:

$$g(vec(A), \Sigma_u) = g_{vec(A)}(vec(A)) * g_{\Sigma_u}(\Sigma_u)$$

The distributions for $vec(A)$ and $\Sigma_u$ are:

$$vec(A) \sim \mathcal{N}(vec(A^*), V_{vec(A)})$$

and

$$\Sigma_u \sim \mathcal{IW}(S_*, n)$$

where $A^*$ is the OLS estimates, $S_* = I_4$, and $n = 5$. For the prior variance of the coefficients parameter, $V_{vec(A)}$, I impose the Minnesota prior. This enables the prior distribution to be tight and that is necessary to overcome the curse of dimensionarity, especially when estimating the global VAR model in Section 6.1.2. First, I set the prior variance of the intercept to be infinity and the prior variance of the $j, k^{th}$ elements of $A_i$ to be:

$$v_{jk,i} = \begin{cases} (\lambda/i)^2 & \text{if j=k} \\ (\lambda\alpha\sigma_j/i\sigma_k)^2 & \text{if j}\neq\text{ k} \end{cases} \tag{12}$$

where $\lambda = 0.2$ and $\alpha = 0.1$. $\sigma_j$ and $\sigma_k$ are obtained from equation by equation OLS estimates of the VAR model. Then $V_{vec(A)}$ is:

$$V_{vec(A)} = \begin{bmatrix} \infty & & & & & & & & & & & & \\ & \ddots & & & & & & & & & & & \\ & & \infty & & & & & & & & & & \\ & & & v_{11,1} & & & & & \mathbf{0} & & & & \\ & & & & \ddots & & & & & & & & \\ & & & & & v_{41,1} & & & & & & & \\ & & & & & & v_{12,1} & & & & & & \\ & & & & & & & \ddots & & & & & \\ & & & & & & & & v_{42,1} & & & & \\ & & & & & & & & & \ddots & & & \\ & & & \mathbf{0} & & & & & & & v_{11,2} & & \\ & & & & & & & & & & & \ddots & \\ & & & & & & & & & & & & v_{44,2} \end{bmatrix}$$

Now, the posterior distributions are:

$$vec(A)|\Sigma_u, \mathbf{y} \sim \mathcal{N}(vec(\bar{A}), \bar{\Sigma}_{vec(A)})$$

and

$$\Sigma_u | vec(A), \mathbf{y} \sim \mathcal{IW}(S, \tau)$$

where

$$\mathbf{y} = vec(Y) \quad \text{and} \quad Y = [y_1, \cdots, y_T],$$

$$vec(\bar{A}) = [V_{vec(A)}^{-1} + (ZZ' \otimes \Sigma_u^{-1})]^{-1}[V_{vec(A)}^{-1} vec(A^*) + (Z \otimes \Sigma_u^{-1})\mathbf{y}],$$

$$\bar{\Sigma}_{vec(A)} = [V_{vec(A)}^{-1} + (ZZ' \otimes \Sigma_u^{-1})]^{-1},$$

$$S = S_* + \sum_{t=1}^{T} (y_t - \mathbf{Z}_t vec(A))(y_t - \mathbf{Z}_t vec(A))',$$

and

$$\tau = T + n.$$

Moreover, $\Sigma_u$ is the OLS estimate, $\mathbf{Z}_t = Z_t \otimes I_4$ and $Z = [Z_0, \cdots, Z_{T-1}]$ with $Z_{t-1} = (1, y_{t-1}^{'}, y_{t-2}^{'})'$.

Here the posterior distribution of $vec(A)$ is conditional on $\Sigma_u$ and the posterior distribution of $\Sigma_u$ is conditional on $vec(A)$. Therefore, the Gibbs sampler is required to draw sample parameters from the joint posterior distribution. A burn-in sample of 20,000 draw is discarded following the literature[30] and then the following steps are taken to generate response functions.

**Step 1:** Draw reduced form parameters $\nu^{*r}$, $A_i^{*r}s$, and $\Sigma_u^{*r}$ and compute the Cholesky decomposition of $\Sigma_u^{*r}$.

**Step 2:** For each $\nu^{*r}$, $A_i^{*r}s$, and $\Sigma_u^{*r}$, draw N random Given's rotation matrix, $Q^{i \in N}$. For each combination of $\nu^{*r}$, $A_i^{*r}s$, $\Sigma_u^{*r}$, and $Q^i$, calculate the response function.

**Step 3:** If the response function satisfies the sign restriction on Table 1 in Section 3.2, keep it. Otherwise, discard the response function.

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

Here N = 1000 and M = 1000. 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.

### A.3 Complete Description of GVAR estimation

For each industry $i$ of a country, I model a VARX($p_i, q_i$):

$$y_{i,t} = c_i + \sum_{j=1}^{p_i} A_{i,j} y_{i,t-j} + \sum_{j=0}^{q_i} B_{i,j} y_{i,t-j}^* + \sum_{j=0}^{q_i} C_{i,j} x_{t-j} + u_{i,t} \tag{13}$$

where $c_i$ is a vector of intercepts; $A_{i,j}$, $B_{i,j}$, and $C_{i,j}$ are coefficient matrices; $u_{i,t}$ is white noise with nonsingular covariance matrix $\Sigma_{i,i}$; $y_{i,t}$ consists of domestic variables (i.e. a vector of output industry $i$ at time $t$); $y_{i,t}^*$ contains foreign variables (i.e. a vector that consists of non industry $i$ output); and $y_{i,t}^*$ is constructed as a weighted average of domestic variables $\forall j \neq i$:

$$y_{i,t}^* = \sum_{j \neq i} w_{i,j} y_{j,t} \qquad \sum_{j \neq i} w_{i,j} = 1 \tag{14}$$

[30] I also calculate the Geweke convergence criteria (Geweke et al., 1991) and almost all of the parameters converged before 4,000 draws

The weight, $w_{i,j}$, is assumed to be constant during the estimation periods. Traditionally bilateral trade flow is used (for example Vansteenkiste and Hiebert, 2011; Galesi and Lombardi, 2009) since GVAR models are often used for assessing international spillover effects. However, since the focus is on industry level interaction, I use 2016 IO table for the UK and 2015 IO table for Japan for the weight[31].

The vector $x_t$, common variable, is the same across industries and has the following VARX $(p_x, q_x)$ specification:

$$x_t = c_x + \sum_{j=1}^{p_x} D_j x_{t-j} + \sum_{j=0}^{q_x} F_j \tilde{y}_{t-j} + u_{xt} \tag{15}$$

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 GDP share of industry $i$.

Given the specifications of equation (13) and exploiting the fact that $y_{i,t}^* = W_i y_t$, where $W_i$ is a link matrix based on the IO table and $y_t = [y'_{1,t}, y'_{2,t}, ..., y'_{I,t}]'$, equation (13) can be transformed to:

$$G_{i,0} y_{i,t} = c_i + \sum_{j=1}^{p_i} G_{i,j} y_{i,t-j} + \sum_{j=0}^{q_i} C_{i,j} x_{t-j} + u_{i,t} \tag{16}$$

where $G_{i,0} = (I - B_{i,0} W_i)$ and $G_{i,j} = (A_{i,j} + B_{i,j} W_i)$. Now we stack all of the industries together to get:

$$G_0 y_t = c + \sum_{j=1}^{p} G_j y_{t-j} + \sum_{j=0}^{q} C_j x_{t-j} + u_t \tag{17}$$

Likewise, using the fact that $\tilde{y}_t = W^* y_t$, where $W^*$ is a link matrix based on the industry GDP share, equation (15) becomes:

$$x_t = c_x + \sum_{j=1}^{p_x} D_j x_{t-j} + \sum_{j=0}^{q_x} F_j W^* y_{t-j} + u_{xt} \tag{18}$$

By combining equations (17) and (18), we can construct a structural Global VAR model:

$$H_0 Z_t = h_0 + \sum_{j=1}^{p} H_j Z_{t-j} + e_t \tag{19}$$

where $Z_t = (y'_t, x'_t)'$, $H_0 = \begin{bmatrix} G_0 & -C_0 \\ -FW^* & I \end{bmatrix}$, $h_0 = \begin{bmatrix} c \\ c_x \end{bmatrix}$, $H_j = \begin{bmatrix} G_j & C_j \\ F_j W^* & D_j \end{bmatrix}$, and $e_t =$

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

$\begin{bmatrix} u_t \\ u_{xt} \end{bmatrix}$. Finally, $e_t$ has the variance-covariance matrix $\Sigma = \begin{bmatrix} \Sigma_{i,j} & \Sigma_{i,x} \\ \Sigma_{x,i} & \Sigma_{x,x} \end{bmatrix}$

Assuming that $H_0$ is invertible. Then we obtain the reduced form Global VAR $(p)$ model:

$$Z_t = k_0 + \sum_{j=1}^{p} K_j Z_{t-j} + \nu_t \tag{20}$$

where $k_0 = H_0^{-1}h_0$, $K_j = H_0^{-1}H_j$, and $\nu_t = H_0^{-1}e_t$.

To estimate the model, I impose $p_i = p_x = q_x = 2$ and $q_i = 0$ so that the estimation is consistent with Burriel and Galesi (2018) and the benchmark specification[32]. I define $y_{it} = IO_{it}$ and $x_t = [CPI_t \quad AT_t \quad VOL_t]'$. Hypothetically, directly estimating equation (20) is ideal, however, given the limited sample size and the number of the parameters to be estimated, it is inevitable to face the curse of dimensionality. To circumvent this problem, I follow the conventional way to estimate a GVAR: estimate the domestic equation (13) and the common equation (15) individually using OLS. Finally, the identification and the Bayesian inference is the same as in Section 3.3 except that this estimate is the mean of the parameters of the prior distribution.

[32]This specification is a VAR model where the endogenous vector contains all of the industry output as well as CPI, central bank total asset, and stock market implied volatility with two lags