Sectoral Effects of Unconventional Monetary Policy Under ZLB and its Cross-Country Implications*

Eiji Goto†

July 31, 2019

(click here for the most recent version)

Abstract

While the real effect of unconventional monetary policy is broadly confirmed, how the effect is decomposed into individual sectors and how the observed patterns differ across countries is not yet known. I use an impulse response function from an estimated structural vector autoregressive model with sign and zero restrictions to estimate the impact of unconventional monetary policy shock on sectoral output and employment under the zero lower bound (ZLB). I do so to investigate the sectoral responses from unconventional monetary policy and its cross-country comparison (the US, the UK, and Japan). The sectoral results using a Bayesian inference show substantial heterogeneity. I find that the policy stimulates the finance sector (except in the UK), that the differential effects of unconventional monetary policy is similar to those in the conventional monetary policy literature, and that the manufacturing sector shows a higher response than the sectors in services (both for output and employment). The last observation suggests a usefulness of policy mix due to fiscal policy generally stimulating the service sector more than the manufacturing sector. The existence of ZLB does not necessarily alter the monetary policy transmission mechanisms and interest rate sensitive sectors are strongly affected by the policy, which implies that policy channels that influence real interest rate, such signaling channel, play an important role under unconventional monetary policy. These findings are similar across the investigated countries and they may provide a better understanding and anticipation of how unconventional monetary policy affect individual sectors for policy makers.

JEL: E32, E51, E52

Keywords: Unconventional Monetary Policy, Structural Vector Autoregressive Models, Sectoral Output

*I am very thankful to my advisor Tara Sinclair for her valuable guidance and support. I also thank Saroj Bhattarai, Michael Bradley, Frederick Joutz, Pamela Labadie, Chandler Lutz, and Roberto Samaniego for their great comments and feedback. Lastly, I thank participants at 13th Economics Graduate Student Conference at Washington University in St. Louis, 45th Eastern Economic Association Conference, 3rd GW Student Research Conference in Economics 2019, Georgetown Center for Economic Research 2019 Conference, 2019 Pennsylvania Economic Association Conference.

† *The George Washington University, 2115 G Street, NW, # 340, Washington, DC 20052*

1 Introduction

Conventionally, a monetary authority manipulates the nominal short-term interest rates to stimulate the economy and stabilize prices. However, once an economy enters the Zero Lower Bound (ZLB), there is very limited room to reduce the policy rate[1]. When the monetary policy rates reach at or near zero, the central banks in highly advanced economies adopt unconventional monetary policy. The purpose of the central banks is to maintain low inflation rate, to promote economic growth, and to stabilize the financial markets. While the current literature overall confirms the effects of unconventional monetary policy on the financial market (for example, Gagnon et al., 2011; Krishnamurthy and Vissing-Jorgensen, 2011; Neely, 2015) and on the aggregate macroeconomic variables (for example, Gambacorta et al., 2014; Bhattarai et al., 2015a), the effects to the individual sectors are not yet known. In this paper, I investigate the sectoral effects of unconventional monetary policy in the US, the UK, and Japan.

Understanding the distributional effects of unconventional monetary policy and what channels cause the difference is important for economics agents. As was mentioned above, unconventional monetary policy has been shown to increase national GDP and price level[2], but that does not necessarily imply that everyone is better off. In the conventional monetary policy literature, interest rate sensitive sectors, such as construction and manufacturing, tend to have larger responses than the national average (for example, Ibrahim, 2005). The conventional monetary policy literature provides benchmark results of how the effects are different across sectors due to mainly this interest rate channel. By studying the sectoral effects of unconventional monetary policy, I observe the similarity and difference of the sectoral responses compared to the effects of conventional monetary policy in the literature, which will also provide implications of potential channels through which unconventional monetary policy works. Given the large volume of quantitative easing[3],it is crucial for central bankers to take into account these heterogeneous responses in order to better understand through what channel how quantitative easing works and in order not to bring about unexpected negative outcomes. In this paper, I use sectoral level data to shed light on the monetary transmission mechanism under unconventional monetary policy which may be lost with aggregation.

It is also of interest to compare the patterns across countries. It has been shown in the literature that the responsiveness of unconventional monetary policy varies across countries (for example Gambacorta et al., 2014). It could be due to some countries possessing sectors which are more responsive than the international averages or some countries possessing uniformly responsive sectors.

[1]Negative interest rate policy allows nominal interest rate to be below zero, while the range of negative interest rate implemented is minimal.

[2]However, there are some skepticism of the effectiveness, such as Greenlaw et al. (2018)

[3]For example, from 2008 to 2014 the Federal Reserve more than quadrupled the size of its balance sheet.

If the first case is true, the monetary transmission mechanism may vary across countries and sectoral heterogeneity obtained in highly advanced economies may not necessarily be helpful to other central banks when planning policies. They need to carefully assess the differential effects when they operate the policy since the determinants of effectiveness varies across countries. If the latter case is true, sectoral characteristics are similar across countries with regard to the disparities in the economic situation and state. For example, manufacturing is a responsive sector for any country. In this case, it is likely that some macroeconomic determinants play a roll when it comes to cross-country heterogeneity, and this is helpful for other central bankers to know so that they can understand how unconventional monetary policy transmits to the economy.

This paper contributes to the literature of monetary transmission mechanism and sectoral characteristics by investigating the sectoral effects of unconventional monetary policy and providing the cross-country differences of the observed sectoral heterogeneity. To investigate this, I adapt an impulse response function from an estimated structural vector autoregressive model with zero and sign restriction as in Gambacorta et al. (2014). I use monthly sectoral data for the UK and Japan and quarterly data for the US to individually estimate the model for each country and each sector. By generating the impulse response functions using a Bayesian inference, I will uncover the sectoral responses to unconventional monetary policy and observe the cross-country variations.

My national results for these countries are overall comparable with the individual estimates found in Gambacorta et al. (2014) and the effects on output are positive and significant despite that estimation method, sample periods, and data frequency are different. However, the shapes of the impulse response functions are not similar to the ones in Gambacorta et al. (2014). This seems likely due to the difference in Bayesian and frequentist inferences.

The sectoral results reveal some insight of unconventional monetary policy. First, the effect of the financial sector was significantly positive and higher than the national averages (except in the UK). This observation is in line with the event study literature which stresses the importance of the financial sector. Second, heterogeneous sectoral responses in the conventional monetary policy literature generally apply to my sectoral output results suggesting that the existence of ZLB does not necessarily alter the monetary transmission mechanisms. Third, the manufacturing sector responds to the shock strongly, while the sectors in services respond weakly. This pattern was also observed when sectoral employment data was used.

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

2 Literature Review

This paper studies the sectoral effects of unconventional monetary policy. There is a large volume of literature investigating the heterogeneous impacts of conventional monetary policy and its monetary transmission mechanism. The heterogeneity typically studied in the literature are sectors and regions. They generally employ an impulse response function from a structural vector autoregressive (VAR) model with Cholesky decomposition to identify the effect of monetary policy in the spirit of Christiano et al. (1999).

Dale and Haldane (1995) initiates the literature of sectoral effects of monetary policy and shows that the industrial sector has larger and quicker responses than the retail trade sectors in the UK. Ganley and Salmon (1997) also adapt the UK data of 24 different industries to investigate the effects of monetary policy and find that the durable goods manufacturing, construction, and distribution sectors display strong responses while the agriculture sector reveals a poor reaction to the shock. The literature of sectoral effects of an interest rate shock exists not only for the UK economy but also for other economies: Dedola and Lippi (2005) consider 5 OECD countries, Ibrahim (2005) examines Malaysia, Alam and Waheed (2006) study Pakistan, Ghosh (2009) studies India, and Hayo and Uhlenbrock (2000) investigate Germany. Among these analyses, the durable goods manufacturing sector is very sensitive to monetary policy. Some of those studies find that the construction, finance and insurance, and wholesale and retail trade sectors are also responsive. On the other hand, the agricultural sector is not a responsive sector. Conventional monetary policy manipulates the short term interest rates, and thus interest rate sensitive sectors tend to react to the shock more (interest rates channel). Those sectors include the durable goods manufacturing, construction, and finance sectors. The findings above overall favor this channel of monetary policy despite that there are some sectors which are responsive but not generally interest rate sensitive, such as wholesale or retail trade. This implies other channels play an important role in the transmission mechanism[4].

On the other hand, Carlino and DeFina (1998) examine the effects of monetary policy in 8 regions in the US. They find that there are some areas that are more responsive (such as the Great Lakes region) and some that are less responsive (such as the South West and Rocky Mountain regions) than the US average. They also show that the regional responsiveness is positively correlated to the share of the manufacturing sector in the district. Similarly, Arnold and Vrugt (2002) measure regional impact for 11 areas in the Netherlands and find that regions with higher construction sectors respond to the shock to a greater extent. Arnold and Vrugt (2002) argue that sectoral heterogeneity is more substantial in magnitude than regional heterogeneity. Their results indicate that the share in the manufacturing or construction, which is an interest rate responsive sector,

[4] Such as credit, exchange rate, and assets price channels.

determines the monetary policy sensitivity. This then implies that the main regional heterogeneity comes from the sectoral composition. Regional effects can be inferred from the sectoral composition in the area, while the reverse is not true. Therefore, investigating the sectoral effect rather than the regional effect of monetary policy will provide a better picture of transmission mechanisms.

Sectoral analysis is not only a common practice in monetary policy literature but also in other macroeconomic fields. For example, in the fiscal policy literature, it is documented that the non-tradable goods sectors (roughly service sectors) are more responsive to the policy than tradable good sectors (roughly manufacturing sectors) (for example Bénétrix and Lane, 2010; Monacelli and Perotti, 2008). Even though disaggregation is coarse[5], the results mildly disagree with the monetary policy literature. On the contrary, the news shock literature shows similar sectoral characteristics as the monetary policy literature. Vukotic (2017) finds that a shock to the future TFP will increase the current TFP of durable goods manufacturing sectors more than non-durable goods manufacturing sectors. It is of interest to compare these studies to how unconventional monetary policy affects individual sectors.

When an economy gets close to the ZLB, there is no margin for further decline in short-term nominal interest rates and the central banks need to influence the economy through unconventional monetary policies. Unconventional monetary policy envelops a wide range of instruments, including quantitative easing (QE) and forward guidance. While each major central banks operate the policies somewhat differently[6], their purpose is to alleviate the financial market stress and promote economic growth (Fawley et al., 2013).

There is a large volume of empirical literature investigating the announcement effects of QE on the financial market using high frequency data (such as Gagnon et al., 2011; Hancock and Passmore, 2011; Krishnamurthy and Vissing-Jorgensen, 2011; Chodorow-Reich, 2014; Lucas and Vissing-Jorgensen, 2014; Neely, 2015). These event studies show that the Federal Reserve's large-scale asset purchases mitigate the medium and long-term yields of various assets. The mechanism is that asset purchases reduce the long-term bond supply and mitigate the yields of other assets that possess similar characteristics (such as maturity) through the portfolio balance channel[7]. These lower yields of securities increase the value of assets held and improve the financial market condition (Chodorow-Reich, 2014). These results suggest that in my VAR framework, I should expect a rise in financial market activity to the unconventional monetary policy shock.

Due to the difficulty of identification strategy, there are only a few examples of empirical litera-

[5]If one disaggregates the sectors finer, the results may be different.

[6]The Federal Reserve and the Bank of England focuses on purchasing long term securities, while the Bank of Japan and the European Central Bank mainly operates the direct lending to banks (Fawley et al., 2013).

[7]The central bank purchases reduce the supply of the security. Public investors shift their portfolio toward other assets whose characteristics (risk or maturities) are similar. This will reduce the yields of these assets as well.

ture examining the impact of unconventional monetary policy on macroeconomic variables. Bhattarai et al. (2015a) study the spillover effects of the US unconventional monetary policy. They use the central bank securities held outright and the long-term interest rates to identify the unconventional monetary policy shock. Using Bayesian panel VAR, they show that the identified shock will increase industrial production as well as price level in the US. They then use a panel VAR to uncover strong spillover effects on emerging economies. They find that the US unconventional monetary policy reduces the US exchange rate and long-term interest rates as well as increases the stock prices and capital flows for those emerging countries.

In the sense that I am trying to uncover the heterogeneous impact of monetary policy, this paper is in line with Burriel and Galesi (2018). In their paper, they study the differential impact and spillover effects of unconventional monetary policy on euro area countries. They find that there is a high degree of heterogeneous responses across countries and there is also a large spillover effect among them. Additionally, they find that the effects of the policy are related to the strength of the banking sector. They follow the identification strategy from Gambacorta et al. (2014).

My paper is closest to Gambacorta et al. (2014) since I follow their identification strategy and examine the cross-country differences. They use the implied stock market volatility and central bank assets to identify the unconventional monetary policy shock. They then estimate a panel VAR to investigate the effect of unconventional monetary policy for highly advanced economies. They discover that the identified shock increases output and prices of these countries. My main focus is to see the heterogeneous responses of unconventional monetary policy within a country and to look at the cross-country differences from the sectoral perspective instead of from an aggregate point of view.

Even though the impacts to the overall economy and financial market are known in the literature, how everything else responds to the policy is not yet known. This paper fills the gap and contribute to a deeper understanding of transmission mechanism of unconventional monetary policy and sectoral characteristics. Additionally, by comparing the sectoral heterogeneity in several countries, this paper also provides implications of sectoral heterogeneity in the international dimension.

3 Data

I analyze the following countries: the US, the UK, and Japan[8]. Based on data availability, the US is of quarterly frequency while the Japanese and UK data are of monthly frequency. The datasets

[8] I exclude the countries in the Euro area since these countries tend to experience strong spillover effects (Burriel and Galesi, 2018) and spillover effect from other countries is out of the scope of this paper.

cover 2008Q1-2017Q4 for the US, 2008M1-2018QM6 for the UK, and 2003M1-2018M2 for Japan. I chose these ranges based on when these central banks operate unconventional monetary policy and when the policy rates are generally below 1, representing the ZLB.

My VAR framework consists of the following four endogenous variables: sectoral output (SO), consumer price index (CPI), central bank total assets (AT)[9] and stock market implied volatility (VOL). These variables, excluding VOL, are seasonally adjusted.

The sectoral output data for the US is real value added and is obtained from the Bureau of Economic Analysis. The UK and Japanese output data are 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[10], I provide a brief description. The series is quantity index and is made to systematically understand the production activities of the various sectors in Japan. The series is of monthly frequency and is available with relatively short time lags[11]. The base year is 2010 which takes the value of 100. For each industry, main products that represent the sector are chosen and the index represents the transitions of quantitative fluctuations of those selected products within the sector. The selected products cover a relatively large share in the sector. For example, for Indices of Industrial Production, the selected products are chosen so that they account for 90% of the aggregate values of the industry.

Figures 1, 2, and 3 represent the sectoral output for each country. The US and UK data are normalized so that the first period of 2010 is 100. For the US, the over all movement is an upward trend. However, the movements of some sectors, such as mining, agriculture, and utilities are quite different and idiosyncratic compared to this trend. For the UK, most sectors also exhibit slight upward movement, and there are also some sectors that behave differntly such as mining and utilities. On the contrary, sectors in Japan behave differently compared to these two countries. Their behaviors do not show a consistent trend. For example, health care and social assistance increases its activity, food and accommodation stays at about the same level, and utilities decreases its activity. Also for a motivational purpose, I plotted the sectoral share of GDP in 2016 for each country in Appendix B (Figures B.1, B.2, and B.3). I also plot the aggregate output, CPI, AT, and VOL series in Figure 4[12]. To combat the financial crisis, these countries implemented unconventional monetary policy and increased the total assets in an unprecedented degree: all of the central banks more than

[9] 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.

[10] Though it was used in Du et al. (2010) and Shintani (2005)

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

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

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 show as much of a rise in these variables. In this paper, I will investigate whether unconventional monetary policy contributes to these rises in aggregate output, whether there exists any heterogeneity in sectoral output, and whether the pattern of heterogeneity is similar across these countries.

There are several limitations of the datasets. First, unlike the US and UK datasets that provide comprehensive coverage of 17 sectors, the sectors in the Japanese datasets are not perfectly comprehensive since the agriculture, government, and other service sectors are excluded. 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)[13]. The quarterly data and limited ZLB periods will provide a small sample period of 40 in the US, while the Japanese data covers a large sample period of 182, thanks to the prolonged ZLB periods. Finally, even though the UK and Japanese data have a bigger sample size, the indices do not cover the comprehensive goods and services of the sector. That is, the series does not capture the entire, but rather, a highlighted movement of the individual sectors.

Lastly, the following is the complete set of sectors examined in this paper: agriculture (excluding Japan); mining; utilities; construction; manufacturing (also durable goods and non-durable goods); wholesale and retail trade; transportation; information; finance and insurance; real estate; professional and business; educational service; healthcare and social activity; arts, entertainment, and recreation; accommodation and food; other services (excluding Japan); and government (excluding Japan).

4 Methodology

Structural VAR models have been widely used for studying an effect 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 monetary policy shock, generate impulse response functions, and assess the sectoral effects. Section 4.1 describes the model, Section 4.2 states the identification, and Section 4.3 depicts the estimation and inference.

4.1 The Empirical Model

I estimate the following VAR (p) model:

[13]They use the interpolation method (Chow and Lin, 1971) to generate a monthly GDP. However, in order to implement this method, I would need relevant monthly frequency data for each sector's output.

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

where p is the number of lags, y_t is a column vector of endogenous variables, ν is a column vector of intercept terms, A_is are coefficient matrices, and u_t is white noise with nonsingular covariance matrix Σ_u. In this paper, y_t consists of the following variables: log of sectoral output (SO_t), log of consumer price index (CPI_t), log of central bank total assets (AT_t), and stock market implied volatility (VOL_t).

Output variables are not first differenced, following Gambacorta et al. (2014) and the standard monetary policy literature (for example, Christiano et al., 1999; Ibrahim, 2005). However, there are some papers in which the authors take the first-difference of the output (for example Arnold and Vrugt, 2002; Carlino and DeFina, 1998). According to Ramaswamy and Sløk (1998), impulse response functions generated from first differenced VAR models tend to show a permanent effect of monetary policy, while impulse response functions generated from level VAR models do not necessarily possess those results. It is not appropriate to presume a permanent effect of monetary policy. Therefore, I use the system of level variables in this paper.

These 4 variables are intended to capture the minimal dynamics of macroeconomics and to identify the unconventional monetary policy shock. As is standard in the monetary policy literature, sectoral output and CPI are in the system to ensure the macroeconomic and sectoral dynamics. While sectoral output itself may not necessarily summarize the aggregate dynamics, I will add aggregate output less the sectoral output in the system in the robustness check to examine whether or not the results will change.

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. There are a few other unconventional monetary policy instruments in the literature, such as long-term nominal interest rate (Gilchrist et al., 2015) and mortgage spread (Walentin, 2014). These variables are straightforward to apply in the structural VAR framework with simple identification. Long-term interest rate can capture the Federal Reserve and Bank of England's long-term security purchases. However, as mentioned earlier, not all of the central banks homogeneously purchased long-term assets. For example, the Bank of Japan carried out the direct lending to banks (Fawley et al., 2013), which is not captured by the long-term interest rate. Mortgage spread is only suitable for analyzing the US economy. The other countries did not directly experience housing crush and thus did not experience the huge hike of the spread. It is difficult to summarize comprehensive effect of unconventional monetary policy into the spread itself.

Central bank total assets can capture the broad range of unconventional monetary policy and can compare the effects of monetary policy across countries of different states and situations. However, this will obviously have some shortfalls. First it will not differentiate the policies. For example, the Federal Reserve's QE1 was mainly to purchase the mortgage-backed securities and agency securities, but the policies after QE2 were 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 did not increase the central bank assets. For example, Operation Twist by the Federal Reserve is not captured in this framework. This policy was 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.

Finally, stock market implied volatility is in the framework to represent financial 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.

4.2 Identification

I follow the identification of 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):

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

where the components of ϵ_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 sectoral output and price. In other words, unconventional monetary policy has at most a lagged impact on output and prices. This zero restriction is a standard assumption and analogous to the Cholesky decomposition in the monetary policy literature.

In order to identify an unconventional monetary policy shock, I apply a short run sign restriction. A shock to the central bank total assets will not increase the stock market volatility. This notion is consistent with the literature that unconventional monetary 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). However, a shock to stock market volatility will increase the central bank total assets. The central banks respond to financial turmoil and economic uncertainty by unconventional monetary policy. Additionally, shocks to central bank assets and stock market volatility will increase their own variables. Because of these conditions, it is possible to disentangle an innovation to unconventional monetary policy from the endogenous response to the financial condition and uncertainty. Without the stock market implied volatility term, one could not differentiate these two distinct effects. Next, a shock to the stock market volatility does not have any contemporaneous impact on output and price when including the stock market implied volatility. Alternatively, shocks to output and price do have contemporaneous effects on central bank assets and stock market volatility.

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. 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 my 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 will relax this assumption in the robustness check to examine how the results are affected.

The following table summarizes the restrictions that I imposed[14].

Table 1: Sign Restriction

	all countries at period = 0	the US at period = 1	the UK & Japan at period = 1
SO	0	*	*
CPI	0	*	*
AT	>0	*	>0
VOL	≤0	*	≤0

4.3 Estimation and Inference

I estimate the reduced form VAR model using the OLS for each sector and for each country. The estimation includes 2 lags of endogenous variables by following Gambacorta et al. (2014). Next, I use the OLS estimates for Bayesian inference of the impulse response functions. I follow the

[14] The complementary restriction (a shock to VOL will increase 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)

Bayesian method of inference of Kilian and Lütkepohl (2017) and Koop et al. (2010).

First, the VAR parameters follow a Gaussian - inverse Wishart prior distribution:

$$vec(A)|\Sigma_u \sim \mathcal{N}(vec(A^*), V \otimes \Sigma_u)$$

and

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

where I imposed $vec(A^*) = [0, 0, \cdots, 0]$, $V = 100 * I_9$, $S_* = I_4$, $n = 5$ by following Koop et al. (2010).

Then the distributions are:

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

and

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

where

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

$$\bar{A} = (A^* V^{-1} + YZ')(V^{-1} + ZZ')^{-1}$$

$$\bar{\Sigma}_{vec(A)} = (V^{-1} + ZZ')^{-1} \otimes \hat{\Sigma}_u$$

$$S = T * \tilde{\Sigma_u} + S_* + \hat{A}ZZ'\hat{A}' + A^* V^{-1} A^{*'} - \bar{A}(V^{-1} + ZZ')\bar{A}'$$

and

$$\tau = T + n.$$

Moreover, $\hat{A} = YZ'(ZZ')^{-1}$, $\tilde{\Sigma_u} = (Y - \hat{A}Z)(Y - \hat{A}Z)'/T$, $\hat{\Sigma_u} = \dfrac{T}{T-4}\tilde{\Sigma_u}$, $Z = [Z_0, \cdots, Z_{T-1}]$ with $Z_{t-1} = (1, y_{t-1}^{'}, y_{t-2}^{'})'$.

Given the posterior distribution, I follow the following steps to generate impulse response functions:

Step 1: Draw reduced form parameters ν^{*r}, $A_i^{*r}s$, and Σ_u^{*r} from the posterior distributions and compute the Cholesky decomposition of Σ_u^{*r}.

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

Step 3: If the impulse response function satisfies the sign restriction on Table 1 in Section 4.2, keep it. Otherwise, discard the impulse response function.

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

Here I set N = 1000 and M = 1000. I sort all of the successful impulse response functions in a descending order and report the upper 84% and bottom 16% of them as a 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. Therefore, the credible band I obtain here tends to be broader than the confidence band obtained from standard short-run restriction models.

5 Results

In this section, I will first provide the national level results and compare them to the existing literature in Section 5.1. Then I will show the results of sectoral output in Section 5.2 and sectoral employment in Section 5.3. I will briefly compare the observed sectoral patterns for these countries in Section 5.4.

5.1 National Results

Figure 5 shows the impulse response functions of a one standard deviation shock to the central bank total assets on aggregate output and CPI for each country for the corresponding sample periods. The 68% Bayesian credible bands are reported as is standard in the literature. The results show that for all of these countries, unconventional monetary policy has a statistically positive impact on both aggregate output and CPI. Figure 5 shows that the shape of the median impulse response functions to aggregate output for these countries are somewhat similar to each other. The effects on aggregate output are long lasting for all of the countries. The effects on price are also last longing, however, the effect in the US is slowly moving towards the original level. The credible band tends to be broader in the US, which may be due to the smaller sample size.

I investigate whether my results are in line with the outcomes in Gambacorta et al. (2014). They report impulse response functions of around 2.7%, 4.5%, and 1.2%[15] rises of central bank total assets for the US, the UK, and Japan, respectively. Therefore, I scale my median impulse response functions accordingly. With regard to aggregate output, my corresponding median peak impulse response functions show that unconventional monetary policy increases aggregate output of the US, the UK, and Japan by 0.16%, 0.29%, and 0.07%, respectively (not reported in Figure 5). The error band at the peak period obtained in Gambacorta et al. (2014) for the US, the UK, and Japan are 0.06% to 0.15%, 0.05% to 0.2%, and 0.02% to 0.2%, respectively. My results for Japan lie within the interval, the US is very close to the interval, however, the UK is off of the range. In terms of the shapes of the impulse response functions, my results are not similar to the results in Gambacorta et al. (2014). Their impulse response functions tend to revert back to the original level. My impulse response functions, however, lead to a higher output level. This observation is

[15] These values represent one standard deviation shocks of central bank total assets for each country

similar to the results in Bhattarai et al. (2015a), despite that the identification is different. These differences of the effects on output may have been driven by how inference is operated[16]. Even though the shapes of the impulse response functions are different from Gambacorta et al. (2014), the quantitative difference is not large.

The effect on price level is also significant for all of these countries. My median peak response of the price in the US, the UK, and Japan are 0.16%, 0.33%, and 0.06%, respectively (not reported in Figure 5). Gambacorta et al. (2014) provide the ranges of the peak price level of the US, the UK, and Japan as 0.04% to 0.11%, -0.04% to 0.05%, and -0.02% to 0.04%, respectively. My values for the US and Japan are close to these intervals, however, none of the countries lie within the intervals in my results. The effect of the UK that I found is very high compared to the range given in Gambacorta et al. (2014). In terms of the shape of the response functions, I found that the US is persistent and is gradually declining, while effects to the UK and Japan seem permanent. While the behaviors of price in the US is similar in Gambacorta et al. (2014), the behaviors of prices in the UK and Japan are different. The results in Gambacorta et al. (2014) show a temporal negative and an insignificant response in the UK and an insignificant response in Japan.

While the inference methods and sample periods are different, my results are overall quantitatively comparable to the results of Gambacorta et al. (2014), especially with regards to output, which is the focus of my paper.

5.2 Sectoral Results

First, I plot the weighted impulse response functions and national impulse response functions on Figure 6 to ensure that the sectoral results approximately sum up to the national results. One of the purposes of this paper is to uncover the heterogeneous responses to the unconventional monetary policy shock. If the sectoral impulse response functions sum up to the national impulse response function, it is credible to argue the validity of the sectoral impulse response functions. The weighted impulse response functions are calculated by following:

$$WIRF_t = \sum_{s=1}^{S} weight_s * MIRF_{st} \tag{3}$$

where $WIRF_t$ represents weighted impulse response function at period t, and $MIRF_{st}$ represents the median impulse response functions for sector s at period t, and S is the total number of sectors. I calculate the weight for the US and the UK the following way. First, I calculate the average

[16] Gambacorta et al. (2014) implement the inference using a frequentist approach while Bhattarai et al. (2015a) uses a Bayesian inference. I used the same sample periods used in Gambacorta et al. (2014) but used the Bayesian approach in section 4.3. Like Bhattarai et al. (2015a), my impulse response functions are persistent. This may be due to Bayesian inference.

gross value added (GVA) of the sample periods for each sector. Then, I sum up the average GVA across sectors and I denote it as total GVA. Finally, I calculate the weight as the average GVA of individual sectors over total GVA. Japanese data provides the weight from the GDP share and so I used the weight for the calculation of the weighted impulse response functions. In Figure 6, for each country, the bold line represents the national impulse response function and the dotted line represents the weighted impulse response function. I also reported the credible bands of the national impulse response functions.

For each country, the weighted impulse response function is very similar but not identical. For example, for the US and Japan, the two series deviate during the first half of the whole period. The potential explanations of the deviations are estimation uncertainty, statistical measurement error between aggregate output and sum of the sectoral output, and missing sectoral comovement due to a single sector estimation. While there are some deviations, for each country the deviation is not large and is always within the credible band (except for the first few periods for Japan). Therefore, the weighted impulse response functions overall match the national results.

Figures 7, 8, and 9 show the sectoral impulse response functions for each country. I report the 16% and 84% credible bands. The results uncover the differential responses to unconventional monetary policy. I find that 12 out of 19 (63%) sectors in the US, 13 out of 19 (68%) sectors in the UK, and 11 out of 16 (69%) sectors in Japan are statistically significant and positive. The number of sectors which are significantly positive is not much different across countries even though I used both GVA and quantity index datasets. While there are some disparities of significant sectors across these countries, there are 7 sectors which are significant for all. These 7 sectors are construction, manufacturing, wholesale and retail trade, information, real estate, professional and business service, and durable goods manufacturing. Thus, this implies that there are some similar patterns of how unconventional monetary policy transmits to each sector in each country.

As mentioned in Section 2, the finance sector has been given a large amount of attention in the literature of unconventional monetary policy. In the UK, the effect on the finance and insurance sectors are indeed negative, which is surprising (I observed this result using both GVA and quantity indices in the UK). However, the US and Japanese impulse response functions indicate that unconventional monetary policy has positive effects on the financial market and this observation is consistent with the literature (such as Krishnamurthy and Vissing-Jorgensen, 2011; Neely, 2015). Additionally, the median peak impulse response functions of the finance and insurance sector are greater than the credible band of the national impulse response functions at the peak period for the US and Japan. In other words, the effects on the sector is stronger than the national average. This effect to the financial market is one of the main goals of unconventional monetary policy.

Table 2 shows the elasticity of monetary policy (% change in median peak response of sectoral output to 1% increase in central bank total asset for the three countries). The effectiveness of unconventional monetary policy on aggregate level seems very similar across countries. However, when it comes to the sectoral level, the elasticity varies by sectors. For the US, the UK, and Japan, the elasticity varies from -0.02 to 0.22, -0.25 to 0.21, and -0.12 to 0.21, respectively indicating that the same policy creates sectors that are expanding and sectors that are contracting. This implies that there are winners and losers.

Table 2: Monetary Policy Elasticity of Output

Country	the US	the UK	Japan
Sector	Elasticity		
Aggregate output	0.06	0.07	0.05
Agriculture	0.01	0.07	N.A.
Mining	0.15	-0.25	-0.12
Utilities	0.09	0.02	0.01
Construction	0.16	0.21	0.10
Manufacturing	0.08	0.06	0.16
Durable goods	0.12	0.13	0.21
Non-durable goods	0.04	0.01	0.07
Wholesale & Retail trade	0.12	0.12	0.07
Transportation	0.04	0.07	0.06
Information	0.11	0.11	0.05
Finance & insurance	0.22	-0.19	0.10
Real estate	0.05	0.05	0.01
Professional & Business	0.12	0.21	0.05
Educational services	0.02	0.01	0.07
Health care & Social assistance	0.01	0.05	0.01
Arts, Entertainment, & Recreation	0.09	0.01	-0.10
Accommodation & Food	0.12	0.05	0.01
Other services	0.08	0.05	N.A.
Government	-0.02	0.01	N.A.

The sectors that showed the strongest median peak responses are finance and insurance in the US, construction in the UK, and durable goods manufacturing in Japan. It is interesting that the most affected sector is different for each country. These three sectors are significant for all of these countries, except for the finance and insurance sector in the UK. The median peak impulse response functions of these three sectors are also greater than the credible band of the national impulse response functions at the peak period for each country. This observation that finance, construction, and durable goods manufacturing sectors are more responsive than the national average is in line with conventional monetary policy literature (for example Ganley and Salmon, 1997). As mentioned in Section 2, interest rate sensitive sectors are usually responsive to conventional monetary policy. The most responsive sectors above are all interest rate sensitive. Despite that under ZLB the interest rate channel is blocked, there are similar results of responsiveness to conventional monetary policy. One possibility is that signaling theory, (such as Chen et al., 2012; Bhattarai et al., 2015b) a central bank's promise to keep the interest rate lower towards the future, will lower the expected short term real interest rates. This will create incentive for capital intensive firms to invest in projects which involve money borrowing. Thus this signaling channel may make the effect of unconventional monetary policy similar to that of conventional monetary policy.

In conventional monetary policy literature, in addition to these responsive sectors mentioned above, wholesale and retail sector is sometimes responsive. My results show that the wholesale and retail trade sector is significant in all of these countries and the effect is stronger than the national impulse response functions (except for Japan not being stronger than the national level). In this respect, I also see a similarity with conventional monetary policy literature. As is also mentioned in Section 2, the agriculture sector does not respond to a conventional monetary policy shock well (Ibrahim, 2005). I find that the agriculture sector is insignificant to the shock in the US but not in the UK.

Finally, there are some sectors which display significantly negative responses to unconventional monetary policy. Those sectors include educational service; and healthcare and social assistance in the US and mining; finance and insurance; Educational service; art, entertainment, and recreation; and government in the UK. In Japan, those sectors include mining; and art entertainment, and recreation. As mentioned in Section 2, the central bankers, without recognizing these sectors which react to the policy in a counter-cyclical manner, might create a policy that may lead to unintended negative outcomes.

5.3 Employment

In the previous section, I found heterogeneous responses of sectoral output to the unconventional monetary policy shock. These changes in sectoral output may result from a change in production decisions (i.e. hiring or investment). In this section, to study the behaviors of firms, I use employment data for each sector for each country to examine how unconventional monetary policy influences sectoral employment. Understanding this transmission mechanism may help understand how firms in each sector make hiring decisions in response to unconventional monetary policy.

The sectoral employment data is taken from the Bureau of Labor Statistics for the US, the Office of National Statistics for the UK, and the Ministry of Internal Affairs and Communications for Japan. The data for the US and Japan are monthly while the data for the UK is quarterly. Time spans are 2008M1 to 2017M12 for the US, 2008Q1 to 2018Q2 for the UK, and 2003M1 to 2018M3 for Japan, representing the ZLB periods for each country. Due to the data availability, the sectoral definitions of employment is different from and is coarser than the definition of sectoral output. In the US, the real estate sector is included in the finance and insurance sector as financial activity; the education and healthcare and social assistance sectors are combined; and the art, entertainment, and recreation and the accommodation and food services are also combined as leisure industry. In the UK, the mining and the utility sectors are combined and the art, entertainment, and recreation sector is included in other services. In Japan, the mining and the utility sectors are included in the manufacturing sector. Additionally, for the UK and Japan, employment data for the durable goods and non-durable goods manufacturing sectors are not available.

To estimate the structural VAR, I replace the sectoral output of endogenous vector, y_t, with log of sectoral employment. The definitions of the other variables and the order of variables in y_t are the same as in Section 4.3. Also, as before, the number of lag, p, is 2.

Figures 10, 11, and 12 display the impulse response function of sectoral employment for each country for each sector. I report the 16% and 84% credible bands.

The effects on total employment are all significant across countries. The effect rises very slowly and it seems that the total employment increases at a constant rate. The behavior is similar to the effects on aggregate output. The elasticity of employment at the peak level for the US, the UK, and Japan are 0.051, 0.042, and 0.031, respectively (not reported). The difference in magnitude might represent the cross-country differences in labor market tightness (such as Ball et al., 2017). Similar to the sectoral output effects, there are also heterogeneous effects on sectoral employment. The behavior of employment represented in the impulse response functions is different from the behavior of output. The effect on output is transitory or permanent and the series shows a radical rise in output and gradually increases or fades out. With regards to employment, some of the sectoral employments stay around zero for a few periods after the shock, then start increasing. Output tends to increase radically, however, employment seems to rise smoothly. This might be the difference of the behavior of output and employment dynamics.

The purpose of studying the effects of sectoral employment is to see how changes in sectoral output are driven by sectoral employment. I calculated how many sectors have the same direction of output and employment changes (including insignificant). I found that 7 out of 16 sectors (43%), 9 out of 14 sectors(64%), and 8 out of 13 sectors (61%) in the US, in the UK, and in Japan have the same output-employment reaction. The UK and Japan have a similar percentage of sectors and the US has a smaller percentage of sectors that have the same effects. It seems that overall change in output is not closely followed by employment change.

Among these countries, the US has a weaker relationship between sectoral output and employment. This observation can be interpreted several ways. First, the US generally has a low level of employment-output pass through. However, the US is known to have a higher Okun's law coefficient (Ball et al., 2017) and the labor market is relatively flexible. It is not likely that employment-output pass through is smaller than Japan, which has the lowest Okun's law coefficient among highly advanced countries. Another possibility is higher TFP in the US. Due to high TFP level, a small negligible change in employment leads to higher output, which is consistent with the higher Okun's law coefficient in the US. However, some sectors such as the agriculture, information or other services has employment dynamics that is opposite of output. It is difficult to argue that higher TFP is the cause of this observation in the US. The most plausible reason is the jobless recovery after the financial crisis in the US. The employment behavior in the US was not as standard. The output was improving while there was a not great deal of employment growth. This unprecedented episode might be summarized in the employment-output relationship.

The sectors whose output reacted strongly to unconventional monetary policy such as construction, manufacturing, and finance and insurance sectors do not necessarily show stronger employment reactions. As mentioned above, those sectors are interest rate sensitive. The strong increase of output of these sectors may be due to investment and the increase of labor is approximately the same as the other sectors within a country.

5.4 International Comparison

Monetary policy literature uncovers heterogeneous sectoral effects. However, these analyses typically limit their attention to a single country and have not compared the sectoral effects across countries[17]. In this section, I will compare the patterns obtained in Section 5.2 and 5.3 across the US, the UK and Japan.

The sectoral output responses show some similarities of how unconventional monetary policy transmits to the individual sectors of each country. First, each of the countries' unconventional monetary policies stimulate components of production sectors, such as construction and durable goods manufacturing, strongly. Despite that the interest rate channel is blocked due to the ZLB, the effects to the sectors still exist and are stronger than the national response as shown in Section 5.2. Figures 7, 8, and 9 display the effects on aggregate manufacturing sector. The sector consists of production sectors including mining, utilities, manufacturing, and construction. This rise in

[17]However, Dedola and Lippi (2005) did explore the industrial impact of monetary policy on 5 OECD countries. Though, the analysis is restricted on sectors within manufacturing.

durable goods manufacturing and construction pushes the output of the aggregate manufacturing sector, even though the non-durable goods manufacturing, mining, and utilities sectors are usually not affected by the shock much.

On the contrary, aggregate service sectors (which consist of approximately 70% of an economy) responded weakly compared to the aggregate manufacturing sectors. Even though sectors such as wholesale & retail trade; finance and insurance; and professional & business responded to the shock stronger the national average, the service sectors as a whole did not result in a strong effect. Sectors in services are usually not interest rate sensitive sectors, which may imply that service sectors respond weaker. Therefore, the aggregate manufacturing tends to respond to the shock stronger than the aggregate services sector. Despite that the aggregate manufacturing and service contain a diverse group of industries, this pattern is observed across countries.

When it comes to sectoral employment, there are also similar patterns with regard to aggregate manufacturing and service, though, the effects on individual sectoral employments are not as obvious as it is in output. Based on Figures 10, 11, and 12, employment of aggregate manufacturing responded stronger than employment of aggregate service for all of the investigated countries. Typically manufacturing sectors consist of capital intensive industries, however, the large increase in aggregate manufacturing output is not only coming from investment but also from hiring.

Finally, coming back to sectoral output, sectors such as utilities, health care and social assistance, and government reacted poorly in all of these countries. These sectors 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 monetary policy affects these sectors in a similar manner.

6 Robustness Analysis

In this section I conduct two robustness analyses. In section 6.1, I add one additional variable, aggregate output excluding the sector, in my VAR framework. In secction 6.2, I estimate the model by changing the length of the effective periods of sign restriction.

6.1 Adding Aggregate Output Excluding the Sector

The modeling of the structural VAR model for monetary policy analysis is derived from the New Keynesian model. The model is a system of aggregate variables, not sectoral variables. Even though this is the underline assumption, there are many papers investigating the sectoral effect of monetary policy without controlling aggregate output. Omitting the aggregate dynamics may lead to a biased estimation. I estimate the model including aggregate output (or GDP) excluding the sector, defined as $AOES_t$ in the endogenous vector, y_t, so that the system is able to capture not only the dynamics of the sector but also the dynamics of the aggregate output and the output of the other sectors. By including aggregate output excluding the sector into the system, the endogenous vector, y_t, consists of five variables. I add log of aggregate output excluding the sector after sectoral output, so that the the endogenous vector, y_t, is now:

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

The inclusion of the variable generates the additional identification assumption. As was stated in Section 4.2, a shock to the central bank total assets and a shock to stock market volatility have at most a lagged impact on aggregate output excluding the sector, while a shock to aggregate output excluding the sector has a contemporaneous impact on central bank total assets and stock market volatility. This identification is reasonable since I impose the same identification on the sectoral 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 4.3. The number of lag, p, is the same as before (p=2).

Figures 13, 14, and 15 show the sectoral impulse response functions where aggregate output excluding the sector is controlled. As before, I report the 16% and 84% credible bands. Even though I controlled the overall dynamics of the economy, there is almost no qualitative difference of the sectoral impulse response functions compared to the results without controlling aggregate output excluding the sector. The results imply that the single sector VAR is generally sufficient enough to generate its own impulse response function.

Exceptions to this are the agriculture and mining sectors in the US. Their results radically changed by the inclusion of the variable. These sectors account for very small shares in GDP. Thus it is likely that not including the aggregate dynamics make the system misspecified. Once I control the aggregate dynamics in the US, the credible bands of the sectors narrowed down and dynamics are altered.

Generally speaking, I find that controlling the overall dynamics make the effects on some sectors weaker and credible bands narrower compared to the single sector VAR, especially in the US. On Figure 13, the effects on construction, professional & business, and accommodation & food sectors declined compared to the single sector VAR, even though they are still significant. Also the credible bands of most of the sectors became narrower. Though this finding is not as applicable in the UK and Japan. This implies that the uncertainty may come from the low sample size in the US.

However, although there are some disparities, sectoral effects of unconventional monetary policy were not largely affected by the inclusion of aggregate output excluding the sector.

6.2 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 monetary policy, identification is a key point 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 my results are, I impose the restriction until the end of the first quarter after the shock. The following table summarizes the new identification. I impose the 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.

Table 3: Sign Restriction (Robustness)

	all countries at period = 0	all countries at period = 1	the US at periods = 2 & 3	the UK and Japan at periods = 2 & 3
SO	0	*	*	*
CPI	0	*	*	*
AT	>0	>0	*	>0
VOL	≤0	≤0	*	≤0

The Figures 16, 17, and 18 show the results. The results are not largely affected by the new specification. Therefore, imposing the sign restriction on Table 1 in Section 4.2 can generate a sufficient inference of unconventional monetary policy.

7 Conclusion

This paper estimates the sectoral effects of unconventional monetary policy for the US, the UK, and Japan using a structural VAR model. Bayesian inference of the sectoral impulse response functions reveal some interesting features of the impacts of unconventional monetary policy. First, unconventional monetary policy stimulates the financial sectors, which is stressed in the literature on event studies. Second, sectors that display stronger or weaker responses in the conventional monetary policy literature have similar implications in my results, suggesting that the monetary transmission mechanisms of conventional and unconventional monetary policy are alike. Third, the manufacturing sector shows a stronger effect while other sectors, especially those in services, have weaker effects, which was also observed once applying employment data.

These differential effects of unconventional monetary policy is lost with aggregation and policy makers should take these effects into account in order to understand the transmission mechanisms, better anticipate the impact, and prevent unintended negative outcomes. While some dissimilar movements exist in some sectors for each country, the overall transmission mechanisms are similar. Given the potential decline of the natural rate of interest in highly advanced countries (Holston et al., 2017), it is likely that the ZLB will spread to other countries and will require other central bankers to implement an unconventional monetary policy. The results obtained in this paper will provide some bottom line predictions for countries that have not yet experienced ZLB and will aid central bankers in creating an unconventional monetary policy. Lastly, this paper did not pursue the determinants of the sectoral effects of the policy. This would be a great subject for future research.

References

Alam, T. and Waheed, M. (2006). Sectoral effects of monetary policy: Evidence from Pakistan. *The Pakistan Development Review*, pages 1103–1115.

Arnold, I. J. and Vrugt, E. B. (2002). Regional effects of monetary policy in the Netherlands. *International Journal of Business and Economics*, 1(2):123.

Ball, L., Leigh, D., and Loungani, P. (2017). Okun's law: Fit at 50? *Journal of Money, Credit and Banking*, 49(7):1413–1441.

Baumeister, C. and Benati, L. (2012). Unconventional monetary policy and the great recession: Estimating the macroeconomic effects of a spread compression at the zero lower bound (No. 2012-21). Technical report, Bank of Canada Working Paper.

Bénétrix, A. S. and Lane, P. R. (2010). Fiscal shocks and the sectoral composition of output. *Open Economies Review*, 21(3):335–350.

Berman, J. and Pfleeger, J. (1997). Which industries are sensitive to business cycles. *Monthly Lab. Rev.*, 120:19.

Bhattarai, S., Chatterjee, A., and Park, W. Y. (2015a). Effects of US quantitative easing on emerging market economies.

Bhattarai, S., Eggertsson, G. B., and Gafarov, B. (2015b). Time consistency and the duration of government debt: A signalling theory of quantitative easing (No. w21336). Technical report, National Bureau of Economic Research.

Burriel, P. and Galesi, A. (2018). Uncovering the heterogeneous effects of ECB unconventional monetary policies across euro area countries. *European Economic Review*, 101:210–229.

Carlino, G. and DeFina, R. (1998). The differential regional effects of monetary policy. *Review of Economics and Statistics*, 80(4):572–587.

Chen, H., Cúrdia, V., and Ferrero, A. (2012). The macroeconomic effects of large-scale asset purchase programmes. *The economic journal*, 122(564):F289–F315.

Chodorow-Reich, G. (2014). Effects of unconventional monetary policy on financial institutions (No. w20230). Technical report, National Bureau of Economic Research.

Chow, G. C. and Lin, A.-l. (1971). Best linear unbiased interpolation, distribution, and extrapolation of time series by related series. *The review of Economics and Statistics*, pages 372–375.

Christiano, L. J., Eichenbaum, M., and Evans, C. L. (1999). Monetary policy shocks: What have we learned and to what end? *Handbook of macroeconomics*, 1:65–148.

Dale, S. and Haldane, A. G. (1995). Interest rates and the channels of monetary transmission: some sectoral estimates. *European Economic Review*, 39(9):1611–1626.

Dedola, L. and Lippi, F. (2005). The monetary transmission mechanism: evidence from the industries of five OECD countries. *European Economic Review*, 49(6):1543–1569.

Du, L., Yanan, H., and Wei, C. (2010). The relationship between oil price shocks and China's macro-economy: An empirical analysis. *Energy policy*, 38(8):4142–4151.

Fawley, B. W., Neely, C. J., et al. (2013). Four stories of quantitative easing. *Federal Reserve Bank of St. Louis Review*, 95(1):51–88.

Gagnon, J., Raskin, M., Remache, J., Sack, B., et al. (2011). The financial market effects of the Federal Reserve's large-scale asset purchases. *international Journal of central Banking*, 7(1):3–43.

Gambacorta, L., Hofmann, B., and Peersman, G. (2014). The effectiveness of unconventional monetary policy at the zero lower bound: A cross-country analysis. *Journal of Money, Credit and Banking*, 46(4):615–642.

Ganley, J. and Salmon, C. (1997). The industrial impact of monetary policy shocks: some stylised facts.

Ghosh, S. (2009). Industry effects of monetary policy: Evidence from India. *Indian Economic Review*, pages 89–105.

Gilchrist, S., López-Salido, D., and Zakrajšek, E. (2015). Monetary policy and real borrowing costs at the zero lower bound. *American Economic Journal: Macroeconomics*, 7(1):77–109.

Greenlaw, D., Hamilton, J. D., Harris, E., and West, K. D. (2018). A Skeptical View of the Impact of the Fed's Balance Sheet (No. w24687). Technical report, National Bureau of Economic Research.

Hancock, D. and Passmore, W. (2011). Did the Federal Reserve's MBS purchase program lower mortgage rates? *Journal of Monetary Economics*, 58(5):498–514.

Hayo, B. and Uhlenbrock, B. (2000). Industry effects of monetary policy in Germany. In *Regional aspects of monetary policy in Europe*, pages 127–158. Springer.

Holston, K., Laubach, T., and Williams, J. C. (2017). Measuring the natural rate of interest: International trends and determinants. *Journal of International Economics*, 108:S59–S75.

Ibrahim, M. H. (2005). Sectoral effects of monetary policy: evidence from Malaysia. *Asian Economic Journal*, 19(1):83–102.

Kilian, L. and Lütkepohl, H. (2017). *Structural vector autoregressive analysis*. Cambridge University Press.

Koop, G., Korobilis, D., et al. (2010). Bayesian multivariate time series methods for empirical macroeconomics. *Foundations and Trends® in Econometrics*, 3(4):267–358.

Krishnamurthy, A. and Vissing-Jorgensen, A. (2011). The effects of quantitative easing on interest rates: channels and implications for policy (No. w17555). Technical report, National Bureau of Economic Research.

Lucas, D. and Vissing-Jorgensen, A. (2014). Comments and Discussion. *Brookings Papers on Economic Activity*, pages 205–227.

Mallick, S., Mohanty, M. S., and Zampolli, F. (2017). Market volatility, monetary policy and the term premium.

Monacelli, T. and Perotti, R. (2008). Openness and the sectoral effects of fiscal policy. *Journal of the European Economic Association*, 6(2-3):395–403.

Neely, C. J. (2015). Unconventional monetary policy had large international effects. *Journal of Banking & Finance*, 52:101–111.

Ramaswamy, R. and Sløk, T. (1998). The real effects of monetary policy in the european union: What are the differences? *Staff Papers*, 45(2):374–396.

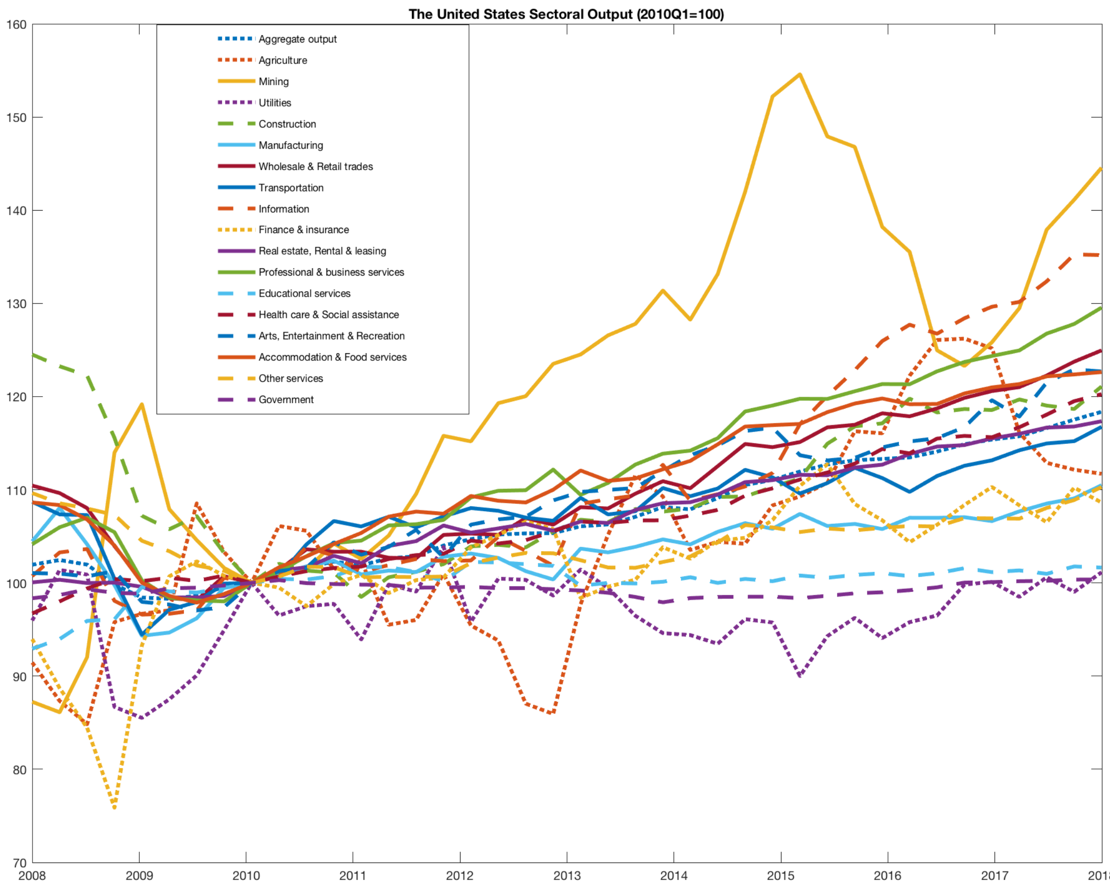
Shintani, M. (2005). Nonlinear forecasting analysis using diffusion indexes: An application to Japan. *Journal of Money, Credit and Banking*, pages 517–538.

Vukotic, M. (2017). Sectoral effects of news shocks. Technical report, Working Paper.

Walentin, K. (2014). Business cycle implications of mortgage spreads. *Journal of Monetary Economics*, 67:62–77.

Figures

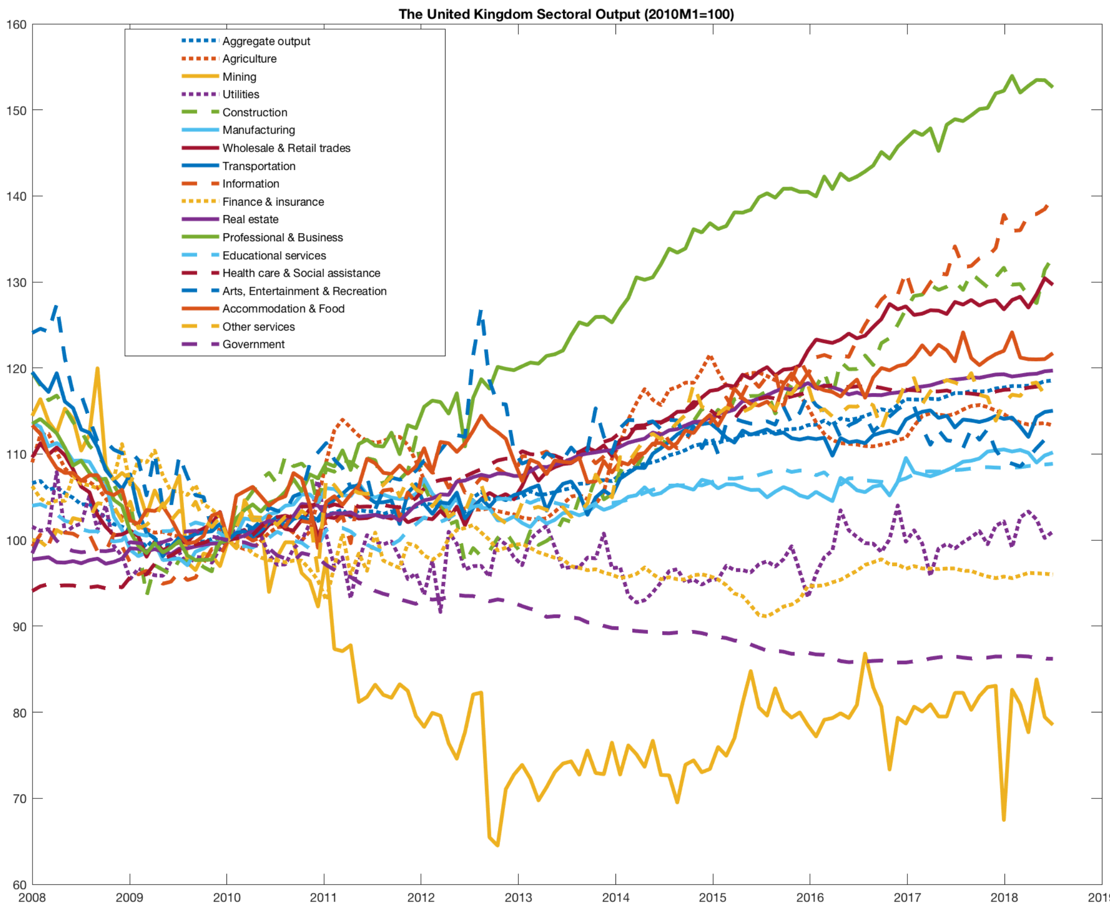
Figure 1: The United States Sectoral Output



Source: The Bureau of Economic Analysis

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

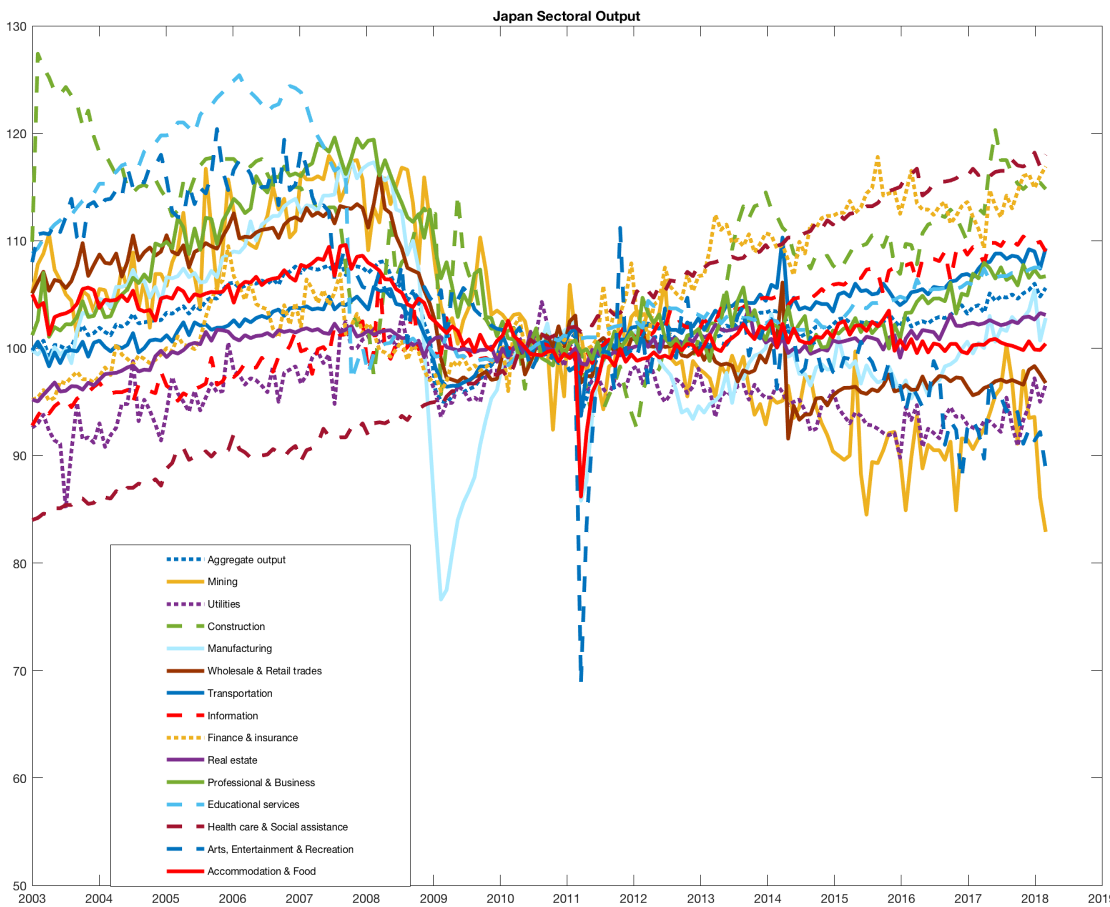
Figure 2: The United Kingdom Sectoral Output



Source: The Office for National Statistics

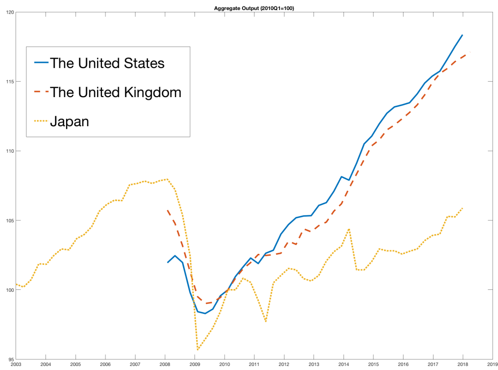
All of the variables are normalized so that 2010M1=100.

Figure 3: The Japanese Sectoral Output

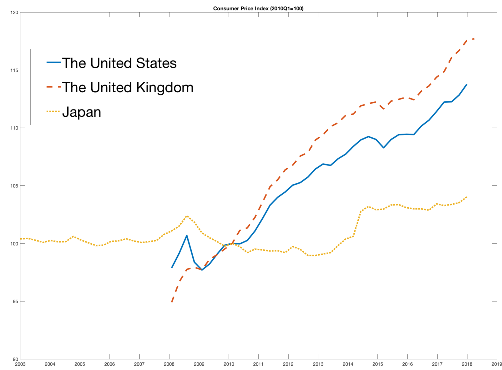


Source: The Ministry of Economy, Trade, and Industry Analysis

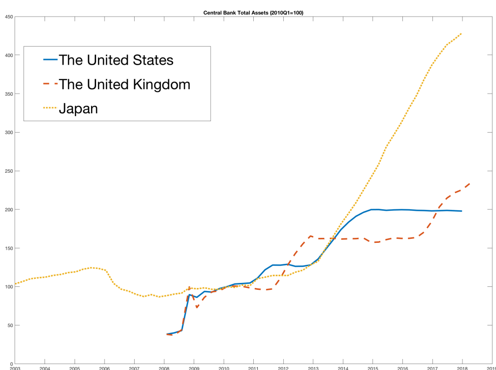
Figure 4: Aggregate Output, Consumer Price Index, Central Bank Total Assets, and Stock Market Implied Volatility



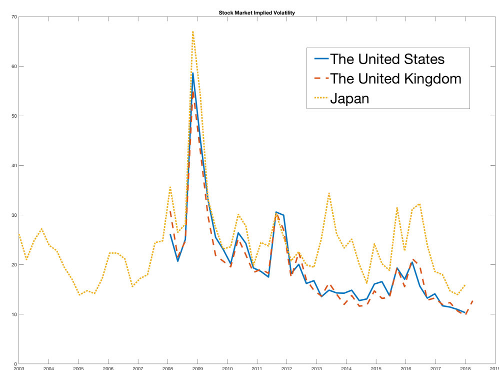
(a) Aggregate Output



(b) Consumer Price Index



(c) Central Bank Total Assets



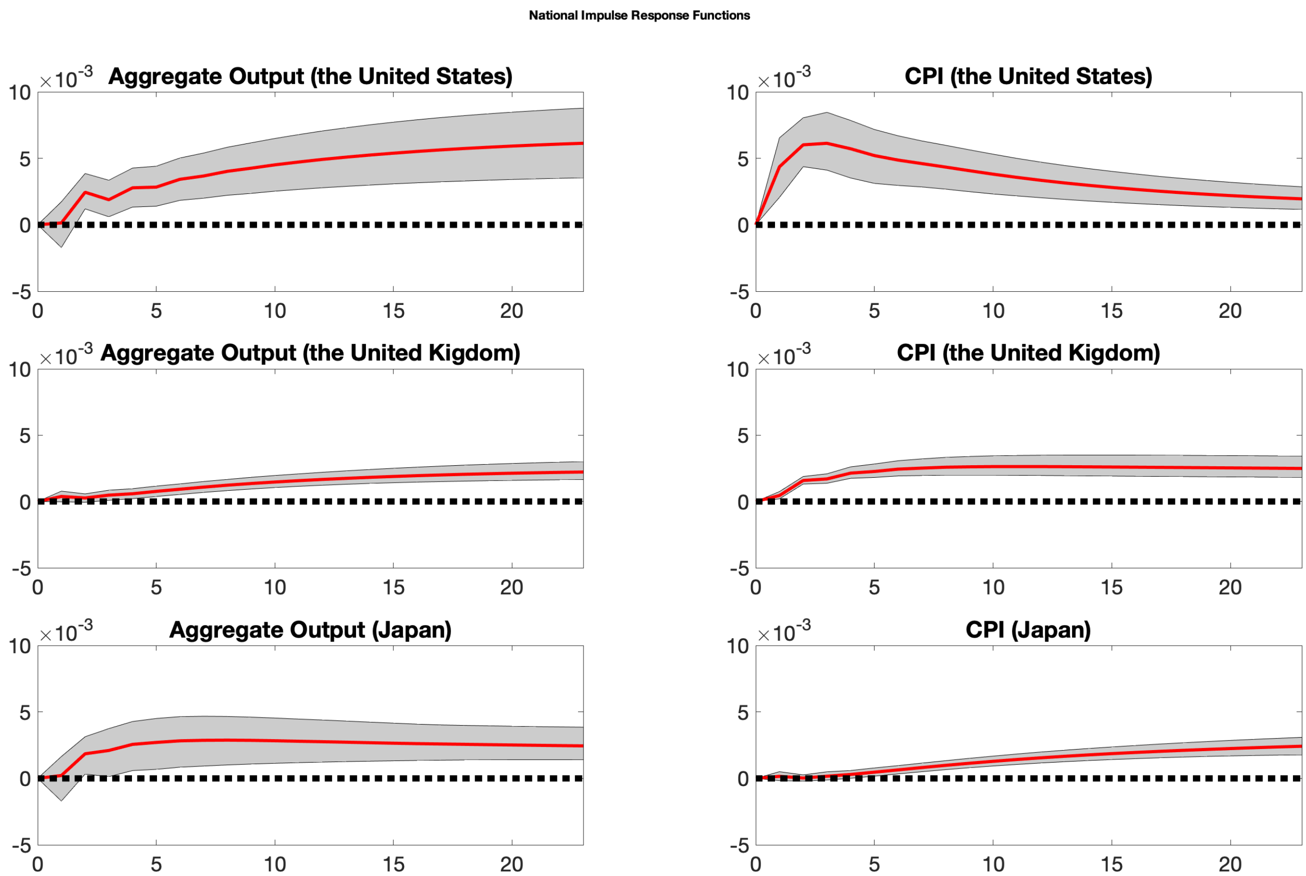
(d) Stock Market Implied Volatility

Sources:

Aggregate Output: the Bureau of Economic Analysis (the US), the Office for National Statistics (the UK), the Ministry of Economy, Trade, and Industry (Japan). CPI: the Bureau of Labor Statistics (the US) and Datastream (the UK and Japan). AT: the FRED database (the US), Bank of England (the UK) and Datastream (Japan). VOL: the FRED database (the US), Datastream (the UK and Japan).

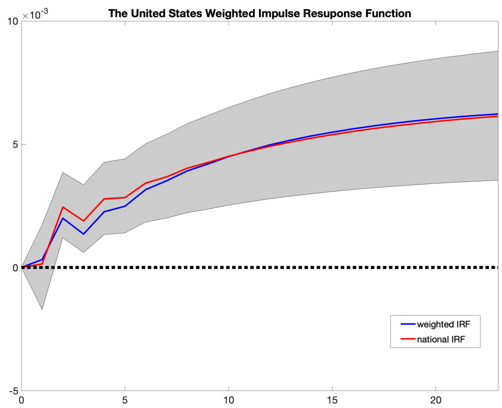
Note: All of the variables except for VOL are normalized so that 2010Q1=100.

Figure 5: National Impulse Functions

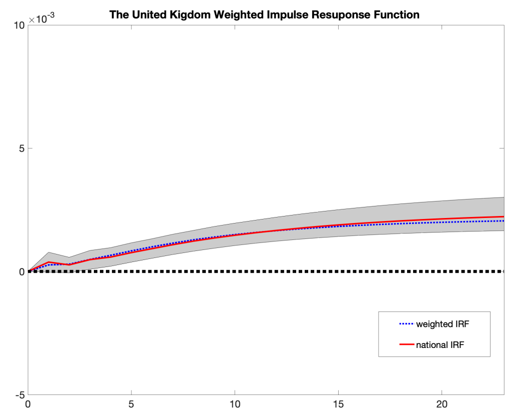


Note: The Median, 16th, and 84th Bayesian percentiles. Quarterly horizon (the US) and Monthly horizon (the UK and Japan).

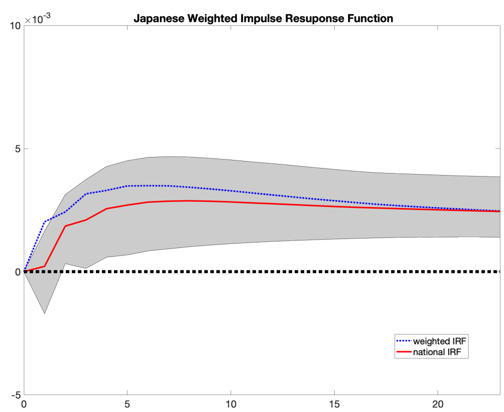
Figure 6: Weighted Impulse Response Functions



(a) The United States



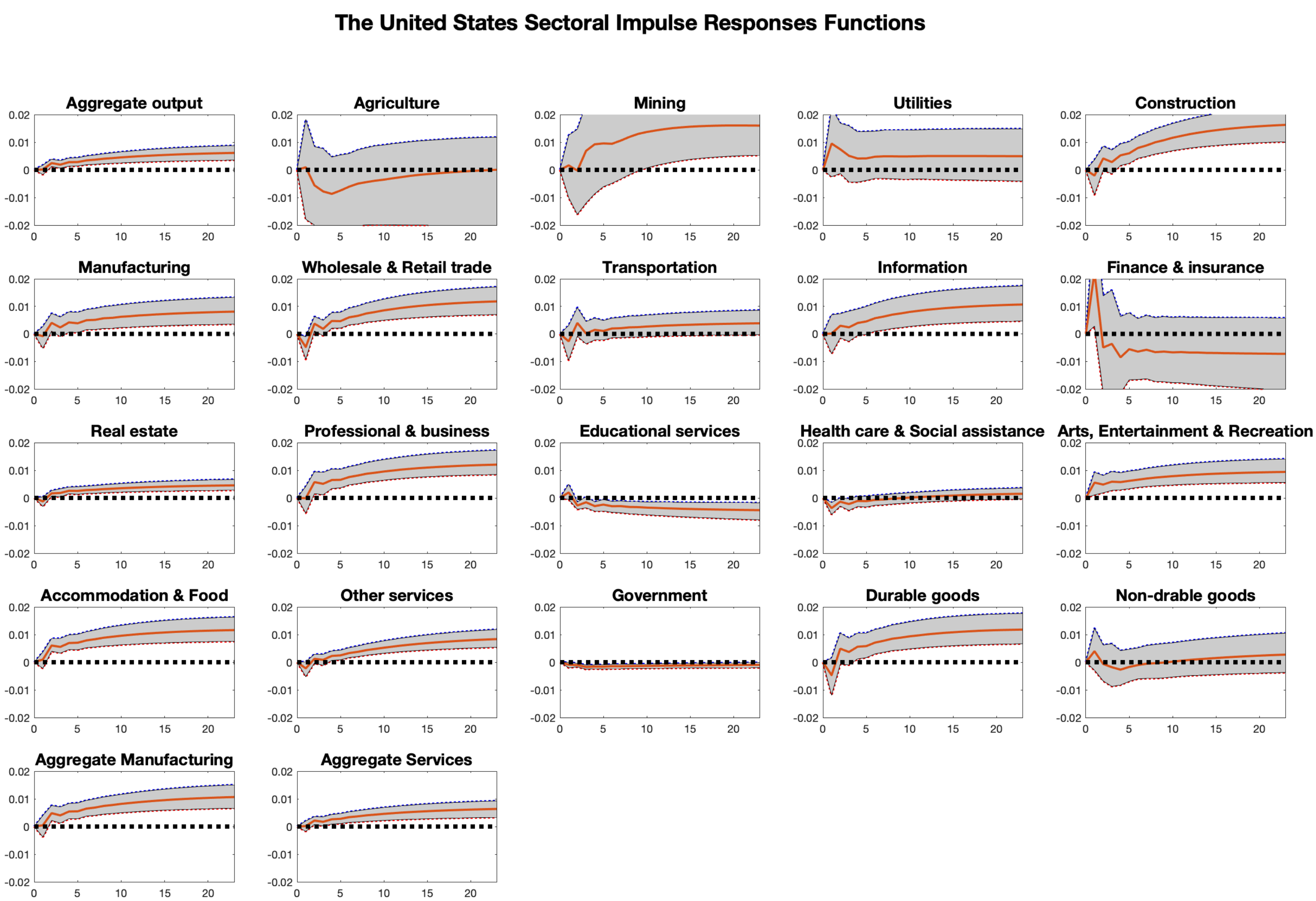
(b) The United Kingdom



(c) Japan

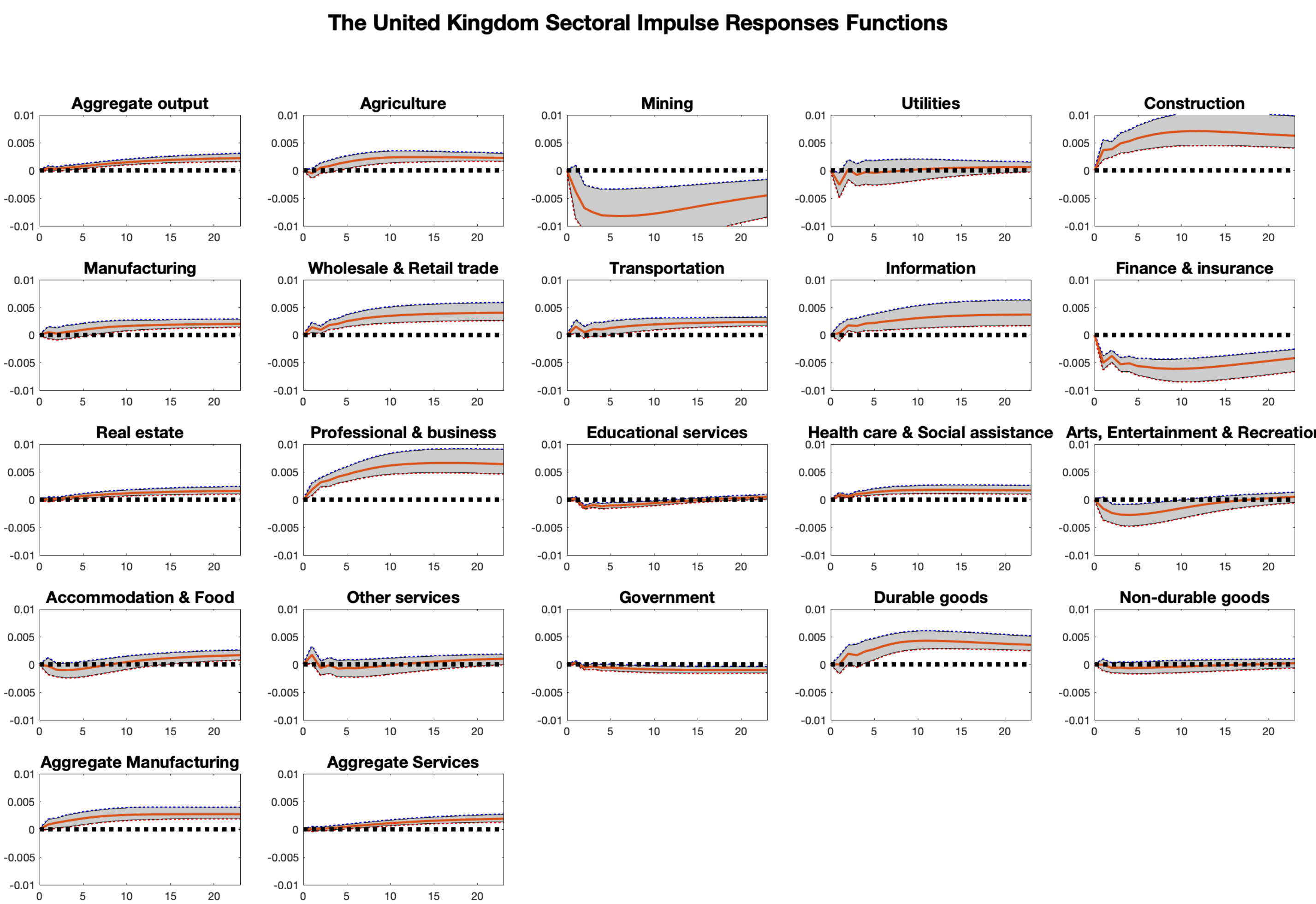
Note: (a),(b) Quarterly horizon. (c) Monthly horizon. The bold lines represent the national impulse response functions and the dotted lines represent the weighted impulse response functions. The error bands are from the national impulse response functions.

Figure 7: The United States Sectoral Impulse Response Functions



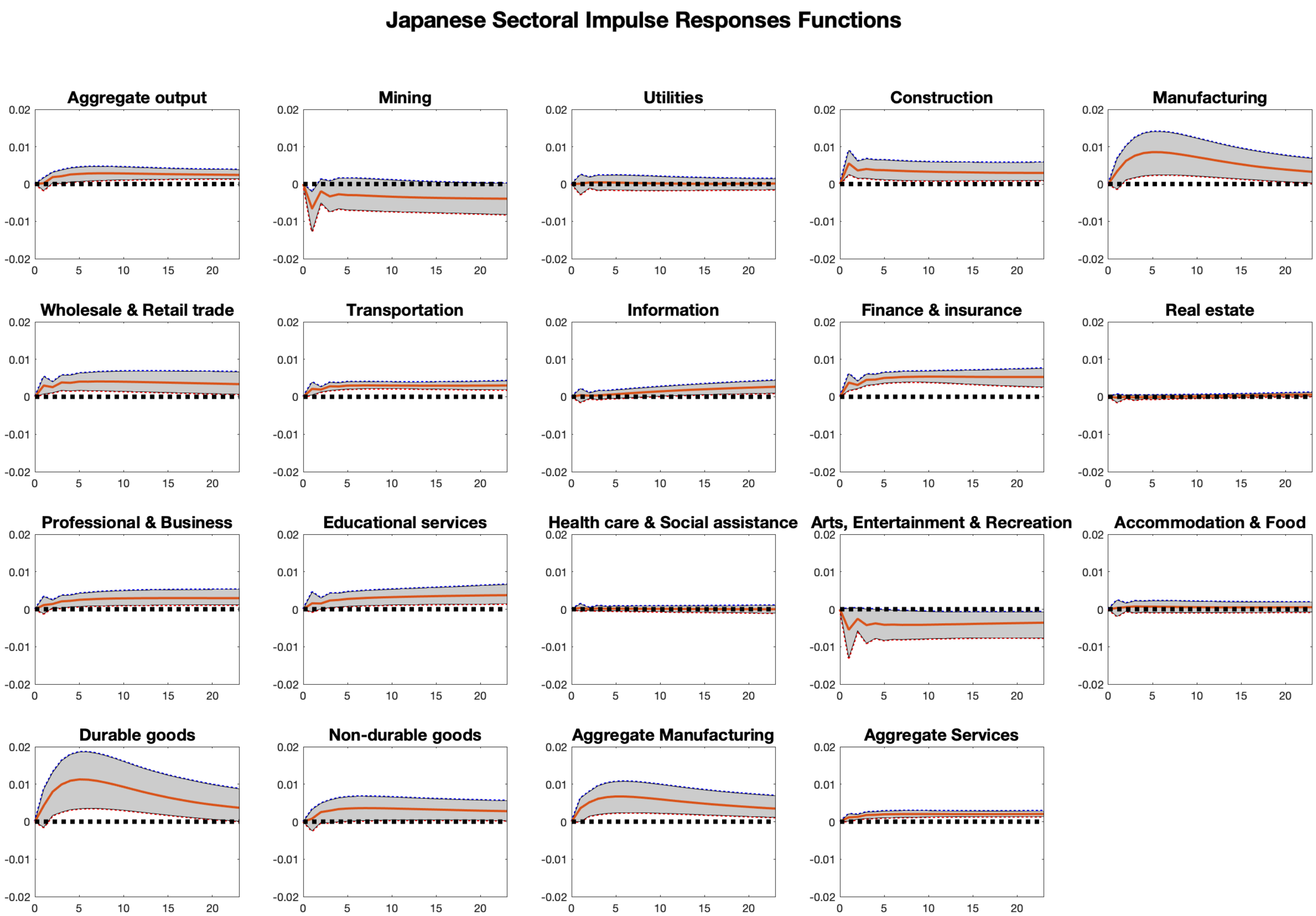
Note: The Median, 16th, and 84th Bayesian percentiles. Quarterly horizon.

Figure 8: The United Kingdom Sectoral Impulse Response Functions



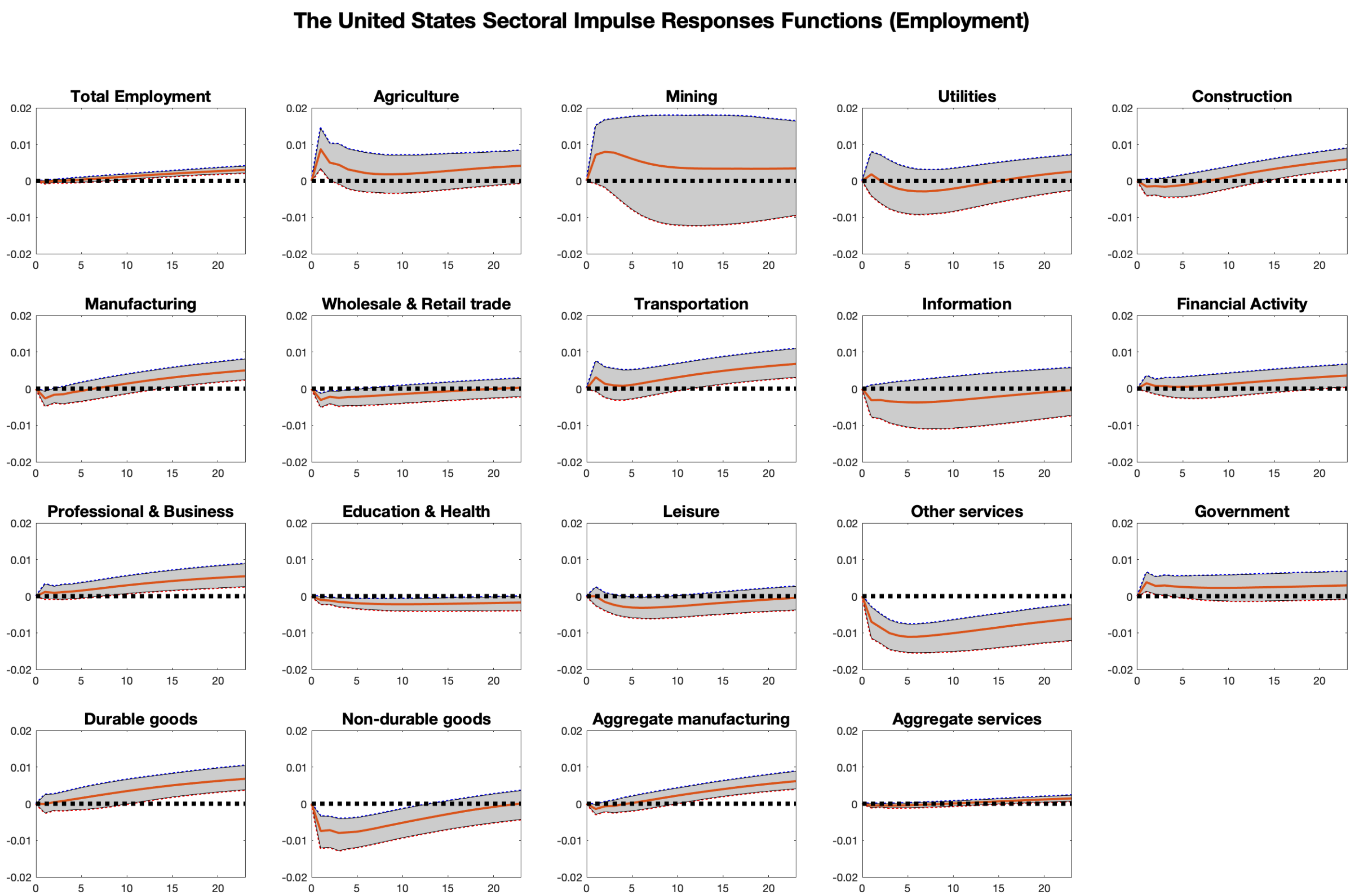
Note: The Median, 16th, and 84th Bayesian percentiles. Monthly horizon.

Figure 9: The Japanese Sectoral Impulse Response Functions



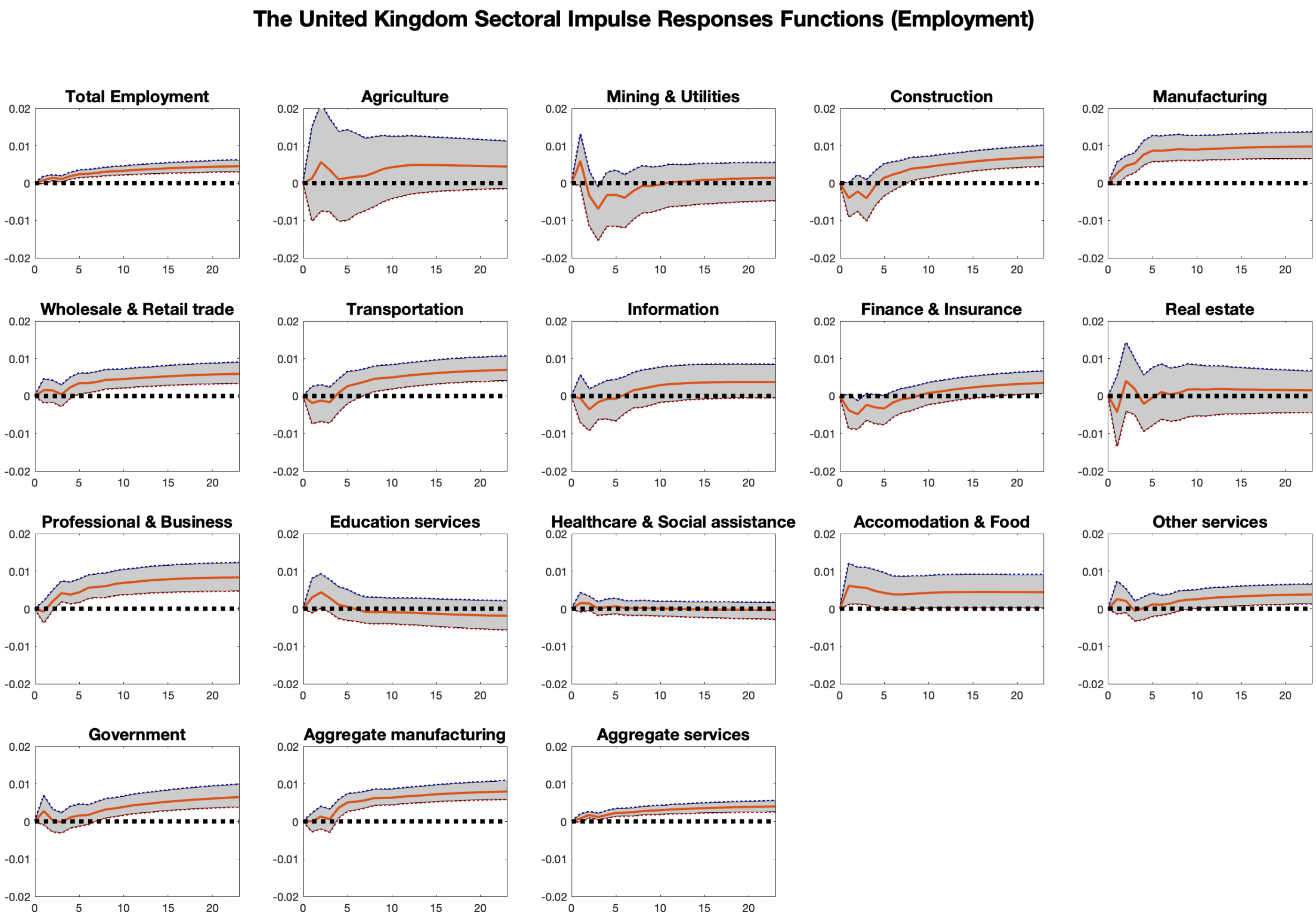
Note: The Median, 16th, and 84th Bayesian percentiles. Monthly horizon.

Figure 10: The United States Sectoral Employment Impulse Response Functions



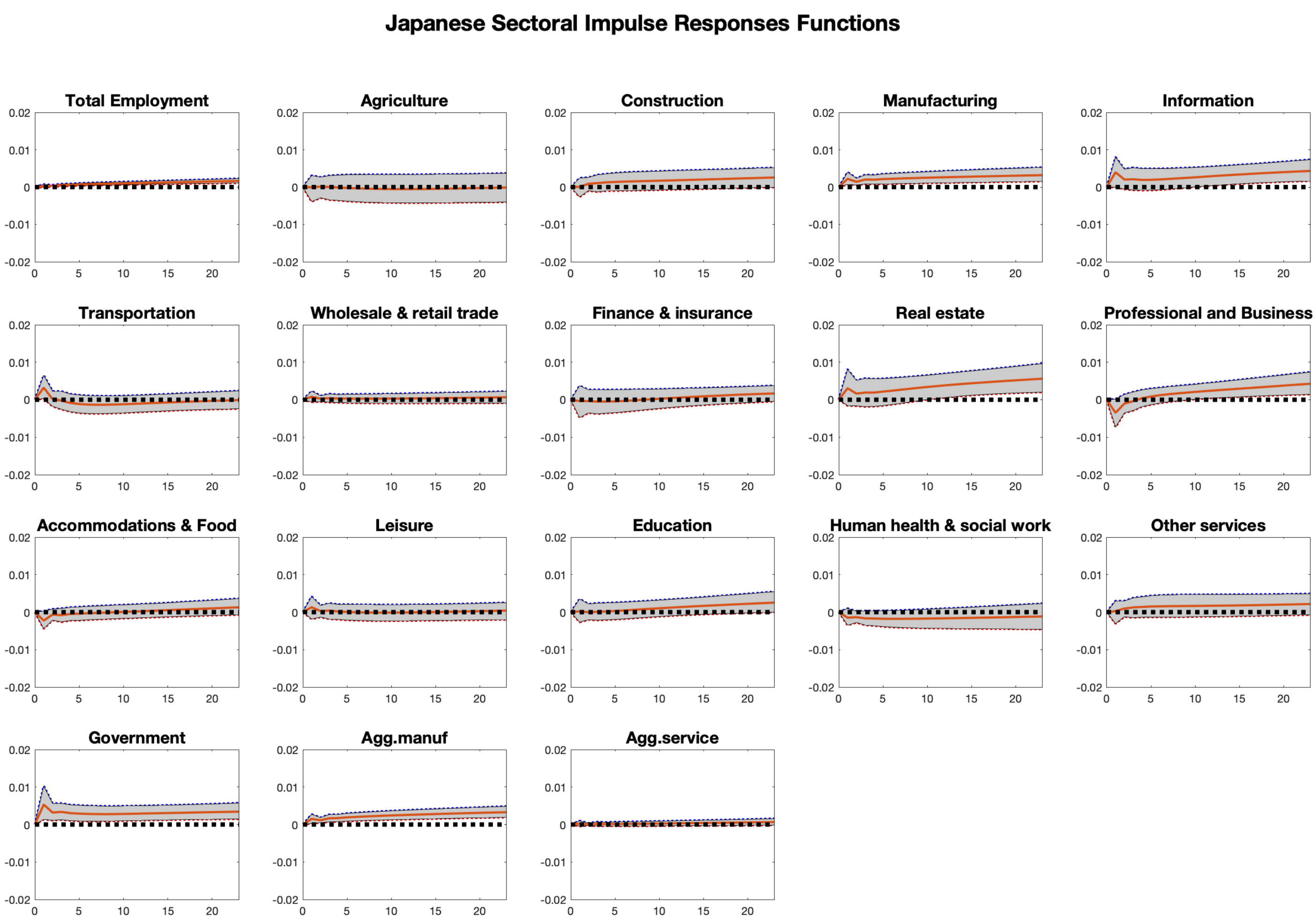
Note: The Median, 16th, and 84th Bayesian percentiles. Monthly horizon.

Figure 11: The United Kingdom Sectoral Employment Impulse Response Functions



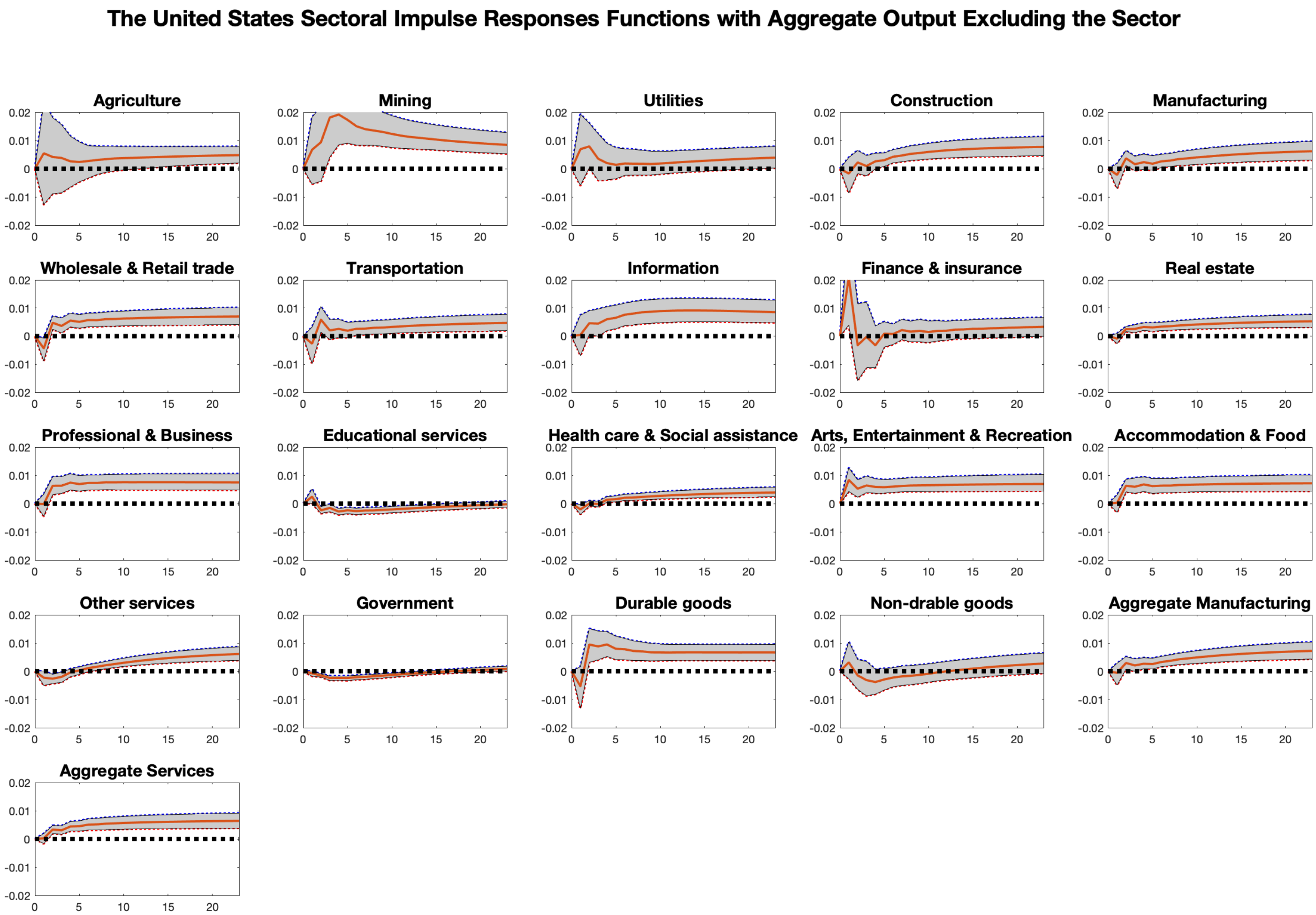
Note: The Median, 16th, and 84th Bayesian percentiles. Quarterly horizon.

Figure 12: The Japanese Sectoral Employment Impulse Response Functions



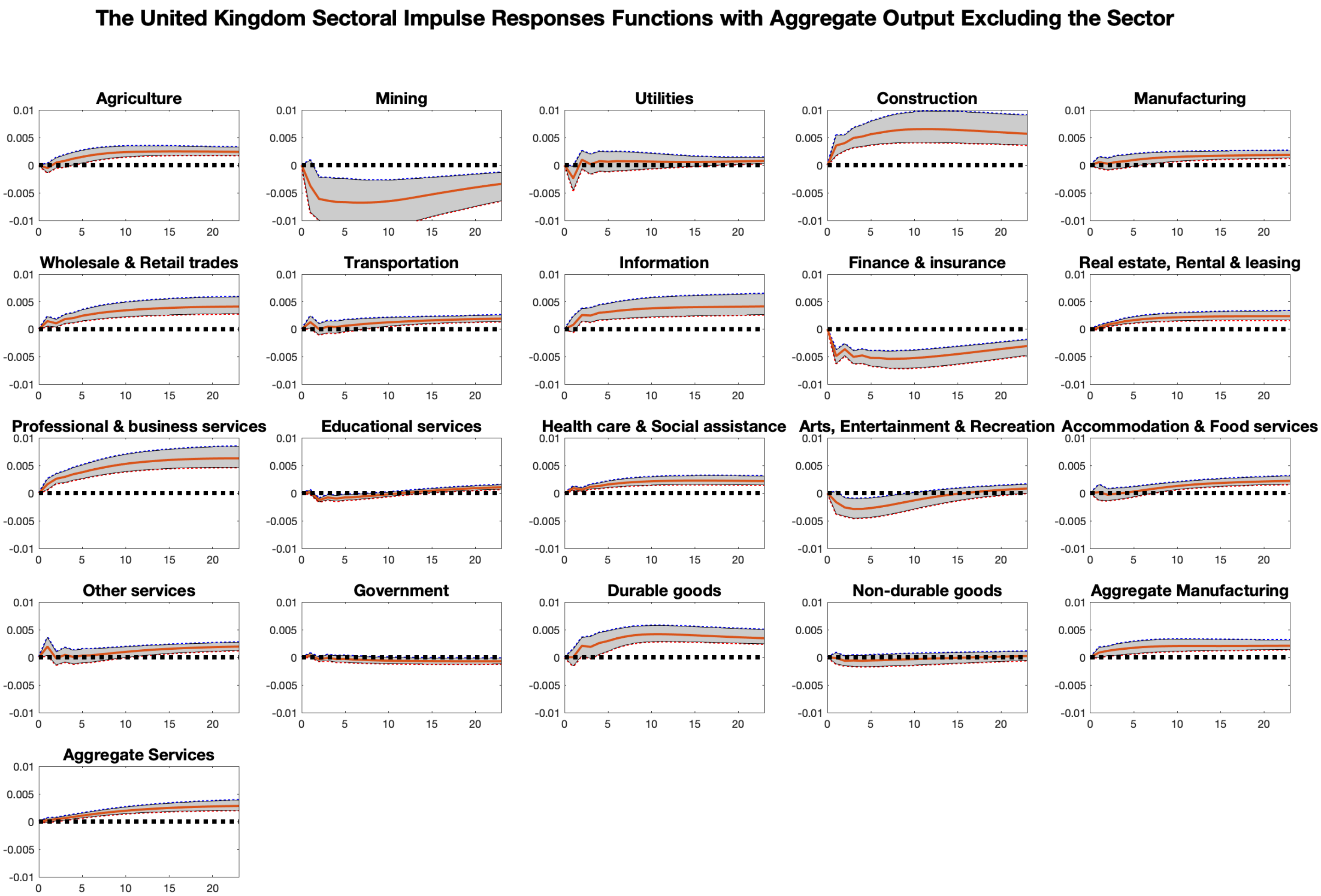
Note: The Median, 16th, and 84th Bayesian percentiles. Monthly horizon.

Figure 13: The United States Sectoral Impulse Response Functions with Aggregate Output Excluding the Sector



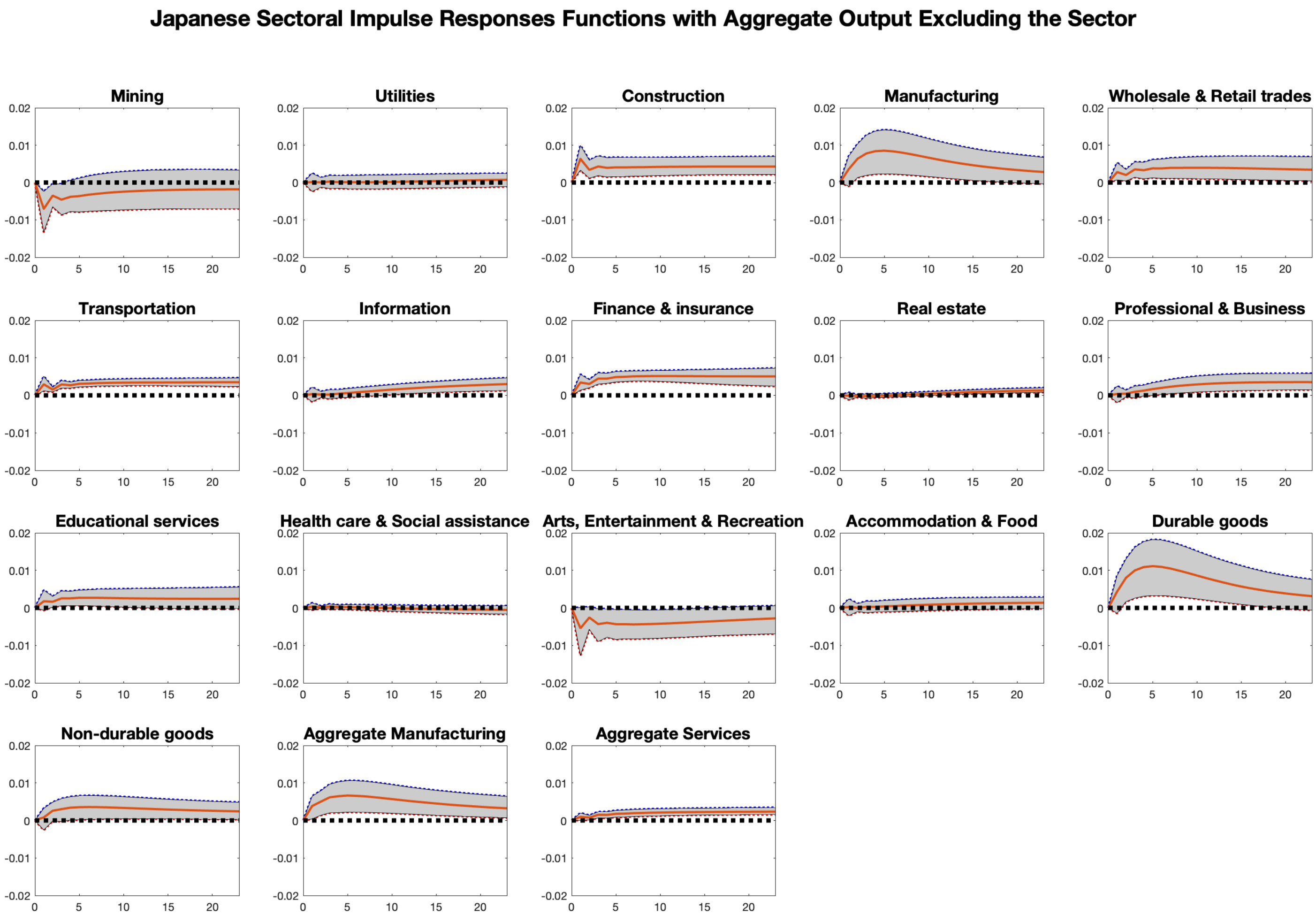
Note: The Median, 16th, and 84th Bayesian percentiles. Quarterly horizon.

Figure 14: The United Kingdom Sectoral Impulse Response Functions with Aggregate Output Excluding the Sector



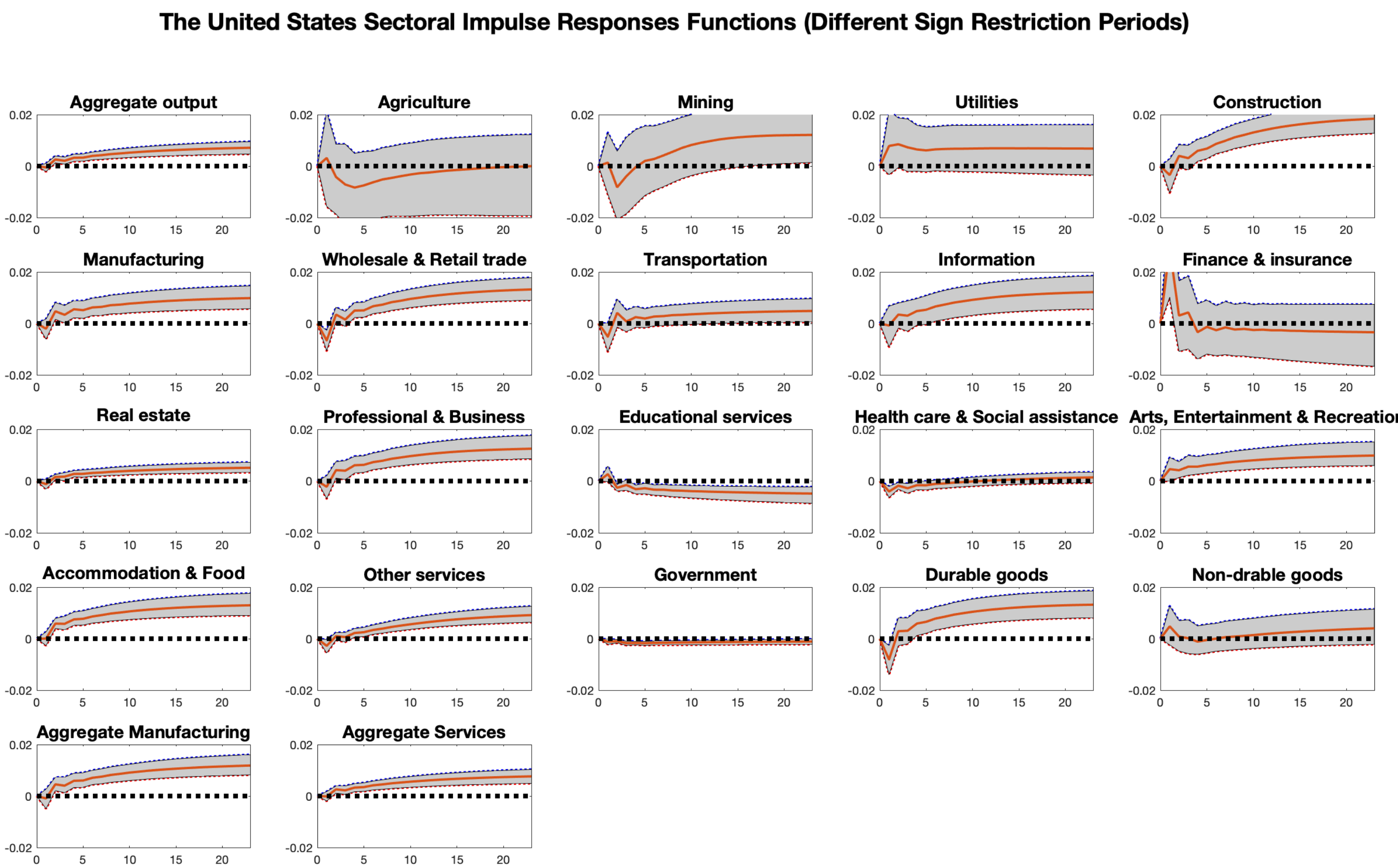
Note: The Median, 16th, and 84th Bayesian percentiles. Monthly horizon.

Figure 15: The Japanese Sectoral Impulse Response Functions with Aggregate Output Excluding the Sector



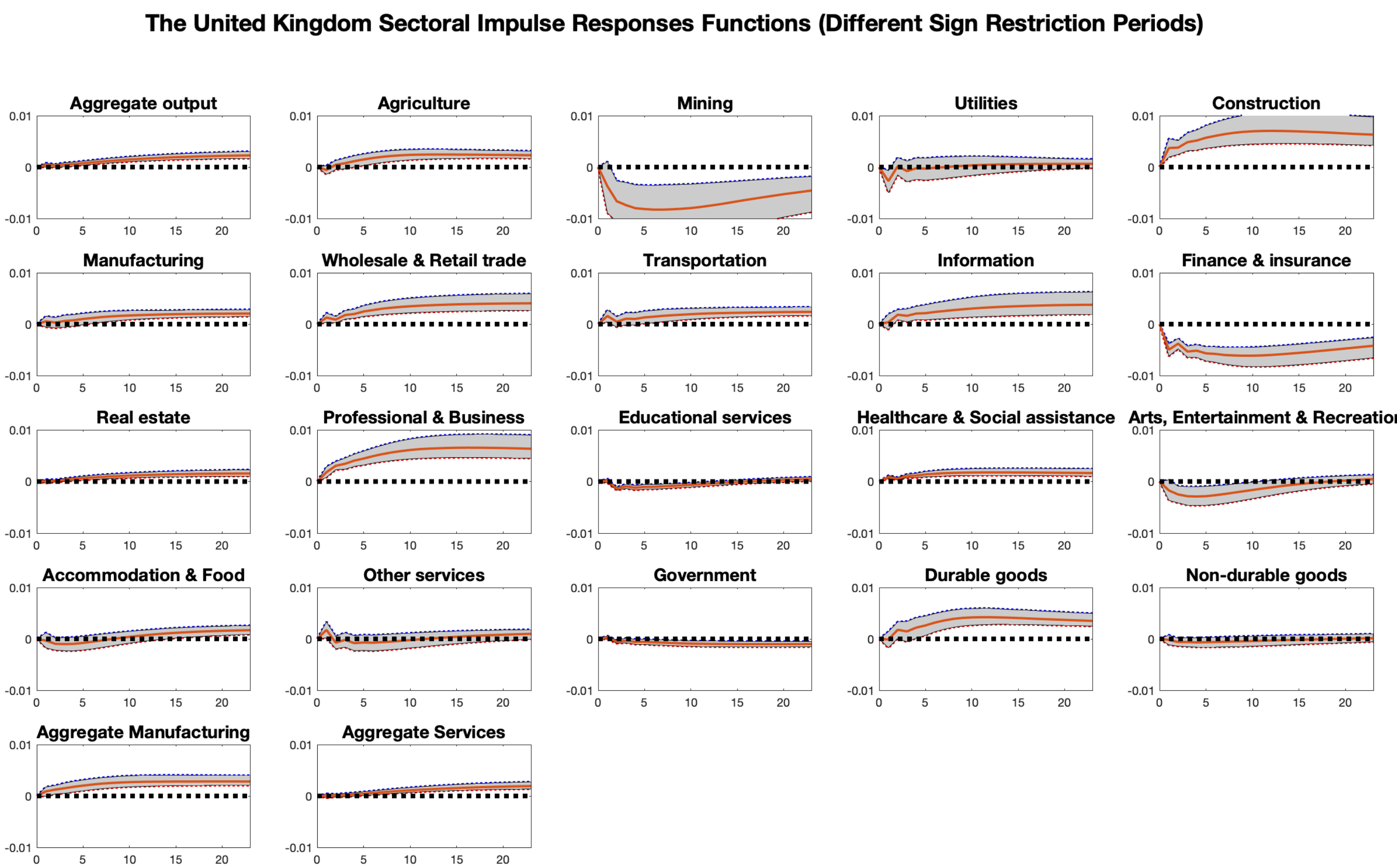
Note: The Median, 16th, and 84th Bayesian percentiles. Monthly horizon.

Figure 16: The United States Sectoral Impulse Response Functions (Different Identification Periods)



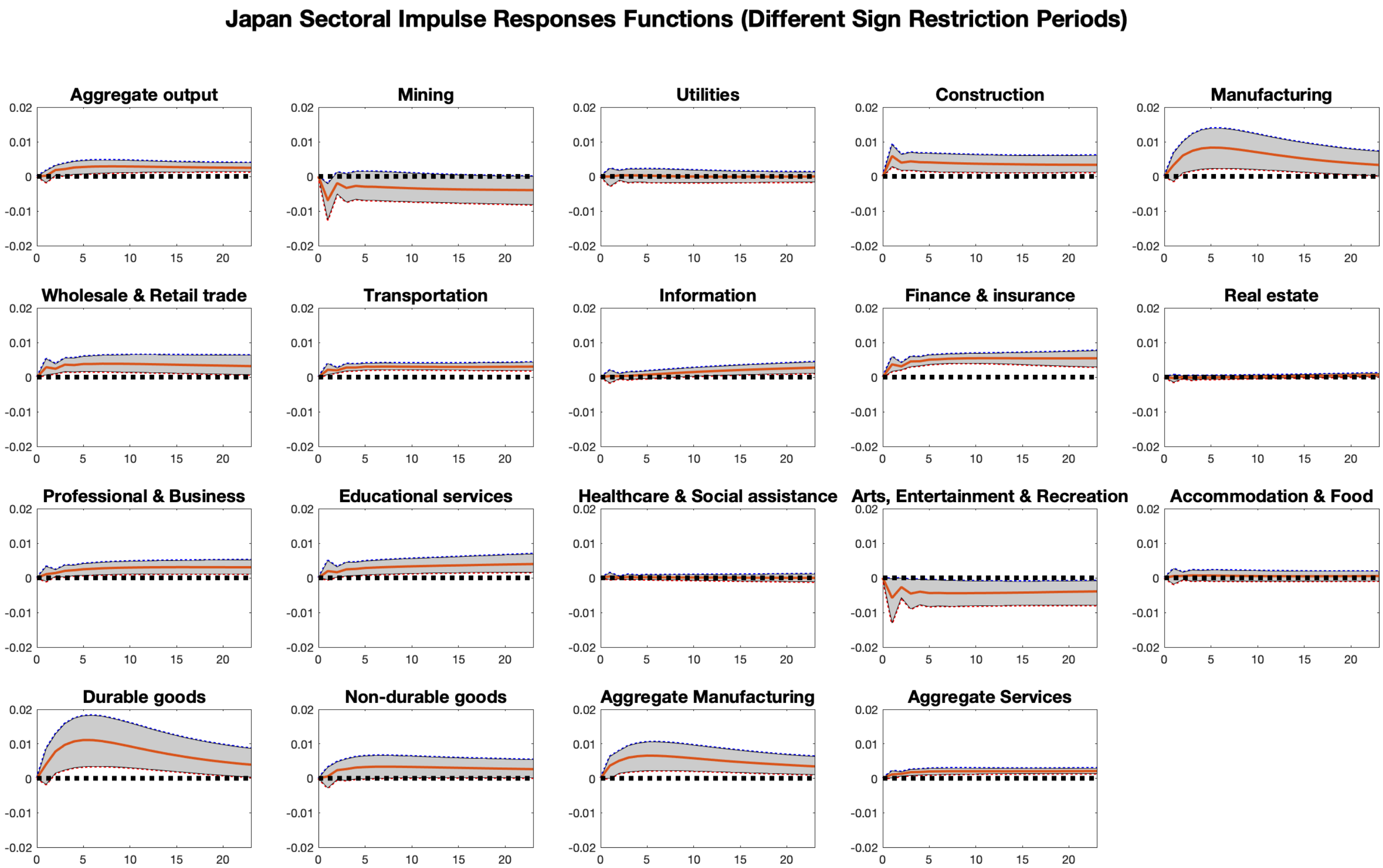
Note: The Median, 16th, and 84th Bayesian percentiles. Quarterly horizon.

Figure 17: The United Kigdom Sectoral Impulse Response Functions (Different Identification Periods)



Note: The Median, 16th, and 84th Bayesian percentiles. Monthly horizon.

Figure 18: Japanese States Sectoral Impulse Response Functions (Different Identification Periods)



Note: The Median, 16th, and 84th Bayesian percentiles. Monthly horizon.

A Appendix: Complete Description of Identification

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

$$\Sigma_u = BB' = BI_4B' = BQQ'B' \tag{5}$$

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

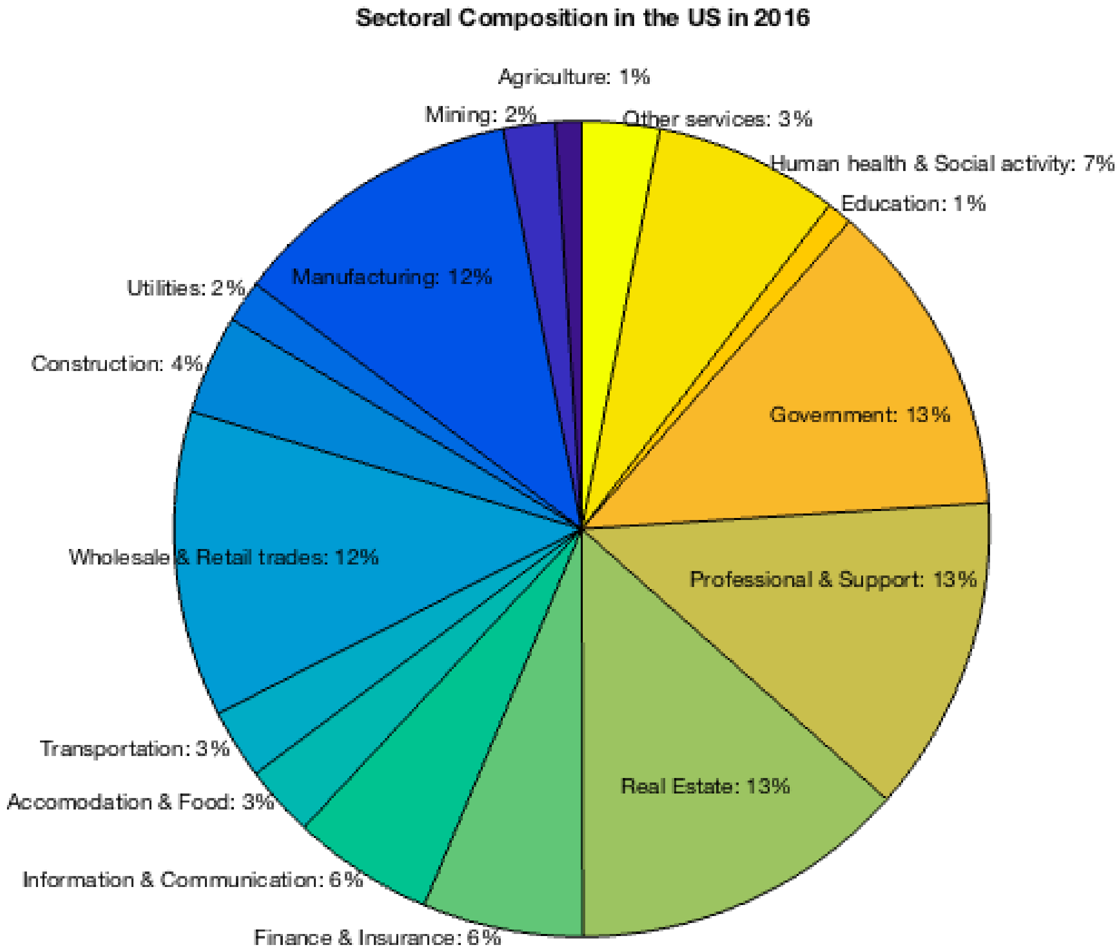
$$Q = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & cos(\theta) & -sin(\theta) \\ 0 & 0 & sin(\theta) & cos(\theta) \end{bmatrix} \tag{6}$$

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

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

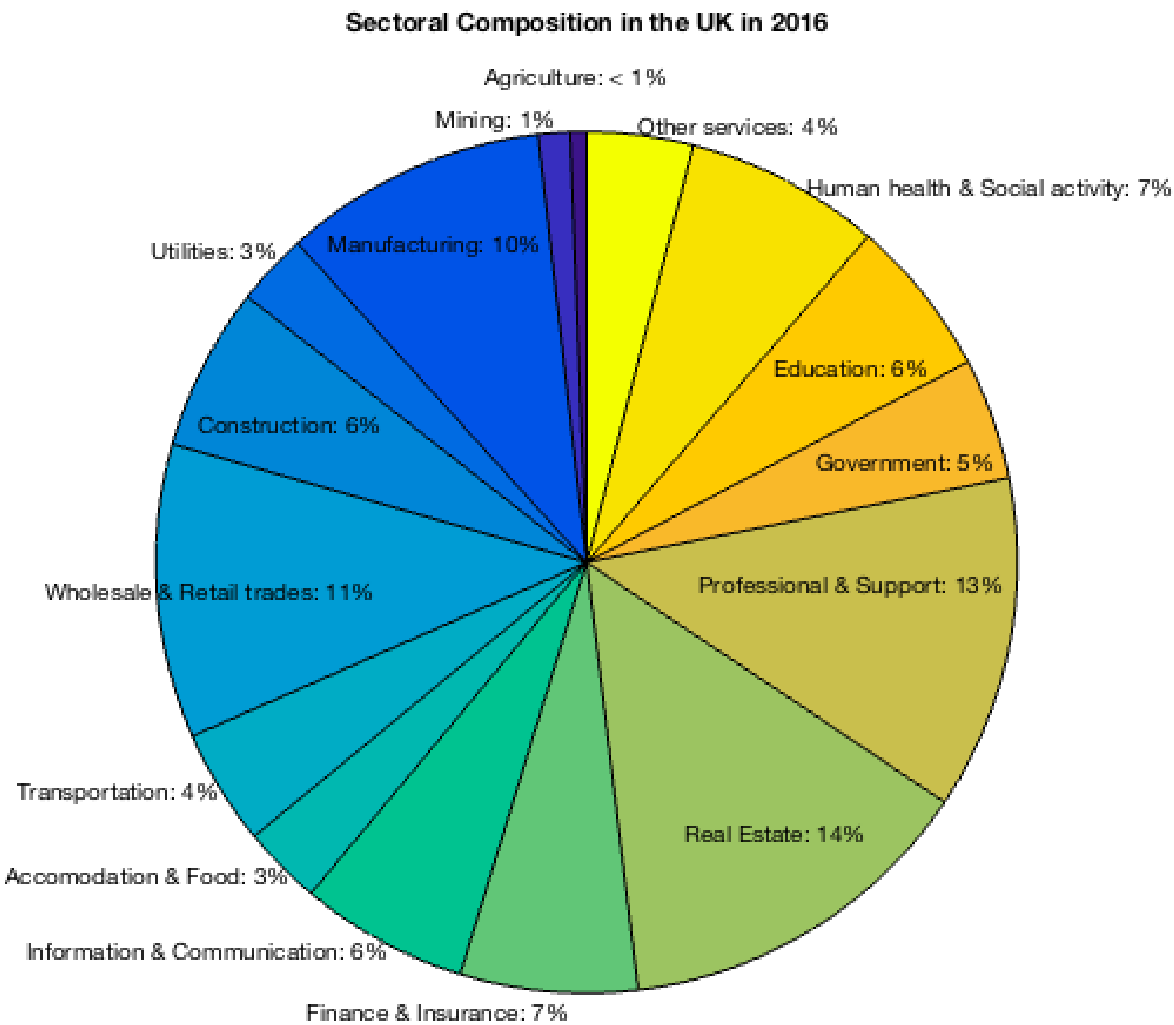
B Appendix: Figures

Figure B.1: The United States Sectoral Composition in 2016



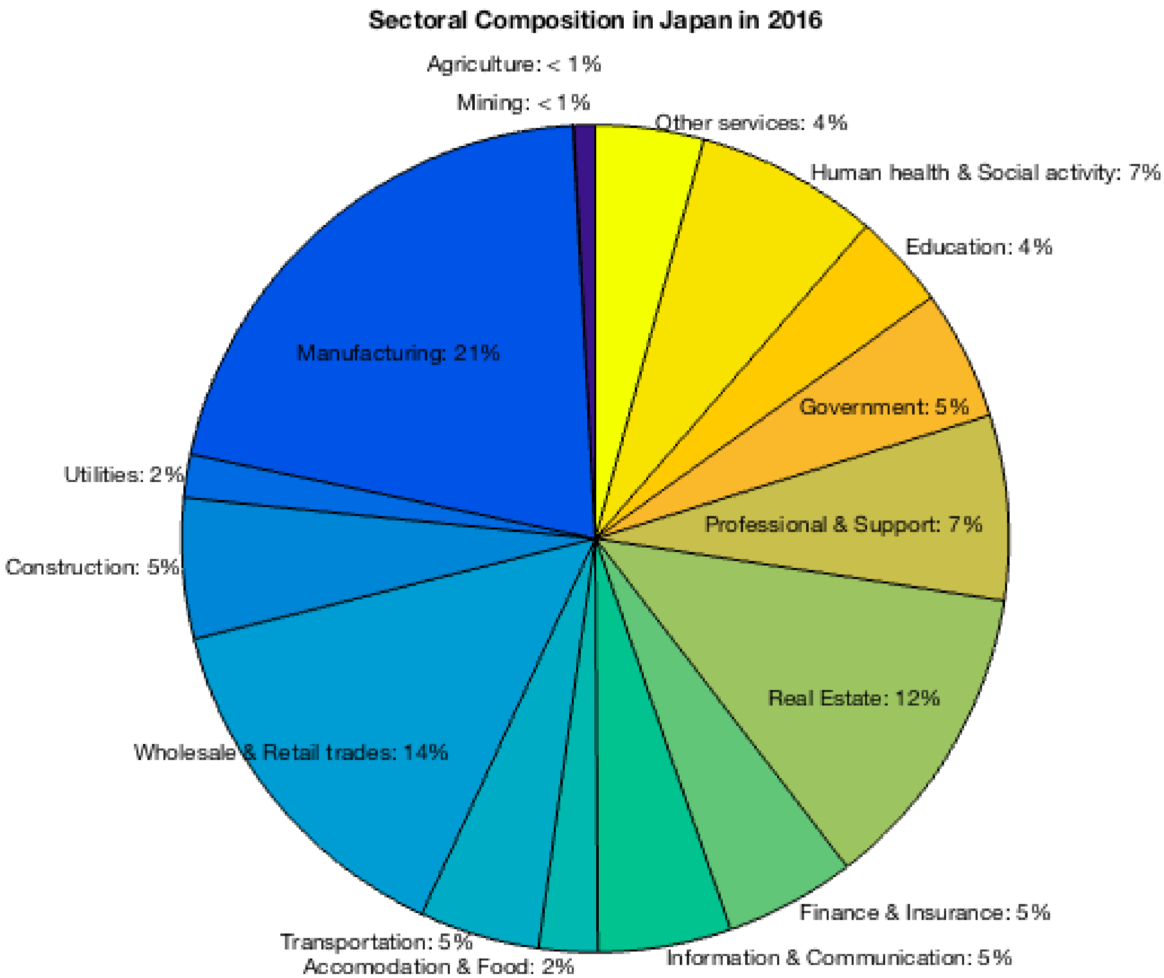
Source: The Bureau of Economic Analysis

Figure B.2: The United Kingdom Sectoral Composition in 2016



Source: The Office for National Statistics

Figure B.3: The Japanese Sectoral Composition in 2016



Source: The Cabinet of Japan