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How Does Unconventional Monetary Policy Affect the Global Financial Markets?: Evaluating Policy Effects by Global VAR Models[1]

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Abstract

This paper examines the effects of unconventional monetary policies (UMPs) by the Bank of Japan (BOJ) and the Federal Reserve (Fed) on the financial markets, taking international spillovers and a possible regime change into account. To this end, we apply the smooth-transition global VAR model to a set of major financial variables for 10 countries and one Euro zone. Our results suggest that the BOJ and the Fed's expansionary UMPs have had significant positive effects on domestic financial markets, particularly in more recent years. Our results also indicate that the BOJ's UMPs have rather limited effects on international financial markets and that the effect of the Fed's UMPs is approximately ten times larger.

Keywords: Monetary policy, Financial linkage, International spillover, Global VAR, Smooth-transition model
JEL classification: C32, E44, F41, F47, O50

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1 Introduction

Since the beginning of the new century, we have observed a number of so-called "unconventional monetary policies (UMPs)," conducted by central banks in the major economies, including the Bank of Japan (BOJ), the Federal Reserve (Fed), the European Central Bank (ECB), and the Bank of England (BOE). This was mostly because the many central banks lowered their policy rates as low as possible after the global financial crisis (GFC) hit the economy in 2008. To conduct further monetary easing, they must rely on UMP instruments, such as large-scale asset purchases and negative interest rates. One obvious question regarding UMPs is their effects on the macroeconomy and financial markets domestically and internationally. In this paper, we tackle this issue, focusing on the UMPs of the BOJ and Fed. Our focus on Japan and the US is not unreasonable for at least three reasons. First, the US economy is the largest in the world, and the Fed's monetary policy is arguably the most influential in the world economy. Second, Japan has the longest history of UMPs, as we briefly describe below. Lastly, the sizes of monetary base, denominated in US dollar, in two countries during the sample period is roughly comparable. Thus it is instructive to compare the effects of monetary base shocks on not only the domestic financial markets, but also the global financial markets.

After the introduction of the zero interest rate policy in February 1999, the BOJ has conducted a series of monetary easing, as a part of its UMPs. Specifically, the BOJ established the quantitative easing (QE) policy in March 2001 that changed the policy targets from the non-collateral call rate to the BOJ's Current Account Balances, significantly increasing the monetary base. Although the policy was terminated in March 2006, the BOJ started the comprehensive easing with an asset purchasing program in October 2010, under which the BOJ purchased various kinds of relatively risky assets, such as Exchange Traded Fund (ETF), Japanese Real Estate Investment Trusts (J-REITs), and corporate bonds. The BOJ also introduced the quantitative and qualitative easing (QQE) policy in April 2013, expanding the monetary base more aggressively. More recently, the BOJ incorporated the negative interest rate policy into QQE in January 2016 and the yield curve control in September 2016. Thus, the analysis of Japanese UMPs is far more informative and interesting than those of other countries, as it has the longest history of UMPs.

In order to assess the effects of UMPs on financial markets, it is extremely important to consider the interdependence within the world economy, since world economies, especially the international financial markets, have been integrated over the past two decades. For example, Christoffersen et al. (2012) examine copula correlations in international stock markets and find a significant increasing trend in both developed and emerging markets. Similarly, Okimoto (2014) documents asymmetric increasing trends in dependence in major international equity markets. Thus, when we analyze the UMPs, it is very important to consider the spillover effects from one country's monetary policy to the economy and financial markets in other countries. To this end, we employ the Global Vector Autoregression (GVAR) model developed by Pesaran, Schuermann, and Weiner (2004). The GVAR model is configured by a system of country-specific VAR models, each of which is connected through the so-called foreign variables in each sub-VAR. A key idea is that the global effects are captured by a deterministic function of other countries' variables in the VAR models, which increases the model tractability but still allows us to take the international transmission mechanism into account.

The GVAR model has been applied to various issues, such as macroeconomics (Dees, di Mauro, Pesaran, and Smith 2007), industrial sectors (Hiebert and Vansteenkiste 2010), bond markets (Favero 2013), real estate markets (Vansteenkiste 2007), fiscal imbalance on borrowing costs (Caporale and Girardi 2013), US credit supply shocks (Eickmeier and Ng 2015), the recent slowdown of the Chinese economy (Gauvin and Rebillard 2015; Inoue, Kaya, and Oshige 2018) and commodity price shocks (Inoue and Okimoto 2018).

The GVAR model has also been applied to examine the impacts of monetary policies, including UMPs. For example, Georgiadis (2016) assesses the global spillovers of US traditional monetary policy shocks and finds considerable output spillovers to the rest of the world, which are larger than the domestic effects in the US for many economies. Chen, Filardo, He, and Zhu (2016) study the US UMP effects on reductions in the US term and corporate spreads and its spillover effects on emerging and advanced economies, showing that the estimated effects are sizable and vary across economies. Dekle and Hamada (2015) and Ganelli and Tawk (2017) document the positive and significant impacts of the BOJ's monetary policy shocks on Asian economies. Chen, Lombardi, Ross, and Zhu (2017) analyze the effects of US and EU UMPs on 24 economies and confirm that US UMPs generally have stronger domestic and cross-border impacts on output growth and inflation than Euro-area nonstandard measures.

Along the same lines, the main contribution of this paper is to examine the effects of BOJ and Fed UMPs on the financial markets, by taking the transmission to the world economy into consideration. More specifically, we try to quantify the impacts of their

UMP shocks on the domestic and global financial markets, based on the GVAR model consisting for 10 countries and one Euro zone for the sample period between 2002-2015.

Our analysis differs from the previous studies in several ways. First, we analyze the effects of UMPs for Japan and the US, which are arguably two of the most interesting and important countries to analyze. Second, we focus on the effects on financial variables, including the government and corporate bond prices and equity prices. This is not unreasonable, as one of our main interests is to examine the possible spillovers of one country's UMP to other countries, and international transmission should be much faster for financial variables than for macroeconomic variables. Focusing on the financial variables also allows us to use monthly data, increasing the sample size significantly compared with macroeconomic variables, some of which can be observed only quarterly. This also makes us possible to incorporate a regime change, providing the last important difference from the previous studies. Specifically, we examine a possible regime change by extending the GVAR model to the smooth-transition GVAR (STGVAR) model. This is relevant, because the BOJ's UMP evolved significantly since the introduction of QE in 2001, as we discussed above. In addition, the Fed started its UMP in December 2008, after the Lehman crisis, giving a solid reason to assume a regime change.

Our findings based on the generalized impulse responses (GIR) analysis are summarized as follows. First, our results suggest that the BOJ's expansionary monetary policy raises the Japanese equity prices and depreciates the values of the yen throughout the sample period. Second, although the BOJ's expansionary monetary policy raises the prices of both Japanese sovereign and corporate bonds in the later stage of UMPs, including QQE, it fails to increase the prices of both bonds in the earlier sample, indicating that the BOJ's UMPs have become more effective in recent years. Third, the Fed's expansionary monetary policy increases US sovereign and corporate bond prices as well as equity prices, and depreciates the dollar values in both regimes. Finally, in terms of its global influence, the BOJ's effects are rather limited, while the effects of the Fed's policy are approximately ten times larger.

The remainder of this paper is organized as follows. Section 2 introduces the GVAR and ST models. Section 3 describes the data and provides the estimation results of the STGVAR models. Section 4 demonstrates the analysis based on the GIR functions. Finally, Section 5 concludes the paper.

2 Models

2.1 GVAR model

In order to quantify the magnitude of monetary policy shock diffusion on both domestic and global financial indices, we use a novel time-series technique, the GVAR model, which was developed by, among others, Pesaran, Schuermann, and Weiner (2004), Dees, di Mauro, Pesaran, and Smith (2007), and Dees, Holly, Pesaran, and Smith (2007).

The GVAR model is configured by a system of country-specific VARX* models. The i-th country-specific VARX*(p_i, q_i) model $(i = 1, \ldots, N)$ is written as:[1]

$$\mathbf{x}_{i,t} = \mathbf{a}_{i0} + \sum_{\ell=1}^{p_i} \mathbf{\Phi}_i^{(\ell)} \mathbf{x}_{i,t-\ell} + \sum_{\ell=0}^{q_i} \mathbf{\Lambda}_i^{(\ell)} \mathbf{x}^*_{i,t-\ell} + \mathbf{u}_{it}, \tag{1}$$

where $\mathbf{x}_{i,t}$ represents the domestic variable vector; $\mathbf{x}^*_{i,t}$ denotes the foreign variable vector; $\mathbf{a}_{i0}$ denotes a vector of constants; p_i represents the lag length of domestic variables; q_i represents the lag length of foreign variables; $\mathbf{\Phi}_i^{(\ell)}$ and $\mathbf{\Lambda}_i^{(\ell)}$ represent the coefficient matrices with order ℓ; and $\mathbf{u}_{it}$ represents the idiosyncratic errors.

These country models are connected through the so-called "foreign" variables in each sub VARs. The foreign variables (sometimes called "star" variables) of country i are constructed as:

$$\mathbf{x}^*_{it} = \sum_{j=1}^{N} w_{ij} \mathbf{x}_{jt} \tag{2}$$

where the term w_{ij} represents the "closeness" between country i and country j with $w_{ii} = 0$ and $\sum_{j=1}^{N} w_{ij} = 1$ for $i = 1, \ldots, N$. Since our model examines the monetary policy shock transmissions between countries mostly through financial markets, our w_{ij} should represent the proximity between a pair of countries in terms of financial activity, as we will discuss in more detail below.

A key idea is that the "foreign" variables are defined as a deterministic function of the other country's domestic variables, which increases the model tractability but still allows us to incorporate the international transmission mechanism into the model. One can think that the term of foreign variables in equation (1) represents the global effects, which are not directly observable, but can be proxied by this term. At the time of

[1] Another commonly used specification in this literature is the global vector error-correction model with exogenous variables. In this paper, however, we do not consider the cointegrating relations among variables.

estimating the parameters, the country-specific VARX* models are estimated one-by-one by assuming that the "foreign" variables are indeed "exogenous." For the dynamic analysis, for example, the GIR analysis, the entire system is solved along with the identity equations (2) that associate the "foreign" variables with the other country's "domestic" variables.

2.2 STGVAR model

The smooth-transition model is developed within the autoregressive model by, among others, Chan and Tong (1986) and Granger and Teräsvirta (1993); its statistical inference is established by Teräsvirta (1994). Since then, the smooth-transition model has been applied to many types of models.[2]

In this paper, we apply the smooth-transition model to the GVAR model. Specifically, our two-regime smooth-transition GVAR (STGVAR) model consists of country-specific two-regime smooth-transition VARX* (STVARX*), given as follows:

$$\begin{aligned}\mathbf{x}_{i,t} = (1 - G_{it}) &\left(\mathbf{a}_{i0}^{(1)} + \sum_{\ell=1}^{p_i} \mathbf{\Phi}_i^{(\ell,1)} \mathbf{x}_{i,t-\ell} + \sum_{\ell=0}^{q_i} \mathbf{\Lambda}_i^{(\ell,1)} \mathbf{x}_{i,t-\ell}^* \right) \\ &+ G_{it} \left(\mathbf{a}_{i0}^{(2)} + \sum_{\ell=1}^{p_i} \mathbf{\Phi}_i^{(\ell,2)} \mathbf{x}_{i,t-\ell} + \sum_{\ell=0}^{q_i} \mathbf{\Lambda}_i^{(\ell,2)} \mathbf{x}_{i,t-\ell}^* \right) + \mathbf{u}_{it}, \end{aligned} \tag{3}$$

where $\mathbf{a}_{i0}^{(j)}$, $\mathbf{\Phi}_i^{(\ell,j)}$, and $\mathbf{\Lambda}_i^{(\ell,j)}$ are parameters for regime j ($j = 1, 2$), $G_{it} = G(z_t; c_i, \gamma_i)$ is a transition function taking values between 0 and 1 with a transition variable z_t and parameters c_i and γ_i. If $G_{it} = 0$, the STGVAR model (3) reduces to the GVAR model (1) with parameters $\mathbf{a}_{i0}^{(1)}$, $\mathbf{\Phi}_i^{(\ell,1)}$ and $\mathbf{\Lambda}_i^{(\ell,1)}$. We refer to this regime as the regime 1. When $G_{it} = 1$, we have the GVAR model characterized by $\mathbf{a}_{i0}^{(2)}$, $\mathbf{\Phi}_i^{(\ell,2)}$, and $\mathbf{\Lambda}_i^{(\ell,2)}$. We refer to this regime as the regime 2. In this sense, the STGVAR model (3) can be seen as a two-regime model. In general, the model at time t will be a weighted average of the GVAR models of each regime with a weight determined by the transition function G_{it}.

The transition function and transition variable are determined according to the purpose of the analysis. For example, Lin and Teräsvirta (1994) investigate a continuous permanent regime change using the logistic transition function with a time-trend transition variable. Following their research, we use a logistic transition function given as

$$G_{it} = G(z_t; c_i, \gamma_i) = \frac{1}{1 + \exp\bigl(-\gamma_i(z_t - c_i)\bigr)}, \quad \gamma_i > 0, \tag{4}$$

[2]See Franses and van Dijk (2000) and van Dijk, Teräsvirta, and Franses (2002) for the details on smooth-transition models.

and a time-trend transition variable $z_t = t/T$, where T is the sample size. We assume $0.05 < c_i < 0.95$, so that we can detect the regime shifts within the sample period, as explained below.

With this choice of transition function and variable, G_{it} takes a value close to zero with a smaller z_t around the beginning of the sample period. Therefore, we can interpret the GVAR model in regime 1 as the GVAR model around the beginning of the sample. On the other hand, toward the end of the sample, G_{it} approaches one with a larger z_t, making the GVAR model in the regime 2 interpretable as the GVAR model around the end of the sample. More generally, if z_t is smaller (larger) than c, the GVAR dynamics become closer to those in regime 1 (regime 2). Thus, we can consider that the location parameter c determines the timing of regime change and the assumption of $0.05 < c_i < 0.95$ ensures that there is a regime change within the sample period. The smoothness parameter γ_i determines the speed of the transition from regime 1 to regime 2 as time goes by. More specifically, when γ_i takes a large value, the transition is abrupt, whereas the transition is gradual for small values of γ_i. One of the advantages of the logistic transition function is that it can express various forms of transition depending on the values of c_i and γ_i. Additionally, c_i and γ_i can be estimated from the data, enabling the selection of the best transition patterns based on the data.

3 Estimation Results of the STGVAR Model

3.1 Data and model specification

In this study, we estimate a STGVAR model (3), consisting of $N = 11$ country-specific VARX* models at a monthly frequency. Those countries include Australia (the mnemonic used in the tables and graphs is `au`), Canada (`ca`), Switzerland (`ch`), Denmark (`dk`), the Euro zone (`xm`),[3] the United Kingdom (`gb`), Japan (`jp`), Norway (`no`), New Zealand (`nz`), Sweden (`se`), and the United States (`us`). Reflecting the size of financial markets, all countries, except for the US, are assumed to be small open economies. This assumption is explicitly modeled by including the foreign variables in their VARX* models. Data are collected from various sources. Our sample covers the periods from May 2002 to December 2015, or 164 months.

The domestic variable vector $\mathbf{x}_{it}$ of country i includes the following four variables (for

[3] The Euro zone consists of Austria, Belgium, Finland, France, Germany, Italy, the Netherlands, and Spain.

$i = 1, \ldots, N$): the sovereign bond price index s_{it} (the mnemonic used in the figures of generalized impulse response functions below, is `sb`), the corporate bond price index c_{it} (`cb`), the equity price index q_{it} (`eq`), and the nominal effective exchange rate e_{it} (`neer`). Two key indices, i.e. the sovereign bond price and the corporate bond price, are obtained from the S&P Dow Jones Fixed Income Index, kindly provided by S&P Dow Jones Indices LLC, Tokyo. The equity price data and the exchange rate data are obtained from CEIC and the Bank of International Settlement (BIS), respectively. All variables are log-transformed. Notice that q_{it}, s_{it} and c_{it} are evaluated in local currency units.

For Japan and the US, the amount of their own base money, $m_{\mathrm{JP},t}$ or $m_{\mathrm{US},t}$, is added to $\mathbf{x}_{it}$. To construct $m_{\mathrm{JP},t}$ and $m_{\mathrm{US},t}$, the end-of-period amount of base money (in local currency units), obtained from the International Financial Statistics of the International Monetary Fund (IMF), is seasonally adjusted, and is then log-transformed. For the seasonal adjustment, we use the X-13 methods in EViews. Table 1 summarizes the names of the series and their data sources for the above-mentioned variables.

Construction of the foreign variables $\mathbf{x}^*_{it}$, as defined in (2), requires the weight w_{ij} (for $i, j = 1, \ldots, N$). In the GVAR literature, it is common to use trade flow data to measure the proximity between any pair of countries (Dees, di Mauro, Pesaran, and Smith, 2007). The choice of trade flow is reasonable if one's main focus is on the real economic activities, such as the fluctuation of GDP or the industrial productions, because the home-country's output is likely to be affected by the variation of trade partner's output. However, since our model examines the shock transmissions between countries mostly through financial markets, the weights should capture the bilateral financial exposures between the countries under investigation.

There are a few previous studies which construct the weights based on the bilateral financial exposures. For instance, Galesi and Sgherri (2009) build the weights by using the cross-country bank lending exposures data of the BIS in order to analyze the regional financial spillover across 26 European countries and the US. Similarly, to investigate the international transmission of bank and corporate distress, Chen, Gray, N'Diaye, Oura, and Tamirisa (2010) adopt the currency exposure measures of Lane and Shambaugh (2010), which summarize bilateral financial asset positions in portfolio equity, direct investment, portfolio debt, other general bank-related debt, and reserves. Also, Eickmeier and Ng (2015) employ three sets of gross bilateral financial claims data to investigate the US credit supply shocks spillover across 33 advanced and emerging economies. Those data are: (1) total portfolio investment asset positions, from IMF's Coordinated Portfolio Investment Survey (CPIS); (2) total foreign direct investment asset positions, from IMF's Coordinated Direct Investment Survey (CDIS); and (3) consolidated international claims of banking groups headquartered in each sample country, from the BIS international banking statistics (IBS). These are three outstanding data of outward portfolio investment. In addition, by reversing the direction of bilateral claims data, Eickmeier and Ng (2015) also construct the inward portfolio investment data. Thus, they create two types of weights, i.e. one represents the asset-side channel of shock transmission (by outward data) and the other represents the liability-side channel (by inward data) for each of three financial claims data.

Since our study focuses on four financial markets that are related to portfolio investments, we compute weights from the IMF's CPIS data by averaging the outward and inward portfolio investment for the period from 2002 to 2016. Thus, for country i, the financial weight with respect to country j is defined as

$$w_{ij} = \frac{\text{sample average of financial stock between country } i \text{ and country } j}{\sum_{\substack{k=1 \\ k\neq i}}^{N} \text{financial stock between country } i \text{ and country } k}$$

See Table 2 for the calculated weights. The numbers in the table sum up to one column wise, and represent the shares of foreign portfolio assets and liabilities of the corresponding country.

Regarding the foreign variables, we make two assumptions. First, given the relative size of the US financial market, we treat it as independent of other markets. This is done by excluding a set of foreign financial variables from the US VARX* model, as in Pesaran, Schuermann, and Weiner (2004). Thus, no foreign variables are included for the US VARX* model. Second, as discussed by Pesaran, Schuermann, and Weiner (2004) and Galesi and Lombardi (2009), due to a strong correlation between domestic and foreign-specific effective exchange rates, the foreign-specific effective exchange rates are excluded from the country-specific VARX* models.

Our model specification of the country-specific VARX* model is summarized in Table 3. Given the increasing importance to the global economy of commodity prices, particularly oil prices, we also use another specification by including the oil price in the US VARX* model to see the robustness of our analysis, as we discuss below.

3.2 Estimation results of the STGVAR model

In this subsection, we report the estimation results of the STGVAR model. Specifically, we estimate the country-specific STVARX* models one-by-one by assuming that the "foreign" variables are exogenous, and the error term follows the multivariate normal distribution with no correlation across-countries.

It is possible in principle to estimate the all the parameters of the STVARX* model (3) simultaneously by maximum likelihood estimation (MLE). However, it is challenging, if not impossible, to maximize the likelihood function with respect to all parameters, because of the large number of parameters and the highly nonlinear structure of the STVARX* model, induced by c_i and γ_i. To overcome this problem, some of the previous studies fix and/or calibrate those parameters. For example, Auerbach and Gorodnichenko (2012) assume $c_i = 0$ and calibrate γ_i without any estimation. Similarly, Weise (1999) fixes c_i at a predetermined value but estimates γ_i by a grid search. Granger and Teräsvirta (1993) also suggest using a grid search for these parameters. Therefore, following Granger and Teräsvirta (1993), we employ a grid search to estimate both c_i and γ_i. Given the fixed values of c_i and γ_i, the STVARX* model becomes a seemingly unrelated regression model with the same set of regressors. In this case, the MLE becomes equivalent to the equation-by-equation OLS. Therefore, using the grid search, we can relatively easily find the maximum likelihood estimates of c_i and γ_i along with other parameters.

In addition, due to the relatively large number of domestic and foreign variables that are included in the country-specific STVARX* models, we have to adopt a parsimonious lag structure. Specifically, we set the maximum lag lengths of both domestic variables, p_i, and foreign variables, q_i, to two. Then, the optimal lag length is determined country-by-country by using the Akaike information criteria (AIC); the results are reported in Table 4.

If the lag structure is too parsimonious, the country-specific STVARX*s may not be able to properly capture the dynamics of variables. Thus, it is reasonable to examine whether there is dynamic misspecification in the regressions of the 46 endogenous variables by employing the serial correlation tests. The right half of Table 4 reports F-tests of serial correlation of order 4 in the regression residuals. Though the model's lag structure is rather simple, 35 regressions out of 46 endogenous variables cannot reject the null of no serial correlation at a 5% significance level. Therefore, although there are cases that need to be investigated more cautiously, overall the test results suggest that the restriction on the maximum lag length is acceptable.

The estimated transition functions (4) are displayed in Figure 1, with the left panel showing results for Australia, Canada, Japan, and the US and the right panel shwoing those for other European economies. By definition, the value of G_{it} increases monotonically with time t, and the value can be considered as the weight of regime 2. As shown, although the timing of changes from regime 1 to regime 2 differs across countries, many of them seem to have experienced abrupt changes at around the GFC. One exception is Japan, whose turning point is identified at around March 2011. For the European countries/region, four countries have their turning points slightly after the GFC, followed by Switzerland, Denmark, and the Euro zone. Based on these observations, in order to evaluate the effects of the UMPs of Japan and US in the next section, we will focus on two regimes, ignoring the transition period, that is, regime 1, roughly corresponding to the first part of the sample period, or the pre-GFC period, and regime 2, corresponding to the end of the sample period, or the post-GFC period.

Next, we examine the weak dependence of the idiosyncratic shocks (See Pesaran, Schuermann, and Weiner, 2004). Table 5 provides the average pair-wise cross-section correlations for $\mathbf{x}_{it}$ as well as the associated STVARX* residuals. In general, the average pair-wise cross-section correlations are high for $\mathbf{x}_{it}$. This is reasonable, since the global financial markets are integrated, so the financial indices comove. Once country-specific models are formulated as being conditional on foreign variables, these correlations sharply drop, and the remaining shocks across markets become weak, as expected. Since the correlation coefficients of "resid" is smaller than that of "resid*" in general, the result is consistent with the idea that the contemporaneous foreign variables function as proxies of the common global factors.

Lastly, we examine the contemporaneous effects of foreign variables on their domestic counterparts. The estimated coefficients, or the elasticity of the domestic financial market index with respect to its foreign counterparts are shown with error bars in Figure 2. The error bars are constructed by using Newey-West heteroskedasticity and autocorrelation-consistent standard errors.

For equity markets, the estimated elasticities are in the range of approximately 0.5 to 1.0 across different markets as well as different regimes. However, if we turn our attention to bond markets, the elasticities become more heterogeneous. In the sovereign bond markets, most of the countries record unit elasticity, although Japan's elasticities are negligible. The tendency becomes more apparent in the corporate bond markets. Though the elasticity of the UK market is again approximately 1, the elasticities of other markets are much smaller.

4 GIR Analysis

In this section, we calculate the GIRs using the estimated STGVAR model. The concept of GIRs was proposed by Koop, Pesaran, and Potter (1996) and has been applied to the VAR analysis by Pesaran and Shin (1998).

Mathematically, the GIR is defined as:

$$\mathcal{GIR}(\mathbf{x}_t; u_{i\ell t}, n) = E(\mathbf{x}_{t+n}|u_{i\ell t} = \sqrt{\sigma_{ii,\ell\ell}}, \mathcal{I}_{t-1}) - E(\mathbf{x}_{t+n}|\mathcal{I}_{t-1})$$

where $\mathcal{I}_{t-1}$ is the information set at time $t-1$, and $\sigma_{ii,\ell\ell}$ is the ℓ-th diagonal elements of the variance-covariance matrix $\mathbf{\Sigma}_{iu}$ for the country i.

GIRs are different from the standard impulse responses (IRs), which are proposed by Sims (1980) and calculated by using the Cholesky decomposition of the covariance matrix of reduced-form errors, assuming the orthogonality of the shocks. In other words, to calculate the IRs using the Cholesky decomposition, we must decide the order of the variables depending on the exogeneity of the variables. For financial variables, however, it is not easy to determine the order of variables. In order to overcome this problem, we use the GIRs, which produce shock response profiles that are invariant to the orders of variables.

In the next subsection, we investigate how a positive unexpected monetary easing shock is transmitted to both domestic as well as global financial markets. As confirmed in Section 3.2, most of the sample countries experienced drastic change around the year 2008. In order to examine the effect of this change, we pay special attention to two regimes, regime 1 (corresponding to roughly the pre-GFC period) and regime 2 (corresponding to the post-GFC period). Our aim is to analyze how the changes in the VARX* parameters between the two regimes have affected the propagation of the UMP shocks. Thus, the two different sets of GIRs are calculated based on the estimated VARX* parameters of regime 1 and regime 2, assuming each regime can last forever.

4.1 Effects of the BOJ's UMP on the domestic/global financial markets

In this subsection, we address the issue of how the BOJ's UMP shock influences the domestic and global financial markets. To answer these questions, we conduct a GIR analysis. The GIR graphs in this subsection show the response paths of endogenous variables to an unpredictable 1% increase in the BOJ's monetary base.

First, the shock to the domestic market is investigated. Figure 3 reports the GIRs of four Japanese financial variables for the two regimes. These graphs are created from the bootstrap estimates of the GIRs. For each set of parameter estimates obtained from the bootstrapped sample, we check the dynamic stability of the system by examining whether the maximum eigenvalue is less than 1. If the calculated maximum eigenvalue is greater than 1, the bootstrap sample is discarded, and another sample is constructed. We continue the procedure until we obtain 500 valid samples. The unit of the horizontal axis is a month, and the vertical line at the value 12 indicates the point 12 months after the shock. The unit of the vertical axis is a percentage. The blue line correspond to the median, the red lines correspond to the upper/lower 16%, and the red dotted lines correspond to the upper/lower 5% of the distribution.

From Figure 3, we identify at least three observations. First, an expansion of the monetary base equally raises the price of equity in the two regimes, although both the duration and the magnitude of the responses become smaller in the second regime. In regime 1, the response is statistically significant even one year after the shock. In contrast, the response in regime 2 is still positive but becomes much smaller in magnitude, and it is only significant temporarily, for a short run. However, this does not necessarily mean that the total effects are smaller in regime 2, since the BOJ accelerated the expansion of the monetary base after the introduction of QQE in 2013, most likely producing more shocks in the Japanese financial markets. Second, in regime 1, both government and corporate bond prices exhibit J-shaped responses, which drop sharply right after the shock and then revert to zero approximately half a year later. This suggests that the injected money only flowed toward the equity market, not toward the bond markets. Since a sharp decline in bond price implies a rise of bond yields, the expansionary monetary policy in regime 1 did not function well. On the other hand, after the expansionary monetary easing in regime 2, two bond prices show the expected responses, suggesting that the BOJ's UMPs have become more effective in recent years. Lastly, although temporary, the effects on the nominal effective exchange rate are significantly negative for both regimes, inducing a depreciation of the Japanese yen regardless of regimes.

In sum, our results indicate that the BOJ's expansionary monetary policy raises the Japanese equity prices and depreciate the values of the yen throughout the sample period. In addition, although the BOJ's expansionary monetary policy raises the prices of both Japanese sovereign and corporate bonds in the later stage of UMP, including QQE, it fails to increase the prices of both types of bonds in the earlier sample, suggesting that the BOJ's UMPs have become more effective in recent years. Although it is not directly comparable due to the difference in the sets of variables used, our results are somewhat different from those of Ganelli and Tawk (2017), who use a shadow rate as a proxy of UMPs and find a similar response on exchange rates but no statistically significant impact on equity prices. They also argue that the shadow rate may not capture all the impact of the BOJ's UMPs on the domestic market, while our results suggest that an unexpected increase in the monetary base can still be a reliable proxy of monetary policy.

Next, we examine the BOJ's monetary policy shocks to the global financial market. The GIRs are plotted in Figure 4.[4] From left to right, the graphs show the distribution of GIRs at one month, three months, and six months after the shock, respectively. The edges of the whiskers correspond to the 5 percentile of the distribution. Similarly, the edges of the box correspond to the 16%, and the circle corresponds to the median of the distribution. The color of the circle indicates the level of significance. See footnote for details.

Figure 4 shows several interesting features. First, there is a clear distinction between the two regimes. In regime 1, the BOJ's monetary policy has significantly positive impacts on the global equity markets, though the effects on government and corporate bond markets are negligible. In contrast, in regime 2, the results indicate significant positive impacts on both bond markets, while the effects on global equity markets have become less significant. Therefore, we observe some comovement of asset prices, i.e., stocks, government bonds, and corporate bonds, across borders, often termed as a "global financial cycle" (Rey, 2016), although the type of assets differs across regimes. Second, even for these significant responses, the magnitudes are far smaller compared with those of Japanese domestic financial markets. For instance, on the equity price in regime 1, the three-month median response of the Japanese market is approximately 0.3%. However, that of the EU market is less than 0.1%. Response sizes are much smaller for other global markets. Thus, even though the BOJ has been conducting a very aggressive monetary easing during the sample period, particularly after the introduction of QQE, its effects on the global financial markets seem to be very limited.

[4]Note that the responses of the US financial market indices are all zero, due to the specification of the US VAR model. As we noted in Table 3, the US market is treated as independent.

4.2 Effects of the FRB's UMP on the domestic/global financial markets

In December 2008, the Fed has started its Large-Scale Asset Purchase (LSAP) program. As the US economy has improved, the Fed ended the LSAP in October 2014, and in December 2015, started the normalization process of UMPs by raising the Federal fund rate target. Given this fact, we next ask the question, "How does the Fed's UMP shock transmit to the US domestic financial market as well as the global financial markets?" To answer, we have calculated the GIRs of a 1% rise in Fed's monetary base and examined its impacts on the domestic and global financial markets.

The GIRs of US major financial variables are plotted in Figure 5. As can be seen, the pattern of the sovereign bond price is quite different from that of the Japanese market. The policy impacts on the sovereign bond price are significantly and persistently positive for a long-term period. Similar phenomena are also observed in the GIRs of corporate bond prices. The median response path peaks at five months in regime 1 and at eight months in regime 2, after the shock, and the response size is 0.4% to 0.2%, which is much larger than the Japanese experience of 0.03% in regime 2. Lastly, for the equity prices, we also observe a long-run positive and significant impact, and the response size is twice as much, compared to the Japanese case, for both regimes.

In sum, regardless of the regime, the Fed's monetary policies seem to be functioning correctly, as every financial variable responds in the direction that theory predicts. In addition, given the fact that the Fed started conducting a very aggressive monetary easing after the GFC, our results suggest that the total effects of the Fed's UMPs could be substantial since the introduction of UMPs, including the LSAP.

Regarding the impacts of the Fed's UMPs on the global financial markets, the results are summarized in Figure 6. There are two clear differences from the results for the BOJ's UMPs. First, the Fed's monetary policy has significantly and positively affected the global financial markets. This tendency is robust across two regimes, different countries, and bonds and equity. Second, unlike the BOJ's impacts on the global markets, which were negligible in most cases, the GIR sizes for the global financial markets are much larger in general and are comparable to those of US domestic financial markets. Our findings are consistent with the view that the US monetary policy is the potential driver of the global financial cycle (Passari and Rey, 2015; Miranda-Agrippino and Rey, 2015). In addition, from the view of an international credit channel, Rey (2016) argues that the

US dollar functions both as a funding currency and as an investment currency. As a consequence, a change in the US monetary policy affects the net worth of investors, financial intermediaries, and firms, not only in the US market but also in the global markets.

4.3 Robustness check: inclusion of crude oil market

In this subsection, in order to take into account the transmission effects through the global commodity market, we extend the model to include the monthly crude oil price o_t, obtained from the World Bank. In this new specification, we treat o_t as an endogenous variable in the US model and as an exogenous variable for other countries, instead of adding a commodity market block as an additional sub-VAR model. The specification is now updated as Table 6.

The calculated GIRs for Japan and US financial markets are displayed in Figures 7 and 8. These results are qualitatively identical to those reported in Sections 4.1 and 4.2. Thus, our findings do not change even if the crude oil market is taken into account.[5]

5 Conclusion

Since the beginning of the new century, we have observed a number of UMPs conducted by the central banks in the major economies. Although there have been a number of studies examining the effects of UMPs on the macroeconomy and financial markets, the economic policy implications of UMPs have remained under debate. Against this backdrop, this paper examined the effects of UMPs in Japan and US on the financial markets, taking international spillovers and a possible regime change into account. To this end, we applied the two-regime STGVAR model to 10 countries and one Euro zone for the sample period 2002-2015.

The results of our GIR analysis indicate that an unpredictable temporal 1% increase in the BOJ's monetary base instantly and significantly increases the Japanese equity prices and depreciates the values of the yen regardless of the regime. In contrast, the responses of the Japanese government and corporate bonds to the same shocks are very different, depending on the regime. More specifically, the UMP shock fails to increase the prices of the Japanese government and corporate bonds in the regime 1, but significantly raises

[5]To save space, we did not report the GIRs for the global financial markets, but they are also qualitatively identical to those reported in Sections 4.1 and 4.2 and available from authors upon request.

the prices of both bonds in the regime 2, suggesting that the BOJ's UMPs have become more effective in recent years, including the QQE period. Thus, we have confirmed the effectiveness of Japanese UMPs on the domestic financial markets, particularly for the later stage of those UMPs. Nonetheless, our results also show rather limited impacts of the Japanese UMPs on global financial markets for both regimes.

Regarding the Fed's UMPs, our results suggest that the Fed's expansionary monetary policy increases the US sovereign and corporate bond prices, and the equity prices, and depreciates the dollar value in both regimes. Since the Fed started the UMPs after the GFC, we can consider the monetary base shock before the GFC, or in regime 1, as the traditional monetary policy shock and after the GFC, or in regime 2, as the unconventional monetary policy shock. Thus, we can conclude that the Fed's monetary policies have had considerable impacts on US domestic financial markets regardless of either the traditional or the unconventional monetary policies. Our results also indicate that the Fed's monetary easing affects the global financial markets significantly and positively for both regimes. The effects could be ten times larger than those of the BOJ, showing the large impacts of US monetary policies all over the world throughout the sample period.

Although we made every effort to make our analysis as reasonable as possible, there are still several important issues remaining that we could improve upon. For example, the closeness of a pair of countries w_{ij} used in this paper in order to construct the foreign variables is calculated from the average of the outstanding of inward and outward portfolio investments. However, in terms of the financial shock transmissions, it might be appropriate to use either the inward or the outward investment. We also limited our analysis to 10 countries and one Euro zone, ignoring several important countries, including China and other Asian developing countries. As the presence of those countries has become much stronger in recent years, including those countries could provide more insight into the global effects of the UMPs of the BOJ and the Fed. Lastly, we focus on the UMPs of the BOJ and the Fed in this paper, setting aside other major central banks, such as the ECB and the BOE. Nor have we considered the possible interaction or coordination among monetary policies of major central banks. Analyzing the effects of UMPs of major central banks more comprehensively by including more central banks and taking policy interaction into account would be challenging but definitely an important future topic.

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Table 1: Variables and their sources of the domestic variables $\mathbf{x}_{it}$

variables	name of the series	source
s_{it}	Total Return Index Value	S&P Dow Jones Fixed Income Index
c_{it}	Total Return Index Value	S&P Dow Jones Fixed Income Index
q_{it}	Equity Market Index: Month End	CEIC
e_{it}	Nominal effective exchange rate	BIS
m_{it}	Base money: end-of-month (LCU)	IMF

Table 2: Financial weight matrix

	us	jp	au	ca	ch	dk	gb	no	nz	se	xm
us	0.000	0.498	0.555	0.654	0.258	0.296	0.383	0.299	0.398	0.329	0.425
jp	0.129	0.000	0.063	0.059	0.032	0.035	0.086	0.067	0.061	0.041	0.072
au	0.058	0.049	0.000	0.024	0.029	0.006	0.037	0.023	0.378	0.016	0.032
ca	0.145	0.026	0.033	0.000	0.035	0.011	0.014	0.028	0.016	0.018	0.026
ch	0.071	0.010	0.018	0.026	0.000	0.025	0.033	0.037	0.007	0.048	0.044
dk	0.011	0.006	0.003	0.004	0.012	0.000	0.010	0.033	0.001	0.055	0.031
gb	0.249	0.087	0.122	0.096	0.102	0.100	0.000	0.130	0.085	0.141	0.291
no	0.013	0.014	0.006	0.004	0.014	0.023	0.011	0.000	0.007	0.052	0.023
nz	0.004	0.003	0.016	0.002	0.002	0.000	0.002	0.001	0.000	0.001	0.001
se	0.026	0.017	0.009	0.008	0.025	0.080	0.019	0.049	0.001	0.000	0.055
xm	0.296	0.291	0.175	0.122	0.492	0.424	0.406	0.333	0.045	0.299	0.000

Note: Figures are calculated by using the data from IMF's Coordinated Portfolio Investment Survey. Mnemonic used in this table are: us (the United States), jp (Japan), au (Australia), ca (Canada), ch (Switzerland), dk (Denmark), gb (the United Kingdom), no (Norway), nz (New Zealand), se (Sweden), and xm (Euro zone).

Table 3: Specifications of the country-specific VARX* models

	US		JP		small-open i	
	$\mathbf{x}_{\mathrm{US},t}$	$\mathbf{x}^*_{\mathrm{US},t}$	$\mathbf{x}_{\mathrm{JP},t}$	$\mathbf{x}^*_{\mathrm{JP},t}$	$\mathbf{x}_{it}$	$\mathbf{x}^*_{it}$
monetary base	$m_{\mathrm{US},t}$		$m_{\mathrm{JP},t}$			
sovereign bond	$s_{\mathrm{US},t}$		$s_{\mathrm{JP},t}$	$s^*_{\mathrm{JP},t}$	s_{it}	s^*_{it}
corporate bond	$c_{\mathrm{US},t}$		$c_{\mathrm{JP},t}$	$c^*_{\mathrm{JP},t}$	c_{it}	c^*_{it}
equity price	$q_{\mathrm{US},t}$		$q_{\mathrm{JP},t}$	$q^*_{\mathrm{JP},t}$	q_{it}	q^*_{it}
neer	$e_{\mathrm{US},t}$		$e_{\mathrm{JP},t}$		e_{it}	

Table 4: Optimal lag length for the VARX* model and tests of residual serial correlation

	optimal lag length		serial correlation test					
	p	q		mb	sb	cb	eq	neer
us	2	2	F(4,136)	5.520 *	2.474 *	6.279 *	0.694	2.723 *
jp	2	1	F(4,124)	0.962	0.924	0.607	1.366	1.473
au	2	1	F(4,128)		0.350	0.186	1.080	0.200
ca	2	2	F(4,122)		2.421	0.889	0.928	1.636
ch	2	2	F(4,122)		1.866	2.923 *	1.648	1.014
dk	2	1	F(4,128)		3.722 *	1.871	0.834	1.126
gb	2	1	F(4,128)		0.422	0.067	1.506	0.301
no	1	1	F(4,136)		3.210 *	0.626	0.850	4.025 *
nz	2	2	F(4,122)		0.875	2.215	2.624 *	1.652
se	2	1	F(4,128)		1.234	0.268	0.801	2.661 *
xm	2	2	F(4,122)		3.977 *	2.413	0.832	1.462

Note: For country/region mnemonic used in this table, see the footnote of Table 2. Mnemonic newly used in this table are: mb (monetary base), sb (sovereign bond price), cb (corporate bond price), eq (equity price), and neer (nominal effective exchange rate). * indicates that the null of no serial correlation is rejected.

Table 5: Average pair-wise cross-section correlations of $\mathbf{x}_{it}$ and residuals

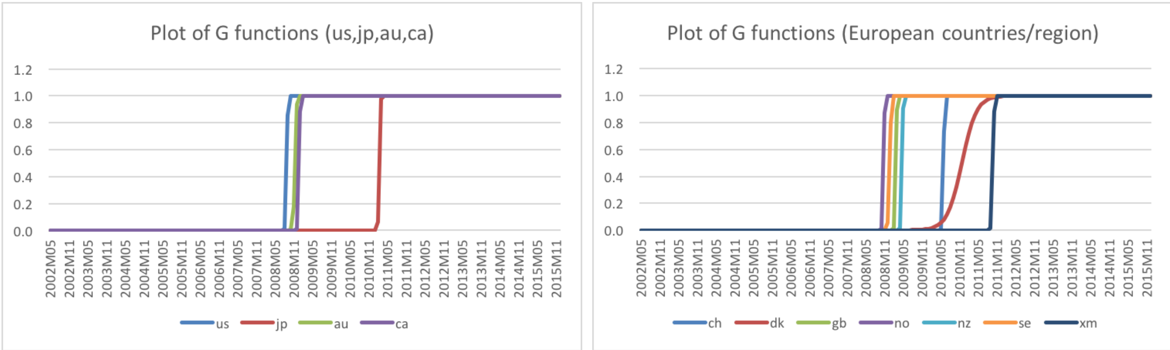
	mb			sb			cb			eq			neer		
	depvar	resid	resid*	depvar	resid	resid*	depvar	resid	resid*	depvar	resid	resid*	depvar	resid	resid*
us	0.75	0.07	0.10	0.98	-0.04	0.56	0.99	-0.04	0.47	0.91	-0.03	0.56	-0.42	-0.26	-0.29
jp	0.75	0.07	0.10	0.97	0.01	0.32	0.98	0.02	0.29	0.75	-0.07	0.50	0.02	-0.02	-0.05
au				0.99	0.13	0.57	0.99	0.10	0.41	0.88	0.03	0.58	0.24	0.10	0.09
ca				0.98	0.06	0.56	0.99	0.03	0.48	0.86	0.01	0.52	0.20	0.03	0.04
ch				0.99	0.13	0.56	0.99	0.09	0.45	0.89	-0.03	0.48	0.02	0.06	0.04
dk				0.99	0.12	0.60	0.99	0.06	0.49	0.86	0.05	0.57	0.02	0.09	0.06
gb				0.99	0.03	0.56	0.99	-0.04	0.46	0.90	-0.01	0.65	-0.24	-0.02	-0.02
no				0.99	0.09	0.55	0.99	0.07	0.41	0.88	0.03	0.62	0.07	0.06	0.05
nz				0.99	0.10	0.45	0.99	0.11	0.34	0.87	0.01	0.42	0.16	0.03	0.04
se				0.99	0.14	0.58	0.99	0.09	0.43	0.89	-0.03	0.57	0.17	0.08	0.08
xm				0.97	-0.06	0.50	0.99	0.07	0.51	0.78	-0.11	0.63	0.09	0.11	0.08

Note: For mnemonic used in this table, see the footnote of Tables 2 and 4.

Table 6: Specifications with crude oil price

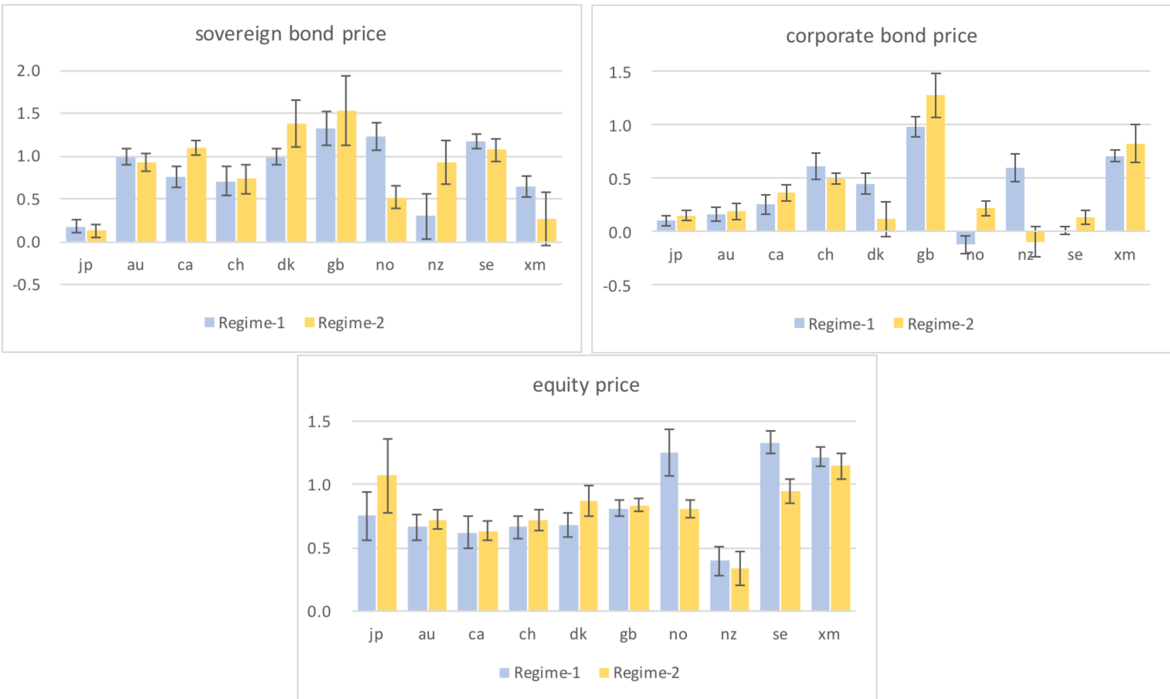
	US		JP		small-open i	
	$\mathbf{x}_{\mathrm{US},t}$	$\mathbf{x}^*_{\mathrm{US},t}$	$\mathbf{x}_{\mathrm{JP},t}$	$\mathbf{x}^*_{\mathrm{JP},t}$	$\mathbf{x}_{it}$	$\mathbf{x}^*_{it}$
monetary base	$m_{\mathrm{US},t}$		$m_{\mathrm{JP},t}$			
sovereign bond	$s_{\mathrm{US},t}$		$s_{\mathrm{JP},t}$	$s^*_{\mathrm{JP},t}$	s_{it}	s^*_{it}
corporate bond	$c_{\mathrm{US},t}$		$c_{\mathrm{JP},t}$	$c^*_{\mathrm{JP},t}$	c_{it}	c^*_{it}
equity price	$q_{\mathrm{US},t}$		$q_{\mathrm{JP},t}$	$q^*_{\mathrm{JP},t}$	q_{it}	q^*_{it}
neer	$e_{\mathrm{US},t}$		$e_{\mathrm{JP},t}$		e_{it}	
crude oil price	o_t			o^*_t		o^*_t

Figure 1: Estimated G functions



Note: For mnemonic used in these figures, see the footnote of Tables 2.

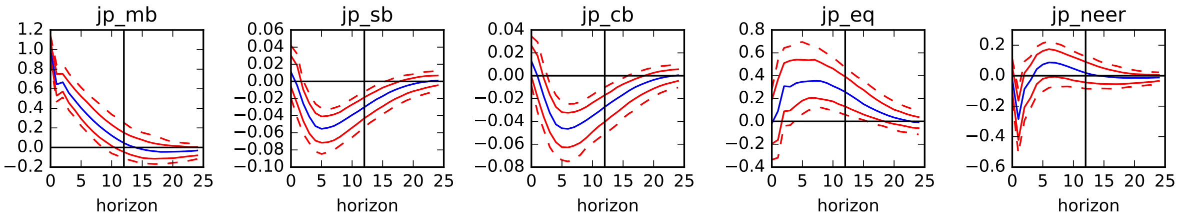
Figure 2: Contemporaneous elasticities of domestic financial market indices with respect to their foreign counterparts in country-specific models (with 1 SE error bars)



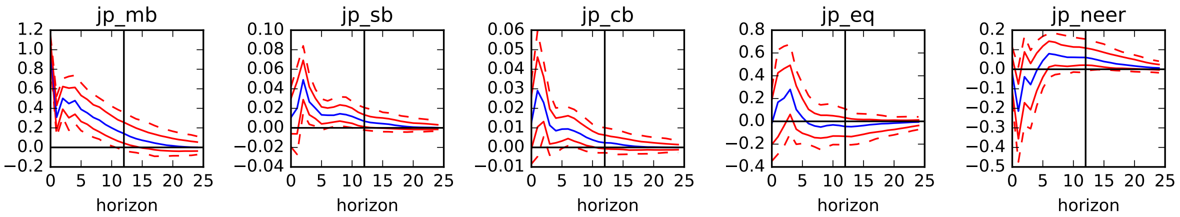
Note: For mnemonic used in these figures, see the footnote of Tables 2.

Figure 3: Responses of the Japanese financial markets to an unexpected 1% increase of m_{JP}

(a) Regime 1 (beginning of the sample)



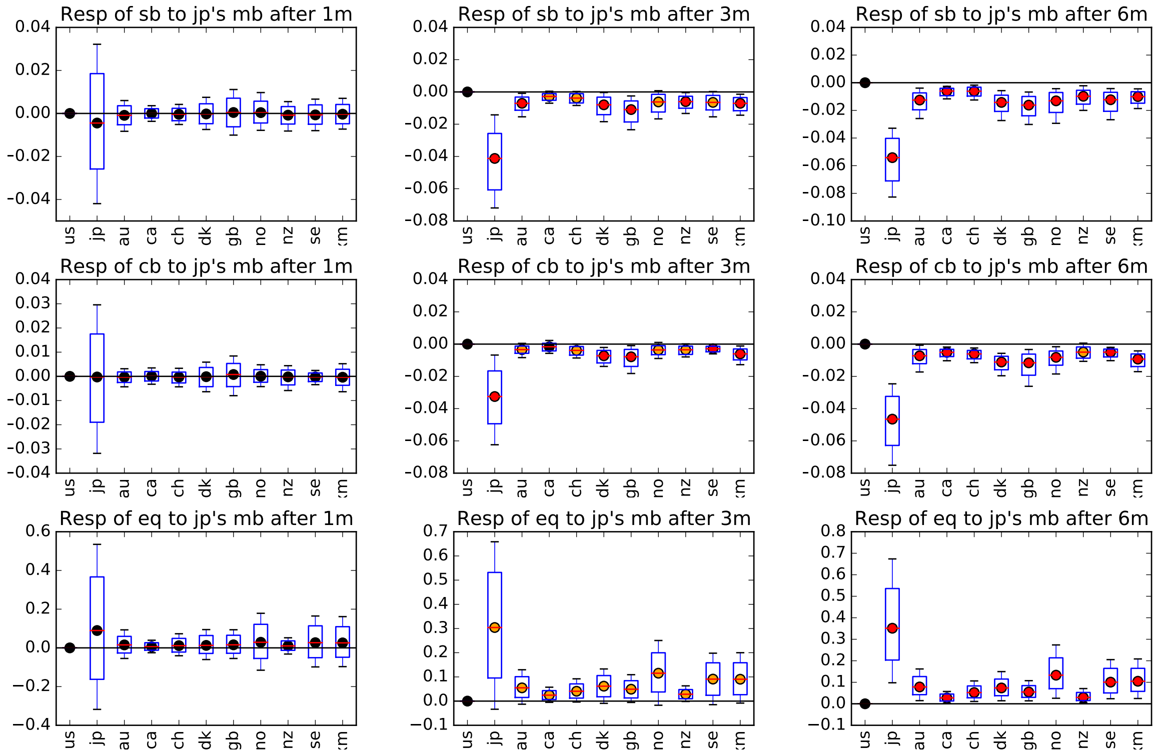
(b) Regime 2 (end of the sample)



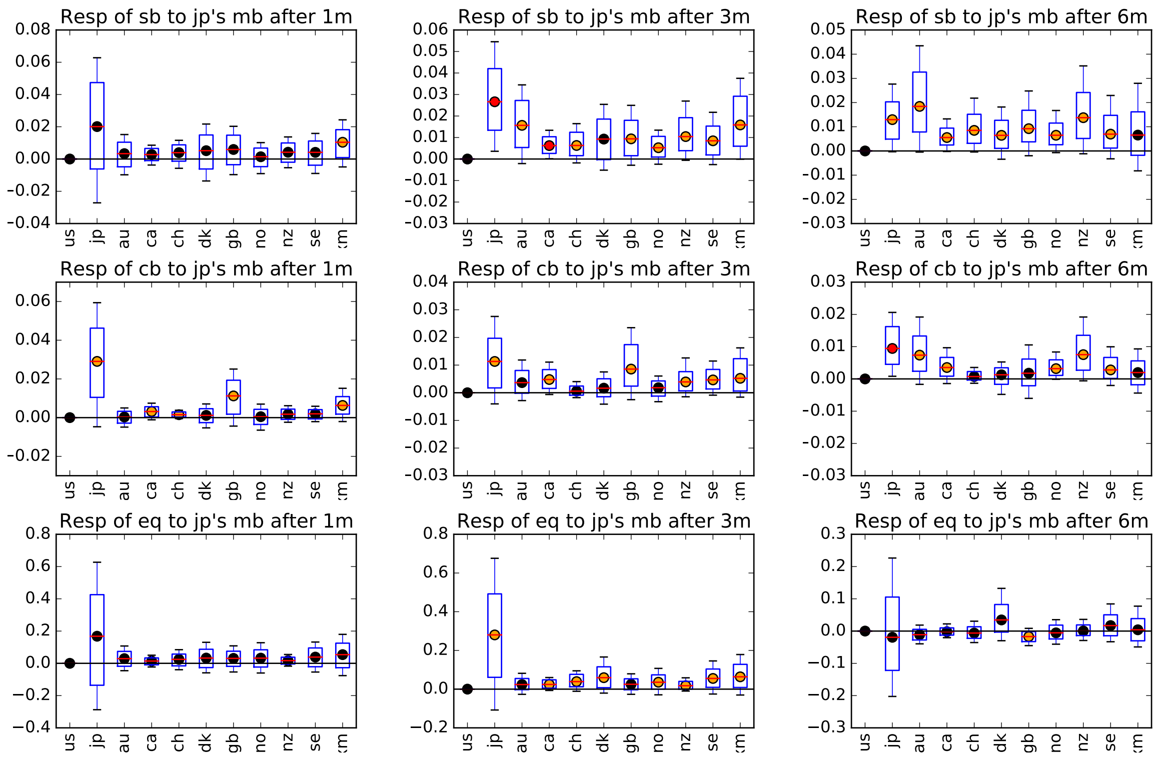
Note: For mnemonic used in these figures, see the footnote of Tables 2 and 4. The number of bootstrap is 500. The blue lines correspond to the median value, the red lines correspond to upper/lower 16% of the distribution, and the red dotted lines correspond to the upper/lower 5% of the distribution.

Figure 4: Responses of the global financial markets to an unexpected 1% increase of m_{JP}

(a) Regime 1



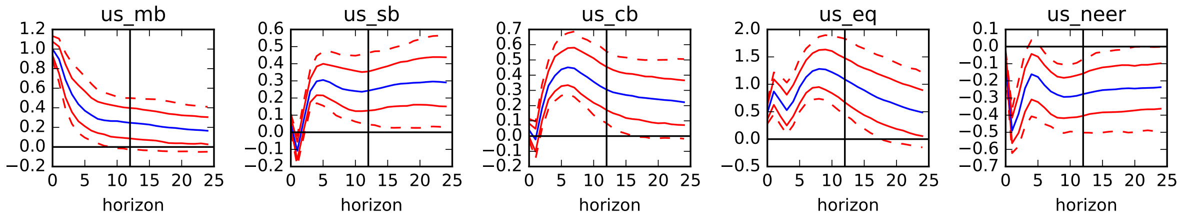
(b) Regime 2



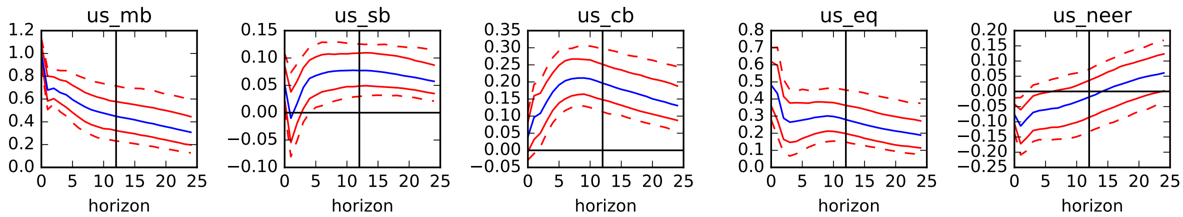
Note: From top to bottom, the responses of the sovereign bonds, corporate bonds, and equity prices are displayed. From left to right, the responses of 1 month, 3 months, and 6 months after the shock are displayed. The number of bootstrap is 500. The circles in the boxes correspond to the median value, the top/bottom of the boxes correspond to upper/lower 16%, and the top/bottom edges of the whiskers correspond to the upper/lower 5% of the bootstrapped distribution. The colors of circle indicate the levels of significance: red is 5%, orange is 16%, and black is insignificant even at 16%.

Figure 5: Responses of the US financial markets to an unexpected 1% increase of m_{US}

(a) Regime 1 (beginning of the sample)



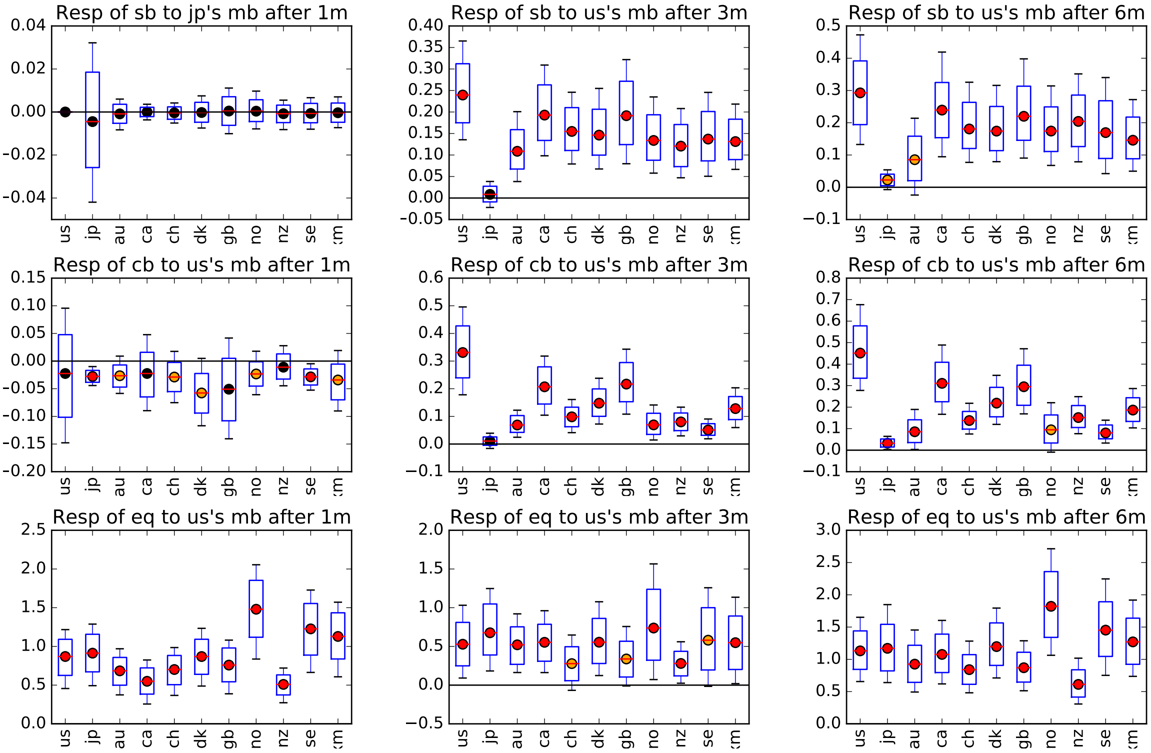
(b) Regime 2 (end of the sample)



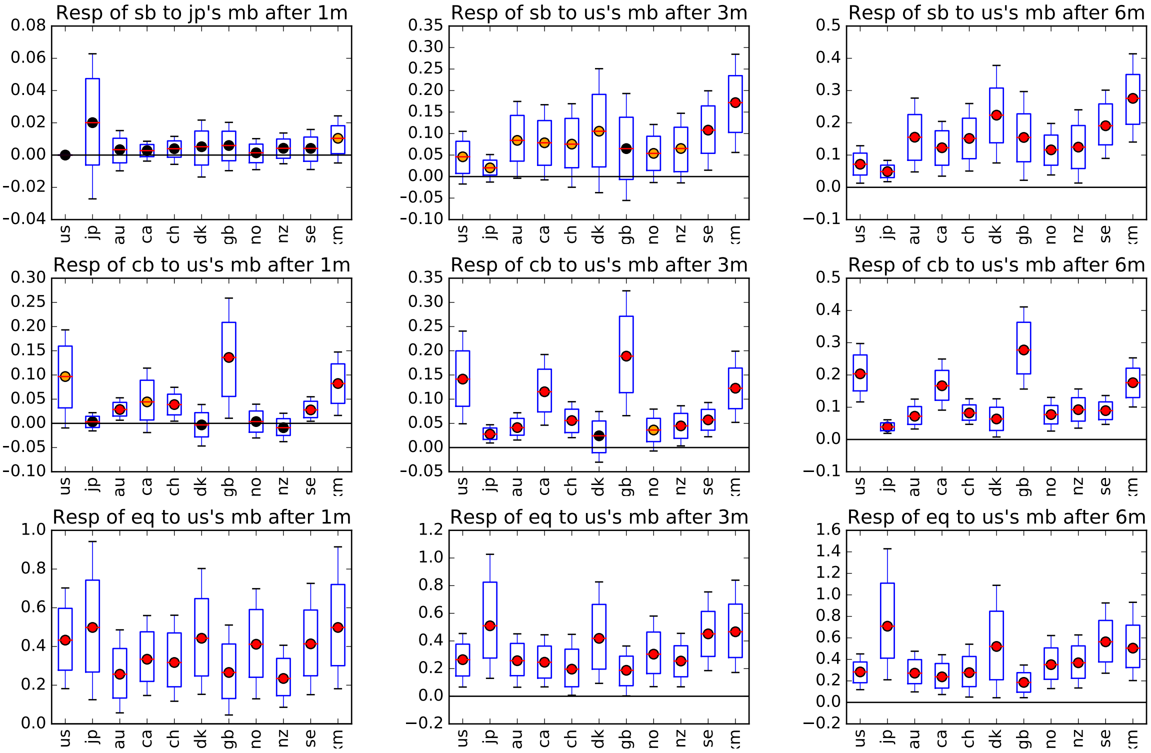
Note: For detail, see footnote of Figure 3

Figure 6: Responses of the global financial markets to an unexpected 1% increase of m_{US}

(a) Regime 1



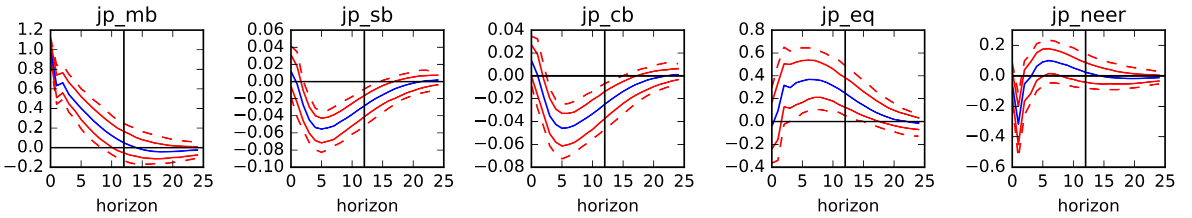
(b) Regime 2



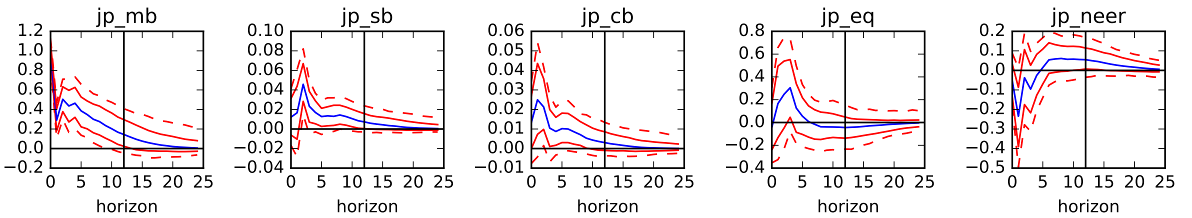
Note: For detail, see footnote of Figure 4

Figure 7: Responses of the Japanese financial markets to an unexpected 1% increase of m_{JP}

(a) Regime 1 (beginning of the sample)



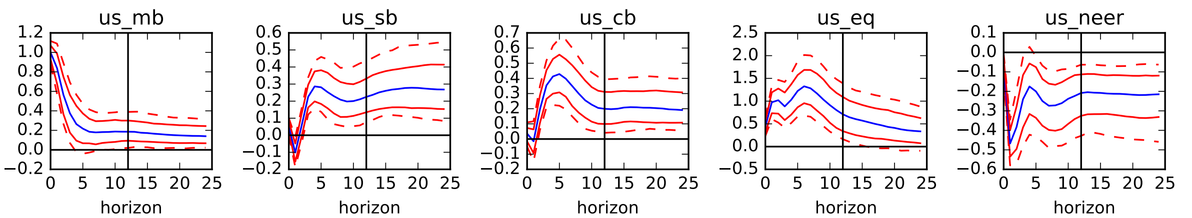
(b) Regime 2 (end of the sample)



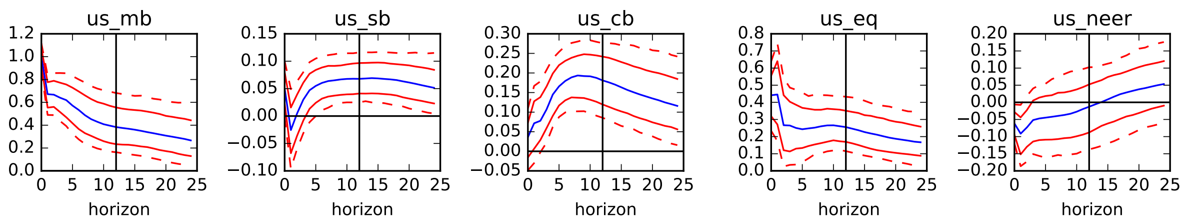
Note: For detail, see footnote of Figure 3

Figure 8: Responses of the US financial markets to an unexpected 1% increase of m_{US}

(a) Regime 1 (beginning of the sample)



(b) Regime 2 (end of the sample)



Note: For detail, see footnote of Figure 3