IMES DISCUSSION PAPER SERIES

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Discussion Paper No. 2015-E-14

IMES

INSTITUTE FOR MONETARY AND ECONOMIC STUDIES

BANK OF JAPAN

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CHUO-KU, TOKYO 103-8660
JAPAN

IMES Discussion Paper Series 2015-E-14
September 2015

The Interaction between Funding Liquidity and Market Liquidity: Evidence from Subprime and European Crises

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Abstract

This paper explores the interaction between funding liquidity and market liquidity. The simultaneous reduction of funding and market liquidities is often observed during financial crises. While Brunnermeier and Pedersen (2009) argue that fragility of liquidity is due to a destabilizing effect of margin calls triggered by uninformed traders' behavior under uncertainty, Nyborg and Östberg (2014) claim that the malfunction in interbank funding markets causes declines in market liquidity in broader financial markets. We demonstrate that Nyborg and Östberg's cause was dominant during the subprime financial crisis, while both causes were valid during the European sovereign debt crisis using a structural vector autoregression model.

Keywords: Funding Liquidity; Market Liquidity; Limits of Arbitrage
JEL classification: G01, G14, G21

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The authors would like to thank Stephen G. Cecchetti, Takaki Hayashi, Kiyoshi Izumi, Wataru Ohta, Kosuke Oya, Katsutoshi Shimizu, participants of 34th JAFEE meeting and workshop of in Osaka University, and the staff of the Institute for Monetary and Economic Studies (IMES), the Bank of Japan, for their useful comments. Views expressed in this paper are those of the authors and do not necessarily reflect the official views of the Bank of Japan.

1 Introduction

One of the characteristics of the recent global financial crises was the synchronized deterioration in the funding liquidity of large financial institutions and market liquidity in broader financial markets resulting from the market wide deleveraging (Brunnermeier, 2009; Adrian and Shin, 2010). While only a few traditional bank runs by depositors occurred during the crises, new types of runs, including systematic market-wide runs such as the run on repo markets devastated financial stability (Gorton and Metrick, 2010). Central banks in advanced economies conduct various unconventional measures such as liquidity provision and asset purchases in response to funding liquidity problems and market liquidity problems.

A number of studies have examined the impact of market-wide systemic runs in short-term funding markets (Gorton and Metrick, 2012; Krishnamurthy et al., 2014). However, the literature has not reached a consensus on the cause of the synchronized reduction of funding and market liquidity. The optimal policy action during crises depends on the cause of such crises. For example, liquidity provision could be effective in dealing with funding liquidity problems. In this paper, we explore the interaction between funding and market liquidity during the subprime financial crisis and European sovereign debt crisis.

There are two different views on the cause of the linkage between funding and market liquidities. First, Brunnermeier and Pedersen (2009) indicate that the fire sale of financial assets by uninformed traders triggers the deviation of asset prices from fundamental values (reduction of market liquidity) and the sudden hike in demand for funding to satisfy margin calls (reduction of funding liquidity) under rising uncertainty. When traders cannot meet their margin calls, they reduce their position and thus accelerate the deviation of asset prices from fundamental values. That is, even though margin calls function as risk management tools for individual market players under normal circumstances, they could destabilize financial markets through synchronized deterioration in funding and market liquidities under significant uncertainty.

Second, Nyborg and Östberg (2014) point out that funding constraints can create the market liquidity problem (liquidity pullback) using evidence of interaction between tightness in the interbank funding market and the market liquidity of stock markets in the US. This is an extension of research on the interaction between monetary policy and asset prices with frictions in interbank funding markets. This implies that the dysfunction of interbank funding markets (reduction of funding liquidity) causes turmoil across all financial markets (reduction of market liquidity).

To test the empirical validity of the two models in a global context, we examine the interaction between interbank funding liquidity and market liquidity in broad financial markets jointly in the US, the euro area, and Japan. As Nyborg and Östberg (2014) focus on the market liquidity of listed stocks that are subject to sudden margin requirements, their results do not directly indicate that the role of funding liquidity is more significant than that of uninformed investors' behavior and margin requirements. In contrast, we analyze the market liquidity of over-the-counter (OTC) securities including derivatives that require investors to post a margin or collateral for a long period of time. Then we examine which models can best explain the behavior of funding and market liquidities.

The framework of the analysis leads us to adopt an approach with two features from standard market liquidity studies. First, we measure the market liquidity of financial assets traded using daily data. Recently, research on market liquidity using high-frequency data is one of the most popular topics in finance because the volume of high-frequency trading has been increasing in the financial markets of major advanced economies. Nevertheless, we focus on the daily behavior of market liquidity. The appropriate frequency of data depends on the analysis objectives (Figure 1). As the mark-to-market valuations and margin calls are conducted at the end of every business day, we examine the impact of margin calls on market liquidity with daily data.

Second, we measure market liquidity by the deviation from the arbitrage relationship between two assets with identical or similar cash flows. Empirical studies on market liquidity often focus on the characteristics of central limit order books (Kyle, 1985; Amihud, 2002; Fleming, 2003). In contrast, the literature on the theory of limits of arbitrage indicates that the deviation from the arbitrage relationship reflects various constraints such as capital constraints, funding constraints, margin requirements, and short-sale constraints and uncertainty (Gromb and Vayanos, 2010). Then we can investigate how market liquidity declines in response to fluctuations in these constraints.

For econometric tractability, we propose an alternative method of integrating cross-market liquidity into one measure based on the systemic liquidity risk indicator (SLRI) by Severo (2012). It is possible to analyze large-scale multinational time-series data using the global vector autoregression (VAR) method of Pesaran et al. (2004) without reducing the dimension of the data. However, this method is not applicable to analyzing the pair-wise interaction between market liquidity and its constraints in this paper because the global interaction is modeled as the relation with a single globally aggregate variable. Instead, we can analyze global and domestic interactions between market liquidity and its constraints properly when market liquidity in broader financial markets is summarized into a single measure in each economy.

The results of our econometric analysis highlight the contrast between the subprime and the European sovereign debt crises. First, the liquidity pullback effects are more significant than fire-sale effects reflecting the uncertainty and margin requirements during the subprime financial crisis. That is the reduction of funding liquidity led that of market liquidity. The liquidity pullback effect spread from the US to the euro area and Japan. This is consistent with the evidence that European banks suffered from difficulties with dollar funding after the Paribas shock in August 2007 and the Lehman Brothers bankruptcy in September 2008 froze interbank funding markets and reduced market liquidity across financial markets (See Irwin, 2013 for details). On the other hand, the impact of fire sales resulting from uncertainty and margin requirements is more significant than the deterioration of funding liquidity dry-up in the European sovereign debt crisis. Funding and market liquidity positively co-moved with margin calls and banks' capital constraints. In this period, the global spillover effect was limited, while the linkages among uncertainty, margin calls, funding liquidity and market liquidity were more visible within each economy.

The rest of the paper is organized as follows. Section 2 reviews the background theory and the literature related to this study. Section 3 proposes a funding liquidity measure and describes the measurement of market liquidity in broad OTC-type financial markets. Section 4 constructs an econometric model to examine the interaction between funding liquidity, market liquidity, and other financial market variables using vector autoregression analysis. Section 5 discusses the implications of the impulse response functions. Section 6 provides concluding remarks.

2 Background theory

There are two strands of literature on the interaction between funding liquidity and market liquidity. The first strand focuses on the market microstructure underlying this interaction. Financial institutions provide liquidity for financial assets via market-making activities. They have to store some inventory of the assets to absorb order imbalances quickly and discover a new price under a new equilibrium immediately after exogenous shocks. The literature on market microstructure-based asset pricing endogenizes inventory costs in asset pricing and shows the relationship between inventory costs and market liquidity measures such as the bid–ask spread (Amihud and Mendelson, 1980, 1986; Ho and Stoll, 1981; Constantinides, 1986; Vayanos, 1998; Huang, 2003). When order imbalances are larger than market makers' inventory, they fail to match the orders and eliminate the difference between the current price and fundamental value (limits of arbitrage). Using a search-theoretic pricing model, Duffie et al. (2005, 2007) demonstrate that inventory costs depend on various macroeconomic conditions, especially in OTC markets. Gromb and Vayanos (2010) and Vayanos and Wang (2013) survey literature on limits of arbitrage and discuss five causes of limits of arbitrage: uncertainty, short-sale constraints, margin requirements, capital constraints, and funding constraints.

Brunnermeier and Pedersen (2009) model the interdependency between market liquidity and its constraints via the behavior of uninformed investors (Figure 2). In their model, the rise in uncertainty triggers a fire sale by uninformed traders. The fire sale causes the deviation of asset prices from their fundamental values. As the funding liquidity of financial institutions worsens because of additional funding demand to satisfy the margin call after the fire sale, the deviation remains uncleared. If some financial institutions fail to obtain funding for their margin calls, they have to reduce their positions (stop loss). The stop-loss trade reduces their capital base and tighter capital constraints worsen the deviation, thus reducing market liquidity.

As discussed above, the cause of the interaction proposed by Brunnermeier and Pedersen (2009) indicates that the tool to stabilize the market volatility, margin calls, can destabilize financial markets and accelerate the interaction between funding liquidity and market liquidity. That is, the function of stabilizing financial market liquidity actually destabilizes financial markets in unintended ways.

Second, the inefficiency of interbank funding markets lowers market liquidity in broader financial markets. The study of the interaction between funding liquidity and market liquidity can also be interpreted as an extension of the study of the impact of monetary policy on asset prices. As simple regressions often indicate a counterintuitive relationship between asset prices and monetary policy, a large number of empirical studies in monetary and financial economics discuss the impact of monetary policy using various econometric techniques such as identification through heterogeneity (Rigobon, 2003; Rigobon and Sack, 2004), factor augmented vector autoregression (Bernanke and Kuttner, 2005), and event study with high-frequency data (Gürkaynak et al., 2005; Nakamura and Steinsson, 2013). While these studies generally find an intuitive relationship between monetary policy and asset prices after controlling for various endogeneities or the impact of omitted factors, they implicitly assume that interbank money markets operate efficiently and money provided by central banks is delivered to financial institutions in need of funding.

The experience of the recent global financial crises has questioned the validity of these assumptions. Interbank funding markets in the real world failed to allocate liquidity efficiently before the financial crises because of the counterparty risk (Bindseil et al., 2009). The inefficiency attracted further attention especially after the Paribas shock of August 2007, the beginning of the subprime financial crisis. While there have been a limited number of bank runs by depositors in advanced economies since 2007, the intermediary function of financial institutions has significantly deteriorated because of malfunctioning short-term funding markets (Gorton and Metrick, 2012). From these observations, Nyborg and Östberg (2014) propose an association between funding tightness in interbank funding markets and market liquidity in broader financial markets (liquidity pullback) as the friction of the effect of monetary policy on asset prices. They document that liquidity pullback exists during normal times as well as times of financial crisis in the US stock market.

In contrast to the Brunnermeier and Pedersen (2009) model, the liquidity pullback hypothesis indicates that the malfunctioning of interbank funding markets causes the interaction between funding liquidity and market liquidity. Thus, these models are not mutually exclusive, but complement each other (Figure 2).

To examine the validity of the two hypotheses, we adopt the deviation from the arbitrage relationship as the measure of market liquidity. The literature on the empirical analysis of market liquidity of exchange traded financial securities such as common stock and listed derivatives usually analyzes the characteristics of central limit order books such as the bid–ask spread, turnover ratio, and market impact (Kyle, 1985; Amihud, 2002; Fleming, 2003; Goyenko et al., 2009). While this methodology is applicable to current OTC markets with electronic transaction platforms, we investigate how well financial institutions intermediate financial transactions and eliminate mispricing via the price deviation between two financial assets with identical or quite similar cash flows. Empirical studies on the deviation demonstrate that it is significantly affected by constraints on market liquidity (Amihud and Mendelson, 1991; Boudoukh and Whitelaw, 1993) and strongly correlated with liquidity measures based on the information from central limit order books (Chan et al., 2008). Then the deviation from the arbitrage relationship is appropriate for testing the two hypotheses.

3 Data and liquidity measures

3.1 Data

Our data set consists of daily data from July 2, 2007 to December 28, 2012 in the US, the euro area and Japan. It covers the subprime financial crisis and the European sovereign debt crisis. There are a large number of studies that use high-frequency data for market liquidity research. In contrast, we focus on the relationship between market liquidity and its constraints involving uncertainty, margin requirements, capital constraints, and funding constraints. As margin calls and mark-to-market valuations are regularly conducted at least at the end of every business day, daily data are appropriate for examining the relationship (Filimonov, 2014).[1]

We construct funding and market liquidity measures and proxies of the constraints of market liquidity with the daily closing price data of the following asset prices from Bloomberg.

1. Two-, five-, and 10-year government bond yields in the US, Germany, and Japan

[1]In some OTC derivatives, margin calls are calculated three or four times in one business day.

2. Five-year CDS spreads and corporate bond spreads with around five-year maturity

3. Spot and three- and six-month-forward exchange rates among the US dollar, euro, Japanese yen, and UK pound

4. Three- and six-month Libor (US dollar), Euribor (euro), and Tibor (Japanese yen)

5. Three- and six-month overnight index swap (OIS) of the US dollar, euro, and Japanese yen

6. Five-year credit default swap (CDS) spread of large financial institutions in the US, the euro area, and Japan

7. Volatility index of stock markets in the US, the euro area, and Japan

We construct market liquidity measures and proxies of funding liquidity, margin constraints, capital constraints and uncertainty, which Gromb and Vayanos (2010) identify as the causes of the violation of the arbitrage relationship. They propose a short-sale constraint as one of the causes of the violation in addition to the above constraints. However, we omit it from the proxies because a short-sale ban was not officially introduced in the markets we consider during 2007–2012.

As the mark-to-market valuation is usually conducted based on the closing prices, the daily closing price data is suitable to reveal the dynamics of the arbitrage at the mark-to-market valuation and margin calls. However, it could miss the lag of the trades executed at the closing prices. Investors who are sensitive to the intraday market liquidity, intend to close or adjust their positions before the closing time of the market. If we investigate only the relationship between funding and market liquidity, such intraday liquidity dynamics matters as well. To examine the dependency among margin calls, capital constraints, funding liquidity and market liquidity, we analyze the dynamics using the daily closing data.

In the analysis of the dependency among the three economies, we construct the data set to reflect the influence of the US funding market' malfunction to the other economies. As we show in the following sections, the impact of the US funding market's malfunction is more significant than that of other funding markets. LIBOR is announced at 10:00am GMT every business day. While market prices in the US and the euro area reflect the funding market conditions, market prices of the same day in Japan do not. Therefore, our cross country data set consists of today's market prices in the US and the euro area and tomorrow's prices in Japan.

3.2 Funding and market liquidity measures

3.2.1 Funding liquidity measure

We define the difference between the three-month interbank funding rate (*Xibor*[2]) and the three-month OIS as a proxy of the funding liquidity of large financial institutions. Our concern is the funding liquidity of large financial institutions playing a major role as market makers in representative OTC markets. Under the funding constraint, large financial institutions cannot store sufficient amount of financial assets as storage to clear order imbalances and eliminate the arbitrage opportunities. However, the data on the funding liquidity of individual institutions are not publicly available in any of the countries we consider in this study[3]. Thus the Xibor–OIS spread is employed as a proxy of the malfunctioning of interbank funding markets (McAndrews et al., 2008; Taylor and Williams, 2009; Angelini et al., 2011; Gefang et al., 2011; Filipović and Trolle, 2013). In fact, after the announcement of a temporary freeze on refunding in two investment

[2] We denote interbank funding rates such as Libor, Euribor, and Tibor as *Xibor* here.

[3] Research papers by central bank economists analyze the data of the loan amounts to individual institutions in liquidity provision programs during the recent global financial crisis (Alexius et al., 2014). In addition, the Federal Reserve has released the actual loan amounts to individual financial institutions under the requirements of the Dodd–Frank Act. However, the liquidity conditions of individual institutions are not available.

funds by BNP Paribas in August 2007 (Paribas shock), the spread increased drastically; while it was around 20–30 bps by July 2007, it reached over 300 bps in the US after the Lehman Brothers bankruptcy in September 2008 (Figure 3, Tables 1 and 2).

As the interbank funding rate is the interest rate on unsecured borrowings, the spread between the interbank funding rate and the OIS mainly reflects funding liquidity as well as counterparty risk. This means that the conventional liquidity measures such as bid ask spread cannot necessarily capture the tightness of interbank funding markets. That is, wider bid ask spread under high counterpart risk may indicate not lower funding liquidity but higher counterpart risk. We alternatively utilize the Xibor-OIS spread to eliminate the impact of counterpart risk of individual financial institutions. However, it still reflects the average counterpart risk of financial institutions. Empirical studies on the Libor–OIS spread document that the primary driving force of the Libor–OIS spread is the funding liquidity of financial institutions although counterparty risk also affects the spread (Angelini et al., 2011; Gefang et al., 2011; Filipović and Trolle, 2013). The extra cost of funding also measures the gap between demand and supply in the interbank funding markets while funding liquidity is essentially measured as the available quantity of fund. Thus, the Xibor–OIS spread is a proxy of the degree of the interbank funding market inefficiency, while it also reflects counterparty risk.

The Xibor–OIS spread is a useful indicator of funding liquidity compared with other similar indicators such as the TED spread (Melvin and Taylor, 2009) and OIS–TB spread (Severo, 2012). Some earlier studies focus on the TED spread or the OIS–TB spread for the analysis of interbank funding markets. These measures reflect noises as well as funding liquidity of large financial institutions (Figure 4). Since the Federal Reserve cut the policy target rate to 0.00%–0.25% in November 2008, the OIS–TB spread was nearly zero in the US under the zero lower bound of nominal interest rates. On the other hand, the TED spread before August 2007 indicates that it reflects other friction cost resulting from the market segmentation resulting from US treasury bill market and interbank funding market in addition to funding liquidity and countertrade risk.

The Xibor–OIS spread reflects funding liquidity after the financial system reform and shift of interbank funding to secured transactions. After the subprime financial crisis, financial institutions in advanced economies reduced their unsecured interbank lending. Then the volume of Xibor-based lendings decreased drastically. However, the volume of overnight transactions is still large and the overnight rate is significantly associated with term lending rates such as the three-month Libor in the US (Cipriani and Cohn, 2015; Cipriani and Gouny, 2015). It is true of the euro area and Japan. Therefore, we conclude that the Xibor–OIS spread is still a more practical and sensitive proxy of funding liquidity than other candidates.

3.2.2 Market liquidity measures

We apply an alternative approach based on the theory of limits of arbitrage to the measurement of market liquidity for OTC markets. The standard approach for the market liquidity analysis is the analysis of order books' characteristics. In this approach, the depth, volume, resiliency, and tightness of order books are used as liquidity measures. As discussed in Section 2, we measure the efficiency of the market making by financial institutions via the deviation from the arbitrage relationship to compare the validity of Brunnermeier and Pedersen (2009) and Nyborg and Östberg (2014).

The literature on limits of arbitrage demonstrates that financial institutions cannot clear order imbalances and limits of arbitrage could appear as funding when they are subject to financial constraints such as capital and funding constraints (Gromb and Vayanos, 2002). Therefore, the degree of violation of the arbitrage relationship is a potential indicator of market liquidity. We construct an aggregate market liquidity risk indicator as the aggregate market value of the friction caused by the limits of arbitrage in major OTC markets. While the SLRI by Severo (2012) is the first principal component of 36 series of the violation of the arbitrage relationship, we measure the aggregate market impact of the violation of the arbitrage relationship. For this aim, we calculate the effective price impact of liquidity reduction using the price sensitivity and transaction volume of individual markets.

The OTC markets for which we measure market liquidity are government bonds, foreign exchange, and corporate bonds. As these markets were not the direct cause of the subprime and European crises, we can measure the behavior of market liquidity in the broader financial markets in the three economies.

We demonstrate the measure of market liquidity of the three markets and construct the aggregate market liquidity indicator (AMLI) in the three advanced economies below.

1. Government bonds

   We define the on–off spread as the market liquidity measure of government bonds. Empirical studies on the market liquidity of US treasury bonds demonstrate that the yield of the latest-issued bonds is relatively low compared with that of the second latest-issued bonds in the US treasury market because the latest-issued bonds are more liquid than the second latest-issued bonds (Amihud and Mendelson, 1991; Krishnamurthy, 2002). The hump of the government bond yield curve is called the on–off spread and referred to as a proxy of market liquidity in government bond markets.

   We construct the market liquidity measure using the on–off spread of two-, five-, and 10-year government bonds in the US, Germany[4], and Japan as follows.

$$ML^{GB}_{t,s,j} = \frac{\partial P_j(t,t+s)}{\partial y_j(t,t+s)} \left(y_j(t,t+s) - y_j(t,t+s-\Delta)\right) \tag{1}$$

[4] In this paper, the on–off spread is an indicator of market liquidity of safe assets. Thus we use the on–off spread of German government bonds as a measure of the market liquidity of euro area government bonds.

where $P_j(t, t+s)$ and $y_j(t, t+s)$ are the s-year bond price and yield of country j's government bonds at time t (Figure 5, Tables 1 and 2). Δ is the interval between the date of the latest bonds' issue and that of the second latest ones in each market.

2. Foreign exchange

We measure the market liquidity of foreign exchange markets using the deviation of foreign exchange swaps from the covered interest parity (CIP). If foreign exchange markets are frictionless and there is no arbitrage opportunity, foreign exchange swaps between currencies i and j are determined such that DEV_t is equal to zero,

$$DEV_t^{(i,j)} = \frac{F_{t,t+s}^{(i,j)}}{S_t^{(i,j)}} \left(1 + r_{t,t+s}^i\right) - \left(1 + r_{t,t+s}^j\right) \tag{2}$$

where $F_{t,t+s}^{(i,j)}$ and $S_t^{(i,j)}$ are respectively the s-term forward and spot rate between currencies i and j, and $r_{t,t+s}^i$ and $r_{t,t+s}^j$ are the s-term interest rates of money market accounts in currencies i and j. While $DEV_t^{(i,j)}$ is stable at low levels in major currencies before the global financial crises, they spiked drastically in the aftermath of the Lehman Brothers bankruptcy.

We extract the impact of the funding liquidity from $DEV_t^{(i,j)}$ in (2), using the method of Baba and Packer (2009). Empirical studies on the market liquidity of foreign exchange with the deviation of foreign swaps from CIP usually utilize Libor as the interest rates of money market accounts, $r_{t,t+s}^i$ and $r_{t,t+s}^j$. This implies that Libor is implicitly assumed to be a risk-free interest rate. However, this contradicts our definition of funding liquidity in Section 3.2.1. Then we subtract the spread between the interbank funding rate (*Xibor*) and OIS from the deviation of CIP in both currencies. This adjusted deviation is a proxy of market liquidity of foreign exchange, ML_t^{FX}

in this paper as follows:

$$\begin{aligned} ML_t^{FX} &= \frac{\partial P_j(t,t+s)}{\partial r_{t,j}} \Big(DIV_t^{(i,j)} - \big(\big(Xibor^j_{t,t+s} - OIS^j_{t,t+s} \big) \\ &\quad - \big(Xibor^i_{t,t+s} - OIS^i_{t,t+s} \big) \big) \Big) \\ &\approx \frac{\partial P_j(t,t+s)}{\partial r_{t,j}} \Big(\ln(F^{(i,j)}_{t,t+s}) - \ln(S^{(i,j)}_t) + \big(Xibor^j_{t,t+s} - Xibor^i_{t,t+s} \big) \\ &\quad - \big(\big(Xibor^j_{t,t+s} - OIS^j_{t,t+s} \big) - \big(Xibor^i_{t,t+s} - OIS^i_{t,t+s} \big) \big) \Big) \\ &= \frac{\partial P_j(t,t+s)}{\partial r_{t,j}} \Big(\ln(F^{(i,j)}_{t,t+s}) - \ln(S^{(i,j)}_t) + OIS^j_{t,t+s} - OIS^i_{t,t+s} \Big) . \end{aligned} \quad (3)$$

As ML_t^{FX} reflects the difference between the short-term bond yield after adjusting for the funding costs of the market makers, it is possible to interpret ML_t^{FX} as the friction of bond investments for foreign investors. We calculate the three- and six-month ML_t^{FX} among the US dollar, euro, Japanese yen, and UK pound. Then we have six series of ML_t^{FX} respectively for the US, euro area, and Japan (Figure 6, Tables 1 and 2).

3. Corporate bonds

   We measure the market liquidity of corporate bond markets using the CDS–bond basis difference between the corporate bond spreads and CDS spreads of the same entity. As the spread varies over the credit ratings of corporations, our sample consists of four corporations in each investment grade, Aa, A, and Baa as follows:

$$ML^{credit}_{t,j} = \frac{\partial P_j(t,t+s)}{\partial R_j(t,t+s)} \left((R_j(t,t+s) - y_i(t,t+s)) - CDS_j(t,t+s) \right) \quad (4)$$

   where $P_j(t,t+s)$, $R_j(t,t+s)$, and $CDS_j(t,t+s)$ are the corporate bond price, corporate bond yield, and CDS spread of company j, respectively (Figure 7, Tables 1 and 2).

3.3 Aggregate market liquidity indicator

We study the movement of the overall financial market liquidity suing the aggregate market liquidity indicator. Literature on market liquidity often focus on market liquidity of individual financial products (Alexius et al., 2014; Buraschi et al., 2015). This approach is useful to explain the anomaly of the individual financial asset prices since funding liquidity is one of the causes of the anomaly in their context. However, we focus on the influence of funding liquidity on broad financial market liquidity via the malfunction of large banks' market-making activities. Thus we measure the aggregate market liquidity which large financial institutions have to control in their market making activities.

We construct the weighted sum of the 13 series of liquidity measures in three major OTC markets derived in Section 3.2.2 as the AMLI integrating the 13 series into a single one as follows:

$$AMLI_t = \sum_{i=1}^{13} volume_t^i \times \left| ML_t^i \right| \tag{5}$$

where $volume_t^i$ and ML_t^i are the market volume and market liquidity measure of asset i.To compare the behavior of the aggregate market liquidity measure across the three advanced economies, we index the market liquidity measure as of January 1, 2007 at 1 to denominate the measures (Figure 8).

The aggregate market liquidity measure defined by (5) is comparable across regions while it is in line with the spirit of the SLRI by Severo (2012). As the SLRI is the first principal component of the underlying series of deviations from the arbitrage relationship, the level of the SLRI in one region is not directly comparable with that of other regions. Moreover, the level and shape of the SLRI depend on the data used in the principal component analysis. For example, there is a vivid difference in the level and shape of the SLRI derived from the data for 2007–2012 among the US, euro area, and Japan, while there is no significant difference in the SLRI derived from the data for 2010–2012 (Figure 9 and Table 3). Our measure is independent of the selection of the sample period and its variability is comparable across regions because it is calculated as the weighted sum of the deviations.

In addition to the comparability, the aggregate market liquidity measure takes into account the heterogeneity of the market volumes of the three markets in each regions as well as the deviations from the arbitrage relationship. As the SLRI is the first principal component of a vector of the deviations from the arbitrage relationship, the SLRI equally reflects all of the deviations in the asset pairs regardless of the market volumes. In contrast, the aggregate market liquidity measure is the weighted sum of the deviations from the arbitrage relationship. It reflects the structure of financial markets as well as summarizes the information of individual market liquidity measures.

3.4 Proxies of market liquidity constraints

3.4.1 Capital constraints

We measure the degree of capital constraints of financial institutions using the CDS spread of Xibor panel banks. Both theoretical and empirical studies on credit risk utilize the information from equity prices to estimate the probability of default (Merton, 1974; Black and Cox, 1976; Arora et al., 2005; Berg, 2010). In fact, changes in stock prices generally Granger-cause CDS spread changes (Norden and Weber, 2009). However, CDS spreads are useful as indicators of banks' capital constraints because CDS spreads are more sensitive than stock prices near the bankruptcy boundary (Bayraktar and Yang, 2011). To control the impact of the counterparty risk in our funding liquidity measure, Libor–OIS spread, we construct a proxy of capital constraints as the CDS spread of the Libor panel banks (Table 4).

3.4.2 Margin call constraints

As discussed in the literature on risk management in listed derivatives such as stock index futures, margin calls and haircuts are designed to cover losses because of the default of transaction counterparties. Thus the level of haircuts is equal to the probable maximum loss measured by Value at Risk, while margin calls are conducted to keep uncleared mark-to-market profits/losses within the initial haircut level (Table 4). In practice, we approximate the rate of hair-cut in the

OTC derivatives with the average of the 99% Value at Risk of the underlying financial assets to measure market liquidity in 250 days observation period. Thus the variation of the VaR is the proxy of the change in the margin call levels in the OTC derivatives markets we discuss in section 3.2.2. Although this does not capture the margin calls of the OTC derivatives, it captures the variation of the hair-cut rate at the beginning of the derivatives contracts (one of the transaction costs for OTC derivatives).

3.4.3 Uncertainty

We measure uncertainty within the broader economy using a stock market volatility index such as the VIX calculated by the Chicago Board of Option Exchange. While a volatility index is also available for the euro area and Japan, the behavior of these volatility indexes is quite similar to each other and the first principal component explains about 97% of the movement of the three indexes. To eliminate the cointegration relationship among the volatility indexes in the VAR model, we include the first principal component of the index instead of the volatility indexes in the set of variables (Table 4).

3.5 The behavior of aggregate market liquidity measures

Before we conduct our econometric analysis using a structural VAR model, we investigate the behavior of the aggregate market liquidity measure and its relation to the funding liquidity measures for 2007–2012. First, the individual component of the AMLI indicates that the market liquidity of foreign exchange leads the other two market liquidity measures, especially government bonds, in all three economies (Figure 10, Table 5). On the other hand, the loss of information in the aggregation is limited because the correlation among the three components is very low (Table 2). This implies that AMLI captures several different fluctuations, but does not exclude the negatively correlated fluctuations because of the summation of several measures. Therefore, AMLI summarize the information of market liquidity in the broader financial markets without loss of information.

4 Vector autoregression

To explore the intertemporal and international relationships among funding liquidity, market liquidity, and other financial variables, we conduct a vector autoregression analysis using funding liquidity, AMLI and other variables, following Chordia et al. (2005) and Goyenko et al. (2011). Before constructing the VAR model, we ran several preliminary statistical tests to determine the degree of differencing and number of lags required in the VAR model.

4.1 VAR model specification

We construct a structural VAR model of first-order differences with one lag according to the preliminary tests and criteria to specify the structure of the VAR model below.

1. Unit root tests

   First, we ran unit root tests to specify the order of difference in the VAR model. The augmented Dickey–Fuller (ADF) test rejects the null hypothesis of a unit root for all variables and does not reject the hypothesis for the first differences for all variables (Table 6-A).

2. Lag order selection

   Second, the lag of the VAR model is one based on the Hannan–Quinn criterion. The Akaike information criterion (AIC) often suggests higher orders than the Bayesian information criterion (BIC). To avoid bias in the order selection from the information criteria, we adopt the Hannan–Quinn criterion because it suggests median orders between AIC and BIC and is consistent with the simulation results (Lütkepohl, 2005). The Hannan–Quinn criterion indicates that the number of lags in the VAR model is one in the full sample and all subsamples (Table 6-B).

3. Simultaneous and cross correlation

   Finally, we examine the correlation structure of the market liquidity measures and four proxies of market liquidity constraints. The cross-correlation matrix indicates that the cross correlation of the one-day lag is significant in more than half of the pairs, while that of the two-day lag is significant in only a few pairs. This is consistent with the result of the Hannan–Quinn criterion. Moreover, the simultaneous-correlation matrix implies that the contemporary interaction among the variables is significant as well (Table 7). Therefore, we construct a structural VAR model to account for the lagged and contemporary interaction of the market liquidity measures and related variables.

4.2 VAR model estimation

To take into account the contemporaneous and lagged interaction among market liquidity and its constraints discussed in Section 3 under the results of the preliminary tests in Section 4.1, we estimate the following structural VAR model under the short-run restriction following:

$$A_0 \Delta Z_t \quad = \quad A_1 \Delta Z_{t-1} + \epsilon_t \tag{6}$$

where Z_t is a vector of AMLIs and four proxies of their constraints in the three economies. A_1 is a coefficient matrix, ϵ_t is a 13×1 vector of white noise variables and A_0 represents the contemporary dependency structure of the structural VAR model (see Appendix A). To consider the liquidity pullback channel (from funding liquidity to market liquidity) and counterparty risk channel (from banks' CDS to market liquidity) as well as the Brunnermeier and Pedersen (2009) mechanism, we add red and yellow blocks in A_0.

The statistically significant parameters depend on the dominant mechanism driving market liquidity fluctuation. As discussed in section 2, the impact of funding liquidity on market liquidity (the red block in A_0) is significant and positive. On the other hand, the other part of matrix A_0 is also significant and positive when the margin calls and capital constraints resulting from fire sales by uninformed traders is dominant.

5 Discussion

In this section, we present the econometric findings of the behavior of the funding and market liquidity measures in the three subsample periods. The findings indicate that: (i) the impact of the dysfunctionality of interbank funding markets on market liquidity is dominant from July 2007 to September 2008 and September 2008 to December 2009; and (ii) margin requirements under uncertainty in the euro area trigger the decline in market liquidity, while the interbank funding market problem is partially significant.

5.1 Before the Lehman Brothers bankruptcy (July 1, 2007 to September 12, 2008)

The results of the structural VAR model demonstrate that the liquidity pullback channel from the US funding liquidity to the other funding and market liquidity in the three advanced economies is dominant from July 2, 2007 to September 12, 2008 (Figure 11, Table 8-A).

The accumulated impulse response functions indicate that the shock originating from US funding liquidity (dollar Libor–OIS spread) significantly affects all the funding and market liquidity measures in the US, the euro area, and Japan. However, the shocks originating from the funding liquidity measures in the euro area and Japan have no significant impact on market liquidity measures in both economies. This result is consistent with the emphasis on dollar funding liquidity in studies on non-US interbank funding markets (Alexius et al., 2014) and ones on market liquidity in foreign exchange markets (Baba and Packer, 2009).

Moreover, the shock originating from the US banks' capital constraint measure affects the funding and market liquidity measures in the US. This is consistent with the fact that large US banks such as Citi group raised various forms of capital such as preferred shares and preferred securities. While financial institutions in other economies also invested in the securitized products of US mortgage loans, US financial institutions, which held the mortgage loans to distribute as securitized products, recorded losses from the US housing market before the crash of the securitized product markets.

On the other hand, the shocks from margin requirements and uncertainty have quite limited impacts on both the funding and market liquidity measures. Even the shocks from banks' CDS spreads are significant only in the US. Consequently, the funding liquidity measures are driven by their own shocks and ones in other economies.[5]

These results imply that the liquidity pullback channel is a dominant determinant of the decline in funding liquidity and market liquidity after the Paribas shock in August 2007, while the Brunnermeier and Pedersen (2009) mechanism plays a limited role. The influence of liquidity pullback is significant in the global context, whereas Nyborg and Östberg (2014) examine the relationship only in the US. That is, the Libor–OIS spread for the US dollar affects the funding liquidity and market liquidity in the advance economies.

5.2 After the Lehman Brothers bankruptcy (September 15, 2008 to December 31, 2009)

The accumulated impulse response functions from September 2008 to December 2009 indicate that banks' capital shortage is another constraint on market liquidity in addition to the funding liquidity decline (Figure 12, Table 8-B).

After the Lehman Brothers bankruptcy in September 15, 2008, the shock originating from the dollar Libor–OIS spread still influences funding and market

[5] In this framework, we cannot quantitatively assess the impact of the manipulation of Libor (the Libor scandal) on funding liquidity measures.

liquidity measures in the three economies except for the funding liquidity measure for Japan. The turmoil in the interbank funding market worsened after the Lehman Brothers bankruptcy in the other economies as well as the US. Central banks in advanced economies drastically expanded their liquidity support programs such as the term auction facility and currency swaps. The influence of US funding liquidity on the funding and market liquidity in the other economies is consistent with these developments of the financial crisis.

In addition, the shocks from CDS spreads of the US and European banks affect the market liquidity measures in the three economies. While the loss recorded by large US banks is generally larger than the one by euro area banks, the US government injected more money to strengthen US banks' capital base than the euro-area governments did for euro area banks. Therefore, the impact of the shock from euro area banks' CDS is more significant than the one from the US banks.

To conclude, the deteriorated conditions of financial institutions in terms of funding liquidity and the vulnerability of their capital base influenced the market liquidity in the three economies. However, the shocks to uncertainty and margin requirements are not significant for the market-liquidity measures. This means that the role of the Brunnermeier and Pedersen mechanism is limited during the period from September 2008 to December 2009. We interpret the influence of the shock from banks' CDS as the counterparty risk channel. Therefore, the liquidity pullback and counterpart risk channel is dominant in this period.

5.3 During the European sovereign debt crisis (January 2, 2010 to December 31, 2012)

In contrast to the former subsample periods, the role of the Brunnermeier and Pedersen mechanism is significant in addition to the liquidity pullback channel during the European sovereign debt crisis (Figure 13, Table 8-C).

First, the shock from the US funding liquidity measure has limited impact on the market liquidity measures. While it has a temporary impact on the US market liquidity measures, it has no significant influence on the market liquidity measures of the other economies.

Second, the shocks from uncertainty and margin requirements in the euro area affect the market liquidity measures in the three economies. The shocks from margin calls in the US and the euro area also have significant effects on the funding liquidity measures in these economies.

These findings are consistent with the funding and market liquidity dry-up mechanism proposed by Brunnermeier and Pedersen (2009). In their model, margin calls associated with fire sales by uninformed traders trigger the drying up of funding and market liquidity. Thus, neither funding liquidity nor market liquidity lead each other, while uncertainty and margin requirements caused the liquidity problems. In the period from 2010 to 2012, the turmoil in the euro area market influenced funding and market liquidity in the three advanced economies via uncertainty and margin calls, while the impact of the dysfunctionality of the interbank funding markets is observed only in the euro area. These findings imply that the Brunnermeier and Pedersen mechanism is dominant for the period January 2010 to December 2012.

6 Concluding remarks

This paper explores the interaction between funding and market liquidity during the recent financial crises in the three advanced economies using a structural VAR model of funding liquidity measures and AMLIs. The econometric analysis indicates that: (i) the dysfunctionality of the interbank funding markets especially in the US severely affected market liquidity in the three advanced economies during the subprime financial crisis from July 2007 to December 2009; and (ii) uncertainty and an increasing number of margin calls is a dominant determinant of the market liquidity decline especially in the euro area during the European sovereign debt crisis from January 2010 to December 2012.

These findings highlight the contrast between the subprime and European crises in two regards. First, the turmoil in the US interbank funding market spread through financial markets in the other economies, while the one in the euro area did not. That is, the liquidity pullback phenomena was a global one during the period from 2007 to 2009. On the other hand, the European crisis had smaller impacts on financial markets in the other economies. The econometric analysis supports the liquidity pullback phenomena in the euro area, but the turmoil did not spread outside the euro area. This is because the euro area banks depend primarily on the interbank dollar-funding market.

Second, the dominant mechanism of the market liquidity decline varies across time and countries. While the liquidity pullback phenomena is observed in the euro area in the period from 2010 to 2012, margin requirements in the euro area influence market liquidity in the US and Japan. While the spiral reduction in funding liquidity and market liquidity via the margin requirements are observed in the euro area, econometric analysis does not support the spiral in the two other economies. This is because the capital constraints are relatively mild in the two economies during this period.

These results indicate the possibility that liquidity provision by central banks would improve the funding liquidity to financial institutions as well as market liquidity to the broader financial markets when the liquidity pullback mechanism is dominant. However, the mechanism of the simultaneous dry-up of funding liquidity and market liquidity is unique to each financial crises. For example, there can exist information asymmetry even between financial institutions, because major financial institutions in advanced economies operate their businesses outside their home countries. The results of the econometric analysis indicate that the impact of the liquidity provision is limited in such a situation. Therefore, it is better for financial authorities to have several different measures to deal with the turmoil in financial markets, including asset-purchase programs and liquidity provision.

Finally we note the intraday dynamics of the relationship between funding and market liquidity as a further research topic. While the daily data analysis is useful to describe the impact of financial constraints such as capital constraints and margin calls on market liquidity, the intraday dynamics of market liquidity is generally more complicated than the daily one. Traders usually reduce their positions if their positions approach the loss and risk limits. It is worthwhile to examine the dependency between the intraday market liquidity and financial constraints using high frequency data of conventional market liquidity measures such as bid-ask spreads and transaction volume.

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A The specification of the structural VAR model (6)

The structural VAR model (6) is characterized by matrix A_0 below,

$$A_0 = \begin{pmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{2,1} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{3,1} & a_{3,2} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{4,1} & a_{4,2} & a_{4,3} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & a_{5,2} & a_{5,3} & a_{5,4} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & a_{6,2} & a_{6,3} & a_{6,4} & a_{6,5} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & a_{7,2} & a_{7,3} & a_{7,4} & a_{7,5} & a_{7,6} & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & a_{8,2} & a_{8,3} & a_{8,4} & a_{8,5} & a_{8,6} & a_{8,7} & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & a_{9,2} & a_{9,3} & a_{9,4} & a_{9,5} & a_{9,6} & a_{9,7} & a_{9,8} & 1 & 0 & 0 & 0 & 0 \\
0 & a_{10,2} & a_{10,3} & a_{10,4} & a_{10,5} & a_{10,6} & a_{10,7} & a_{10,8} & a_{10,9} & 1 & 0 & 0 & 0 \\
a_{11,1} & a_{11,2} & a_{11,3} & a_{11,4} & a_{11,5} & a_{11,6} & a_{11,7} & a_{11,8} & a_{11,9} & a_{11,10} & 1 & 0 & 0 \\
a_{12,1} & a_{12,2} & a_{12,3} & a_{12,4} & a_{12,5} & a_{12,6} & a_{12,7} & a_{12,8} & a_{12,9} & a_{12,10} & a_{12,11} & 1 & 0 \\
a_{13,1} & a_{13,2} & a_{13,3} & a_{13,4} & a_{13,5} & a_{13,6} & a_{13,7} & a_{13,8} & a_{13,9} & a_{13,10} & a_{13,11} & a_{13,12} & 1
\end{pmatrix}$$

B Database of market liquidity measures

We construct the market volume data of the three markets below

1. Government bond
    - United States: "General government gross debt" by Securities Industry and Financial Markets Association (SIFMA)
    - Euro Area: "Central government securities" by the European Central Bank
    - Japan: "Issuing, Redemption and Outstanding Amounts of Bonds" by Japan Securities Dealers Association
2. Foreign exchange
    - "Notional amounts of outstanding of OTC foreign exchange derivatives" in "Triennial Central Bank Survey of foreign exchange and derivatives market activity" by Bank for International Settlements
3. Corporate bond
    - United States: "Non-financial Corporations" of "Debt Securities Statistics" by Bank for International Settlements
    - Euro Area: "Non-financial corporations, long-term debt securities" by the European Central Bank
    - Japan: "Issuing, Redemption and Outstanding Amounts of Bonds" by Japan Securities Dealers Association

Table 1. Descriptive statistics of components of AMLI and funding liquidity measures

A. Level

	United States				Euro Area				Japan			
	Government Bond	Foreign Exchange	Corporate Bond	Libor-OIS	Government Bond	Foreign Exchange	Corporate Bond	Euribor-OIS	Government Bond	Foreign Exchange	Corporate Bond	Tibor-OIS
mean	0.35	1.31	1.68	0.42	1.15	1.16	1.53	0.44	0.51	0.91	1.06	0.23
standard deviation	0.24	1.17	1.03	0.48	0.85	1.04	0.88	0.37	0.39	0.82	0.70	0.17
skewness	2.02	3.85	1.44	3.13	2.21	3.20	1.40	1.50	1.20	4.02	0.93	1.26
median	0.29	1.06	1.34	0.28	0.92	0.87	1.33	0.31	0.39	0.69	1.01	0.14
25 percentile	0.19	0.65	0.93	0.15	0.58	0.54	0.92	0.20	0.21	0.50	0.53	0.12
75 percentile	0.46	1.57	2.25	0.49	1.43	1.57	1.81	0.64	0.70	1.09	1.50	0.39

B. First difference

	United States				Euro Area				Japan			
	Government Bond	Foreign Exchange	Corporate Bond	Libor-OIS	Government Bond	Foreign Exchange	Corporate Bond	Euribor-OIS	Government Bond	Foreign Exchange	Corporate Bond	Tibor-OIS
mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
standard deviation	0.10	0.22	0.13	0.03	0.20	0.21	0.10	0.02	0.15	0.15	0.06	0.01
skewness	-1.02	1.95	-0.08	1.77	0.76	1.35	0.31	0.50	0.37	-0.28	1.15	3.14
median	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25 percentile	-0.04	-0.05	-0.07	0.00	-0.08	-0.05	-0.04	-0.01	-0.08	-0.03	-0.02	0.00
75 percentile	0.04	0.04	0.07	0.00	0.09	0.04	0.04	0.00	0.08	0.03	0.02	0.00

Note. Xibor-OIS spread is basis points. The three components of aggregate market liquidity measures are indexed on July 1, 2007.

Table 2. Dependency structures of components of AMLI

A. July 1,2007- December 31, 2012

	US FX	US GB	US CREDIT	EU FX	EU GB	EU CREDIT	JP FX	JP GB	JP CREDIT
US FX	1.000								
US GB	−0.089	1.000							
US CREDIT	−0.028	0.008	1.000						
EU FX	0.967	−0.095	−0.028	1.000					
EU GB	0.029	0.046	−0.030	0.015	1.000				
EU CREDIT	0.069	0.002	0.008	0.067	−0.022	1.000			
JP FX	0.813	−0.095	−0.026	0.710	0.025	0.062	1.000		
JP GB	0.008	−0.034	0.027	0.007	−0.011	−0.016	0.024	1.000	
JP CREDIT	0.109	0.024	0.037	0.117	0.018	−0.096	0.068	0.003	1.000

B. July 1, 2007- September 12, 2008

	US FX	US GB	US CREDIT	EU FX	EU GB	EU CREDIT	JP FX	JP GB	JP CREDIT
US FX	1.000								
US GB	0.000	1.000							
US CREDIT	−0.048	0.087	1.000						
EU FX	0.938	0.004	−0.020	1.000					
EU GB	0.122	−0.050	−0.157	0.105	1.000				
EU CREDIT	−0.087	−0.036	−0.002	−0.077	0.063	1.000			
JP FX	0.640	0.017	−0.017	0.499	0.000	−0.042	1.000		
JP GB	0.008	−0.098	0.085	0.009	−0.027	−0.061	−0.010	1.000	
JP CREDIT	−0.018	0.058	0.008	0.009	−0.028	−0.267	−0.073	0.040	1.000

C. September 15, 2008-December 31, 2009

	US FX	US GB	US CREDIT	EU FX	EU GB	EU CREDIT	JP FX	JP GB	JP CREDIT
US FX	1.000								
US GB	−0.131	1.000							
US CREDIT	0.009	−0.069	1.000						
EU FX	0.973	−0.136	0.014	1.000					
EU GB	0.042	0.069	−0.060	0.015	1.000				
EU CREDIT	0.159	0.006	0.022	0.158	−0.017	1.000			
JP FX	0.847	−0.156	−0.017	0.766	0.048	0.147	1.000		
JP GB	0.001	−0.011	0.016	0.005	−0.030	0.000	0.052	1.000	
JP CREDIT	0.124	0.028	0.082	0.137	0.051	−0.093	0.086	−0.027	1.000

D. January 1, 2010-December 31, 2012

	US FX	US GB	US CREDIT	EU FX	EU GB	EU CREDIT	JP FX	JP GB	JP CREDIT
US FX	1.000								
US GB	0.009	1.000							
US CREDIT	−0.098	0.059	1.000						
EU FX	0.962	−0.013	−0.096	1.000					
EU GB	0.002	0.056	0.016	0.002	1.000				
EU CREDIT	−0.089	0.009	0.000	−0.072	−0.048	1.000			
JP FX	0.781	0.059	−0.070	0.614	0.015	−0.107	1.000		
JP GB	0.024	−0.037	0.009	0.011	0.001	−0.009	0.032	1.000	
JP CREDIT	0.138	0.004	0.012	0.119	0.009	−0.032	0.134	0.007	1.000

Table 3. The variation of the dependency structure of SLRI by Severo (2012)

A. SLRI generated by data of July 2007-December 2012

	United States	Euro Area	Japan
United States	1.00		
Euro Area	0.43	1.00	
Japan	-0.03	0.41	1.00

B. SLRI generated by data of January 2010-December 2012

	United States	Euro Area	Japan
United States	1.00		
Euro Area	0.41	1.00	
Japan	0.30	0.53	1.00

Table 4. Descriptive statistics of proxy of market liquidity constraints

A. July 2, 2007-December 30, 2012 (Full sample)

	Volatility Index	US MARGIN	EU MARGIN	JAPAN MARGIN	US BANK CDS	EU BANK CDS	JAPAN BANK CDS
mean	25.36	0.00	0.00	0.00	149.61	146.26	89.52
standard deviation	10.59	0.04	0.06	0.07	68.46	90.33	35.91
skewness	2.04	0.25	1.36	0.58	0.86	0.92	−0.06
median	22.42	0.00	0.00	−0.01	140.39	119.71	89.61
25 percentile	18.26	−0.01	−0.03	−0.03	104.82	81.36	65.62
75 percentile	27.90	0.02	0.03	0.02	191.06	195.85	116.68

B. July 2, 2007-September 12, 2008

	Volatility Index	US MARGIN	EU MARGIN	JAPAN MARGIN	US BANK CDS	EU BANK CDS	JAPAN BANK CDS
mean	22.60	0.02	0.03	0.02	80.70	58.82	51.39
standard deviation	3.59	0.04	0.06	0.06	37.61	26.63	31.44
skewness	0.05	2.65	2.13	2.04	0.23	0.52	0.93
median	22.78	0.02	0.01	0.01	78.18	55.49	45.64
25 percentile	20.13	0.00	−0.01	−0.02	48.65	38.85	26.64
75 percentile	25.14	0.04	0.04	0.04	114.16	78.11	73.22

C. September 15, 2008-December 31, 2009

	Volatility Index	US MARGIN	EU MARGIN	JAPAN MARGIN	US BANK CDS	EU BANK CDS	JAPAN BANK CDS
mean	30.62	0.00	0.00	−0.01	173.41	107.46	88.84
standard deviation	13.15	0.04	0.07	0.07	66.34	26.77	27.82
skewness	1.39	0.48	1.59	0.20	1.76	0.66	0.72
median	25.56	0.00	−0.01	−0.01	147.55	102.27	82.79
25 percentile	21.60	−0.01	−0.04	−0.04	133.20	84.48	66.16
75 percentile	36.82	0.01	0.03	0.02	196.58	125.53	106.64

D. January 1, 2010-December 31, 2012

	Volatility Index	US MARGIN	EU MARGIN	JAPAN MARGIN	US BANK CDS	EU BANK CDS	JAPAN BANK CDS
mean	20.96	−0.01	0.00	−0.01	163.83	243.76	113.34
standard deviation	6.79	0.03	0.05	0.06	57.18	73.30	24.87
skewness	1.58	−2.36	0.31	0.42	0.09	0.07	0.20
median	18.31	0.00	−0.01	−0.01	165.02	242.67	112.45
25 percentile	16.48	−0.02	−0.03	−0.03	108.09	179.44	92.12
75 percentile	22.16	0.01	0.02	0.01	208.68	303.38	131.95

Note. Volatility index is percent point. CDS spreads are basis points.

Table 5. Granger causality between the components of AMLI

A. United States

t-1 \ t	Government Bond	Foreign Exchange	Coporate Bond
Government Bond		0.462 (0.630)	1.130 (0.323)
Foreign Exchange	6.500 (0.002)		3.560 (0.029)
Coporate Bond	10.586 (0.000)	2.614 (0.074)	

B. Euro Area

t-1 \ t	Government Bond	Foreign Exchange	Coporate Bond
Government Bond		1.307 (0.271)	0.683 (0.505)
Foreign Exchange	0.445 (0.641)		5.950 (0.003)
Coporate Bond	3.955 (0.019)	14.218 (0.000)	

C. Japan

t-1 \ t	Government Bond	Foreign Exchange	Coporate Bond
Government Bond		2.639 (0.072)	2.170 (0.115)
Foreign Exchange	5.630 (0.004)		0.998 (0.369)
Coporate Bond	0.106 (0.890)	1.010 (0.333)	

Note. The numbers above and within the parenthesis are F-statistics and p-values.

Table 6. Preliminary test for the VAR model specification

A. Unit root test (ADF test)

	Level	Fisrt difference
volatility index	0.277	0.000
US margin call	0.341	0.000
Europe margin call	0.232	0.000
Japan margin call	0.127	0.000
US Bank CDS	0.345	0.000
Europe Bank CDS	0.488	0.000
Japan Bank CDS	0.414	0.000
US Libor-OIS	0.171	0.000
Europe Euribor-OIS	0.194	0.000
Japan Tibor-OIS	0.614	0.000
US AMLI	0.179	0.000
Europe AMLI	0.185	0.000
Japan AMLI	0.170	0.000

Note. The number indicates p-value in which the null hypothesis of the unit root rejects.

B. Lag length test

(1) July 2, 2007-December 31, 2012

	AIC	BIC	Hannan-Quinn
0	−36.66	−36.61	−36.64
1	−37.59	−36.93 *	−37.34 *
2	−37.73 *	−36.45	−37.25
3	−37.73	−35.82	−37.02
4	−37.72	−35.19	−36.77
5	−37.71	−34.56	−36.53
6	−37.73	−33.96	−36.32
7	−37.67	−33.28	−36.03
8	−37.64	−32.63	−35.77
9	−37.58	−31.95	−35.48
10	−37.59	−31.34	−35.26

(2) July 2, 2007-September 12, 2008

	AIC	BIC	Hannan-Quinn
0	−11.29	−11.14 *	−11.23
1	−12.34 *	−10.17	−11.47 *
2	−12.19	−8.01	−10.52
3	−11.85	−5.66	−9.38
4	−11.77	−3.56	−8.49
5	−11.77	−1.55	−7.69
6	−11.62	0.61	−6.73
7	−11.37	2.88	−5.68
8	−11.22	5.04	−4.72
9	−10.96	7.32	−3.66
10	−10.82	9.47	−2.71

(3) September 15, 2008-December 31, 2009

	AIC	BIC	Hannan-Quinn
0	−31.75	−31.61 *	−31.70
1	−32.98	−30.92	−32.16 *
2	−33.14 *	−29.18	−31.56
3	−33.10	−27.23	−30.76
4	−33.00	−25.23	−29.90
5	−32.80	−23.11	−28.94
6	−32.72	−21.13	−28.10
7	−32.62	−19.12	−27.24
8	−32.56	−17.15	−26.42
9	−32.58	−15.27	−25.68
10	−32.75	−13.53	−25.09

(4) January 2010-December 2012

	AIC	BIC	Hannan-Quinn
0	−46.51	−46.43 *	−46.48
1	−47.02	−45.93	−46.60 *
2	−47.04 *	−44.95	−46.24
3	−46.98	−43.88	−45.79
4	−46.86	−42.75	−45.28
5	−46.68	−41.57	−44.71
6	−46.54	−40.41	−44.18
7	−46.39	−39.26	−43.64
8	−46.29	−38.15	−43.16
9	−46.13	−36.98	−42.61
10	−45.92	−35.77	−42.02

Note. * indicates the optimal length in each criterion up to 10 days.

Table 7. Correlation matrix of AMLI and the proxies of its constraints

A. Simultaneous correlation matrix

	VI	US_MARGIN	EU_MARGIN	JP_MARGIN	Bank CDS North America	Bank CDS Europe	Bank CDS Japan	Libor−OIS	Euribor−OIS	Tibor−OIS	AMLI US	AMLI Europe	AMLI Japan
VI	1.00												
US_MARGIN	0.16	1.00											
EU_MARGIN	0.19	0.54	1.00										
JP_MARGIN	−0.02	0.43	0.35	1.00									
Bank CDS North America	0.26	0.02	0.11	−0.11	1.00								
Bank CDS Europe	0.32	0.04	0.23	−0.09	0.51	1.00							
Bank CDS Japan	0.08	0.09	0.11	−0.08	0.31	0.31	1.00						
Libor−OIS	0.22	0.03	0.02	0.04	0.10	0.10	0.08	1.00					
Euribor−OIS	0.30	0.14	0.15	0.03	0.17	0.17	0.19	0.32	1.00				
Tibor−OIS	0.07	0.12	0.07	0.03	0.08	0.08	0.19	0.22	0.19	1.00			
AMLI US	0.17	0.05	0.13	0.02	0.19	0.21	0.13	0.22	0.12	0.08	1.00		
AMLI Europe	0.02	0.06	0.09	0.02	0.05	0.04	0.09	0.13	0.10	0.02	0.27	1.00	
AMLI Japan	0.06	0.04	0.10	0.03	0.08	0.10	0.15	0.15	0.11	0.06	0.18	0.14	1.00

B. Cross correlation matrix (one day lag)

t \ t−1	VI	US_MARGIN	EU_MARGIN	JP_MARGIN	Bank CDS North America	Bank CDS Europe	Bank CDS Japan	Libor−OIS	Euribor−OIS	Tibor−OIS	AMLI US	AMLI Europe	AMLI Japan
VI	−0.15	0.03	0.08	−0.12	0.27	0.19	0.38	0.03	0.07	0.07	0.12	0.09	0.08
US_MARGIN	−0.02	0.42	0.27	0.27	−0.01	0.00	0.05	0.01	0.06	0.10	0.03	0.04	0.02
EU_MARGIN	0.01	0.24	0.19	0.18	0.05	0.03	0.08	0.03	0.04	0.05	0.05	0.07	0.03
JP_MARGIN	0.00	0.21	0.13	0.15	−0.07	−0.03	−0.04	0.01	0.04	0.02	−0.03	−0.01	0.00
Bank CDS North America	−0.08	0.03	0.08	0.02	0.29	0.24	0.27	0.02	0.04	0.09	0.10	0.10	0.13
Bank CDS Europe	−0.06	0.04	0.06	0.00	0.24	0.28	0.40	0.02	0.01	0.13	0.11	0.15	0.15
Bank CDS Japan	−0.12	0.03	0.03	0.10	0.06	−0.02	0.16	0.06	−0.04	0.07	0.01	0.04	0.04
Libor−OIS	−0.02	0.06	0.03	−0.03	0.10	0.08	0.20	0.19	0.17	0.29	0.09	0.09	0.09
Euribor−OIS	−0.07	0.09	0.12	−0.01	0.17	0.03	0.19	0.11	0.05	0.16	0.05	0.09	0.07
Tibor−OIS	−0.09	0.06	0.00	0.05	0.03	−0.02	0.01	0.00	0.08	0.13	0.01	0.04	0.02
AMLI US	−0.05	0.02	0.02	−0.01	0.03	0.06	0.10	0.06	0.05	0.08	−0.17	0.04	0.03
AMLI Europe	−0.04	0.03	0.04	0.00	−0.01	−0.02	−0.04	0.12	0.04	0.03	0.04	−0.03	0.04
AMLI Japan	0.01	0.02	0.02	0.00	0.01	0.03	0.06	0.14	0.03	0.07	0.03	0.02	−0.15

Note. Shadow column indicates the pair-wise correlation is significantly different from zero at 1% confidence level.

Table 8. Accumulated impulse response functions of the structural VAR model

A. July 2, 2007-September 12, 2008

	United States		Euro Area		Japan	
	LIBOR-OIS	AMLI	EURIBOR-OIS	AMLI	TIBOR-OIS	AMLI
1 Volatility Index					+	
2 US_MARGIN			+			
3 EU_MARGIN						
4 JP_MARGIN						
5 US Bank CDS	+	+				
6 EU Bank CDS						
7 JP Bank CDS						
8 LIBOR-OIS	+	+	+	+	+	+
9 EURIBOR-OIS			+			
10 TIBOR-OIS					+	
11 AMLI US		+		+		
12 AMLI Europe	+			+		
13 AMLI Japan	+					+

B. September 15, 2008-December 30, 2009

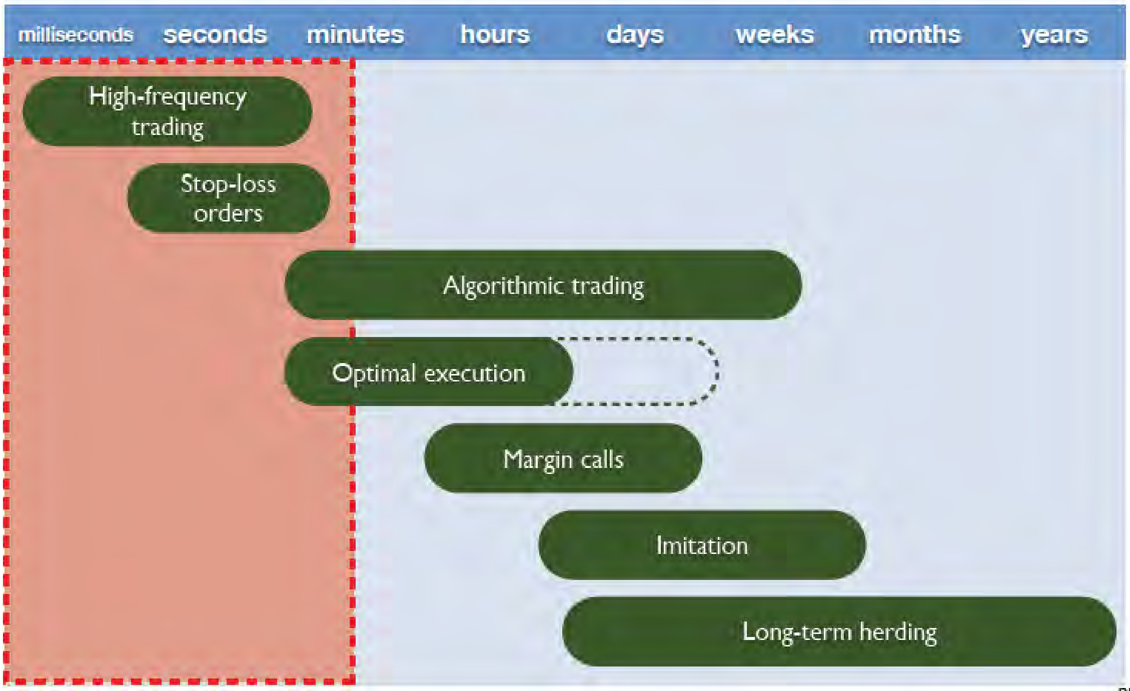
	United States		Euro Area		Japan	
	LIBOR-OIS	AMLI	EURIBOR-OIS	AMLI	TIBOR-OIS	AMLI
1 Volatility Index		+	+			+
2 US_MARGIN					+	
3 EU_MARGIN						
4 JP_MARGIN						
5 US Bank CDS	+	+	+	+		
6 EU Bank CDS	+	+	+	+		+
7 JP Bank CDS			+		+	
8 LIBOR-OIS	+	+	+	+		+
9 EURIBOR-OIS			+			
10 TIBOR-OIS					+	
11 AMLI US		+		+		+
12 AMLI Europe				+		
13 AMLI Japan						+

C. January 2, 2010-December 30, 2012

	United States		Euro Area		Japan	
	LIBOR-OIS	AMLI	EURIBOR-OIS	AMLI	TIBOR-OIS	AMLI
1 Volatility Index		+				+
2 US_MARGIN	+		+			
3 EU_MARGIN		+	+	+		+
4 JP_MARGIN						
5 US Bank CDS		+	+			
6 EU Bank CDS				+		
7 JP Bank CDS						+
8 LIBOR-OIS	+	+				
9 EURIBOR-OIS			+	+		
10 TIBOR-OIS					+	
11 AMLI US		+		+		
12 AMLI Europe				+		
13 AMLI Japan						+

Note. "+" means a significantly positive response to a shock. The shadow cell means the accumulated response is significant over 10 days.

Figure 1. Endogenous dynamics between price and news



Source: Filimonov (2014)

Figure 2. Mechanism of the interaction between funding and market liquidity

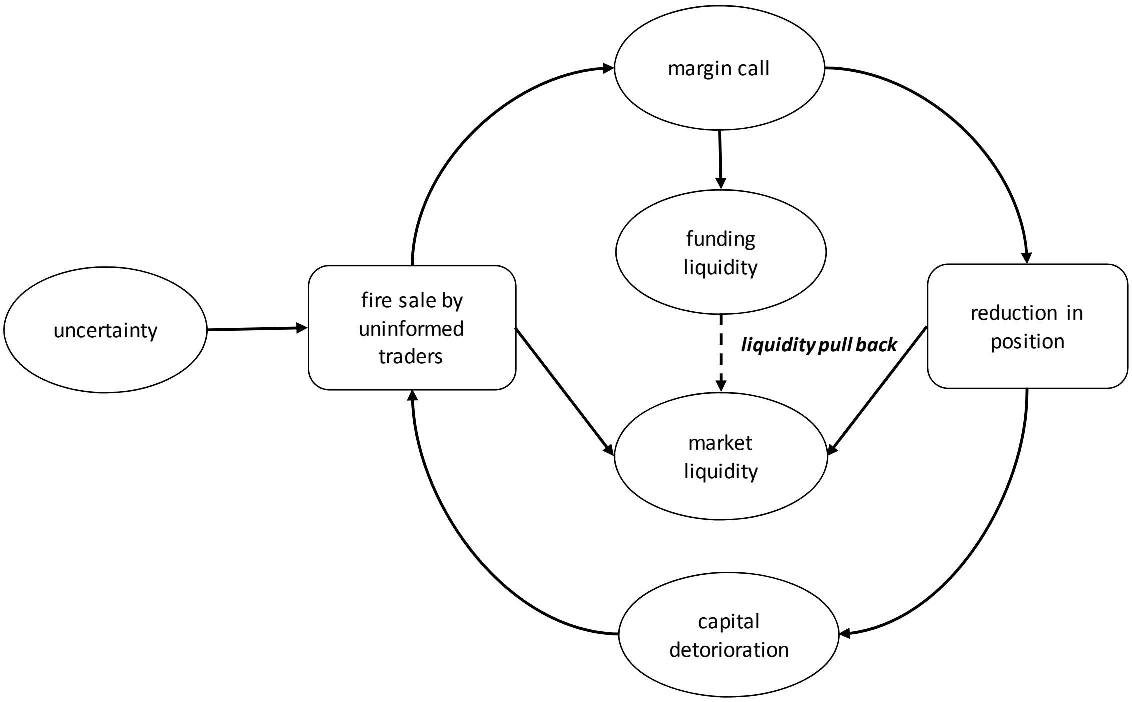


Figure 3. The spread between interbank funding rate and OIS

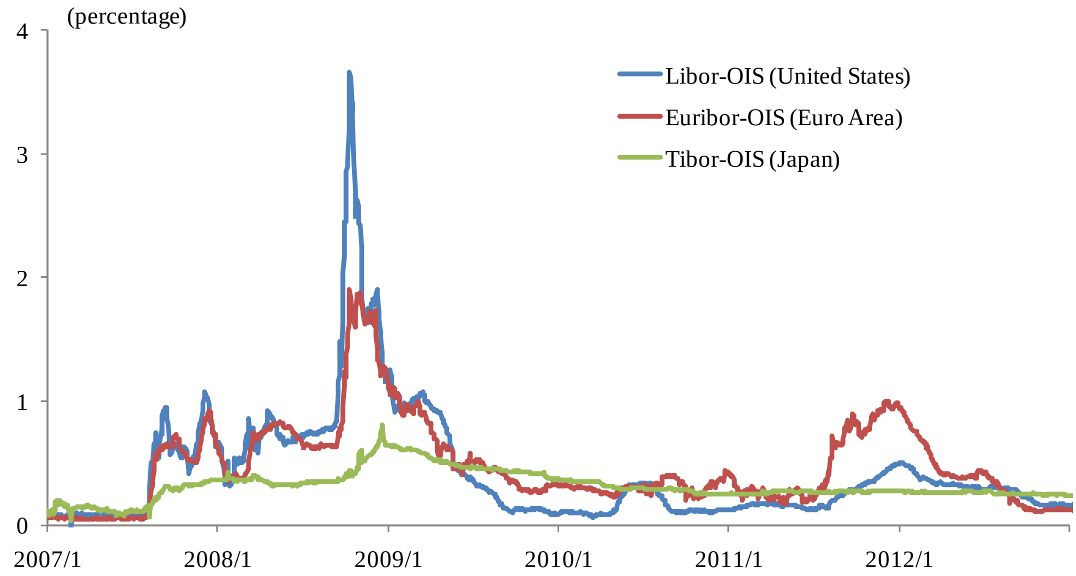


Figure 4. Candidates for interbank funding liquidity measures

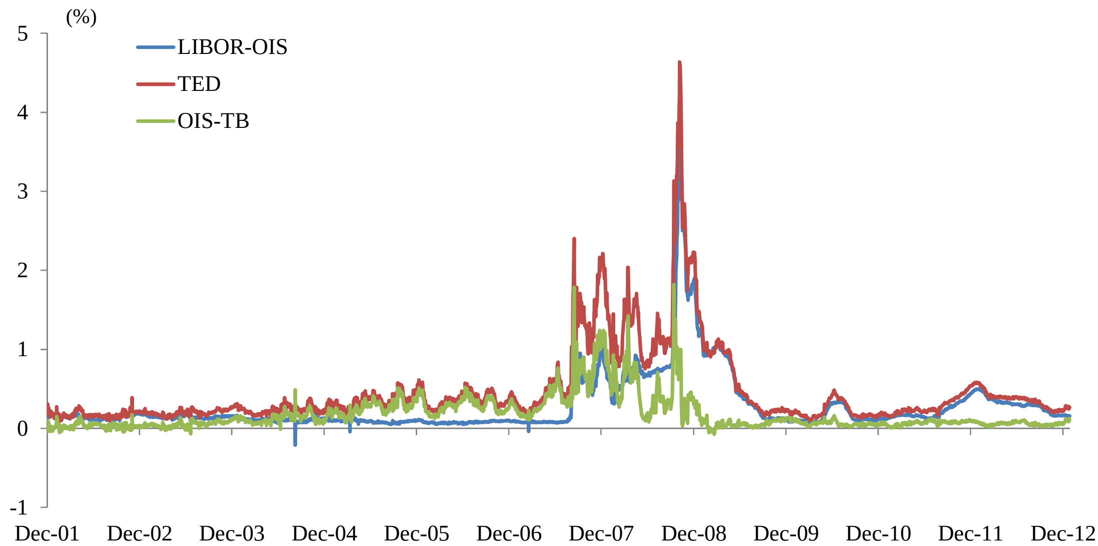


Figure 5. On-Off spread of government bonds (5 year)

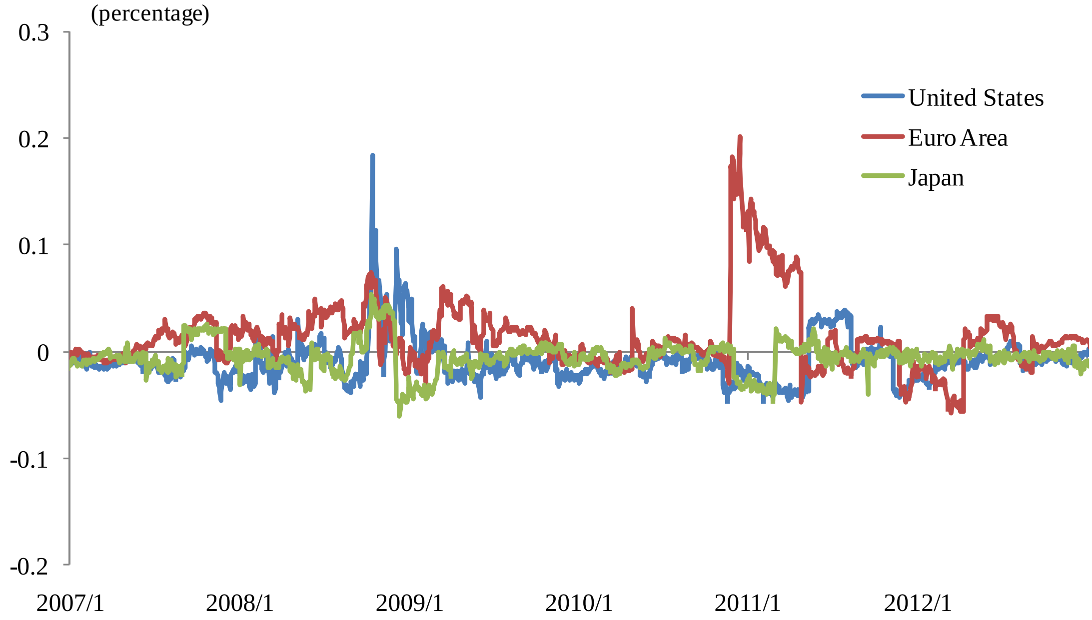


Figure 6. The deviation of FX swap from the covered interest parity

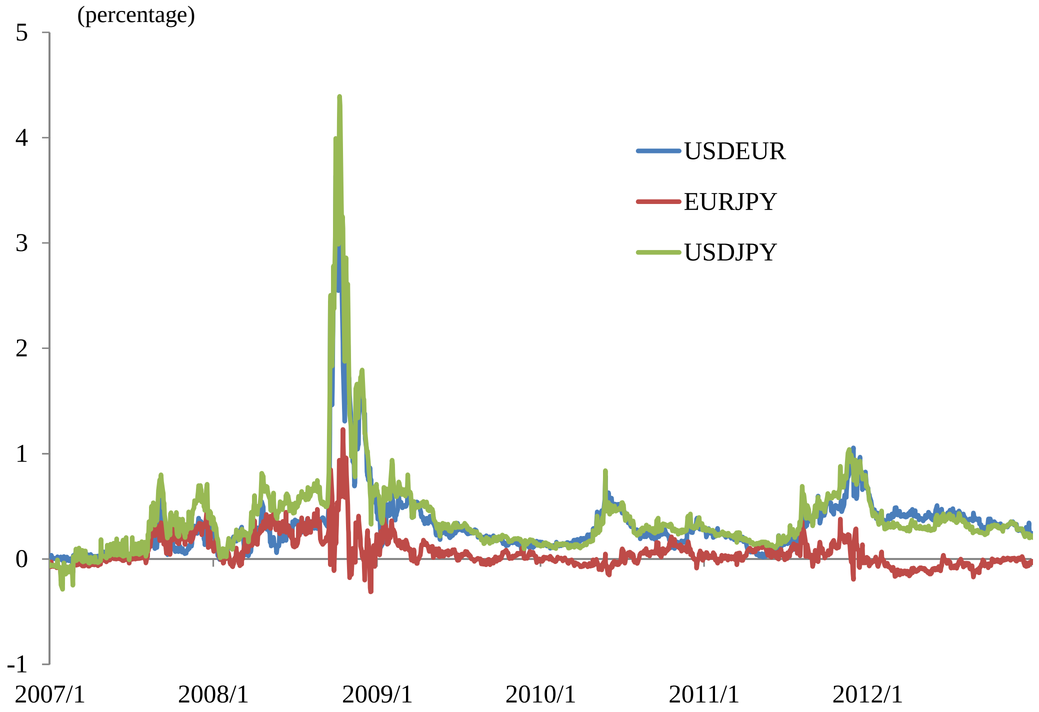


Figure 7. CDS-Bond Basis

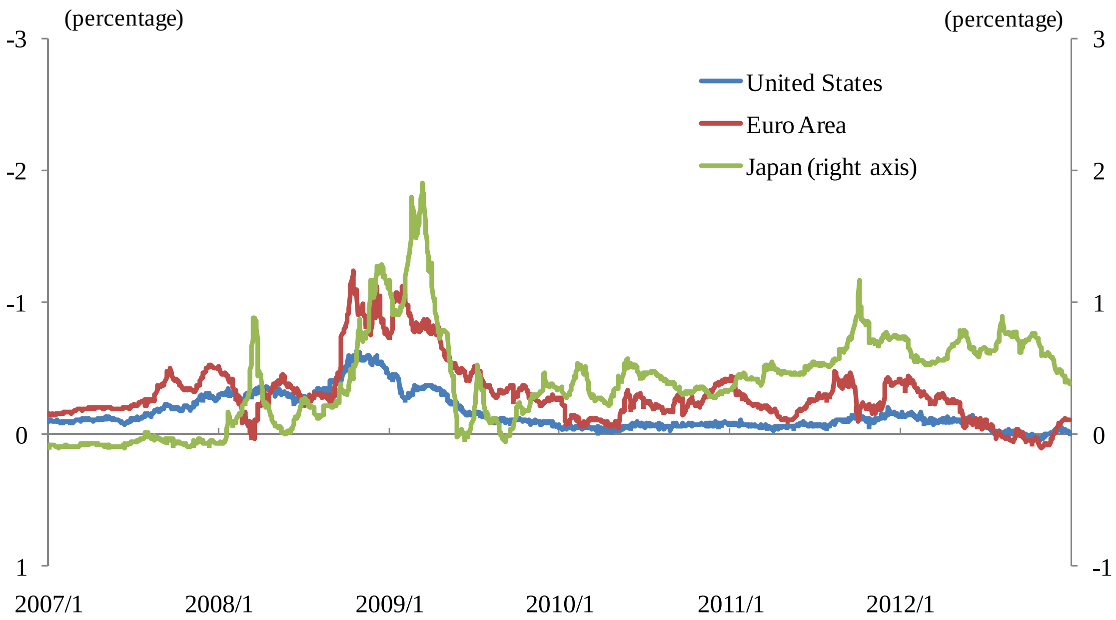
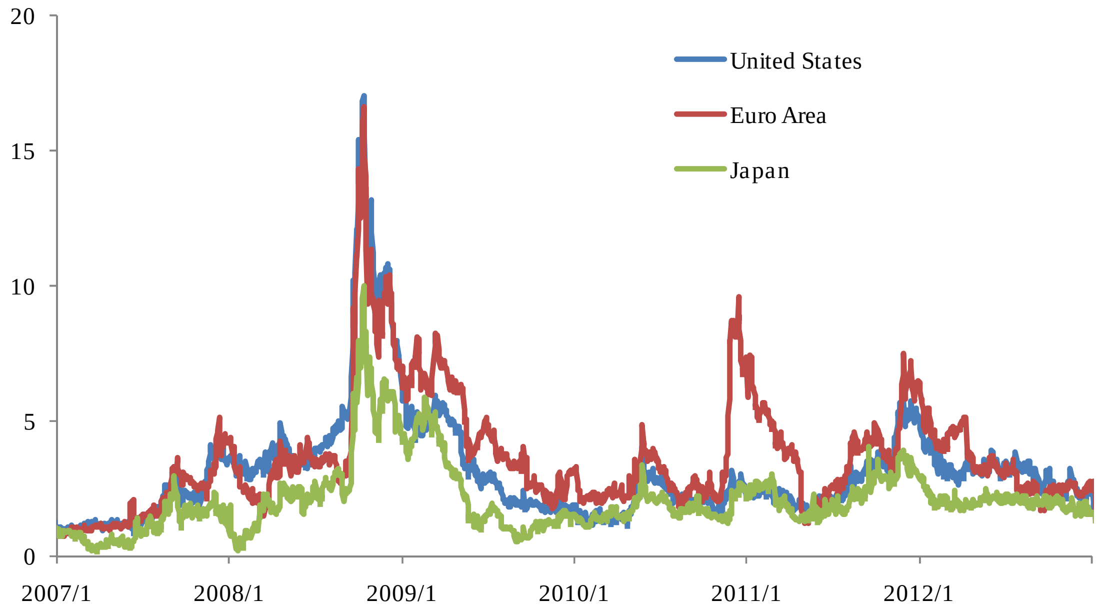


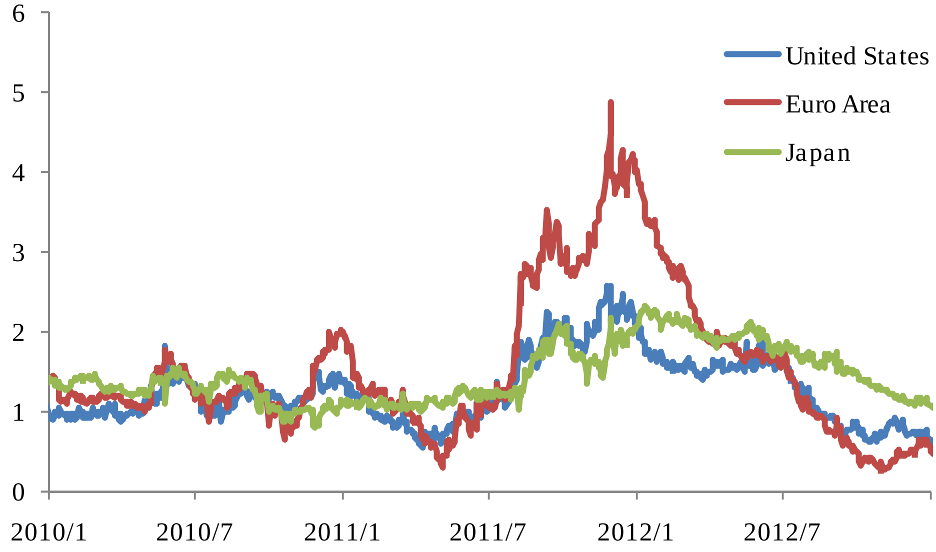
Figure 8. Aggregate market liquidity indicator



Note. All indicators are indexed at 1 as of January 1, 2007.

Figure 9. Non-uniqueness of SLRI by Severo (2012)

A. SLRI generated by data of July 2007-December 2012



B. SLRI generated by data of January 2010-December 2012

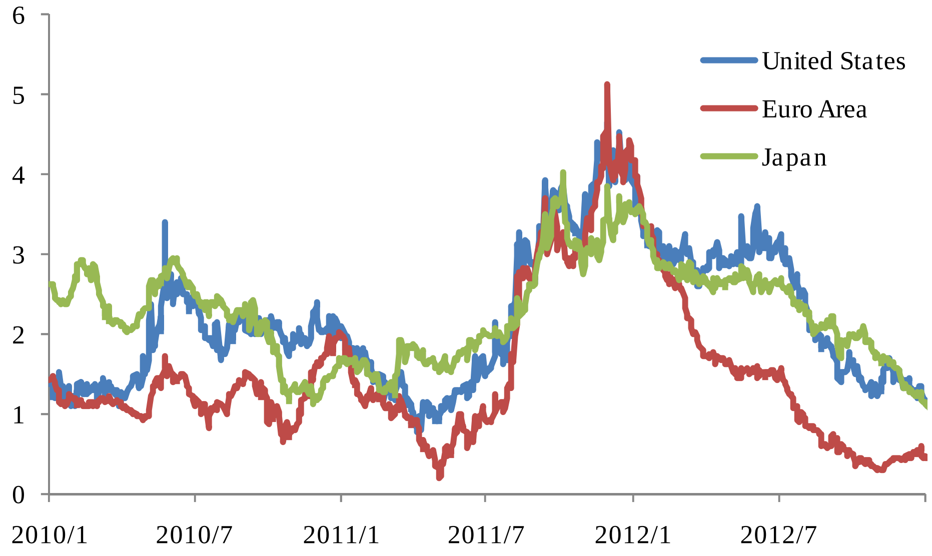
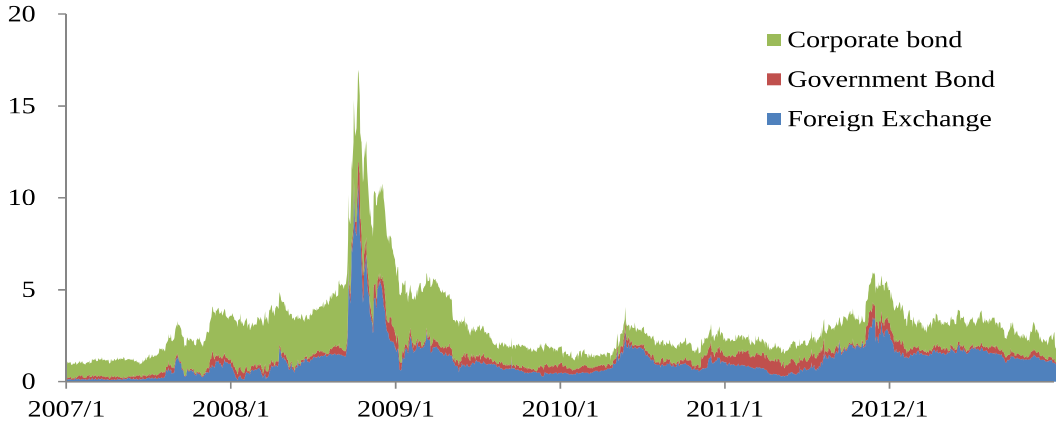
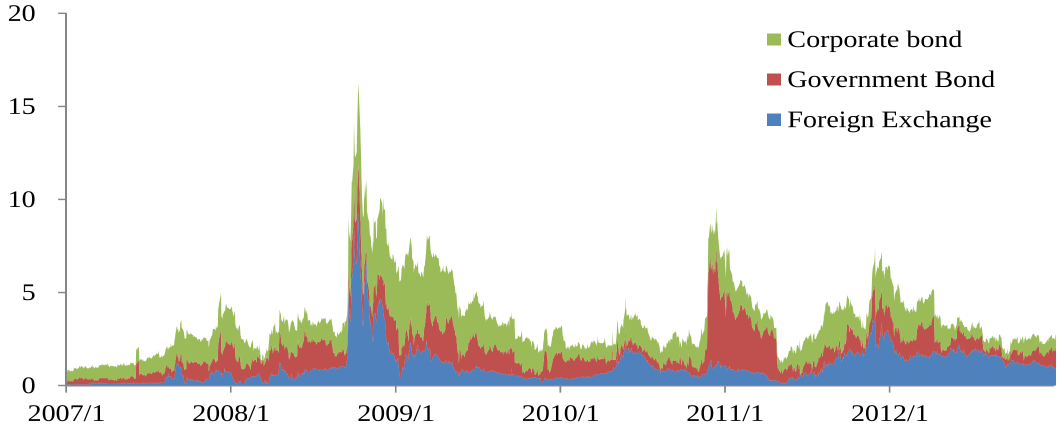


Figure 10. Components of aggregate market liquidity measures

A. United States



B. Euro Area



C. Japan

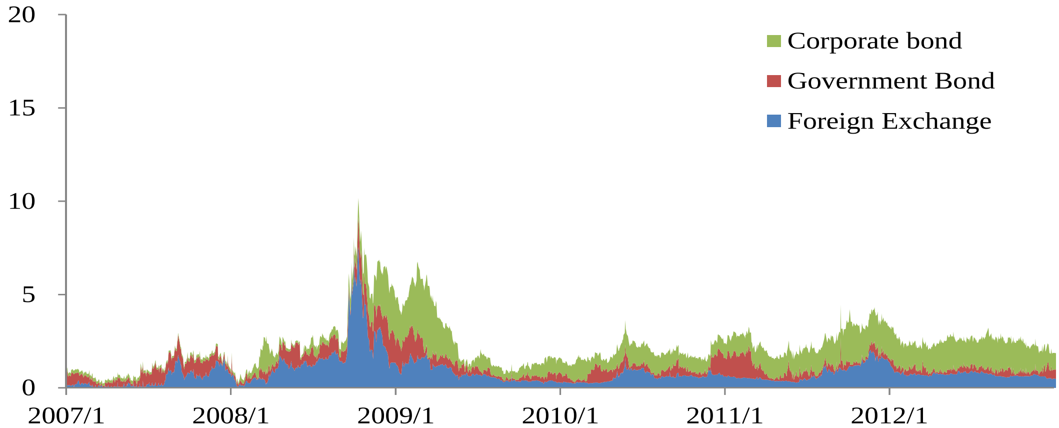
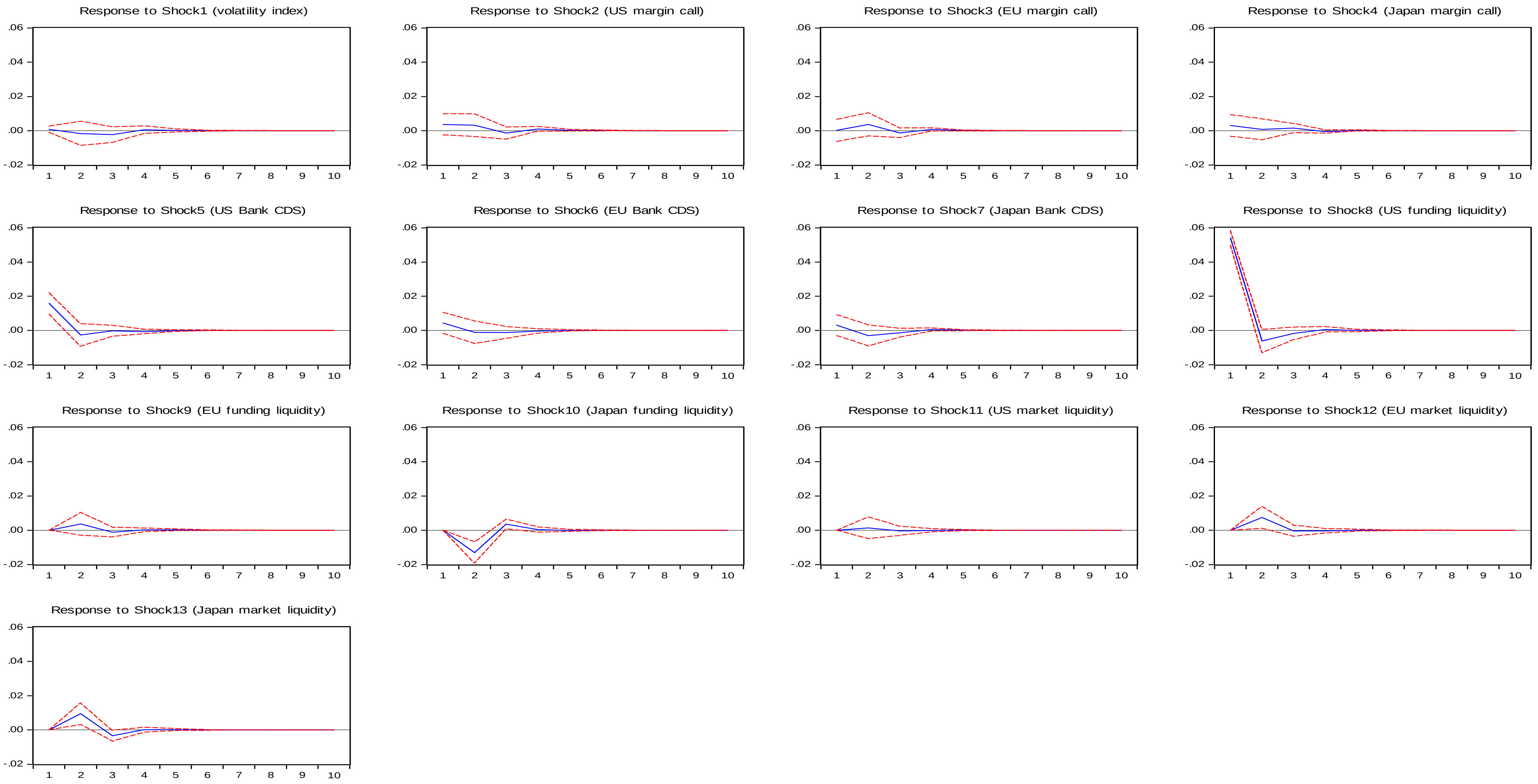
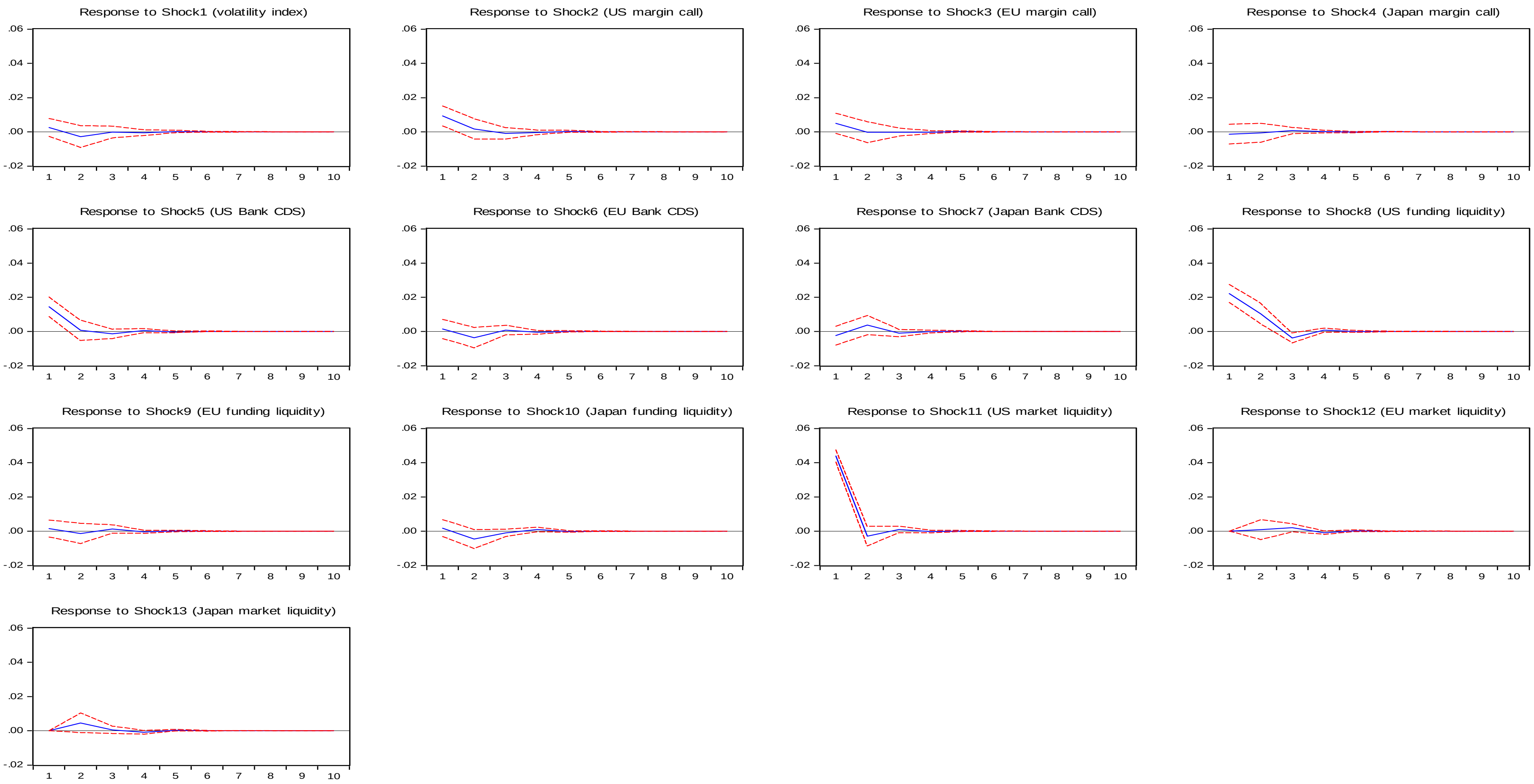


Figure 11. Impulse response functions from July 2, 2007 to September 12, 2008

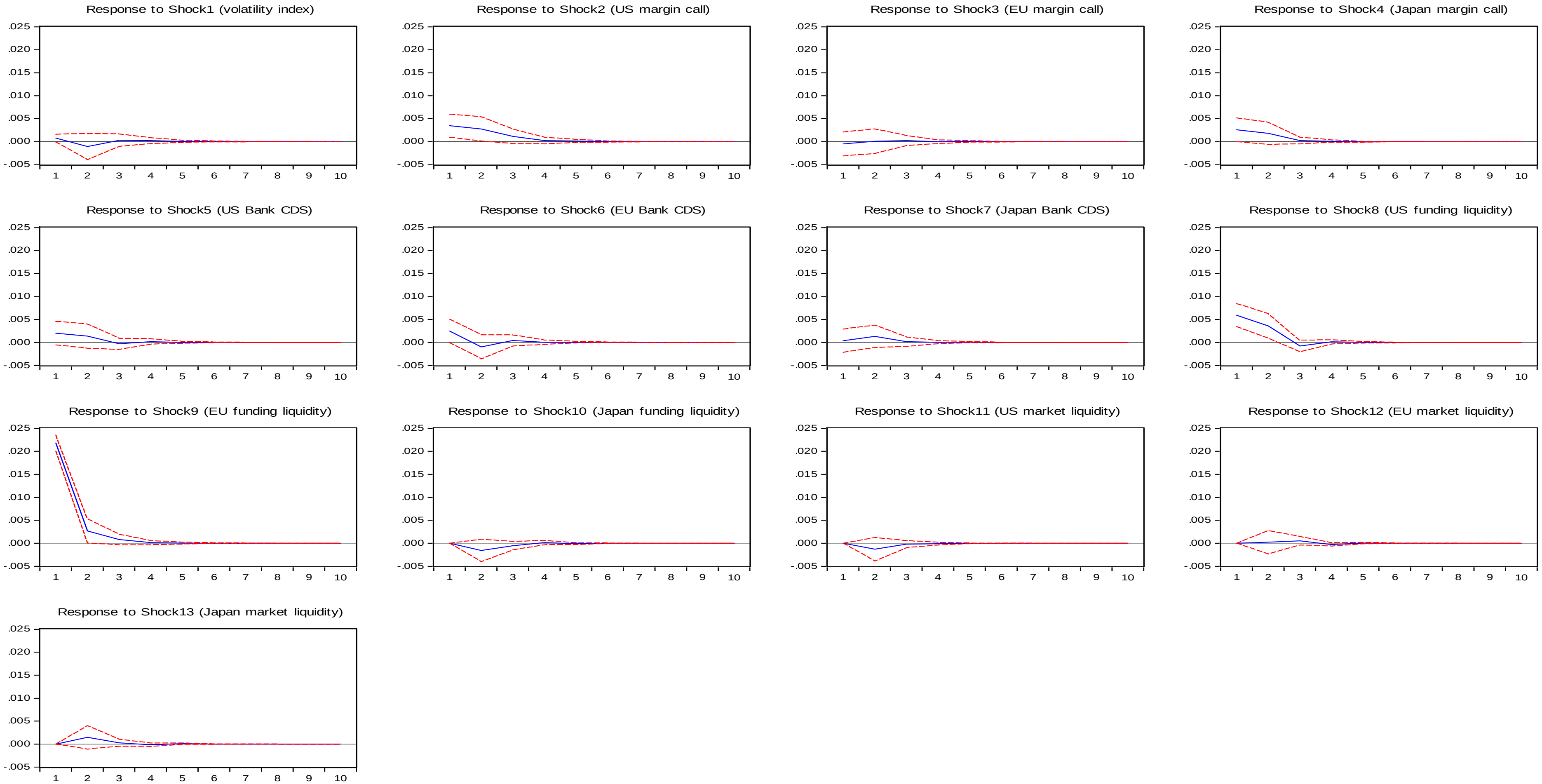
A-1. US funding liquidity



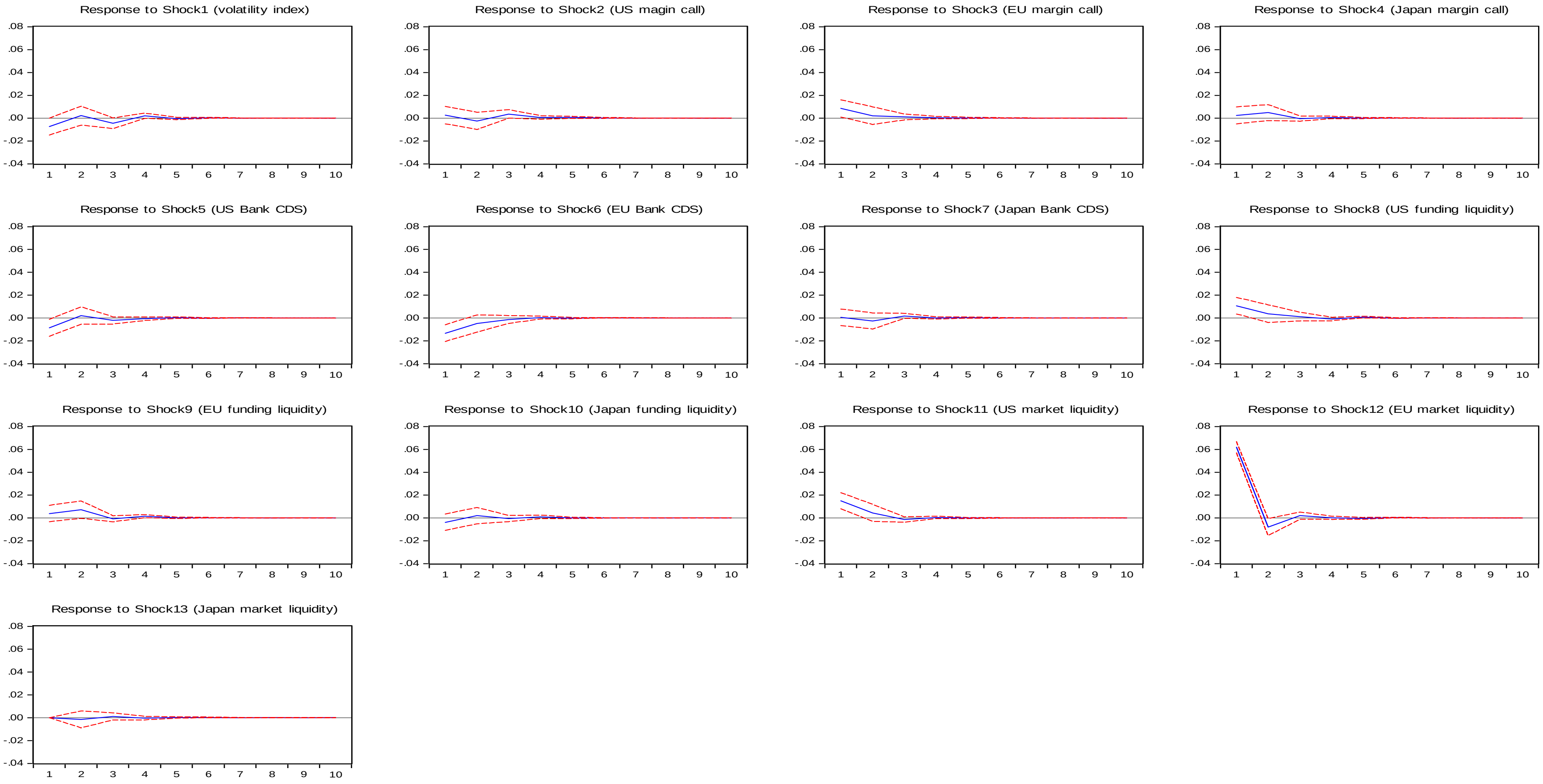
A-2. US market liquidity



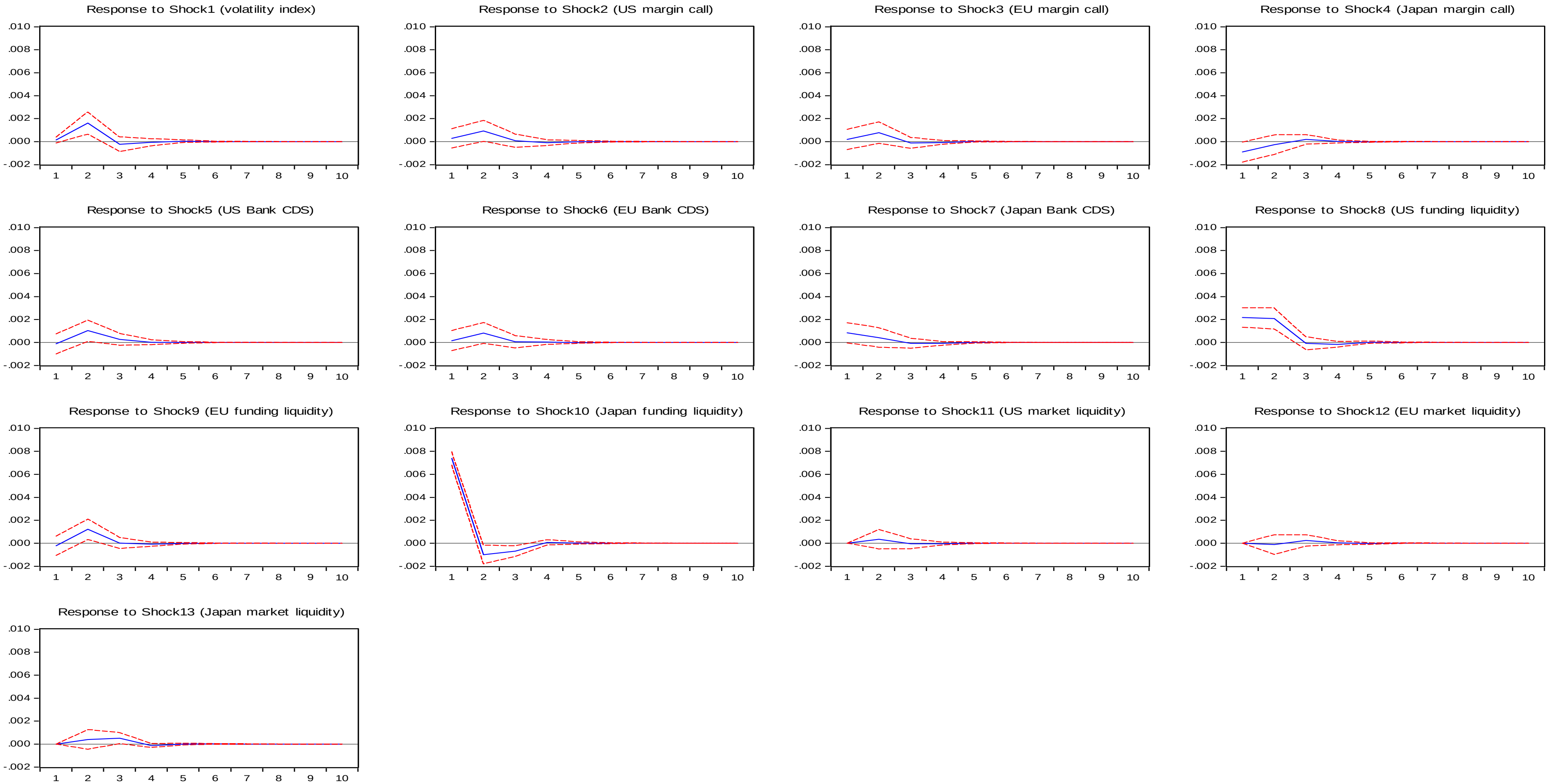
B-1. Euro Area funding liquidity



B-2. Euro Area market liquidity



C-1. Japan funding liquidity



C-2. Japan market liquidity

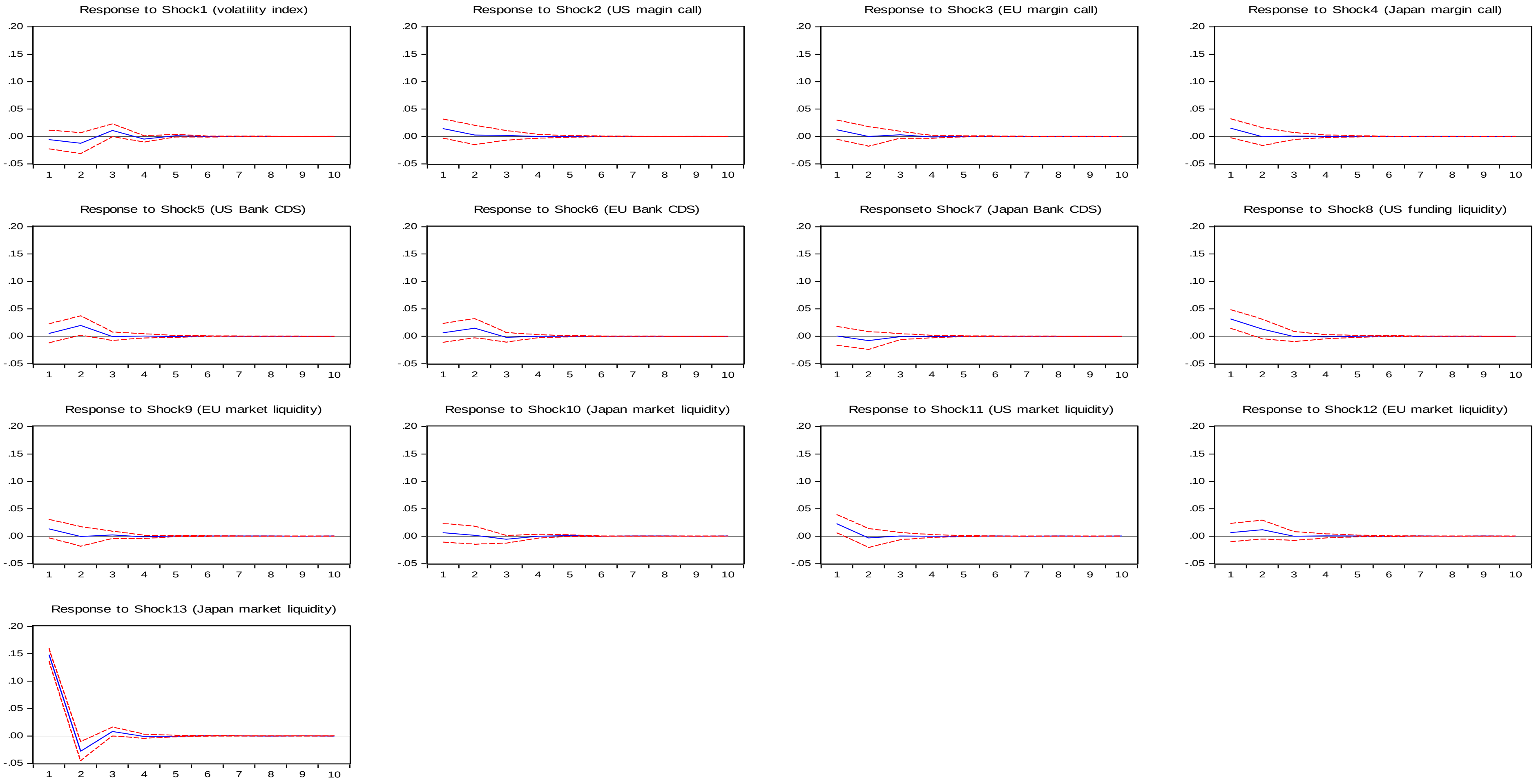
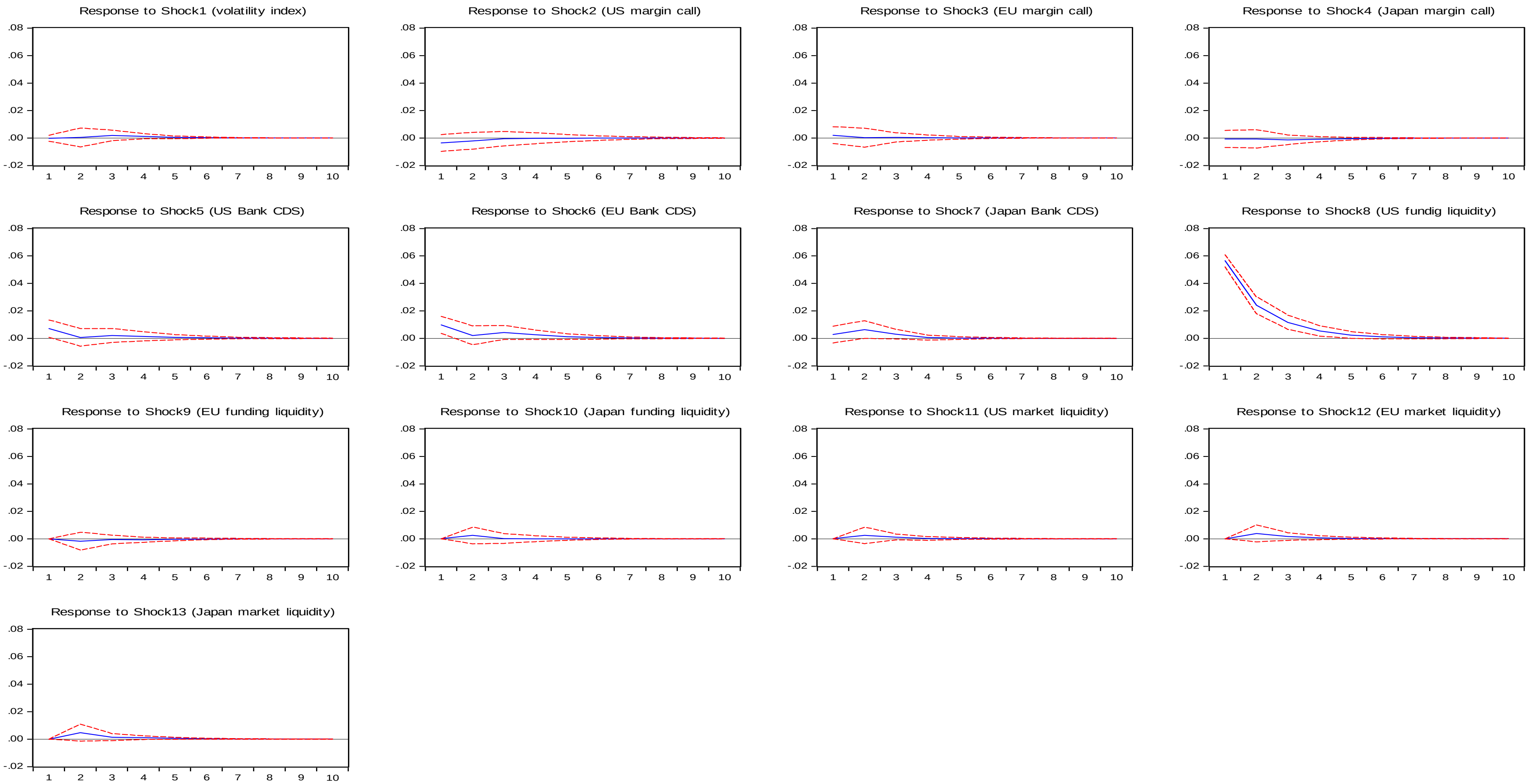
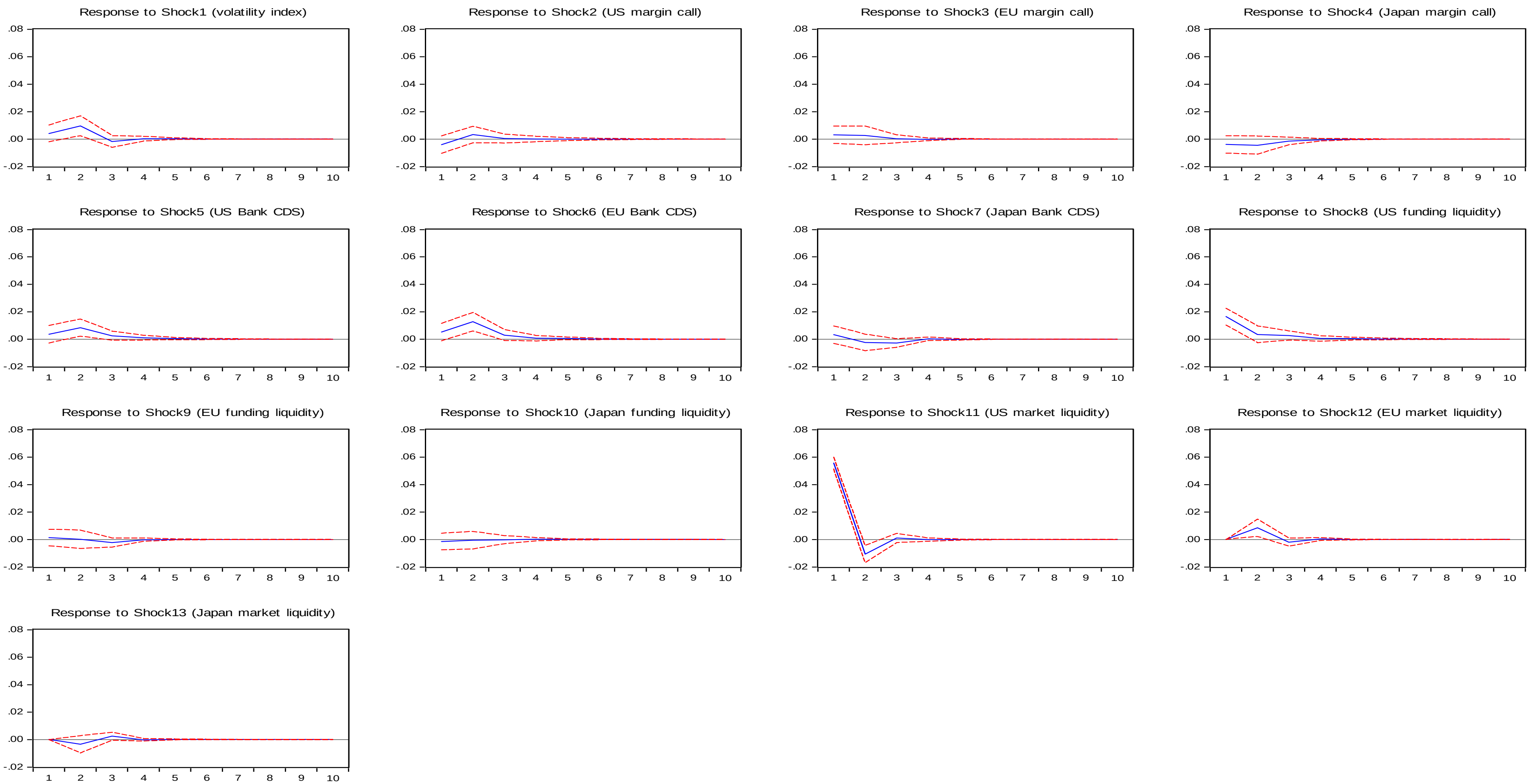


Figure 12. Impulse response functions from September 15, 2008 to December 30, 2009

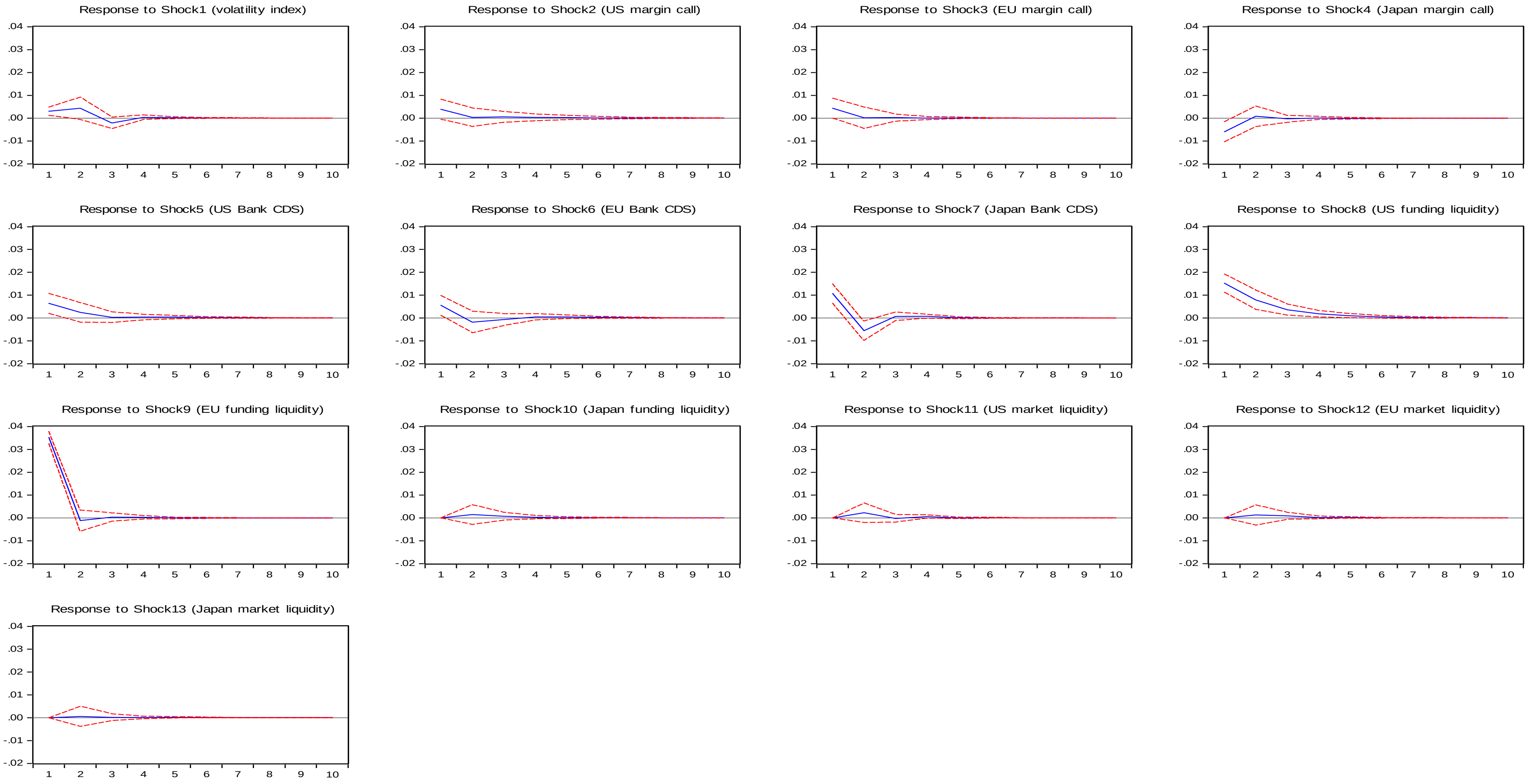
A-1. US funding liquidity



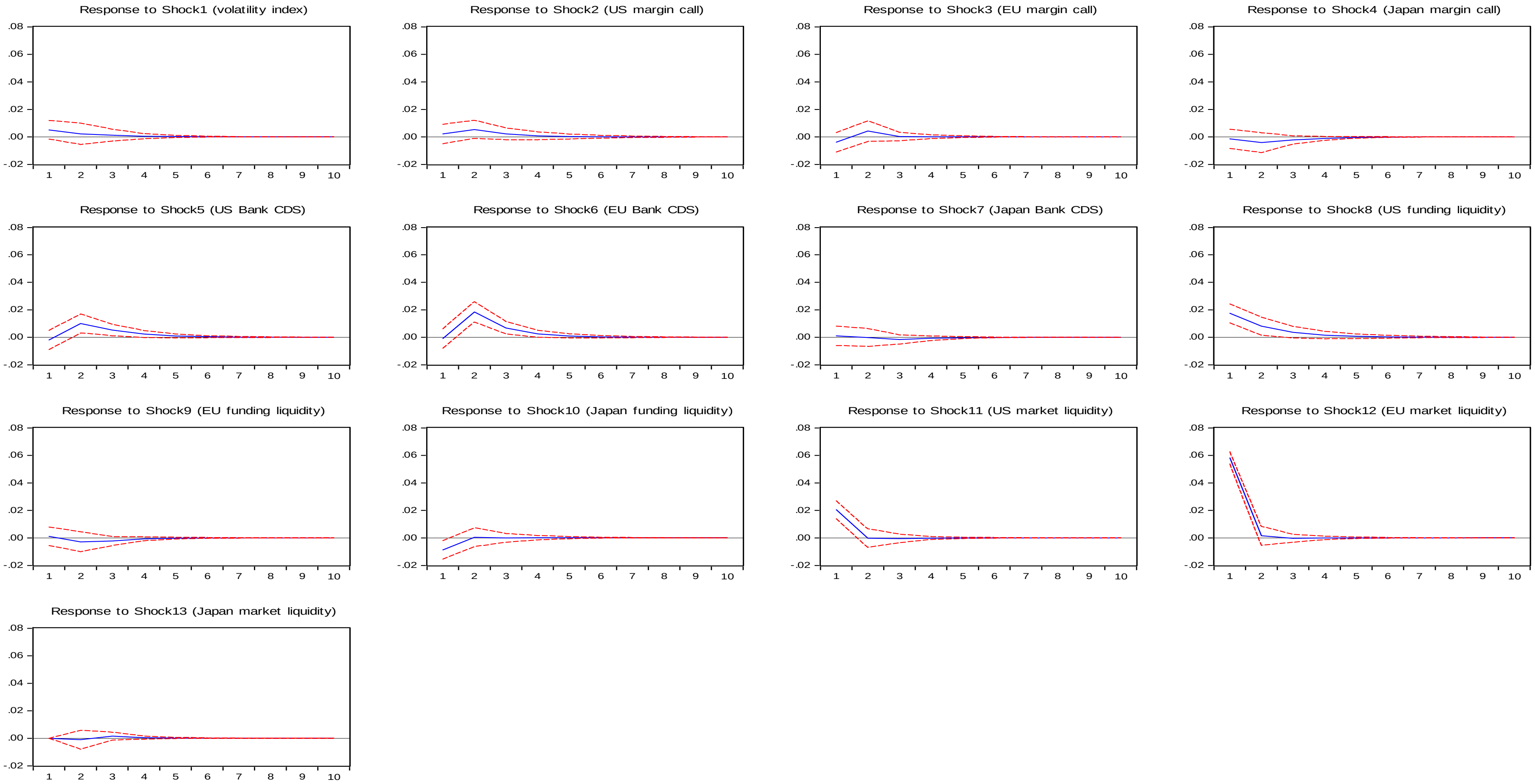
A-2. US market liquidity



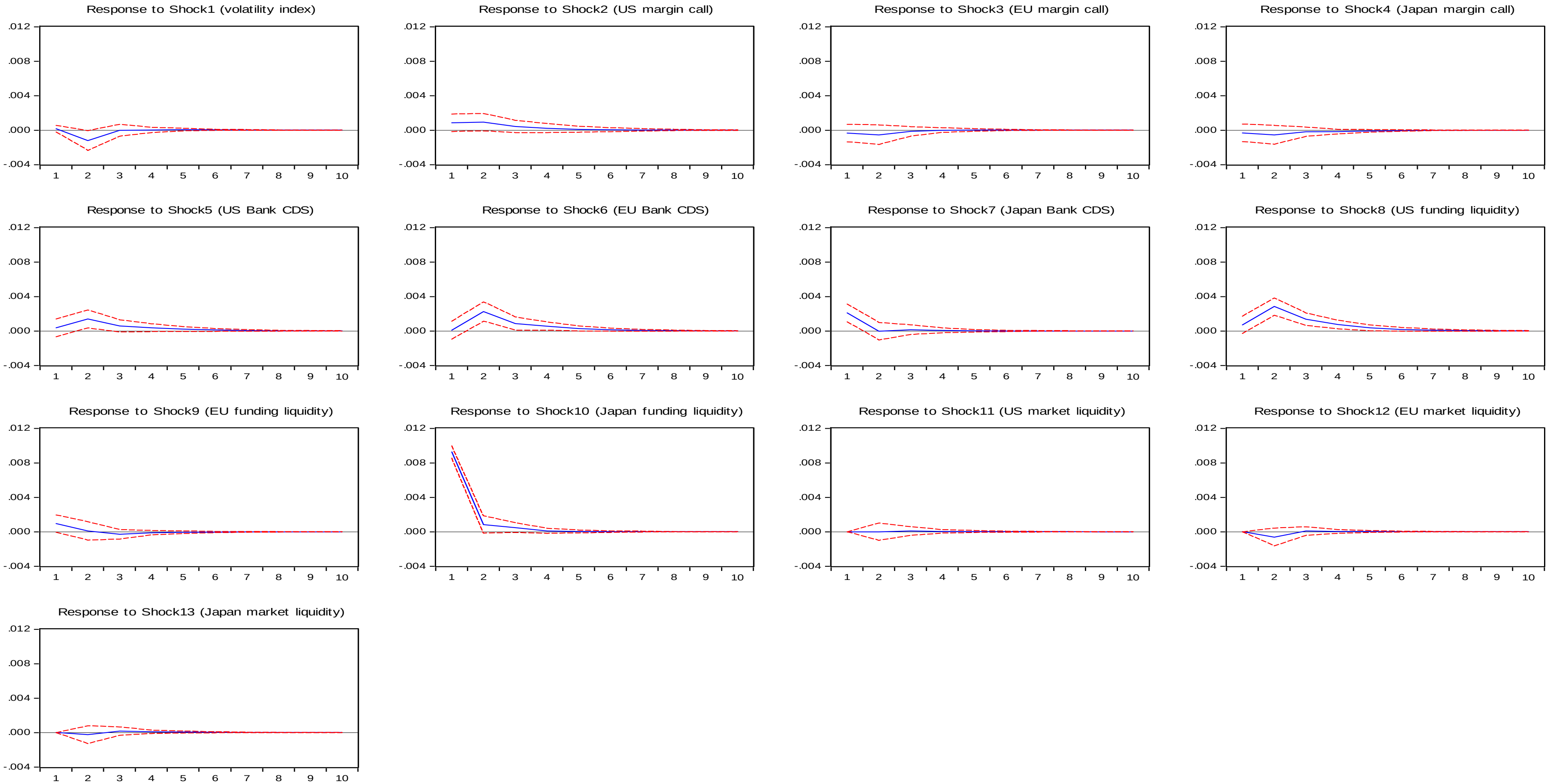
B-1. Euro area funding liquidity



B-2. Euro area market liquidity



C-1. Japan funding liquidity



C-2. Japan market liquidity

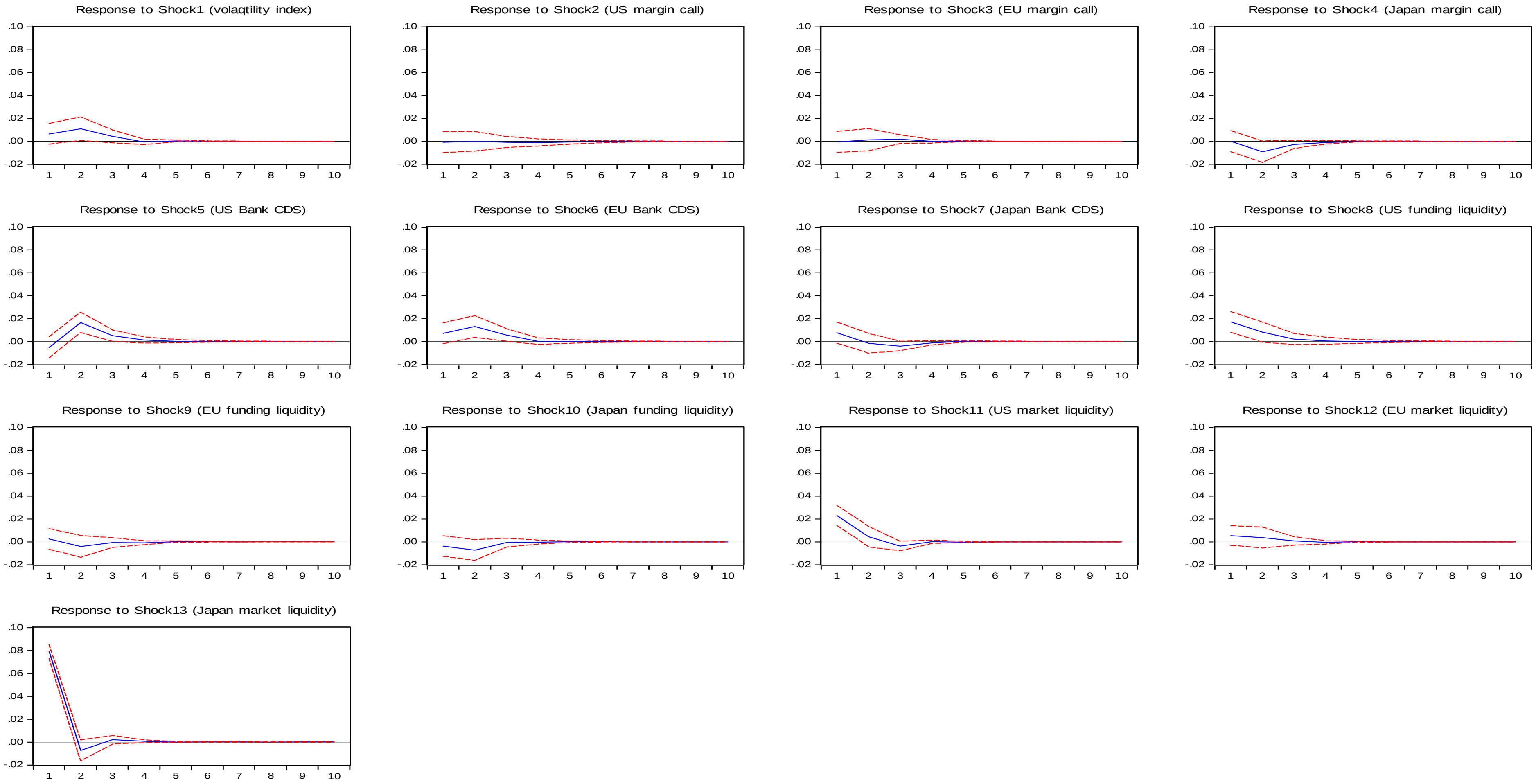
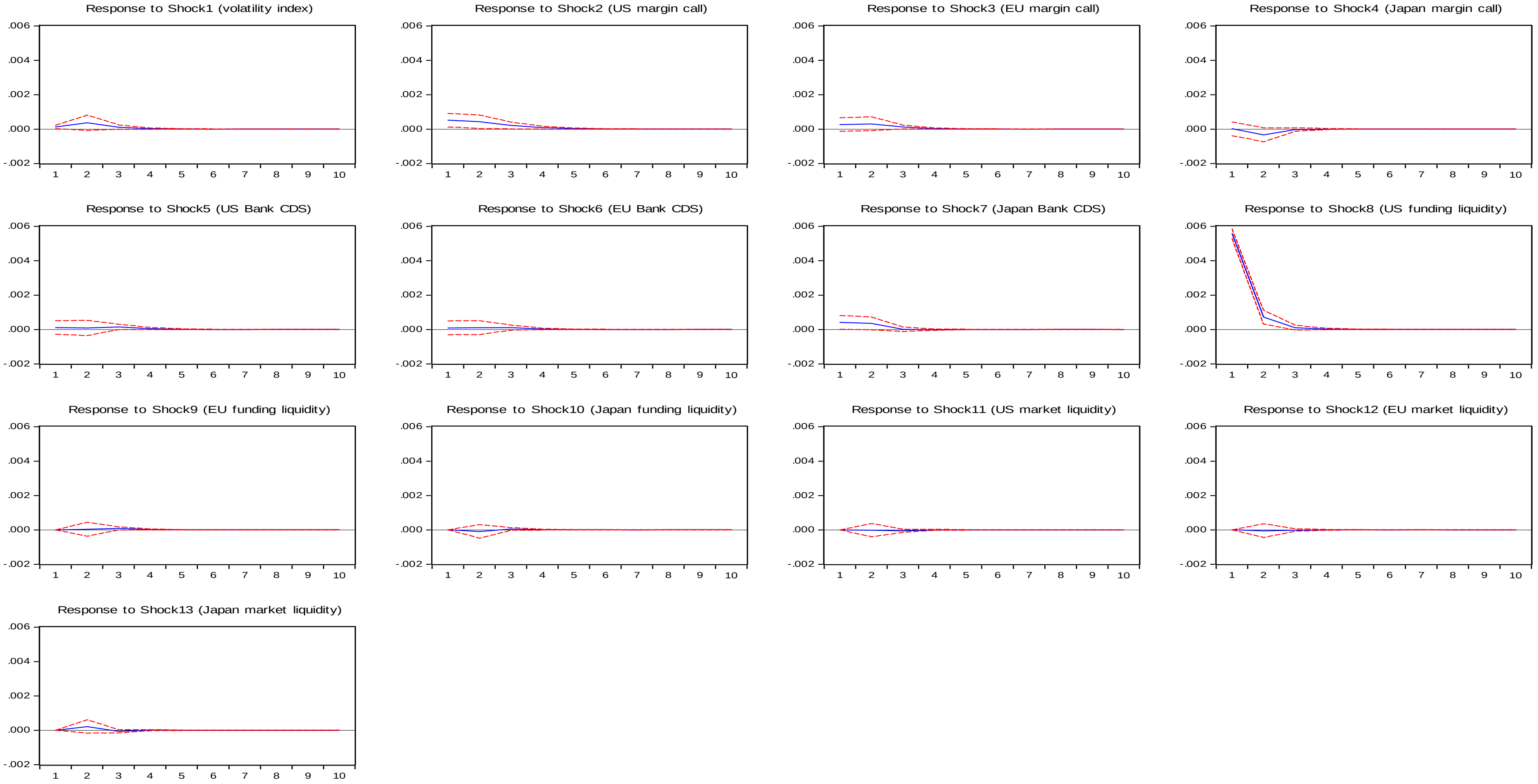
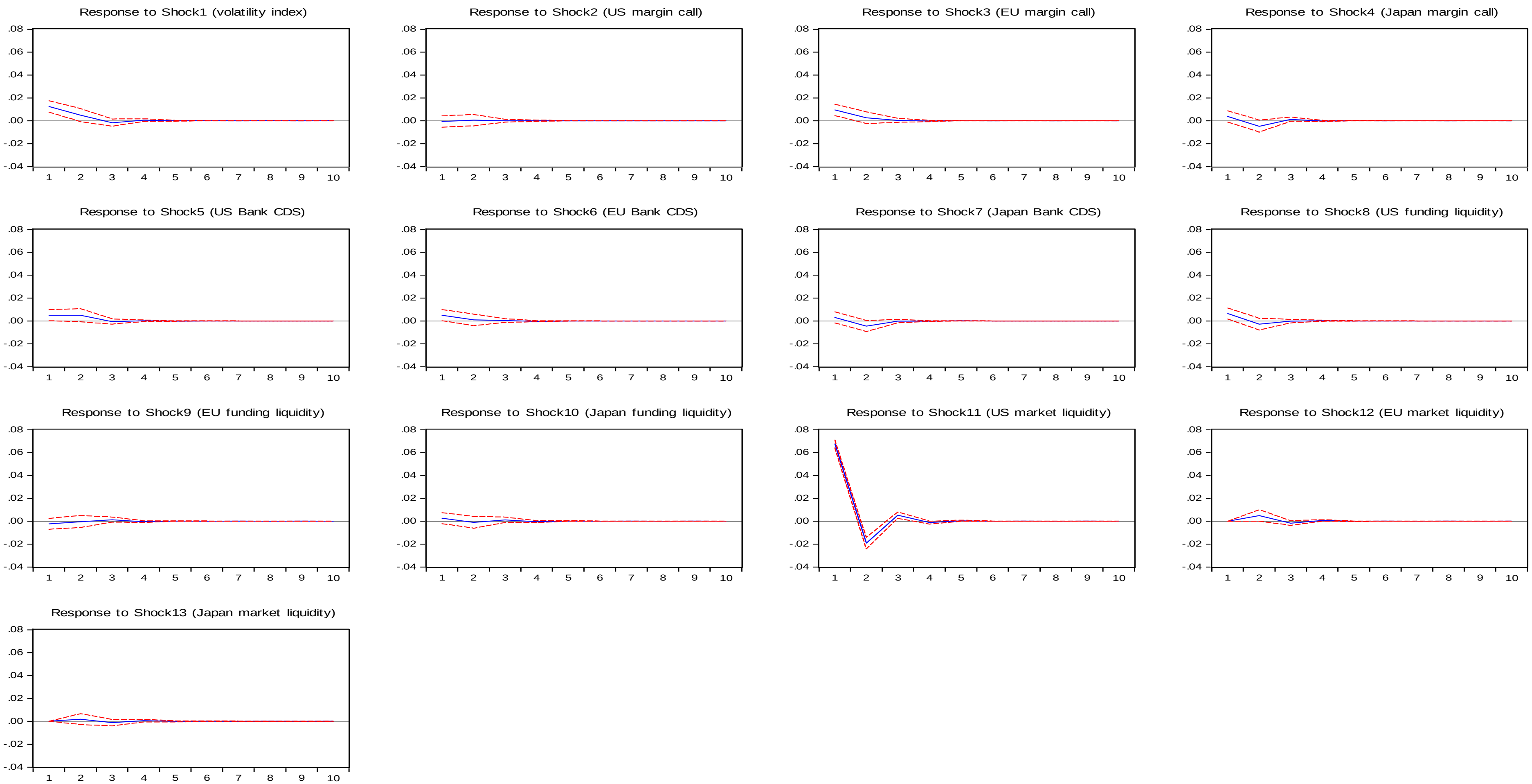


Figure 13. Impulse response functions from January 2, 2010- December 30, 2012

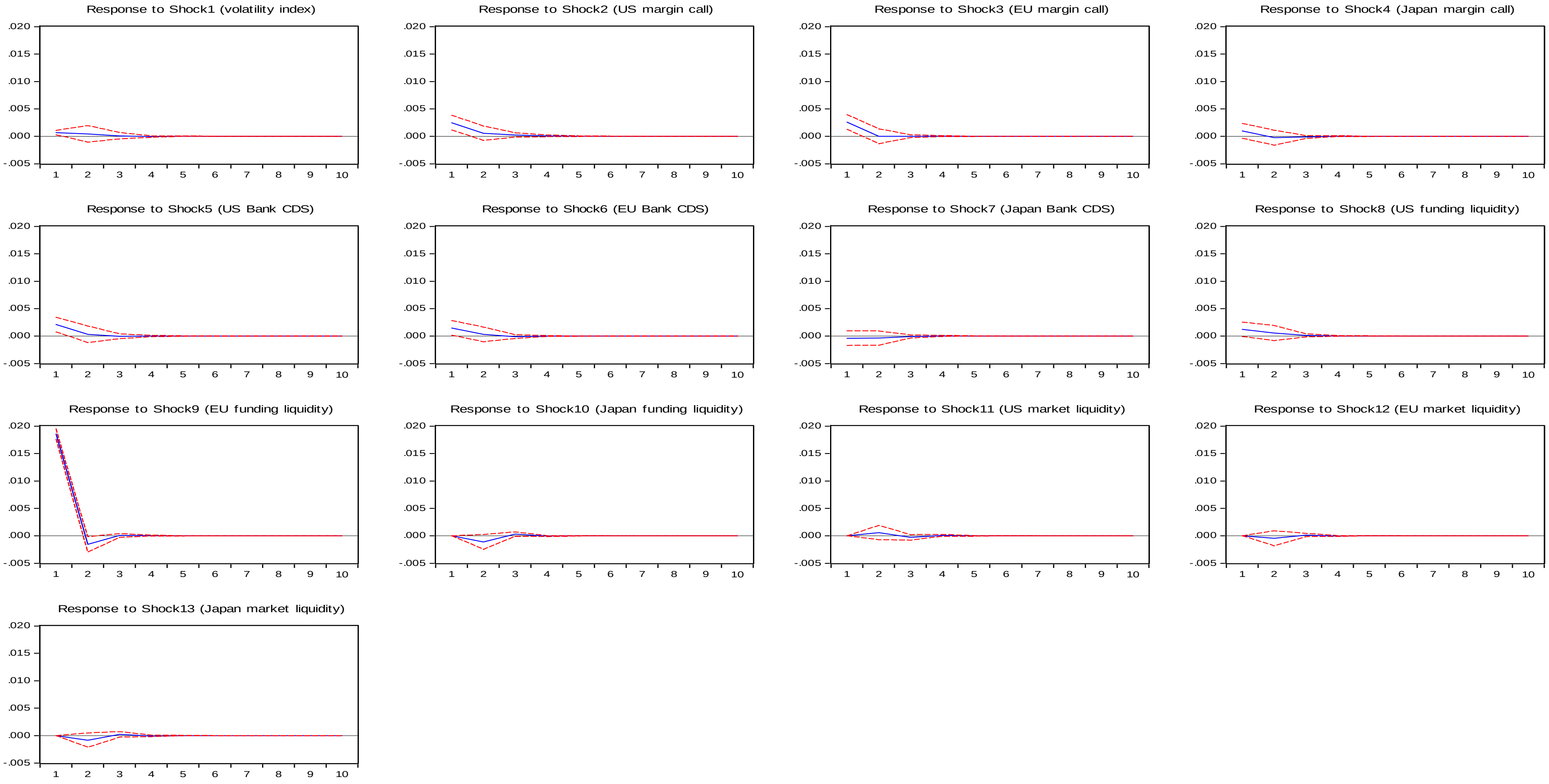
A-1. US funding liquidity



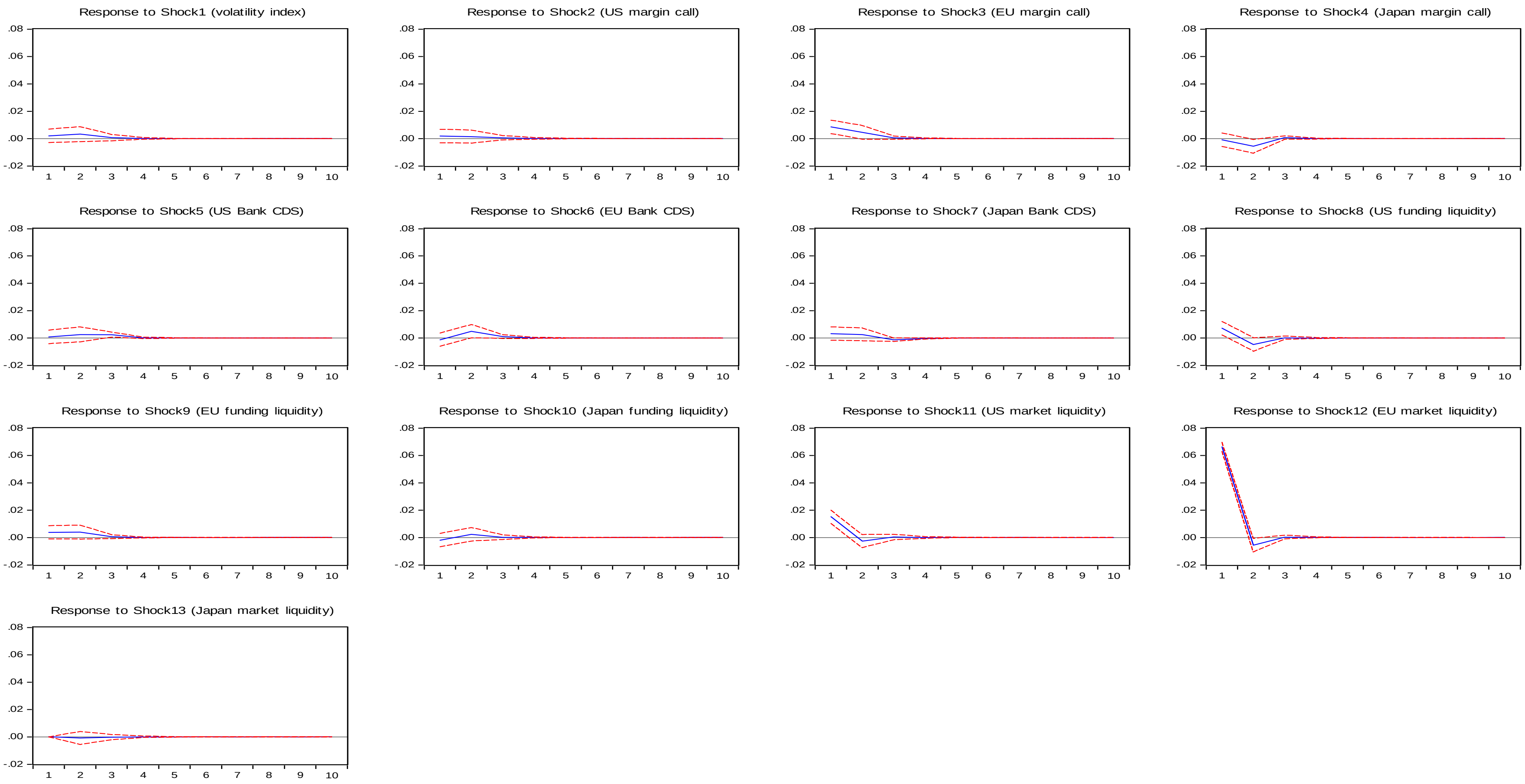
A-2. US market liquidity



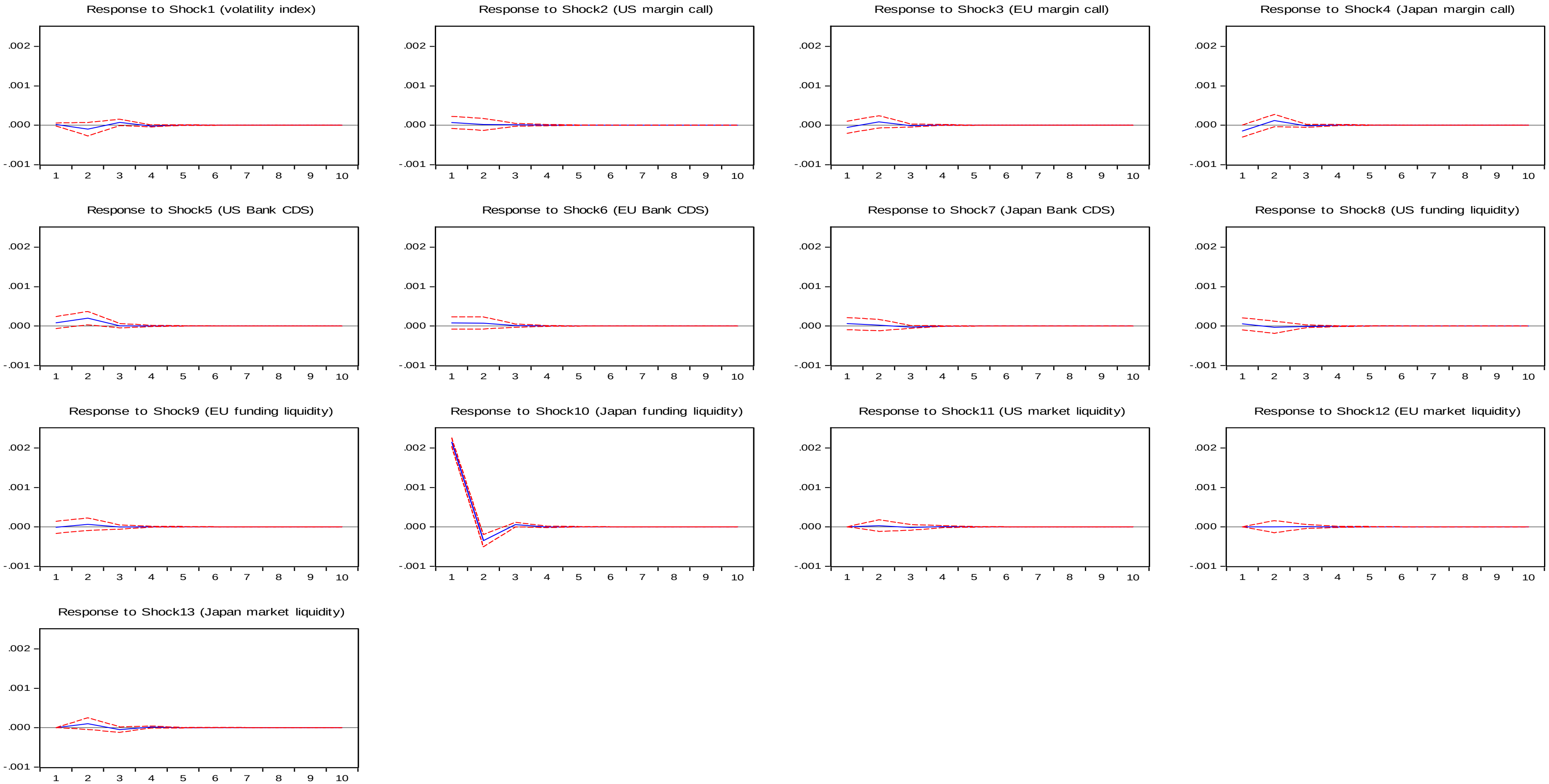
B-1. Euro area funding liquidity



B-2. Euro area market liquidity



C-1. Japan funding liquidity



C-2. Japan market liquidity