U.S. Quantitative Easing Policies: Their Effect on the Global Bond Markets

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Abstract

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Since the 2007 U.S. subprime crisis, major economies have suffered from severe recessions. Even cutting short-term interest rates to almost zero has not been enough to stimulate depressed economies. Under these circumstances, the Federal Reserve implemented an unconventional monetary easing policy in 2008; the Quantitative Easing (QE) policy. Within this U.S. QE framework, long-term U.S. assets, and in particular, long-term U.S. Treasuries, have been absorbed, with increasing reserves on the Fed's balance sheet. This policy was initially designed to tackle domestic recession problems: it significantly reduced long-term U.S. interest rates and lowered unemployment levels. Due to the U.S.'s role in global markets, these U.S. QE policy effects are certain to spill over to other markets and economies.

This study investigates the U.S. QE spillover effects on ten-year bond markets in both developed and emerging economies for the period 2007 to 2016. I apply both Structural VAR (SVAR) model and Dynamic Conditional Correlation-GARCH (DCC-GARCH) model to address the interactions among global bond markets when examining the U.S. QE spillover effects. The inclusion of both short- and long-term U.S. QE policy shocks better measures the policy shocks from each U.S. QE policy. Empirical evidence suggests a growing trend in integration levels between U.S. bond market and global bond markets during each U.S. QE period. This indicates a more substantial U.S. QE spillover effect to the global bond markets. Further, the results also reveal that long-term U.S. QE policy shocks will significantly reduce bond yields, particularly in developed markets, across all three U.S. QE periods. The results also show limited evidence which supports short-term U.S. QE spillover effects on bond yields. This means that long-term assets purchase activities will provide more long-lasting and substantial spillover effects on reducing long-term foreign bond yields. Furthermore, the results show pronounced volatility spillover effects, from both short-term and long-term U.S. QE policy shocks, although mainly on emerging bond markets. This significant U.S. QE volatility spillover effect indicates that although bond yields in emerging markets may not be subject to U.S. QE

spillover effects, as a result of less developed financial market foundations, compared to the developed bond markets, they are more vulnerable and sensitive to the exogenous monetary shocks from leading economies.

Keywords: Quantitative Easing, monetary policy shock, global bond market, spillover effect, volatility spillover, market integration, SVAR model, DCC-GARCH model

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Chapter 1

Introduction

1.1 Background

After the collapse of the Lehman Brothers in September 2008, major economies around the world faced severe recessions. The increasing needs to support aggregate demands and ease financial conditions led to a variety of monetary policy innovations to deal with this “unconventional” circumstance (Klyuev et al., 2009). Of all the unconventional monetary policies applied, the Quantitative Easing (QE) strategy seems to be the most popular method of stimulating economies. QE policy has developed over time, with various changes made since it was first invented. QE has been defined as the means through which central banks increase the market liquidity level in the economy through purchasing long-term securities with increasing reserves on central bank balance sheet (Bernanke & Reinhart, 2004; Benford et al, 2009). Blinder (2010) later concludes that through these asset purchasing programs, QE policy not only increases the size of bank’s balance sheet but also, changes the composition of the bank balance sheet as well. More specifically, securities purchased under QE programs include long-term Treasuries, agency mortgage-backed securities (MBS), and agency bonds (Krishnamurthy & Vissing-Jorgensen, 2011). The main aim of QE policy is to lower the long-term interest rates through purchasing long-term assets and therefore spur economic activity when short-term interest rates are at zero lower bound. Since the government bond markets, especially the leading government bond markets which have a large volume and are widely traded, the QE policy of purchasing domestic government bonds implemented in developed countries such as Japan, United States (U.S.), and the United Kingdom (U.K.) (see Table 1.1) are certain to have large spillover effects to other economies (De Grauwe & Ji, 2015).

Table 1-1 Quantitative Easing Programs in the U.S., U.K. and Japan

Bank Name	Policy	Start	End	Volume	Security Type
Fed (Federal Reserves)	QE1	2008	2010	$600 billion, later raised to $1.7 trillion	Agency mortgage-backed Securities (MBS), agency debt, long-term Treasuries
Fed	QE2	2010	2011	$600 billion	Long-term Treasuries
Fed	QE3	2012	2014	$40 billion monthly, then increased to $85 billion monthly	Long-term Treasuries, Mortgage-backed Securities (MBS)
BOE (Bank of England)	QE1	2009	2011	£75 billion, gradually increased to £200 billion	Medium and long-term Gilts (government bonds issued by the U.K.)
BOE	QE2	2011	2012	£75 billion	Medium and long-term Gilts
BOE	QE3	2012	2012	£50 billion then raised to £100 billion	Medium and long-term Gilts
BOJ (Bank of Japan)	QE	2001	2006	¥0.4 trillion monthly, then increased to ¥1.2 trillion monthly	Long-term JGBs (Japanese government bonds), asset-backed securities (ABS)
BOJ	CME (Comprehensive Monetary Easing)	2010	2012	¥35 trillion, gradually increased to ¥101 trillion	JGBs, commercial paper, corporate bonds, exchange-traded funds, real-estate investment trusts
BOJ	QQE (Quantitative and Qualitative Monetary Easing)	2013		¥50 trillion annually, the increased to ¥80 trillion annually	JGBs, exchange-traded funds

Source: (Bernoth et al., 2015)

1.2 QE Policies in Japan

Though unconventional monetary policies, such as the QE policy, have been widely implemented in the U.S. as well as the U.K., it is widely accepted that the first QE policy was launched in Japan. In the early 1990s, Japan suffered a persistent depression as a result of the Japanese Asset Pricing Bubble. The Bank of Japan (BOJ) implemented many conventional means, including cutting interest rates to stimulate the economy. In September 1995, the BOJ started to cut the overnight rate, gradually reduced it from 6% to 0.5%; a rate which remained in place until September 1998. Apart from several transient recovery periods, the economy deteriorated again in 1998. Finally, in February

1999, the BOJ successively lowered the overnight rate to the zero lower bound (Girardin & Moussa, 2011). According to Keynesian economics (1936), once the short-term interest rate is either at, or close to, zero, the economy slips into the “liquidity trap;” in other words, the common open market option can no longer lower the interest rate, hence conventional monetary policies cease to be effective (Krugman et al., 1998). New policies must be created in order to resolve these circumstances; these policies have become known as unconventional monetary policies. The BOJ first launched the Zero Interest Rate Policy (ZIRP) during the period of April 1999 to August 2000. This policy generated some expected results, with the economy recovering and prices stabilising in 2000. However, the economy fell into a further depression with the cessation of the ZIRP in 2001. These policies are thus ineffective unless they are continued on a long-term basis. In this case, the BOJ had to implement more aggressive monetary easing policies to further stimulate the economy. Hence, in March 2001, the BOJ announced the QE policy and began purchasing Japanese Government Bonds (JGBs) (Ugai, 2007). The BOJ decided to terminate the QE policy and stop buying government bonds five years later, in March 2006, when the key inflation rate rose and was expected to remain positive for the foreseeable future. The Japanese QE1 policy achieved great results. The QE policy provided ample liquidity to the domestic economy and stabilised the domestic financial system, while simultaneously fulfilling the rising liquidity demands of financial institutions. The Japanese QE policy commitment to continue zero interest rates,created a perfect environment which allowed economic recovery (Shirai, 2014).

In 2010, after the 2007 U.S. subprime loan crisis and the resulting global financial crisis, the BOJ reintroduced the Comprehensive Monetary Easing (CME) programs in response to persistent economic deflation (Berkmen, 2012). This CME program, announced in October 2010, consisted of purchasing government securities and corporate bonds to the value of 35 trillion yen. This was gradually expanded to 101 trillion yen in December 2012. The CME program also included other liquidity-stimulating components such as equity investments, asset-based lending, and U.S. dollar lending arrangements to support economic growth. A key goal of the CME program was to establish price stability in the medium and long term, or more precisely, to achieve a 2% inflation rate (Ugai, 2015).However, this goal has not been achieved.

After Shinzo Abe became the Prime Minister in December 2012, the Japanese government established a new policy package to end long-term deflation and restore sustained growth, named “Abenomics.” It included three main “arrows” (components): easy monetary policy, structural reforms for growth, and “flexible” fiscal policy. Under Abenomics, the BOJ launched their new monetary policy framework in April 2013; the so-called Quantitative and Qualitative Easing (QQE)

(Fukuda, 2014; Ho, 2015). The government's commitment to achieve its 2% inflation target (already stated in CME) was renewed in January 2013 and was expected to remain in force for two years. The BOJ noted however, that the QQE would remain in force for longer than this it was necessary to maintain the price stability target. The BOJ planned to double the monetary base in two years, increasing it by ¥60 trillion to ¥70 trillion in a year. The BOJ expanded its Japanese government bond (JGB) purchase programs to approximately ¥50 trillion annually across all maturities. It also doubled its exchange-traded fund (EFT) purchases and Japan real estate investment trusts (J-REIT) (Kawai, 2015).

Although the QQE policy managed to increase the inflation rate (to about 1%), it is still far from the expected 2%. As a result, in October 2014, the BOJ announced it was expanding the current QQE program (also termed as QQE2) (Coy, 2014).The QQE2 program would increase the monetary base from ¥60-70 trillion set within the QQE annually to ¥80 trillion. The asset size of BOJ, together with the monetary base, would increase to approximately 80% of the GDP. The BOJ decided to increase the Japanese Government Bonds (JGBs) purchases (from 50 trillion to 80 trillion yen) and extend their maturities (to 7-10 years). At the same time, the BOJ tripled its exchange-traded fund purchases (ETF) and Japan real estate investment trusts (J-REIT) (expanded from ¥1 trillion to ¥3 trillion, and from ¥30 billion to ¥90 billion, respectively). One of QQE policy's main purposes was to transform the inflationary mindset. The BOJ was almost the only buyer of JGBs in the secondary markets (Ugai, 2015). Therefore, the next step for the BOJ and Japanese government is to deal with many JGB related issues, including the management of public debt, and the BOJ's balance sheets.

1.3 QE Policies in the U.S.

In 2007, with the subprime crisis, the U.S. faced its worst recession since 1937-1938 (Blinder, 2010). As with the Japanese situation, even with short-term market interest rates reduced to almost zero, the economy failed to revive; conventional methods of stimulating the economy proved largely unsuccessful. The Federal Reserve (Fed) thus launched a series of unconventional monetary policies (including QE policy) to stimulate the depressed economy; it lowered long-term interest rates (Krishnamurthy & Vissing-Jorgensen, 2011). Before the recession, the Fed held around $700 to $800 billion of Treasury notes on its balance sheet. However, after the implementation of the U.S. QE1 policy in late 2008, it gradually accumulated $600 billion of long-term securities, including Treasuries, agency bonds and agency mortgage-backed securities (MBS). These bonds peaked at $2.1 trillion in June 2010. This first round of U.S. QE policy has since been named the U.S. "QE1".

As the recovery of the economy faltered in November 2010, the Fed issued a new quantitative easing policy (QE2),which involved gradually purchasing $600 billion of long-term Treasuries by the end of the second quarter of 2011 (Censky, 2010). On the 21st of September 2011, the Fed issued their new maturity extension policy (MEP). This policy stated that by the end of June 2012, the Fed would purchase $400 billion of Treasuries, with maturities varying from six to thirty years. At the same time, the Fed also sold roughly the same amount of Treasuries with maturities between three months to three years. In other words, without changing the total assets scale, the Fed exchanged short term Treasuries with long-term securities (Meaning & Zhu, 2011).

On 13 September 2012, the Fed annnounced another quantitative easing policy (QE3). The Fed implemented a new, open-ended bond purchasing program of $40 billion on a monthly basis. This was seen as an effective means through which the Fed could reduce $40 billion per month of commercial housing debts (Jansen, 2012). On 12 December, the Fed raised the assets purchasing scale from $40 billion to $85 billion per month. Owing to continued positive economic data, on the 19th of June, 2013, the Fed Chairman Bernanke announced that the Fed would reduce its bond purchasing scale from $85 billion to $65 billion monthly. He also indicated the possibility of exiting the current QE policy by mid-2014. He mentioned that the Fed might consider increasing short-term interest rates when the inflation rate reaches 2% and the unemployment rate declines to 6.5%. The stock markets instantly dropped in response to these signals, with a 4.3% decrease three days after Bernanke's announcement. The Dow Jones declined 659 points between the 19th and 24th of June, closing at 14,660 on the 24th of June (Walsh, 2013). Finally, on the 29th of October 2014, the U.S. QE3 policy was discontinued having added $4.1 trillion of securities to the Fed’s balance sheet.

1.4 QE Policies in the U.K.

In addition to the BOJ and Fed, the Bank of England (BOE) also issued their own unconventional monetary policies to curb the recession. The BOE cut interest rates sharply, from 5% in early 2008 to 0.5% in March 2009. Unlike its counterparts, the BOE judged that it would be unrealistic to achieve the 2% target inflation rate without aditional policies (other than the typical way of cutting short-term nominal interest rates). Thus, the BOE established a new program whereby they made large-scale purchases of both public and private assets in March 2009. They announced the gradual purchase of £200 billion of medium and long-term government bonds (gilts), which accounted for roughly one third of the free-floated gilts. These gilts were valued at approximately 14% of the nominal GDP. This became known as the U.K. QE1 policy, and was accomplished by January 2010 (Joyce et al., 2011).Most of the gilts purchased were bonds with maturities varying from 5 to 25 years. By the end of the U.K. QE1 period, 40% of the outstanding gilts with under 10 year maturities were purchased, half of the free-floated gilts with 10 to 25-year maturities and 15% of gilts with longer-term (over 25 years) maturities were also purchased. In addition to the various gilts purchased under the U.K. QE1 policy, the BOE also purchased other securities including commercial paper and corporate bonds; however, these securities were purchased in much smaller quantities and were sold again by December 2009 (Steeley, 2015). All in all, the U.K. QE1 policy expanded the size of the BOE's balance sheet by threefold compared to the pre-crisis period (Fawley & Neely, 2013).

In response to the euro sovereign crisis, and to meet its 2% target inflation rate, the BOE expanded the U.K. QE1 policy with further purchases of £75 billion in October 2011 (Churm et al., 2015). In February 2012, the BOE expanded their assets purchase scale to £50 billion; these purchases were finalised in early May 2012. This was yet another quantitative easing program (the U.K. QE2 policy) (Steeley & Matyushkin, 2015). Two-month later, in July 2012, the BOE extended the U.K. QE2 policy with another £50 billion gilts purchasing program (the U.K. QE3 policy), which raised the total assets purchase ceiling to £375 billion gilts (Bernoth et al., 2015). In September 2015, the BOE announced that it would maintain the short-term interest rate at 0.5% (set during the U.K. QE1 period) and would also keep the same scale of assets purchase (£375 billion) decided in July 2012 (Lea, 2015).

1.5 QE Policies in the Euro Zone

When the global financial crisis impacted the countries in the European Union, the European Central Bank (ECB) reacted differently, using more conventional methods, including interest rate cuts. It adopted unconventional measures much later than the U.S. Differences between ECB's and Fed's monetary policies could be explained by the different characteristics of the potency (Ferreira, 2015). Unlike other markets which have control over their domestic currencies, the European Union does not. It consists of 28-country economies and political partnerships only 19 of the countries share a common currency (Euro). All of the member countries must approve political or economic measures. Therefore, the ECB experienced significant difficulty in adopting QE policies to revive the economy. In relation to the ECB's government bonds purchase policies, German government and economists argued that there must be a balance of both monetary and fiscal policy to manage credit default risks in some EU member countries. However, some researchers (De Grauwe & Ji, 2015; De Groen, 2015) believed that it was possible for the ECB to implement QE policies without creating future risks, but only if the interest paid by the governments to the ECB were refunded. More specifically, when some member countries stopped paying interests on the bonds held by the ECB, the ECB could stop paying interest to the defaulting government. Hence, the ECB would only pay interests to non-defaulting member countries.

On the 22nd of January 2015, the ECB announced its first QE program of repurchasing private and public debts, including government bonds that amounted to between 1,100 and 1,600 billion euro by the end of 2016, or 60 billion euro per month (Rey & Mazur, 2015). They stated that policy may continue for a longer period until the target inflation rate is achieved. The ECB QE policy purchased sovereign bonds as well as investment-rated corporate bonds. There were some special conditions imposed on some of the bonds, where issuing countries are under reform programs (such as Greece). The ratio of bonds purchased was decided using the capital key (the GDP weights). The risk-sharing mechanism designed in the ECB QE policy only covered 20% of the total losses by using the captial key, while the rest (80% losses induced by the ECB QE policy) were to be borne by the national central banks (Watt, 2015). Roberto (2016) argued that the ECB QE policy would directly influence the cost of public debt, which creates inflation and depreciates the real cost of debt at the same time.

1.6 Consensus of QE

There are several commonalities across countries relating to the implementation and effect of QE policies. Unconventional monetary policies, like the QE policy, signifcantly lowered long-term asset yields, not only domestically, but also internationally, though mainly in other developed markets (Roberto, 2016). This, in turn, had a positive impact on the long-term interest rates by decreasing them, generating extra liqudity and promoting economic recovery. This process has been documented in previous research. For example, Bernanke et al. (2004) found that both changes to relative asset quantities and changes in market expectations about the related assets can affect asset returns. Similarly, Gagnon et al., (2011); He et al. (2010) and Joyce et al. (2012) found that the Fed's purchase of long-term Treasuries and mortgage-backed securities significantly lowered nominal interest rates on Treasuries, corporate bonds, and mortgage-backed securities during the early U.S. QE phases (U.S. QE1 and QE2 periods). In terms of Japan, Ugai (2007) concluded that the government bonds generated lower yields over the Japanese QE period. Likewise, Meier (2009) discovered that long-term gilt yields declined following the initial U.K. QE announcement in March 2009.

In addition to the impact of QE policies in domestic markets, previous research has also determined that the implementation of unconventional monetary policies in advanced countries (especially in the U.S.) not only impacted on developed markets but also emerging ones. For instance, Bredin et al. (2010) found evidence of significant U.S. spillover effects in both Germany and the U.K. bond markets. Dahlhaus et al. (2014) found that U.S. QE significantly increased Canadian GDP and import demands. Fic (2013) concluded that QE policies launched by leading economies (that is, the U.S., U.K., Japan and Euro Zone) affected long-term yields, equity prices, and exchange rates in both developed and developing economies. Kim and Nguyen (2009) also revealed that unexpected U.S. QE announcements may have led to negative responses in Asian-Pacific stock markets. Moreover, Bhattarai et al. (2015) found that the U.S. QE policy induced the appreciation of domestic currencies in emerging markets against the U.S. dollar, growth in emerging stock prices, as well as the capital inflows to emerging markets. Furthermore, Rogers et al (2014) determined that the U.S. QE spillover effects on other developed markets were larger than the spillover effects on the U.S. markets from the QE policies of other advanced economies (such as the U.K. and Japan).

QE policies not only affected market returns, but also market volatility. The U.S. QE policies had an even more noticeable impact than most. Li & Giles (2015) compared the U.S. and Japanese QE volatility spillover effects on emerging markets. They found that the U.S. QE volatility spillover effects were more pronounced than those of the Japanese market on the emerging markets they sampled. Mukherjee & Bhaduri (2016) found a pronounced increase of volatility in the Brazil, Russia, India, China and South Africa (BRICS) markets during the U.S. QE periods. However, the authors noted that these volatility spillover effects gradually disappeared as a result of market adjustments or stricter regulations in these markets. Ghosh & Saggar (2016) examined the U.S. QE volatility spillover effects on the BRICS markets and some other emerging markets during the tapering talk period. The authors noticed a contemporaneous volatility covariance between the U.S. markets and other emerging markets, both for equities and government securities. Yang & Zhou's study (2016) concluded that the U.S. QE policy was the primary driver for intensifying volatility spillover effects in global stock markets and could explain roughly half of the variations of spillover effects.

A key belief of scholarship is that only unanticipated changes in the target rate affect financial markets, especially stock markets, whereas anticipated changes do not. This finding is consistent with the Efficient Market Hypothesis (EMH). The semi-strong-form efficiency hypothesis states that stock prices can rapidly respond to the latest public information. Thus, there are no excess returns by trading on that information. Meanwhile, the EMH theory also highlights a negative correlation between unanticipated changes of the target rate and stock returns. In other words, an unanticipated increase of the target rate leads to negative stock returns and vice versa (Chuliá et al., 2010). In this scenario, market volatilities tend to increase in response to unanticipated policy changes. For example, Gospodinov and Jamali (2012) found that stock volatilities could significantly and positively increase after the Fed funds rate surprises, while there was no significant response to the expected target rate change. Kishor and Marfatia (2013) showed a significant and dynamic response from the global equity markets (36 leading equity markets including the U.S.) towards the

U.S. monetary policy surprises. However, the situation was slightly different in the bond markets. Bredin et al. (2010) found no statistically significant impact from a U.S. monetary policy surprise on the three chosen markets' (the U.S., U.K., and Germany) excess bond returns. Thus, although the unexpected U.S. policy changes were found to influence global stock markets, there was still a gap on international bond markets.

1.7 Research Problem

The current study examines the spillover effects of the U.S. QE policies on the global bond markets following the 2008 global financial crisis, in particular, from both bond yield and volatility perspectives. Meanwhile, there is also study on the market integration changes among the global bond markets. The results of this study enhances the understanding of bond market interactions during the crisis period and provides information for policy makers as well as investors about the international political corporation and investment decision making in especially international bond markets.

1.8 Research Objectives

a. To investigate changes in the level of market integration in global bond markets during the U.S. QE phases.

b. To investigate spillover effects of the U.S. QE policy shocks on the global bond yields.

c. To examine U.S. QE volatility spillover effects on the global bond markets.

1.9 Research Contribution

Previous studies have analyzed the impact of the U.S. QE policies (focusing primarily on U.S. QE1 and QE2 policies) on the financial markets (mainly stock markets) or on real economies. However, few studies have focused on the global bond markets and even fewer cover the U.S. QE3 period. Moreover, previous studies apply either the event study approach or the time-series models. Only a few have included the exogenous U.S. monetary policy shocks into these models. This is the first study that attempts to assess the cumulative U.S. QE spillover effects from both bond yield and volatility perspectives on global bond markets for the entire U.S. QE period (covering all three U.S. QE policies).Exogenous U.S. QE policy shocks will be calculated independently from the models and distinguished in each U.S. QE phase.

This research expands scholarship on the U.S. QE spillover effects on global bond markets from both the yield (return) and volatility perspectives. In order to achieve these objectives, in this study, both

DCC-(T) GARCH and SVAR models are applied. Additionally, unlike most previous studies, which do not distinguish between U.S. QE policy shocks, here I define both the short-term and long-term exogenous U.S. QE policy shocks from three different U.S. QE phases. The results of our study will bridge the gap in the literature by identifying the (volatility) spillover effects of the U.S. QE policies on different bond markets and assist researchers and investors to better understand the market responses and movements resulting from uncoventional monetary policies like the QE policies.

1.10 Structure of the Thesis

The thesis is divided into five chapters. Chapter One introduces the research problem and objectives, identifies the significance of the study and provides background information about specific quantitative easing policies. Chapter Two reviews relevant literature relating to QE effects. Chapter Three outlines the research methodology and the data used in this study. Chapter Four reports and discusses empirical results in relation to each specific research objective. Chapter Five summarizes the study's major findings, proposes policy implications, highlights limitation of the research and provides recommendations for future studies. Ultimately this study argues that during U.S. QE period, the level of market integration in the international bond markets significantly improves. This explains the pronounced spillover effects from especially the long-term U.S. QE shocks on decreasing bond yields in developed markets and increasing bond yield volatilities in emerging markets. These results suggest an increasing need in cross-market policy coordination with leading economies for policy makers and a higher requirements for risk management in investing in emerging market assets for market participants.

Chapter 2

Literature Review

2.1 Introduction

Having introduced the details of QE policies adopted in developed markets (the U.S., U.K., Japan and Euro Zone) in the previous chapter, this chapter reviews literature about the formation and development of the U.S. Quantitative Easing Policies. It also examines some recent empirical research that investigates both the domestic impact and international spillover effects triggered by U.S. QE policies. The literature about U.S. QE spillover effects is discussed from both return and volatility perspectives. Thus, this chapter reviews several strands of literature relating to the implementation and effect of these policies. More specifically, the chapter explores the rationale for the shift from conventional to more unconventional monetary policies under liquidity trap. Next, the chapter details the transmission channels through which QE policy may affect both the domestic and international financial markets. Besides the literature which is concluded on the domestic impacts of QE programs, this chapter discusses the theoretical basis of monetary spillover effects on other countries. Then this chapter reviews the empirical methods used to estimate the QE impact upon financial variables and the change of market integration level and the spillover effects. The chapter also outlines the spillover effects of U.S. QE policy on different bond yields as well as the volatility spillover effect of U.S. QE policy across markets. The chapter ends with a brief summary of the literature.

2.2 Development of Quantitative Easing

Post 2000, conventional monetary policy has become increasingly unsuitable, especially in the wake of rapidly falling short-term interest rates in major economies. According to the classical economic theory, monetary policy tools cease to be effective when short-term interest rate reach zero lower bound, with no room for further decreases (Krugman et al., 1998). In such circumstances, investors are unwilling to invest in the financial markets, regardless of liquidity rates .The possibility of alienating investors, however, does not seem to deter most central banks from modifying their interest rates. When short-term interest rates led to a liquidity trap, central banks simply adjust long-term interest rates so as to inject extra liquidity into the depressed economy. Hence, central banks purchase long-term government bonds in order to reduce long-term interest rates. It is for these reasons that unconventional monetary policies, such as the QE policy, were developed to spur major economies in the wake of almost certain financial collapse post 2000.

2.2.1 Conventional Monetary Policies

Monetary policy has been a key topic of academic discussion since the 1990s. At that time, the main focus was on examining and quantifying the effects and transmission channels of monetary policies launched worldwide (Bernanke & Blinder, 1992; Mishkin, 1996). More recently, with the subprime loan crisis in 2007, there has been a notable increase in research that addresses monetary policies, with the introduction and implementation of various unconventional monetary policies (Baltensperger et al., 2007; Bernanke, 2012). Some researchers conclude that monetary policy typically has two aims (Borio, 1997; Disyatat, 2008; Borio & Nelson, 2008). The first goal is to signal future policy stances or more specifically, interest rate changes over time, which refers to interest rate policy. The second relates to the central bank's balance sheet and how they can achieve this goal, what is commonly known as balance sheet policy (Borio & Disyatat, 2010). As these methods are used to manage central bank reserves they are referred to as "liquidity management operations."

2.2.1.1 Conventional Monetary Policy

During periods of financial stability (such as before the 2007 subprime loan crisis), monetary policy generally focused on short-term interest rates and used "interest rate policy," or conventional monetary policy. This approach provides information to the markets and is the domain of most central banks. Using this approach, central banks set an overnight interest target in the interbank money market through signalling the desired policy rate (Bruno, 2015).

In order to maintain price stability, central banks can lower policy rates during economic downturns and increase it during economic upturns. The key interest rate can affect the real economy through different channels. Figure 2.1 shows how conventional monetary policy influences the real economy and markets through five different transmission channels: interest rate channel, wealth channel, balance sheet channel, credit channel and exchange rate channel (Bruno, 2015).

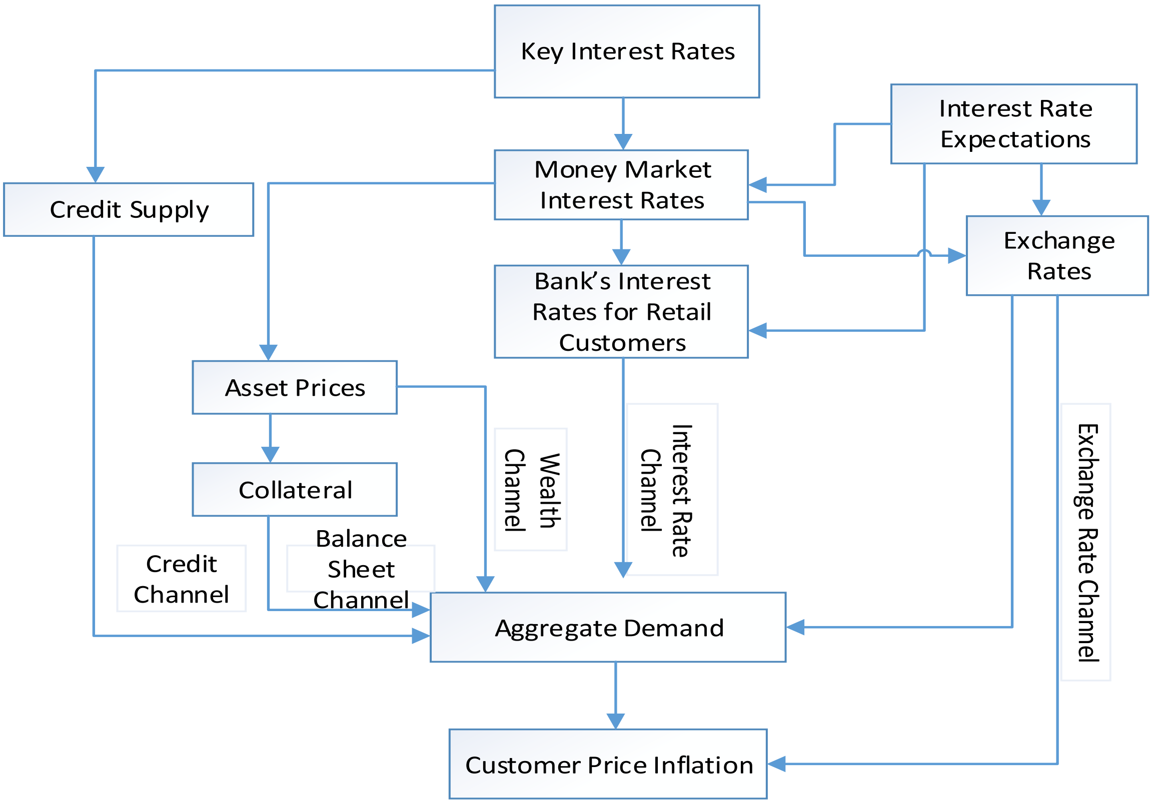

Figure 2-1 Conventional Monetary Policy Transmission Channels

Source: https://www.oenb.at/en/Monetary-Policy/How-Monetary-Policy-Works.html

2.2.1.2 Conventional Monetary Policy Transmission Channels

The interest rate channel is the primary means through which conventional monetary policy works (Kuttner & Mosser, 2002). Any increase in key interest rates trigger an increase in short-term interest rates through this channel. This, in turn, increases savings, lowers consumption and investments. When the central bank reduces key interest rates, short-term interest rates also decrease. Therefore, real interest rates and the cost of capital falls, leading to reduced savings and higher investment, boosting aggregate demand and likewise inflation.

In the life-cycle model (Ando & Modigliani, 1963), household wealth is a core factor of consumption. The wealth channel affects the price of both securities such as stocks and bonds, and real estate via interest rates. Falling interest rates, due to policy changes, can increase the value of these assets (Kuttner & Mosser, 2002). For example, once the central bank lowers key interest rates, stock prices increase, since investors discount future dividends with a lower interest rate. Real estate prices increase because mortgages are cheaper, thus increasing demand for housing. Growing real estate and stock prices increase householders' wealth as well as shareholders', leading to higher consumption and therefore, to increasing aggregate demand and inflation.

The balance sheet channel measures the role of collateral of the central bank's assets. In a similar process to the wealth channel, when the central bank decreases key interest rates, asset prices increase, which leads to a growth in net assets in the balance sheet. Therefore, the value of collateral on loans increases, thereby increasing lending and investment spending, hence aggregate demand and inflation. Meanwhile, the changes of the balance sheet's size also related to the effects of another channel, the credit channel (Bruno, 2015).

The credit channel refers to the impact of key interest rate on the credit supply. When the central bank lowers key interest rates, banks pay lower interest rates on households' deposits and their balance sheet improves as well. Since banks can refinance themselves more easily, they tend to finance more loans and thus, increase the credit supply. Consequently, central bank credit easing leads to more investment, consumption and higher inflation (Mishkin, 1996).

The exchange rate channel represents the impact of changing interest rates on the exchanging of domestic currency with foreign currencies. When domestic interest rates decrease, domestic assets become less attractive than foreign assets, which leads to a decline in the value of domestic assets compared to foreign assets. This decline in the value of domestic assets indicates a depreciation of the domestic currency. The depreciation of the domestic currency makes domestic products cheaper than the foreign products, thereby resulting in increasing net exports as well as in aggregate output (Mishkin, 1995). This channel relies upon the openness of the domestic economy; the more open it is, the more this channel affects the economy. Transmission via the exchange rate channel directly affects inflation (Bruno, 2015).

2.2.2 Liquidity Trap

Modifying short-term interest rates is the most efficient means through which central banks can influence the real economy during non-crisis periods. Increasing key interest rates can cool an overheated economy (Bruno, 2015). During economic downturns or recession periods, central banks can lower key interest rates to low levels (even to almost zero) to stimulate depressed economies. If the central bank fails to boost the aggregate demand and inflation in this situation (when the short-term nominal interest rate is close to zero) , the real economy falls into what is called the "Zero Lower Bound" (ZLB) (Bruno, 2015). In ZLB, cutting short-term interest rates cease to be effective, since the short-term nominal interest rate cannot drop any lower (below zero percent). This causes a "liquidity trap," originally defined by Keynes (1936) as a situation in which economic agents prefer holding cash instead of borrowing money at a very low interest rate, hence pushing down investment, consumption, aggregate demand and inflation. Therefore, any injection of money into the system through conventional monetary policy will cease to be effective (Farmer, 2012). For example, following the 2007 subprime loan crisis, the Fed reduced the policy rate from 5.25 percent in July 2007 to 0.15 percent in December 2008. In order to deliver further monetary stimulus, the Fed further lowered the policy rate to -5 percent, well below its lower bound of zero (Rudebusch, 2009). Since the policy rate could not be reduced any further, conventional monetary policies (that is, through the interest channel) ceased to be effective. The Fed was thus forced to adopt unconventional policy tools (Fawley & Neely, 2013). The liquidity trap raises concerns about the credibility of the monetary policy (Krugman et al., 1998). For example, after the Japanese asset price bubble in the early 1990s, the Japanese economy struggled with a persistent depression. The BOJ gradually reduced the policy rate to zero lower bound in February 1999 (Girardin & Moussa, 2011). As there was no room for further reductions, market participants did not believe that the BOJ could sustain conventional monetary expansions (Ugai, 2007). Therefore, apart from more traditional counter-cyclical policy measures, central banks should institute unconventional monetary policies not only to ensure financial stability and spur economic growth, but also to improve economic environments beyond short-term interbank interest rates (Bean, 2012; Bruno, 2015).

2.2.3 Unconventional Monetary Policy

Compared with interest rate policies, balance sheet policies may influence broader financial environments more directly. Balance sheet policy decisions influence the economy by changing either the composition or the size of the central bank's balance sheet (Disyatat, 2008). Central banks such as the Fed, BOE and BOJ have adopted balance sheet policies to counter economic deterioration triggered by the 2008 global financial crisis. In some extreme cases, central banks may decide to change both the size and structure of their balance sheet at the same time (for example, the QQE policy in Japan) (Kawai, 2015). These measures are commonly known as "unconventional monetary policies." However, not all balance sheet policies are that unconventional. For example, foreign exchange intervention is one of the most familiar forms of balance sheet policy. This approach seeks to influence the exchange rate separately from the policy rate by either purchasing or selling a certain amount of foreign currency. It can therefore either expand or reduce the size of the central bank's balance sheet. As it can be separated from the policy rate, it can be adopted regardless of whether the policy rate is close to zero or not. In other word, in balance sheet policy, foreign exchange intervention can be exerted at both "conventional" and "unconventional" times (Borio & Disyatat, 2010).

Unconventional monetary policies fall under two broad categories: quantitative easing (QE) and credit easing (CE) policies, conventionally known as qualitative easing (Fratzscher et al., 2018). These strategies are used in response to problems which cannot be solved by many conventional theories of monetary policy. Once short-term interest rates reaches a liquidity trap and cannot decrease any further, the central bank attempts to lower long-term interest rates through absorbing an unprecedented scale of long-term securities, thus effectively enlarging the size of their balance sheet (Dahlhaus et al., 2014). The purpose of long-term assets purchase programs is to decrease long-term private borrowing rates. Long-term Treasuries are treated as benchmarks for pricing various private assets, thus decreasing long-term Treasury yields are expected to decrease the interest rates for both private securities and loans (Klyuev et al., 2009). Since late 2007, the Fed started to aggressively lower its federal funds rate target (the policy rate). This came at a time when inflation was arguably increasing (Curdia & Woodford, 2010). Core interest rates no longer matched U.S. policy rates as they typically did after August 2007. At this time, there was a dramatically spread between the London Interbank Offered Rate (LIBOR) and the Overnight Indexed Swap (OIS) Rate. This exceedingly volatile LIBOR-OIS spread on U.S. dollar was induced by the 2008 global financial crisis that triggered stress in the U.S. money markets (Ji & In, 2010). Other studies noted that banks must take the changes to this spread into account when deciding on their monetary policies (such as Taylor, 1993, 2008). In short, unconventional monetary policies, such as expanding the central bank credit intermediation, emerged as a means to boost the economy, even after short-term interest rates reaches the zero lower bound (Gertler & Karadi, 2011). Some researchers (Goodfriend, 2011; Shiratsuka, 2010) distinguish these unconventional monetary policies from QE and CE policies.

The differences between QE and CE policies have been widely discussed. King (2009) defines QE as the purchase of securities with higher liquidity, such as government bonds, to stimulate the money supply. In contrast, policies focused on improving liquidity in certain credit markets, through asset purchases, are part of CE policy. Other research suggests that QE policy is an expansion of the central bank balance sheet (especially the money base) without changing the structure of the bank's balance sheet (Goodfriend, 2011; Lenza et al., 2010; Shiratsuka, 2010). In other words, central bank asset portfolios do not alter and the share of each asset category does not change substantially, with no new assets added into the holding portfolio. On the liability side of the bank's balance sheet, the increase in monetary base is reflected in an accumulation of central bank reserves. In terms of the CE policy, the overall size of the central bank balance sheet stays unchanged, instead, central banks alter the composition of asset holdings with some unconventional assets replacing conventional ones. Ugai (2015) further notes that CE policy focuses on the central bank's asset portfolio, with risky assets purchasing, while QE policy focuses on the liability side of the central bank balance sheet through purchasing government bonds. In other words, both QE and CE policies influence the central bank balance sheet, just in different ways.

2.3 QE Policy Transmission Channels

The 2008 global financial crisis and the subsequent launch of various unconventional monetary policies in many developed countries, has meant that QE policy, especially the QE policy transmission channel, has become a hot topic in academia (Krishnamurthy & Vissing-Jorgensen, 2011; Aysun & Hepp, 2011; Bauer & Rudebusch, 2014; Dahlhaus et al., 2014; Ehlers, 2012). This is because the transmission channel explains how QE policies can affect both domestic and international markets. Benford et al. (2009) outlines several channels through which the central banks' unconventional monetary policies can affect the real economy. Purchases of securities financed by the central bank's reserves increase security prices; higher security prices lower borrowing costs, which in turn promotes investment and consumption. This practice increases asset holders' wealth and encourages them to spend their money. The announcement of large asset purchasing programs can affect the prices of both target assets and other related assets. For example, QE programs purchasing large amounts of government bonds will lower their yields and indirectly affect the company bonds at the same time. QE announcements also alter the investors' future expectations.

Joyce, Lasaosa, et al. (2011) identified five transmission channels through which QE policy may influence the real economy: signalling (macro news) channel, portfolio balancing channel, liquidity channel, bank lending channel and confidence channel (see Figure 2.2). Park and Um (2015) suggest that unconventional monetary policies such as QE policies can influence asset prices and foreign exchange rates through three of these channels (signalling channel, portfolio rebalancing channel and liquidity channel), which indicates that QE policies not only impact the domestic economy and markets, but also the international market due to the spillover effects. It is thus necessary to understand the QE transmission channels when estimating the spillover effects of QE policy.

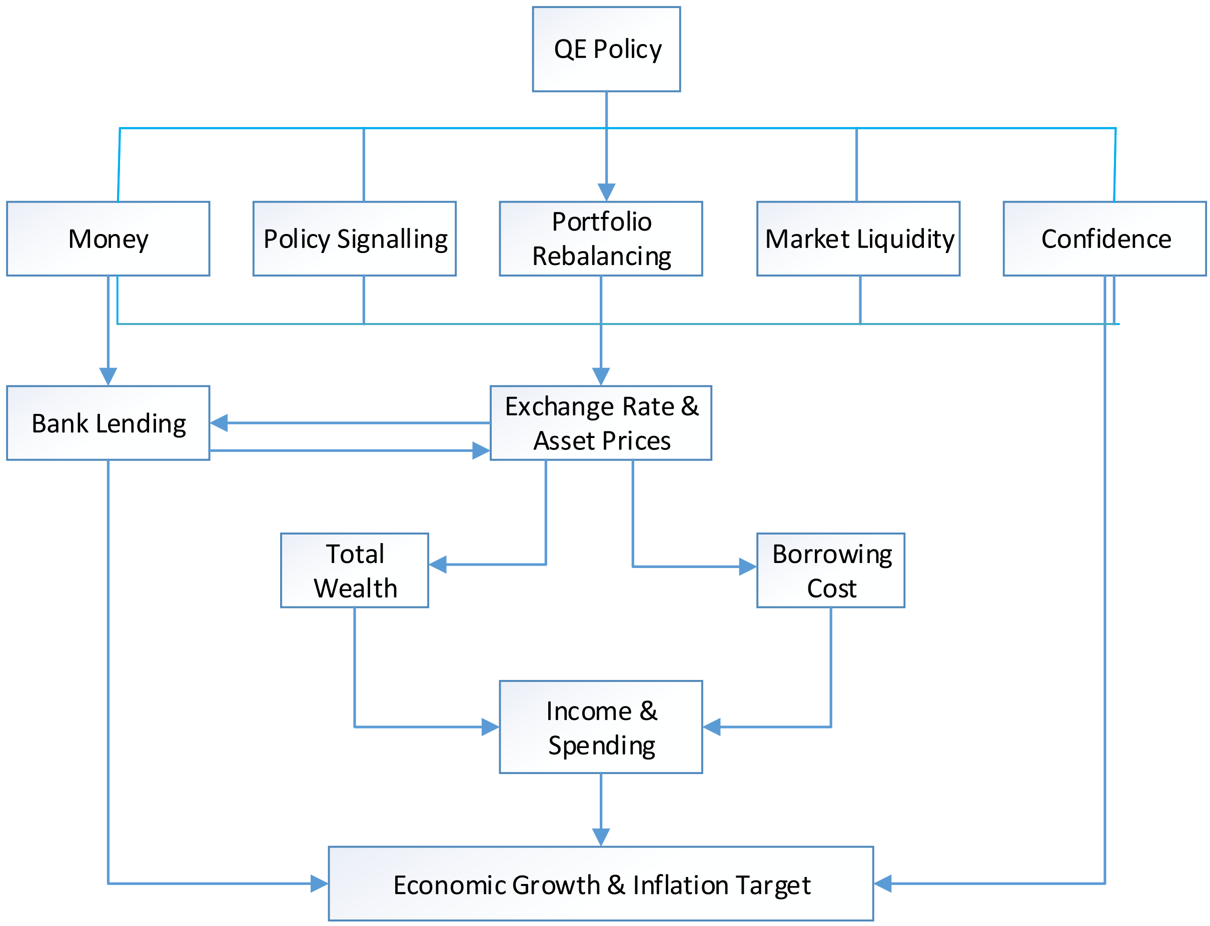

Figure 2-2 Unconventional Monetary Policy Transmission Channels

Source: Adapted from Bruno (2015); Joyce, Tong, et al. (2011)

2.3.1 Signalling Channel

QE purchase announcements convey information to market participants about the economic environments and how central banks may react to future developments. This channel can capture information about future policy rates, and thus is also known as the macro or policy news channel (Joyce, et al., 2011). QE policy is far more likely to influence the real economy than conventional monetary policy. This is because QE policy aims to alter long-term interest rates. Further, monetary policy effectiveness relates to signalling effects, especially in terms of financial indicators (such as long-term interest rates), which reflect future monetary policy expectations. The monetary policy stance should be assessed in terms of expected future monetary policy intentions rather than the current setting of short-term nominal interest rates (Andersson et al., 2006). In regards to the future of the short-term interest rate path, the information conveyed through this channel can be both direct (explicit) and indirect (implicit) (Woodford, 2012). It not only affects the bond yields, but also influences other asset prices which themselves are influenced by relevant discount rates. However, there are many debates about the impact of QE policies through this channel. Joyce, et al. (2011) found the overall impact on yields or prices are ambiguous. Typically, safe, long-term government bond yields can be decomposed into the sum of the average short-term interest rates over the maturity of the bonds (the risk-neutral rates) and the term premium. In specific, the term premium can compensate investors for the uncertainty induced by holding bonds for long period (such as uncertainty of future inflation rates). Concerns about future inflation rates are often cited as one of the reasons why investors sell their long-term bonds (Bauer & Rudebusch, 2014; Kim & Wright, 2005). QE announcements may suggest lower future rates in the short run, but can also indicate higher future inflation rates, which can mean either lower or high yields. According to Gagnon et al. (2011), the Fed does not use QE policies to signal future short-term policy rates. Hence, the U.S. QE policies may play a more important role in signalling future long-term interest rates.

2.3.2 Portfolio Balancing Channel

Research on the portfolio balancing channel[1] has been transformed since its inception, in the work of Tobin (1958) and Brunner and Meltzer (1973). Based on conventional New Keynesian theories, QE policies cannot influence broader economic environments. Eggertsson (2003) claims that there are no portfolio balance effects for QE policies since the decrease in private sector portfolio risks can be offset by a corresponding increase in the riskiness of public sector portfolios due to the uncertainty of future taxes and spending. He suggests that the cancelling out of these risks makes QE policies ineffective in the portfolio rebalancing channel. However, other studies (Andrés et al., 2004; Harrison, 2012) argue that if incomplete markets, financial frictions, and imperfect substitutes between different assets have been taken into consideration, then QE policies can influence asset prices by altering the supply and maturity structure of different securities. Bernanke (2010) contends that QE policies work primarily through the portfolio balancing channel by altering the quantity of various securities held by the public. Based on the assumption of imperfect substitutability between different assets, QE purchasing programs lead investors’ to rebalance their asset portfolios. The changes in net supply of one asset within investors’ portfolios influence their yields and other relative assets. Impacts can be felt immediately after QE policy announcements may take longer, as investors adjust their portfolios. When the central bank absorbs securities (such as long-term Treasuries), sellers’ money increases. Since money cannot be a perfect substitute for the sold securities, sellers must rebalance their portfolios through purchasing better substitute securities (Dale, 2010; Joyce, Lasaosa, et al., 2011). During this process, security prices will continue to increase

[1] Portfolio balance channel is also known as the “term premium” channel (Glick & Leduc, 2012) or the “duration” channel (Krishnamurthy & Vissing-Jorgensen, 2011).

until investors are willing to maintain the overall supplies of securities and money. Yields and borrowing costs will decrease, which in turn stimulates spending through raising asset holders' total wealth. As QE policies (especially the U.S. QE policies) purchase large scale, long-term Treasuries and other long-term risky assets, they may also reduce the term premium (the spread between long-term and short-term interest rates) and risk premium (spread between risky securities and the risk-neutral securities) through the portfolio rebalancing channel (Gagnon et al., 2010; Joyce et al., 2011).

More importantly, the U.S. QE effects can also spread to other financial markets through the portfolio rebalancing channel. Since the U.S. dollar is the dominant reserve currency in the global economy, the U.S. Treasuries play a special role in the global financial markets and cannot be perfectly substituted by other sovereign or private debt instruments (Neely, 2010). When the U.S. QE policy reduces the U.S. long-term bond yields, investors may turn to other securities (issued on the market from countries other than the U.S.) of similar maturities, for larger returns. This could stimulate security prices and decrease long-term interest rates in financial markets other than the U.S. As a result, it effectively injects more liquidity into the real economies. Therefore, owing to globalization and concomitant growing market integration level, the spillover effect from a domestic monetary easing policy in a leading economy (especially from the U.S.) is inevitable, though the size of such spillover effect may vary across markets based on the strength of cross-border transmission channels (Chen et al., 2012).

2.3.3 The Liquidity Channel

Unlike the signalling and the portfolio balance channels, which may decrease bond yields, central banks can raise the yields of some securities via the liquidity channel. When implementing QE policies, central banks purchase long-term securities in the market and pay back by increasing reserve on banks' balance sheets. The increasing liquidity level can ease banks' credit levels and allow banks to provide more loans to investors (Park & Um, 2015). Since the reserves are of higher liquidity than the long-term securities, the QE policy of increasing market liquidity levels can decrease liquidity premium on most of liquid bonds. It is widely thought that treasury bonds carry a liquidity price premium, and that liquidity premium is higher during periods of severe crisis. At these times, markets becomes more volatile and riskier. Thus, more liquid assets will be valued higher and the liquidity premium enlarges. QE policy can expand liquidity, which in turn leads to a reduction in liquidity premiums and increases Treasury yields (Krishnamurthy & Vissing-Jorgensen, 2011). According to Joyce et al. (2011), this effect can be temporary and only limited within the asset purchase periods since this channel relies heavily upon the capital flow generated by the asset purchases.

2.3.4 The Bank Lending Channel

The bank lending channel can be considered as a supplementary channel of the monetary policy. As previously stated, QE policy releases a large scale of liquidity to the banks; this means that banks can increase their levels of credit and lending (Joyce et al., 2011; Butt et al., 2014). The operation of bank lending channel relies heavily on the supply of loans and credits which banks provide. Changes in banks' loans supply also impact upon the real economy (Apergis et al., 2014). When securities are purchased from non-banking sectors, the banking sector obtains extra reserves from the central bank and a corresponding growth in the deposit sector. Although these transactions seem to contemporaneously alter deposits from non-banking sectors, Butt et al. (2014) found that these changes have limited impact on the lending sector. Furthermore, they suggest that if the QE policy of raising deposits are short-lived in any given bank, then the bank lending channel diminishes. Joyce and Spaltro (2014) also conclude that the QE policy effect in altering bank lending is limited.

2.3.5 The Confidence Channel

Higher asset prices induced by asset purchases may have broader confidence effects on financial assets (Joyce et al., 2011). It may alter investors' risk appetite and investors' portfolio decisions as well as the security prices (Fratzscher et al., 2018). For instance, U.S. QE policy announcements can be considered as a signal of deteriorating future economic conditions, as a result, it may encourage the sale of assets or trigger a flight to safety[2]. This signal can also enlarge the portfolio rebalance activities in especially international market and thus, enhancing the spillover effects of U.S. QE policies (Neely, 2010).

2.3.6 Summary

Previous literature (Park & Um, 2015) demonstrates that there are three major channels through which QE policy can affect other countries: the signalling channel, the portfolio rebalancing channel and the liquidity channel. Information regarding reducing interest rates can lead to increasing interest differential between the U.S. and other countries, therefore inducing capital flows into other countries. In turn, this process affects prices and trading volume of foreign-held securities. Owing to the imperfect substitutability between assets in various markets, the U.S. QE policy

[2] Flight to safety refers to when investors move their capital from riskier investments to 'safer' programs (Noeth & Sengupta, 2010).

absorption of U.S. Treasuries can increase investors' demand for assets in other markets, which in turn lowers the yields in other markets. The U.S. QE program exchanges U.S. Treasuries with reserves; this activity can also raise the liquidity level of the financial markets. It results in decreasing borrowing costs as well as asset returns in other markets

2.4 QE Effects at the Domestic Level

This section reviews the literature relating to the domestic impact of QE programs on both the economy and market, focusing primarily on the domestic government bond market. QE policies have been adopted in several advanced countries, but the domestic responses varies. Some of the QE programs (such as the U.S. and U.K.) have had positive responses in the economy and the markets, while there is little evidence of the impact in other countries such as Japan.

2.4.1 QE Effects on Domestic Economies

After the 2007 subprime mortgage crisis, major economies suffered serious recessions. In order to stimulate depressed economies, most central banks launched QE policies (Klyuev et al., 2009). However, the response from domestic markets varies. In terms of the Japanese QE program, there is a marginal positive response documented in the literature. Several studies (Berkmen, 2012; Fujiwara, 2006) have reported a positive, albeit insignificant change in the economic growth and key inflation rate, triggered by the Japanese QE policy. Despite the achievement of positive core consumer price index (CPI) inflation (0.5% when the first Japanese QE policy was terminated), Shiratsuka (2010) argues that the monetary easing policy had a limited impact on output and inflation. Watzka and Schenkelberg (2011) found that although long-term interest rates in Japan declined, and output increased as a result of the Japanese QE policies, the inflation target was not met. One explanation suggests that the BOJ's impaired balance sheets reduced the potential effects of the Japanese QE policy (Berkmen, 2012).

QE policies in the U.S. and U.K. had more of an impact. For example, Kapetanios et al., (2012) reported that the U.K. QE policies kept a half year and one year increase on the domestic GDP and inflation rate, respectively. In general, the U.K. QE policy raised the domestic GDP by 1.25% and the inflation rate by 1.5%. Chung et al. (2012) claimed that the U.S. QE policy reduced the deterioration in the labour market and the deflation in the economy. U.S. QE policies also promoted the real GDP level, prevented deflation and reduced the unemployment rate (Chung et al., 2012). Lenza et al. (2010) provided evidence that the European Central Bank's (ECB) QE policies successfully reduced dysfunction in financial markets, while also promoting economic output. Furthermore, it has been suggested that the ECB QE policies also promoted the inflation rates although with a lag.

Using a counterfactual scenario analysis, Baumeister and Benati (2010) explored the macroeconomic effects of lowering the long-term bond yields for the U.S., U.K., Euro and Japan during the 2007 – 2009 recession period. They found that the shrink in long-term yield spreads significant impacted on output growth and inflation rates for all of the sample economies. Their counterfactual simulation results also indicated that both the U.S. and U.K. QE polices managed to reduce the risk of deflation and collapse in the economic output which occurred during the recession. In short, the U.S. and U.K. QE policies were superior to the Japanese QE policy in recovering their economies. However, other researchers such as Martin and Milas (2012) contend that since QE policies have been implemented alongside other policies such as fiscal policy which also affect the real economy, it is impossible to assess the impact of QE policies alone.

2.4.2 QE Effects on Domestic Bond Markets

QE policies effects on the real economy, tend to be indirect. However, when it comes to the domestic government bond markets, these effects are more direct (D'Amico & King, 2013; Joyce, Lasaosa, et al., 2011; Shirai, 2014) (see Figure 2.3).

The U.S. QE policies have significantly enlarged the size of the Fed's balance sheet and fuelled one of the longest bull markets in American history. The Standard & Poor's 500-stock index rose 131% since U.S. QE1 policy was instituted in November 2008 (Lu & Jennifer, 2015). The Fed's balance sheet expanded significantly during the U.S. QE periods (Michel & Moore, 2014), from $850 billion to more than $4.4 trillion (see Figure 2.4). Specifically, there was a sundden surge of the Fed's balance sheet scale in early September, 2008 as shown in Figure 2.4. This is due to the chain reactions in the collapse of Lehman Brothers. On September 15th 2008, Lehman Brothers declared for bankrupcy. This led to the chain reactions where the money fund broke the buck, that is, unable to maintain a net asset value of $1 per share. Therefore, the Fed helped to stabilize the money funds by enlarging their balance sheet scale. In Figure 2.5, the shaded areas measure the different U.S. QE phases. Besides expanding the size of the Fed's balance sheet, Carpenter et al. (2013) reveal that the structure of the Fed's balance sheet also underwent significant changes during the U.S. QE periods. The Fed absorbed more mortgage-backed securities (MBS) in the U.S. QE1 phase and yet it still accounted for approximately 40% of the balance sheet at the completion of the U.S. QE3 policy, which was not on the balance sheet before the crisis. Although the proportion of Treasury securities (TS) held by the Fed dropped, they constituted half of the total assets (reducing from over 90% to approximately 50%). Furthermore, Figure 2.6 reveals that the Fed gradually contracted the scale of short-term Treasuries (with maturities less than a year) and amassed significant amounts of medium and long-term Treasuries (with maturities longer than a year). Following the introduction of the

Fed's Maturity Extension Program in September 2011, the Fed issued another $400 billion purchase program. Prior to the implementation of the U.S. QE3 policy, there were no short-term Treasuries held on the Fed's balance sheet (Ehlers, 2012).

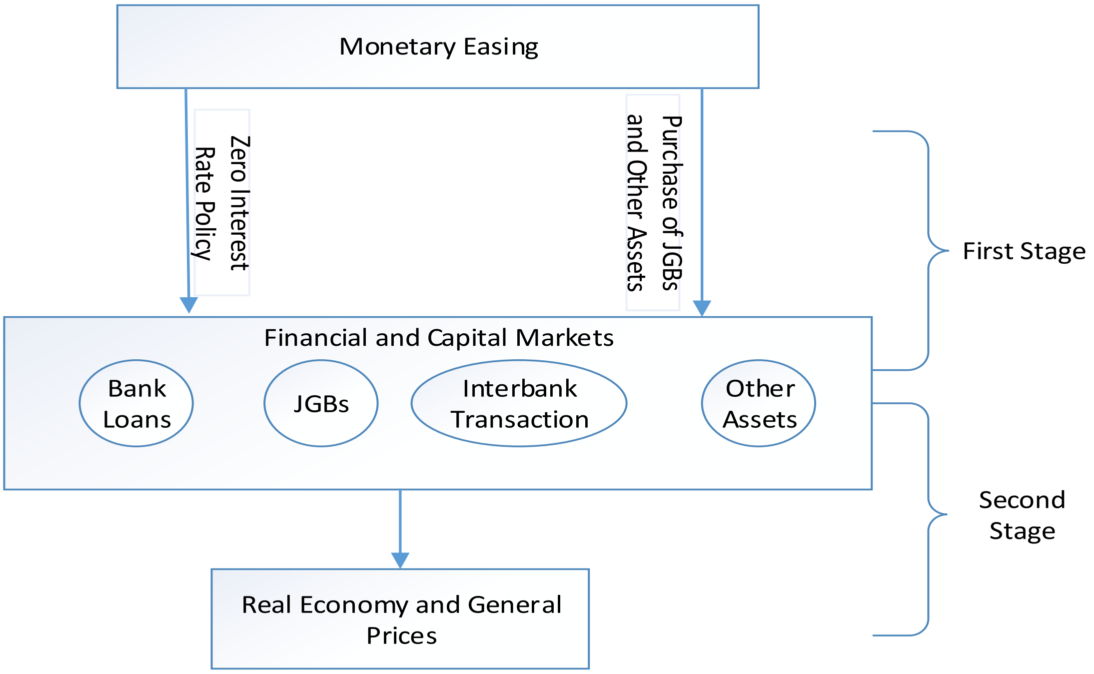

Figure 2-3 Japanese QE Transmission Mechanisms

Source: Shirai (2014)

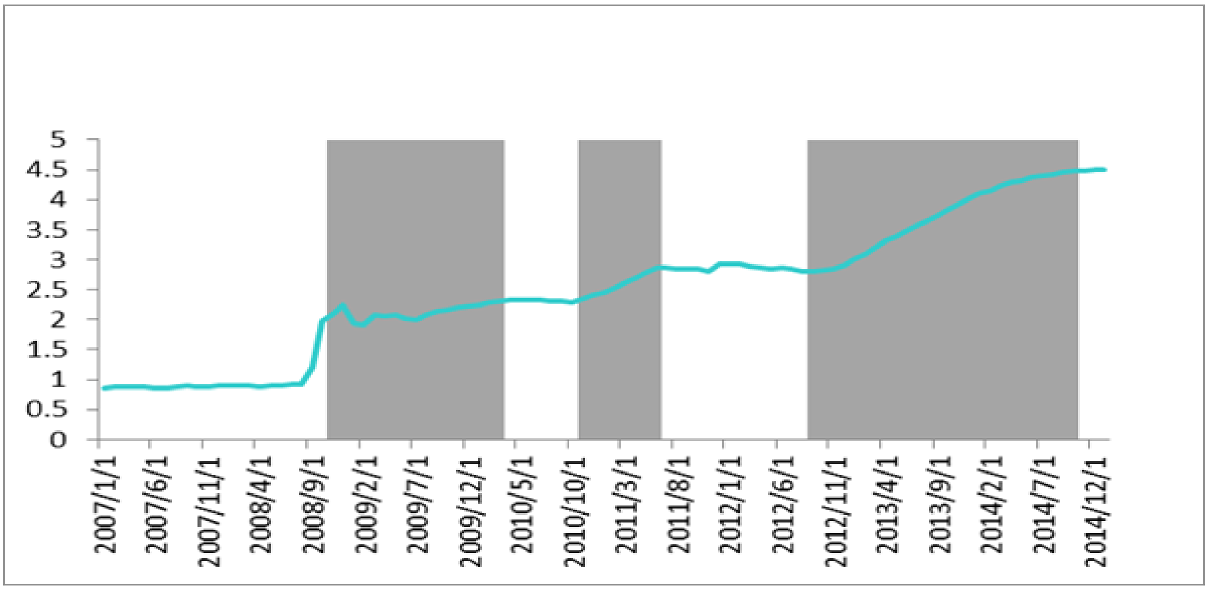

Figure 2-4 Total Assets held by the Fed ($trillion)

Source: Author's Calculations based on the U.S. Federal Reserve System

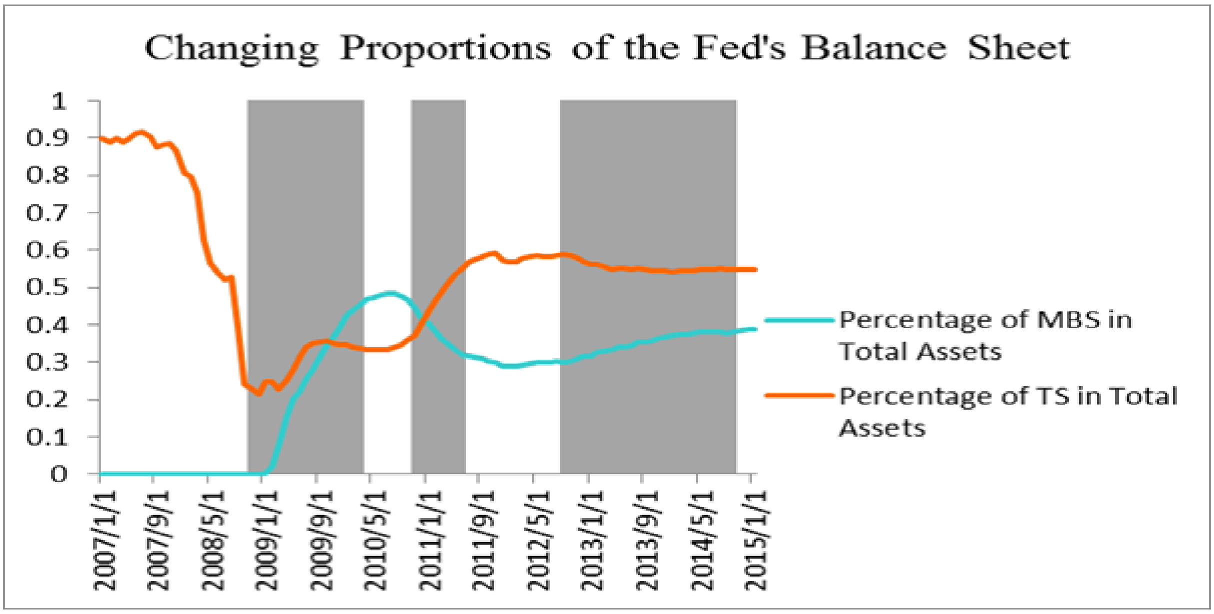

Figure 2-5 Changing Compositions in the Fed's Balance Sheet

Source: Author's Calculations Based on the U.S. Federal Reserve System

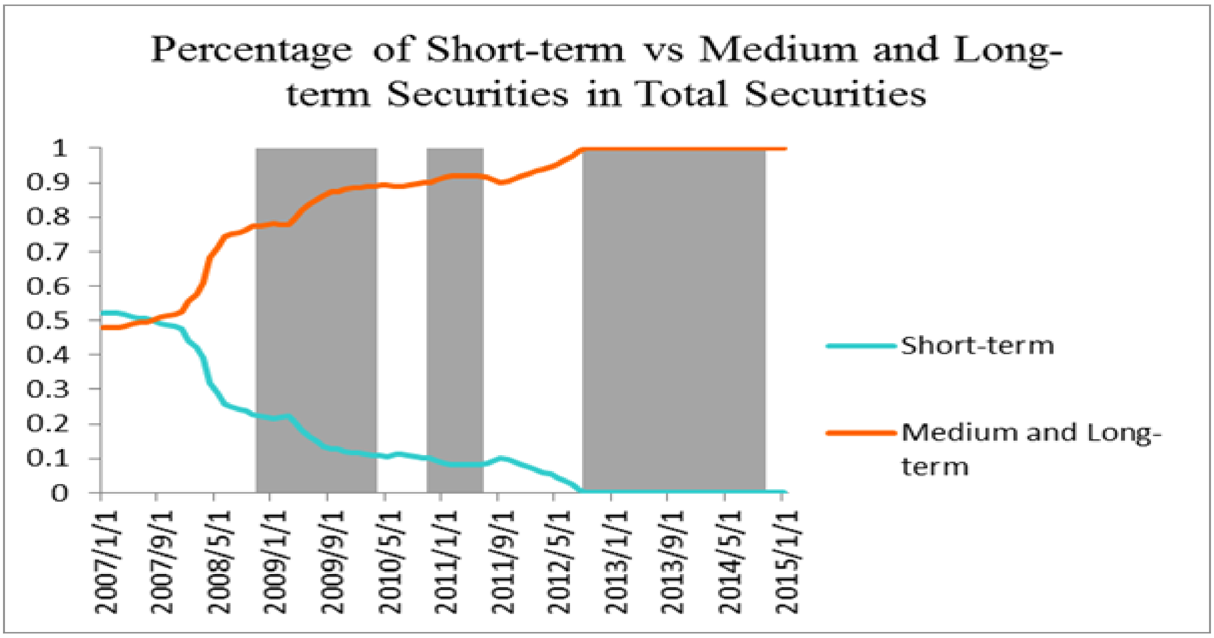

Figure 2-6 Short, Medium and Long-Term Treasury Securities held by the Fed

Source: Author's Calculations Based on the U.S. Federal Reserve System

All three U.S. QE policies encouraged purchasing large amount of U.S. Treasuries, which directly affected the supply and demand relationship in the Treasury market. Doh (2010) found that the U.S. QE policy lowered the term premium in long-term bond yields by altering the supply in long-term bonds. These changes in the term premium are linked to market participants' risk aversion. During crisis periods, investors' risk aversion is higher, therefore the U.S. QE policy triggered a more substantial decrease in term premium. Moreover, he also concluded that U.S. QE policy may be more effective in reducing long-term interest rates when liquidity is reached at the time of liquidity trap.

Similarly, Meaning and Zhu (2011) found that bond yields responded to the U.S. QE announcements with decline across maturities. The five- and ten-year Treasury yields were affected the most by the U.S. QE policies. There was a reported 0.8% total drop in the ten-year U.S. Treasury yields following the U.S. QE announcement. This is in line with Gagnon et al. (2011) study which estimated that the total decrease in the ten-year term premium on the U.S. Treasuries was between 30 and 100 basis points. Meaning and Zhu (2011) also found that the one-year Treasury yield decreased by about 30 basis points, which indicates that Treasuries with shorter maturities are less influenced by the U.S. QE announcements, probably because their yields were already very low at the time.

Similarly, Swanson et al. (2011) presented evidence relating to the U.S. QE2 effects based on the experience of the 1961 Operation Twist using the event study method. The study shows that with high-frequency data, the U.S. QE2 policy exhibited a highly statistically significant effect on long-term Treasury yields, though the effects are moderate (around 15 basis points). They explained that due to the imperfect substitutability between corporate bonds and long-term Treasuries, long-term corporate bond yields declined less than the Treasuries.

With regards to the U.K. market, Meaning and Zhu (2011) revealed that the ten-year gilts yields dropped by 0.5% during the U.K. QE1 period. This result is consistent with Glick and Leduc's (2012) findings that a cumulative 49 basis points decline in gilts was triggered by the U.K. QE1 announcement. At the same time, Lam (2011) found that after the announcement of CME, ten-year JGB yields were reduced by 24 basis points. It is important to note that some researchers (Wright, 2012; Belke et al., 2016) claim that results gained using the event-study method only focus on the QE announcements within the short term and neglected downward trends in global financial markets. In short, these studies may overestimated QE effects because the event-study method simply gives too much credit to QE announcements.

2.5 The Theoretical Basis of Monetary Policy Spillover Effects

The literature on the QE impact on the U.S. bond markets primarily focuses on the domestic level; research on the U.S. QE spillover effects on global bond markets is still emerging. Given the elevated degree of trade openness and market integration, markets are interwoven and integrated with each other. Although the U.S. QE policies were implemented primarily to solve domestic recession problems, they had world-wide effects, due to both global market integration and America's role in the international markets (Chen et al., 2012). Studying the U.S. QE spillover effects in further detail is essential for understanding global financial market movements (Belke et al., 2016).

2.5.1 Mundell-Fleming Model

Monetary Policy spillover effects have been a popular topic for researchers for many years. As early as 1963, Mundell identified how monetary easing policies in one economy influenced other markets with a standard two-country Mundell-Fleming Model. The author predicted that monetary policy easing could increase domestic output and hence, lead to the depreciation of domestic currency. Mundell argued that domestic currency depreciation also leads to an increase in domestic CPI but a drop in foreign CPI. This means that the real consumption of a foreign currency increases and benefits the foreign country (Kawai, 2015).

2.5.2 New Open Economy

A more recent theory, new open-economy macroeconomics (Corsetti & Pesenti, 1997; Obstfeld & Rogoff, 1995, 2000), further explains the international spillover effects of monetary policy. This theory suggests that if nominal prices are rigid, the spillover effect is subject to differences in the exporting companies' price-setting behaviours. When both domestic and foreign companies trade in foreign currency (the producer's currency), domestic monetary easing policy will increase the costs of import but not for the export sectors. Consequently, in this case, domestic monetary easing policies have a negative impact upon domestic trade activities but improves trade in foreign markets (Corsetti & Pesenti, 1997). The situation is reversed when both the domestic and foreign firms use domestic currency. In this case, domestic monetary expansion raises the domestic price of exports while the import price remains unchanged. As a result, the domestic monetary easing policy privileges domestic consumers through stimulating domestic output and trade. Meanwhile, it will produce a negative spillover effect on neighboring markets (Obstfeld and Rogoff 1995). The situation is more complicated when different currency pricing is adopted in different markets. In this case, domestic monetary easing policies can generate either positive or negative spillover effects on international markets (Buiter et al. 2001).

2.6 Modelling Quantitative Easing

Much research has tried to quantify the impact of QE policies on either financial or macroeconomic variables with different econometric methods. Event-study method is applied to measure the immediate responses of financial variables to QE announcements (Bernanke et al., 2004; Gagnon et al., 2010; Joyce et al., 2012; Krishnamurthy & Vissing-Jorgensen, 2011). Several other studies have adopted time-series type models[3] to quantify persistent effects of financial variables from a cross-country perspective (Bayoumi & Bui, 2012; Bredin et al., 2010; Ghosh & Saggar, 2016; Ji & In, 2010; Kapetanios et al., 2012; Kishor & Marfatia, 2013).

2.6.1 Event Study and QE

Event-study compares the expected percentage change of one financial asset value relative to the expected percentage change in its value when an event is announced. It is based on the efficient market hypothesis, which suggests that when the markets are efficient and the announcement of the event is unanticipated, the impact on the value of financial assets will be quick and persistent (MacKinlay, 1997). Following the 2007 subprime crisis and the launch of QE policies, event-study has been used by numerous studies to test the immediate reactions of financial variables to QE announcements. For instance, Bernanke et al. (2004) used event-study to estimate the impact of unconventional monetary policies (such as QE policies) when nominal interest rates reach a liquidity trap. They first adopted event studies with a narrow window to assess the responses of the financial assets following central bank statements. They found both direct and indirect influences from the Federal Open Market Committee (FOMC) statements on private sector expectations. Aït-Sahalia et al. (2009) adopted event study method using a three-day window around the Fed's monetary policy announcement dates and found an immediate positive market response to QE announcements. Similarly, Gagnon et al. (2010) presented a comprehensive event-study on the Fed's QE effects with a one-day window on eight important LASP announcements during the U.S QE1 period. They examined financial variables including long-term government bonds, agency bonds, MBS, swap rates and corporate bonds. They found that QE programs could significantly lower term premium, successfully reduce longer-term private borrowing rates and stimulate the economy. Joyce et al. (2012) estimated the gilt reactions over a two-day period after six QE announcements released by the Bank of England (BOE). They also ran robust tests with one-day and three-day windows event-study methods and found that the initial QE announcement exhibits greater downward pressure on gilt yields than later announcements.

Although event-study method provides a way to measure instant responses to financial variables, it is not perfect. For instance, Bernanke et al. (2004) point out that the estimated results from event-studies only focus on the short-term responses of the market, but cannot track long-term effects. Aït-Sahalia et al. (2009) note that event study cannot fully capture the macroeconomic impact and

[3] For example, the Vector Autoregressive Model (VAR) and Generalized Autoregressive Conditional Heteroskedasticity Model (GARCH) are two time-series models.

structural factors that might affect market responses to policy announcements. Some researchers (Martin & Milas, 2012; Steeley & Matyushkin, 2015) have suggested that event studies implicitly assume constant characteristics of bonds within the event window. However, some bonds may have different characteristics during the event window while others do not. A recent study (Belke et al., 2016) claims that results estimated using the event-study model may overestimate the QE effects on decreasing interest rates. They contend that some of these studies do not consider global downward trends. As a result of this oversight, and the neglect of high integration level among advanced markets, event study estimates overestimate the QE impact generated by such announcements.

2.6.2 GARCH Models on Quantitative Easing

Apart from event-study methods, there are also time-series models which can be used to test persistent and cross-country responses toward the Fed's QE. Unlike the event-study approach, which depends upon the event window length, time-series models allow for multiple factors to be examined both dynamically and simultaneously (Steeley & Matyushkin, 2015). The Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model is one of the models applied in the financial analysis of time-series data.

Based on the Autoregressive Conditional Heteroskedasticity (ARCH) model developed by Engle (1982), Bollerslev (1986) introduced the GARCH model, which permits the conditional variance to follow an autoregressive moving average (ARMA) process. The GARCH model allow for both autoregressive and moving average components in the heteroskedastic variance (Enders, 2008).

The GARCH model is popular for modelling financial data because the variance specification of these types of models are able to measure the commonly observed features of the time-series financial variables. It is useful to model volatility as well as changes in volatility dynamically (Hill et al., 2008). There is also new developments in the GARCH model relating to the analysis of multivariate data. The Multivariate GARCH (MGARCH) model takes advantage of the fact that contemporaneous shocks from different markets can be correlated. In other words, the MGARCH models suggests that volatility spillover effects in one financial asset may influence the volatility of other related financial assets (Enders, 2004).

Engel's (2002) Dynamic Conditional Correlation (DCC) model is one of the most practical forms of MGARCH models. It is developed based on the Constant Conditional Correlation (CCC) model and it is applied to capture the dynamic process of conditional volatilities and conditional correlations simultaneously. However, unlike the CCC-MGARCH model, which assumes the constant correlation among variables, the DCC-MGARCH model allows for dynamic conditional correlation, which is more practical in modelling the time-varying spillover effects among different markets (Celık, 2012). Another merit of the DCC-MGARCH model is that it estimates correlation coefficients of the standardized residuals as well as accounting for heteroscedasticity directly. Therefore, the dynamic correlation is free of bias from volatility (Chiang et al., 2007; Celık, 2012).

Since the 2007 subprime loan crisis, many researchers have utilized GARCH-type models to examine the impact of the Fed's QE policies, from both yield and volatility perspectives. For instance, in order to capture the dynamic reactions of the global stock markets to the Fed QE policy shocks, Kishor and Marfatia (2013) applied GARCH (1, 1) model under a time-varying parameter (TVP) framework. Their results show that the U.S. monetary policy shocks had more spillover effects on the international stock markets during the 2007 subprime crisis periods. They also noted that emerging stock markets tended to be more volatile than developed stock markets.

Similarly, GARCH type models, especially the MGARCH type models, have been widely applied in estimating the volatility spillover effect among different markets. For example, Celık (2012) examined the financial contagion effects among several foreign exchange markets during the subprime loan crisis using a DCC-MGARCH framework. The author found significant contagion effects between most developed and emerging markets. Furthermore, the result showed that, compared with developed exchange markets, there were larger spillover effects in emerging exchange markets from the U.S. subprime loan crisis.

Li and Giles (2015) examined the volatility spillover from the U.S. stock market in seven Asian stock markets (including the Japanese stock market) using an asymmetric MGARCH model. Their empirical study provided evidence of a unidirectional spillover effect from U.S. stock markets to both Japanese and other Asian emerging stock markets. This was the case in both the short-and-long run. These effects were not only more apparent, but also more significant for emerging markets than the ones triggered by Japan after its QE policies were launched. This implies that the Fed's QE policies had more powerful spillover effects than their Japanese counterparts.

Ghosh and Saggar (2016) used both univariate and multivariate GARCH (MGARCH) models to assess the volatility spillover effects triggered by the U.S. QE policies in several emerging equity markets (BRICS). The study found a pronounced volatility clustering in their sample markets during the taper talk period of QE. Ghosh and Saggar (2016) also noted contemporaneous volatility covariance on both equities and government bonds between the U.S. and emerging markets (including BRICS).

Guerello (2016) investigated the financial stability's effect on the QE transmission mechanisms with a MGARCH-in-mean model. The author demonstrated that if the structural breaks in volatility series are triggered by monetary policy changes the low volatility of macroeconomic variables (due to these breaks) cannot lower the financial stability directly. *I build our DCC-MGARCH model using both Kishor and Marfatia (2013) and Engle (2002) studies. This model addresses research objectives 2 and 3.*

2.6.3 VAR models and QE

The Vector Autoregressive (VAR) model is another kind of time-series model utilized to examine the international spillover effects of QE policies. The VAR model, developed by Sims (1980), is a natural generalization of univariate auto-regressive models. It captures the responses of both macroeconomic and financial variables in relation to certain shocks (such as the QE policies). These variables can be either domestic or international, which provide the opportunity to evaluate cross-border spillover effects of certain financial activities. Indeed, the VAR model has been commonly used to analyse such cross-border linkages (Bayoumi & Bui, 2012). For instance, Imakubo et al. (2008) utilized the VAR models to examine the interdependence of LIBOR–OIS spreads in major currencies from the U.S., the U.K., Japan, the Eurozone and Australia. They noticed co-movements in the spreads for the U.S. dollar, euro and Japanese yen. Apart from the spillover effects, VAR models can also be used to examine the dynamic movements between financial variables. In order to assess the economic conditions under the zero lower bound, Bernanke et al. (2004) estimated the dynamics of employment, inflation rate, the federal fund rate, and the Eurodollar futures rate using a VAR model. They found a significant long-term effect of these variables on Treasury yields. Bredin et al. (2010) adopted the VAR model to assess the impact of monetary policy shocks on international bond yields. They found a significant divergent relationship between domestic monetary policies and on excess bond returns in the U.S., the U.K. and Germany.

Besides the studies conducted related to the U.S. QE policies, there are some literature focusing on the U.K. QE policies. For example, Kapetanios et al. (2012) used different VAR models to assess the impact of the U.K. QE policies during the U.K. QE1 period. Their Bayesian VAR (BVAR) results clarified that real GDP would have reduced by even more during 2009 and inflation would have reached lower or even negative levels without the implementation of QE policies. Their findings were supported by their Markov Switching Structural VAR (MS-SVAR) and Time-varying Parameter SVAR (TVP-SVAR) results. Joyce et al. (2012) incorporated several exogenous variables (the growth rate of industrial production, RPI inflation, and the slope of the yield curve) into their VAR model, with both excess returns and asset shares, to measure the exogenous impact on asset demand and supply. Their results showed a large decrease in the expected excess returns on gilts, corporate bonds, and equities in response to the U.K. QE policies. They noted that these effects could last for over six months. *The current study uses a Joyce et al.'s., SVAR model (2011) to test bond market integration level during each U.S. QE period. This answers research objective 1.*

2.7 Market Integration and Spillover Effects

Recently, the global markets, especially the developed markets, suffered from a severe financial crisis initiated by a bubble in the U.S. housing market. The co-movements of different financial markets generated debate around contagion as it affected different countries and the interdependence of global financial markets (Celık, 2012).

The definition of the spillover effect has gone through a gradual refinement process since the 1990s (Cho & Parhizgari, 2008). Initially, the contagion effect was measured using a static measure of correlation between different markets. Further development of the contagion effect added testing co-movements, causality, error correction models, and co-integration among different market returns (Cho & Parhizgari, 2008; Darbar & Deb, 1997; Karolyi & Stulz, 1996; Pascual, 2003). The co-movement describes the strong correlation among the asset returns. In terms of the co-integration, it means the two time series have the same stochastic trend and their linear combination can be stationary even though they may be non-stationary. Some later researchers (Cho & Parhizgari, 2008; Engle, 2002) highlighted that correlation estimates should be dynamic in order to capture the continuous market changes when identifying the contagion effect among different markets. Today, the magnitude of the spillover effects are considered to be subject to market integration levels. Given the elevated level of market integration, financial assets across various markets are bound to be influenced by external shocks from leading economies (Chen et al., 2012).

However, it is difficult to properly distinguish and identify levels of market integration, since it encompasses different aspects of interdependence across various markets. For example, some researchers identify market integration as the proportion of market returns which can be explained by external factors. The market is more segmented if the proportion is small, while a larger market response to exogenous shocks may thereafter be explained as higher levels of market integration (Pukthuanthong & Roll, 2009; Stulz, 1981; Errunza & Losq, 1985). Some others (Lane & Milesi-Ferretti, 2008; Fecht et al., 2012) note that in a well-integrated markets, investors may be benefit through risk sharing, and also from improvements in capital allocation efficiency and a reduction in transaction costs.

From the perspective of a portfolio investor outside the region, stock market integration suggests that separate markets move together and have high correlation. Some theorists (Prasad et al., 2005; Baele et al., 2004) consider market integration as beneficial; this is a central theme in international finance and helps economic growth via risk sharing, reducing macroeconomic volatility and transaction costs Therefore, drawing on Kim et al.'s (2006) study, I only consider co-movements across asset returns, or in particular the daily bond yields.

Market integration levels have attracted much scholarly attention. For example, Kim et al (2006) assessed the degree of integration in European government bond markets over the period of 1998 to 2003. They found significant contemporaneous linkages between Germany and other Euro zone markets. Later studies (Abad et al., 2010) have compared the levels of integration between 15 Euro zone bond markets, world markets and the Euro Monetary Union (EMU). They found that the 15 EU bond markets are more integrated than the EMU markets or the world markets. Other studies have examined Asian markets. For example, Click and Plummer (2005) investigated the levels of market integration in Southeast Asian Nations. Their results suggest an increasing trend in market integration, although the level of integration is far from complete.

The literature on QE effects on market integration is still very limited. Steeley (2015) employed the DCC-GARCH model to assess the U.K. QE impacts on U.K. capital market integration; the author found limited effects on both stock and bond correlations. However, the author noted that the QE policies impacted upon volatility persistence. Some researchers (Pukthuanthong & Roll, 2009) have argued that correlation is not suitable to represent market integration since some perfectly integrated markets may have weak correlations with others. I therefore employ the Structural VAR model to examine changes to market integration levels in global bond markets during the various U.S. QE phases.

2.8 The U.S. QE Spillover Effects on Global Bond Yields

Much of the earlier literature focuses primarily on the U.S. QE impact on financial and macroeconomic variables at a domestic level. However, due to the increasing levels of market integration, monetary policy implemented in the developed economies can also affect other markets as well (Kim & Nguyen, 2009). Of the QE policies implemented by advanced economies, the spillover effects from the U.S. QE policies were more wide-reaching and noticeable than other advanced nations. This could be because the Fed was the first to respond to the 2008 global financial crisis. Additionally, they amassed the largest amount of government bonds in the U.S. QE policies[4] (Bernoth et al., 2015; Christensen & Krogstrup, 2015). Another reason why the early literature tends

[4] The U.S. QE1 policy was announced in November 2008. The Fed purchased $ 4.1 trillion treasuries over a period of several years (November 2008 to October 2014 when the QE3 policy was terminated). The U.K. QE1 policy was launched in March 2009 and the BOE accumulated £ 375 billion government bonds by July 2012.

to focus on the U.S., relates to the country's central position in global markets; the sheer number of trades that occur in U.S. dollars impact upon financial markets (Chen et al., 2012). This study sheds light on how different bond yields responded to external policy shocks generated by the leading economy.

There is still some debate about the factors which affect the magnitudes of the QE spillover effects to other countries (Park & Um, 2015). Several studies (Chen et al., 2014; Neely, 2015) contend that the magnitude of the spillover effect relies upon several macroeconomic factors, including the foundations of the banking system, the current deficit and real GDP growth. Eichengreen and Gupta (2015) emphasize that both market size and liquidity level also matter. Following sections summarize the literature which attempts to quantify the U.S. QE spillover effects on the returns perspective.

2.8.1 The U.S. QE Spillover Effects on Macroeconomic Variables

U.S. QE policies not only impacted the American economy (section 2.4.1), but also, those of other nations. Examining the impact of the U.S. policies on Canada, Dahlhaus et al. (2014) found that the Canadian GDP increased by 2.2% due to drops in long-term spreads induced by the U.S. QE policies in both economies. The authors also noticed that the positive spillover effect of the U.S. QE policies led to a stronger Canadian demand for imports, which somehow reduced the net exports.

Edwards (2012) investigated the U.S. QE spillover effects on short-term interest rates in seven developing markets during the 2000s. Using weekly data, Edwards found that the extent of transmission of interest rate shocks from the U.S. QE policies differed in each country. The author further explained that the U.S. QE shocks affected interest rates in the three sampled Asian markets (Indonesia, Korea and Philippines), while for the Latin America economies, the magnitude of spillover effect on interest rates was only one half. These results suggests that the adjustment process in Asian countries was significantly faster than in Latin America. This indicates that short-term interest rates in less mobile countries[5] (in terms of capital) were more sensitive to the U.S. QE policy shocks than economies which were more integrated in global markets.

Foreign market responses to U.S. monetary policies vary over time (Kishor and Marfatia, 2013). Kishor and Marfatia (2013) contend that the fixed-coefficient approach of measuring U.S. monetary policy spillover effects is inappropriate. They explain that responses can be due to the dynamic movements of market integration and the business cycle. Kishor and Marfatia's results showed significant dynamic responses in the Asian-Pacific and Latin American markets in relation to the U.S.

[5] Edwards (2012) categorised that the three Asian countries have less mobility of capital than the four nations in Latin America.

monetary policy surprises. Furthermore, they found that the announcements had a larger impact on most of the Asian-Pacific and Latin American equity markets during the recession and crisis periods. In short, they concluded that emerging stock markets were more sensitive to the Fed's monetary policy shocks during the crisis phases.

Capital flow is another key theme in the literature on U.S. QE spillover effects. Dahlhaus and Vasishtha (2014) examined the U.S. QE spillover effects on emerging markets. Their results suggest that the effect of the U.S. monetary "policy normalization shock" on capital flows to emerging markets is economically small. Lavigne et al. (2014) identified some possible negative U.S. QE spillover effects on emerging markets. The U.S. QE policies may have led to more capital flows into emerging markets and this may have put unwelcome pressure on asset prices and exchange rates. In spite of these negative spillover effects on emerging markets, Dahhaus and Vasishtha (2014) argue that the majority of U.S. QE spillover effects on emerging markets were positive since the U.S. QE policies generated economic trade and market confidence. These benefits are even more significant, given U.S. exits from the QE programs in improved economic conditions. They also predicted that without the U.S. QE policies, emerging markets may even have suffered from weaker demand for their exports.

More recent studies have assessed the U.S. QE spillover effects on emerging markets. For example, Miyakoshi et al. (2017) applied the VAR model to examine the responses from eight Asian emerging markets to the U.S. QE policy shocks and found that the U.S. QE policies contributed to significant rises in stock prices in the sampled markets. Kryzanowski et al. (2017) examined the U.S. QE spillover effects on cross-market correlations among stocks, bonds and forward contracts for 31 markets. Incorporating the different U.S. QE indicators in the DCC-GARCH model, the authors found that the U.S. QE policies had considerably different spillover effects on cross-market correlations triggered by conventional U.S. monetary policies.

2.8.2 The U.S. QE Spillover Effects on Global Bond Yields

Since most of the QE policies include purchasing large amount of government bonds, an investigation of the QE spillover effects on the global bond markets is necessary. Some research has focused on the U.S. QE spillover effects in the global bond market from the return perspective. However most of these studies only focus on long-term government bonds in advanced markets[6].

[6] For example, Krishnamurthy and Vissing-Jorgensen (2011), Rosa (2012) and Neely (2010).

There has been little discussion of the U.S. QE spillover effects on global bond yields with emerging markets included.

At the domestic level, Krishnamurthy and Vissing-Jorgensen (2011) found that the QE policy signal does significantly lower yields on bonds with various maturities, but that the intensity depends on bond maturity. They found that the signalling channel does a better job in reducing bond yields with shorter maturities than ones with longer maturities. As Krishnamurthy and Vissing-Jorgensen (2011) explain Fed may keep lower bond yields until the economic recovery and thereafter, sell the amassed assets; in short, they are not a long-term investment However, this is not the only view. Rosa (2012), for example, employed a similar approach and identified unanticipated changes in U.S. QE announcements using newspaper articles to estimate the U.S. QE effects on both bond and stock markets. According to this study, the total effect of U.S. QE policy on the financial markets was roughly equal to an unexpected cut of zero (three-month Treasury) to 197 basis points (ten-year Treasury yields). Rosa (2012) noted that the U.S. QE acquisition of large-scale, long-term Treasuries significantly changed the supplies of long-term bonds, which then led to a decline in premium in long-term Treasury yields. Consequently, long-term Treasury yields decreased. Doh (2010) notes that changes in term premium depend on investors' risk aversion. During crisis periods, investors' risk aversion is typically higher than in non-crisis periods, therefore, QE policies may trigger a more substantial decrease in term premium.

At the global level, Neely (2010) examined the spillover effect of the U.S. QE announcements on long-term foreign bond yields in five advanced markets (the U.S., U.K., Canada, Japan, and Germany), using the event study method. He found a significant decline in all bond yields, which followed on the heel of U.S. QE announcements. Neely (2010) argued that the U.S. QE1 policy reduced the ten-year U.S. Treasury yields by 107 basis points. On average, the U.S. QE1 policy also led to a decline in the ten-year foreign bond yields for roughly 53 basis points. This finding is in line with Glick and Leduc (2011) study which estimated that the U.S. QE1 policy reduced the U.K. gilt yields by approximately 46 basis points. This is equivalent to almost the same impact induced by the U.K. QE1 policy on U.K. bond yields. According to Neely (2010), the success of the U.S. QE policies in lowering the long-term government bond yields in both the U.S. market and foreign markets suggests that the monetary authority is not powerless when facing the zero lower bound. In particular, the decrease in all bond yields (either in the U.S. or in foreign bond markets) indicates that the U.S. QE policy should have substantial effects not only on the domestic market, but also on international markets. As the U.S. QE policies have had spillover effects on global financial markets, Neely (2010) suggests it is necessary to coordinate policies among central banks to avoid potential contradictory or overly simulative effects.

Rogers et al. (2014) extended the scope of their original analysis of the spillover effects from the Fed to four major central banks (the Fed, BOE, BOJ and ECB) with high frequency intraday data. Their results show an asymmetric spillover effect from monetary policies within these economies. More specifically, the study found that the U.S. policy spillover effects on non-U.S. yields are higher than the other way around. This is in line with Christensen and Rudebusch's (2012) study and they explained this asymmetric spillover effect as "institutional and investor differences" between the U.S. and U.K. markets.

Neely (2015) assessed the U.S. QE spillover effects on long-term yields of the U.S. and other markets (Australia, Canada, Germany, Japan and U.K.). The author found a significant yield decrease for all sample markets in response to the U.S. QE policies. Bauer and Neely (2014) decomposed the yield changes following the U.S. QE policy into changes induced by signalling and portfolio balance effect. Using dynamic term structure models, Bauer and Neely (2014) concluded that for those markets which show strong yield responses to conventional U.S. monetary policies (such as Canada), the U.S. QE signalling effects are larger. In terms of the markets that have higher bond yield covariance with the U.S. Treasury yields such as Australia, the U.S. QE spillover effects through the portfolio rebalancing channel were higher. For the Japanese market, the portfolio effects were small and there were no significant signalling effects from the U.S. QE policies.

One conclusion can be drawn based on the existing literature. The U.S. QE policies have had pronounced spillover effects across markets and economies. However, there are also some gaps in the study of the U.S. QE spillover effects in the global financial markets from the return perspective. Unlike studies at the domestic level, most of the studies conducted from an international perspective focus mainly on the stock markets or only on the ten-year government bond yields in developed markets; few studies have been conducted on bond yield responses in emerging markets. Moreover, most of the studies on the U.S. QE spillover effects do not consider the dynamic interaction and simultaneous interdependence among markets, which may overestimate or underestimate U.S. QE spillover effects. Additionally, the measurements of the U.S. QE policies in previous studies rely either on the event window length, or on policy shock measures based on the residuals generated in the VAR or GARCH models; no specific identification of the exogenous U.S. QE policy shocks have been estimated. All of these issues may lead to a lack of accuracy in measuring the U.S. QE policy shocks and assessing of the U.S. QE spillover effects.

2.9 U.S. QE Volatility Spillover Effects on Global Financial Markets

Literature on the U.S. QE spillover effects focuses mainly on the return or yield perspective of financial assets. However, the volatility spillover effects across financial markets are also important for both policy makers and market participants. It is for this reason that this topic has come to the attention of several scholars. The potential volatility spillover effects of the leading economies have been a hot topic, especially during periods of financial crisis[7] (Buiter et al., 1998; Mishkin, 1999). Some researchers (Ghosh & Saggar, 2016) believe that the world has become more integrated after the 2008 global financial crisis; according to these theorists, policies of leading markets are almost instantaneously transmitted to emerging market economies. This increasing level of integration among the markets results in more pronounced volatility spillover effects from advanced economies to the rest of the world.

In terms of the volatility spillover effects of the U.S. QE policies, Li and Giles (2015) examined stock market linkages among the U.S., Japan and six other Asian (developing) markets. The study found that although emerging markets are more vulnerable to their own past shocks in both the short and long-term, the U.S. QE volatility spillover effects were not only more pronounced than before, but also larger than those of the Japanese market. Mukherjee and Bhaduri (2016) adopted Diebold-Yilmaz spillover index within the VAR model framework to measure the U.S. QE volatility spillover effects on the BRICS markets. Their findings showed significant bursts of volatility in the sample countries during the U.S. QE periods. However, the authors also pointed out that these volatility spillover effects were severe during the early U.S. QE periods and gradually declined because of market adjustments or stricter regulations in these markets. Another study (Ghosh & Saggar, 2016) employed the MGARCH model to investigate the U.S. QE volatility spillover effects on BRICS markets and some other emerging markets during the taper talk period[8]. The authors found a pronounced volatility clustering phenomenon in emerging bond markets. They also noticed contemporaneous volatility spillover effects from the U.S. markets to other emerging markets, both for equities and government securities. The market interactions are more significant in the bond market.

Yang and Zhou (2016) used implied volatility indices to assess the U.S. QE volatility spillover effects on global stock markets. The authors found the U.S. volatility spillover effects intensified three times during the U.S. QE periods. They also pointed out that the U.S. QE policy was the primary driver of

[7] For example, the European exchange rate mechanism crisis in 1992 and the tequila crisis in 1994.
[8] The taper talk period was from 22 May 2013 to end of August 2013 and included Bernanke's first remark on May 22 that the Fed could taper QE and his June 19 testimony in which he clarified that the Fed could begin tapering by the end of the year (Ghosh & Saggar, 2016).

intensifying volatility spillover effects and could account for about half of the variations of spillover effects. These results indicate that despite the benefits generated by the U.S. QE policy, there was also a potential cost of increasing global systematic risks.

There are some gaps in the previous studies. First, most of these studies focus on the stock markets; there is a notable lack of study on global bond yield volatilities throughout the entire U.S. QE periods. In addition, the application of either VAR or MGARCH models may only capture contemporaneous interactions among the markets; however, none of the studies above explicitly define the U.S. QE policy shocks. The disturbance terms, which measure U.S. QE policy shocks, generated in both models, is inappropriate to capture the unexpected component of the U.S. QE policies. One explanation is the including of omitted variables other than the policy shocks in the distrubance term. For example, the credit quality or credit rating can affect the bond yields and bond volatilities, the higher the bond or asset rating is, the lower the risk suggested by the rating agencies (such as Moody's and Fitch). However, the credit rating is highly related to these individual rating agencies and generally, this factor is not included in the models as independent variable. Thereafter, this factor is typically included in the disturbance term and the relying on the disturbance terms in identifying the policy shocks may lead to biases in estimating the U.S. QE volatility spillover effects.

2.10 Summary

This chapter has reviewed the literature on the development of the U.S. QE policies, the emprical methods employed in previous studies on the U.S. QE spillover effects, on market integration and the U.S. QE spillover effects from both the return and the volatility perspectives. According to previous studies, the U.S. QE policies (especially the U.S. QE1 policy), significantly lowered bond yields and other financial variables, both at domestic and international levels. However, there are still some gaps in the literature. Firstly, previous studies on the U.S. QE spillover effects focus primarily on the initial QE policy (QE1), with less attention paid to later policies (the U.S. QE2 and QE3 policies). Secondly, although many researches include ten-year government bonds in their study, they treat it as the benchmark in estimating long-term interest rates; only a few researchers estimate the U.S. QE effects on government bonds at the domestic level. There is still a notable gap in the literature on U.S. QE spillover effects on global bond markets. Thirdly, in terms of the U.S. QE spillover effects on other markets, most of the studies focus on assets return or yield perspective; few studies examine the U.S. QE volatility spillover effects. Most importantly, to the best of our knowledge, no research has been conducted regarding the U.S. QE volatility spillover effects on global bond markets.

Our study attempts to fill these gaps and investigates the U.S. QE spillover effects on global bond markets from both yield and volatility perspectives. The different spillover effects induced by each individual U.S. QE policy are also compared. This will shed light on how global bond markets respond to policy shocks from leading economies. Our results will provide information for both policy makers and market participants regarding either cross-market corporation or investment choices in global bond markets when facing exogenous monetary policy shocks. Next chapter will firstly discuss the data and then the empirical models using in this study.

Chapter 3

Methodology

3.1 Introduction

Having concluded the literature of QE policies and previous studies on particularly the U.S. QE impact on the international markets, this chapter discusses the data and the empirical methods used to assess the three research objectives. Specifically, this chapter describes the time-series data collected from different bond markets and the unit root tests used to examine data stationarity. Next, the chapter depicts the measurement of both short- and long-term U.S. QE policy surprises. The chapter also presents the Structural VAR (SVAR) model which is used to examine global bond market integration levels during the U.S. QE periods (research objective 1) and the empirical models used to estimate the U.S. QE spillover effects on global bond yields (research objective 2) and volatilities (research objective 3), respectively. The chapter ends with a brief summary of the empirical methods.

3.2 Data and Stationarity Test

This section describes the time-series daily yield data from different bond markets applied in the current study. Price data relating federal funds futures contracts, as well as ten-year Treasury futures contracts, are used to calculate both short- and long-term U.S. QE policy surprises (the independent variable), respectively. Some control and dummy variables are included in the estimation.

3.2.1 Data

This study covers the period from the 1st of January 2007 to the 31st of December 2015, which includes all three of the Fed’s QE periods; U.S. QE1 covers the 25th of November 2008 through the 25th of March 2010, U.S. QE2 covers the 3rd of November 2010 to the 25th of June 2011, and U.S. QE3 covers from the 13th of September 2012 to the 29th of October 2014. The bond yield data were obtained from Bloomberg and DataStream. The daily data applied in this current study includes the federal funds futures data, the ten-year Treasury futures data, the ten-year government bond yields from ten bond markets, and the price data from international stock markets. Daily data was chosen because it provides more information about the immediate responses to exogenous shocks which typically only last for a couple of days rather than relying on weekly and monthly data (Gallagher & Twomey, 1998; Worthington & Higgs, 2004).

The first data set contains information about on the 30 days Federal funds futures contract or more specifically, tracks the overnight Federal funds rate for each month (Kishor & Marfatia, 2013). It is calculated with 100 minus the expected average effective Federal funds rate for the delivery month. This data is used by the current study to calculate short-term U.S. monetary policy shocks generated by the U.S. monetary policies. In addition to the measurement of short-term U.S. policy shocks, I also measure the long-term U.S. monetary policy shocks using the ten-year Treasury futures data. Short- and long-term U.S. monetary policy shocks that correspond to each QE period are generated by multiplying short-and long-term U.S. monetary policy shocks by a dummy variable which represents each individual U.S. QE round (see section 3.3).

Another data set consists of the daily bond yield data from ten long-term (ten-year) government bond markets based on Fratzscher et al. (2018) and Kishor and Marfatia (2013) study. Of all the assets purchased by the Federal Reserves within the U.S. QE policy framework, the largest purchase was on long-term government bonds, and in particular, the ten-year bonds (Gagnon et al., 2010; Neely, 2015). It is for this reason that the current study chooses to focus on these bonds to evaluate QE impacts.

I include some variables to control for changes in both international and domestic economic environments in our study. Since the data used in this study is daily, common macroeconomic variables such as inflation rate and GDP growth are difficult to include. Unlike financial market data, which is available daily or at even higher frequencies, macroeconomic data is usually released monthly, or sometimes quarterly. This means it is challenging to include macroeconomic variables in financial models which use daily based data. However, it is still possible to incorporate changes in economic environments using daily data. The most readily available proxy variable adopted in the previous study (Steeley & Matyushkin, 2015) is the stock market return. I include return data from each sample stock markets as a control for the changes in the stock performance. Apart from daily stock returns, the lag value of bond yields are also incorporated to represent previous information generated within each bond market.

All markets in the study sample are divided into developed markets and emerging markets according to Fratzscher et al. (2018) study, as shown in Table 3.1. The comparison of responses from different groups will provide more detailed information on how the global bond markets respond to the U.S. unconventional monetary policies. The six developed markets include the United States (US), the United Kingdom (UK), Japan (JP), Australia (AU), France (FR) and Germany (GE). The emerging markets included in this study are China (CH), Brazil (BR), India (IND), and Russia (RU). They are markets that either have great impact on the global economy, that is the U.S., the U.K. and Japan

(Yang, 2005) or ones which play a more pronounced role in the global markets such as Brazil, Russia, India and China (BRIC markets). In addition to these markets, I also include bond yields from other markets. I consider bond yields from Hong Kong, Canada and New Zealand for developed markets. In terms of emerging markets, I include Pakistan, South Africa, Thailand, and Malaysia. However, due to missing data, especially for some essential U.S. QE starting and ending dates, I exclude these markets. For example, there are 1893 data for Hong Kong market and the entire sample size is 2349. Moreover, there is still a debate on the definition of emerging markets. For instance, Malaysia is not in the group of BRICS+ Next Eleven markets nor in the Columbia University Emerging Market Global Player (EMGP) groups. Pakistan is not accepted by S&P, Dow Jones and Russell Investment in the emerging markets. Indonesia is not on the Columbia University EMGP list and Thailand is not in the BRICS+ Next Eleven. Therefore, I only choose the BRIC markets, the four largest and well-known emerging markets for my study.

Table 3-1 Markets Included in the Current Study

Developed Market	Emerging Market
United States (US)	China (CH)
United Kingdom (UK)	Brazil (BR)
Japan (JP)	India (IN)
Australia (AU)	Russia (RU)
France (FR)	
Germany (GE)	

Based on (Fratzscher et al., 2018; Kishor & Marfatia, 2013)

3.2.2 Stationarity of Data and Break Points

The stationary series is the one with a constant mean, variance and auto-covariance for each given lag. In other word, the stationary series has all these statistical properties with constant over time. This is very different from non-stationary variables, which have time dependent means and covariance. A random process time series is integrated in the order d; in the series the random process requires a difference of d time in order to guarantee stationarity (Engle & Granger, 1987).

It is necessary to test for stationarity in time series data before running a regression analysis because there will be spurious regression results when running traditional regression analysis with non-stationary time series variables (Granger & Newbold, 1974). The R^2 may be high and the t statistics may be significant for a spurious regression result, but the results are meaningless statistically. In short, the output will appear significant due to the non-consistent least squares estimates and the t statistics do not follow the normal t distribution. Therefore, the integration properties of the data should be examined in advance of any regression analysis. In this study, I use the Augmented Dickey Fuller (ADF) test, Dickey Fuller Generalized Least Square (DFGLS) test, Phillips-Perron (PP) test and Break Point Unit Root test, respectively. Specifically, I run the tests for both the level and first-difference of the bond yield data.

Besides the unit root tests, based on different U.S. QE programs, I also run the break point tests to examine the potential structural break dates in the bond yield series. In addition to the Break Point Unit Root test discussed in section 3.2.2, I also apply the Chow test to examine if the key U.S. QE announcement dates (Including the starting and ending dates of each U.S. QE policy) are the potential structural break points for the sample series.

3.3 Identification of U.S. QE Policy Surprises

It is often argued that global bond yields are driven by monetary policies implemented by the Federal Reserves. Empirical evidence suggests that advanced market, such as German bond yields, responded more to U.S. macroeconomic shocks than shocks from elsewhere, including domestic economic shocks (Andersson et al., 2009; Goldberg & Leonard, 2003). As Andersson et al (2009) and Goldberg and Leonard (2003) explain, this is due to the country's integration with U.S. markets and the U.S's central role in global economic growth. Therefore, it essential to have correct measures for U.S. monetary policy changes so that investors and policymakers are able to respond appropriately. Bredin et al. (2010) identifies two methodological issues in relation to monetary policy. The first issue is endogeneity or omitted variables between different bond markets. The second issue relates to the need to properly capture the surprise or unanticipated element of monetary policy changes.

Many researchers put a lot of effort into avoiding endogeneity and omitted variables in identifying monetary policies. However, they are unlikely to include all of the influences and there can still be omitted variables. Previous studies, however, demonstrate that the issue of endogeneity or omitted variables have very limited impact upon the results. For instance, Rigobon and Sack (2004) attempted to develop a robust estimator with controls added for endogeneity and omitted variables problems. They found that the failure to account for any endogeneity is rather limited practically. Later studies have also demonstrated that omitted variables bias and endogeneity are of limited value when examining the relationship between interest rates (Valente, 2009).

Meanwhile, Bredin et al. (2010) examined the responses from international bond yields to the monetary policies in the US, the UK and Germany. The endogeneity problem they identified was between the monetary policy shocks and bond yields. The authors explained that it was strange to believe that the bond yield changes may affect the setting of monetary policy targets. My thesis is also about the monetary policy shocks on the global bond yields. Similar to the Bredin et al. (2010) study, I assume that there is little endogeneity problem since the monetary policy targets are not decided by the changes of bond yield, or in other words, the monetary authorities do not design their monetary policy in response to the bond yield changes. Instead, they will consider to adjust their monetary targets to the broader economic changes. Therefore, the bond yield changes should not affect the monetary policy shocks and there should not be large endogeneity issue. Moreover, there are other studies which support the exogenous U.S. QE policy shocks. For example, Barroso et al. (2016) examined the U.S. QE policy impact on the capital flows in the Brazilian markets. Specifically, they used the U.S. term spread as the exogenous variable to represent the foreign impact that U.S. QE policy has on the Brazilian markets.

Based on the theoretical assumptions of efficient market hypothesis (EMH), only unexpected policy changes affects asset prices. The expected monetary policy changes should have been fully transmitted into market price (Malkiel & Fama, 1970). In other words, once policy rate change, asset prices should respond only to the unexpected policy change. The expected component should have been reflected into the asset prices prior to the policy statement. Consequently, analysis (Cook & Hahn, 1989; Roley & Sellon, 1995; Sellin, 2001) which is unable to decompose monetary policy changes into anticipated and unanticipated elements are likely to have biases in the results due to the errors in the variable. One common method suggested by the existing studies is to use futures data to differentiate between unexpected and expected changes in monetary policies (Bredin et al., 2010; Kuttner, 2001). Therefore, I adopt the federal funds futures data and ten-year Treasury futures data to calculate both the short and long-term U.S. monetary policy shocks. I use the federal funds futures data since it provides a better means of predicting the future path of monetary policy (Gürkaynak et al., 2007). In addition, it can avoid the biases of model selection and the 'generated regressors' problems (Kishor & Mafartia, 2013). Hence, I calculate the short-term U.S. monetary policy shocks with the federal funds futures data. Moreover, since unconventional monetary policies like the U.S. QE policies, include absorbing a large proportion of long-term (especially ten-year) Treasuries, I develop the long-term U.S. monetary policy shocks with ten-year Treasury futures data. In order to capture unanticipated monetary policy changes, I adopt the method developed by Bredin et al. (2010) based on Kuttner (2001). The first day short-term U.S. monetary policy surprise is computed as:

$$\Delta r_t^{ST} = \frac{m_s}{m_s - \tau}(f_{s,\tau}^{0} - f_{s,\tau-1}^{0}) \tag{1}$$

Where Δr_t^{ST} the short-term policy surprise[9], m_s is the number of days in month s, $f_{s,\tau}^0$ is the present futures rate on day τ of month s and $f_{s,\tau-1}^0$ is the current futures rate on day $\tau-1$. The model is applied for all the days within a given month, with the exception of the first and last day. When the monetary policy change happens on the first day of a month, its expectations would have been reflected in the previous month spot rate, therefore, the 1-month futures rate on the last day of the previous month, $f_{s-1,\tau-1}^1$ is utilized instead of $f_{s,\tau-1}^0$. Similarly, when the short-term U.S. monetary policy change takes place on the last day, the difference in the 1-month federal futures rate is used. When the short-term U.S. monetary policy change takes place on the last day of the month, it would not influence the spot policy rate, since the federal funds rate does not change until the day following the target changes. Furthermore, in order to reduce the amplification of the month-end effect, no scaling adjustment is made when the U.S. monetary policy change statement is issued within the last 3 days of each month.

Similar to the definition of the short-term U.S. monetary policy shocks, I also calculate the long-term U.S. monetary policy shock Δr_t^{LT} in the equation (2):

$$\Delta r_t^{LT} = \frac{n_s}{n_s - \upsilon}(g_{s,\upsilon}^0 - g_{s,\upsilon-1}^0) \tag{2}$$

The short-term and long-term policy shocks defined in equation (1) and (2) are not specific to the U.S. QE policy shocks, but the U.S. monetary policy shocks during the sample period (2007 to 2016). Next, the short- and long-term U.S. monetary policy shocks are multiplied with the dummy variables (see Table 3.2), which represent different U.S. QE periods to obtain the U.S. QE policy shocks.

Table 3-2 Dummy Variables Represent Each U.S. QE Round

Dummy Variable	1	0
d_1	25th, November, 2008 to 25th, March, 2010	Otherwise
d_2	3rd, November, 2010 to 25th, June, 2011	Otherwise
d_3	13th, September, 2012 to 29th, October, 2014	Otherwise

[9] The monetary policy surprise can be zero, which indicates either that there are no monetary policy changes or announcements made on that specific day.

3.4 Market Integration during Different U.S. QE Periods

In order to measure the global bond market integration level during the U.S. QE periods (*the first research objective*), I designed our SVAR models equation (3) as outlined below:

$$AY_t = A_1Y_{t-1} + A_2Y_{t-2} + A_3Y_{t-3} + ... + A_pY_{t-p} + B\varepsilon_t \qquad (3)$$

Y_t is a nx1 vector of stationary endogenous variables, which represents the bond yield changes from ten sample markets. A is an nxn invertible matrix of structural coefficients, which captures the dynamic interactions between the n variables. B is another nxn matrix of structural coefficients which represents the effects of structural shocks. P is the lag length determined by information criteria Akaike Information Criterion (AIC) which is in line with previous studies (Kang et al., 2016; Kilian 2001; Yang 2005). Kilian (2001), in particular, claims that AIC is of higher accuracy in terms of confidence intervals than other information selection criteria such as SIC in VAR impulse response analysis. ε_t is the white noise structural error term with $E(\varepsilon_t) = 0, E(\varepsilon_s\varepsilon_t^{'}) = 0 \forall s \neq t$.

The corresponding reduced form VAR model can be estimated by pre-multiplying equation (3) with the inverse of matrix A, A^{-1} and described in equation (4).

$$Y_t = C_1Y_{t-1} + C_2Y_{t-2} + C_3Y_{t-3} + ... + C_pY_{t-p} + u_t \qquad (4)$$

Where C_i is equal to $A^{-1}A_i$. The error term u_t in equation (4) is equal to $A^{-1}B\varepsilon t$. Since on the right hand side of reduced VAR does not contain time t endogenous variables, therefore, no variable has a direct contemporaneous effect on the other variables. Meanwhile, the relationship between the reduced form residuals, u_t, and the structural residuals, ε_t, suggested by Amisano & Giannini (1997) are described in equation (5).

$$Au_t = B\varepsilon_t \qquad (5)$$

In order to identify the parameters in the structural matrices, restrictions are needed on the matrices. The necessary numbers of restrictions to identify A and B matrices is equal to n(n-1)/2, where n is the number of variables. Ten variables are included in our study. Therefore, at least 45 restrictions should be imposed to estimate the models.

Since our focus is on the QE policies (especially on the U.S. case), I assume that the U.S. bond shocks can affect all sample bond markets (including the U.S. bond market), while no shocks other than the U.S. bond shocks can affect the U.S. bond markets. Since the U.K. and Japan both implemented their own QE policies during the sample periods (2007 to 2016), I assume that bond shocks from both the U.K. and Japanese bond markets can affect other markets (except for the U.S. bond markets). The U.K. shocks can affect all of the markets (including the U.K. bond market) with the exception of the U.S. bond markets. Japanese bond shocks can affect markets other than the U.S. and the U.K. This order is simply determined due to the important effects the market has in the global economy. The A and B matrices are defined in equation (6) and (7), respectively.

$$A=\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ a_{21} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ a_{31} & a_{32} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ a_{41} & a_{42} & a_{43} & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ a_{51} & a_{52} & a_{53} & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ a_{61} & a_{62} & a_{63} & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ a_{71} & a_{72} & a_{73} & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ a_{81} & a_{82} & a_{83} & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ a_{91} & a_{92} & a_{93} & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ a_{101} & a_{102} & a_{103} & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad (6)$$

$$B=\begin{bmatrix} b_{11} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & b_{22} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & b_{33} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & b_{44} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & b_{55} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & b_{66} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & b_{77} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & b_{88} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & b_{99} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & b_{1010} \end{bmatrix} \quad (7)$$

Once the SVAR models are defined, I identify three sub-samples based on the actual implementation of the U.S. QE periods (see Table 3.2). I examine the SVAR model with both the entire sample period (2007 to 2016) and sub-sample periods (the U.S. QE1, QE2 and QE3 periods). In order to measure market integration levels within different sample periods, I then apply the impulse response function analysis generated using the SVAR models. According to Hill et al. (2008), this is an appropriate technique to analyse monetary policy changes on financial market. It shows the dynamic effect the shock of one standard deviation to a variable on the other variables, and the interdependence between each variable (Helmut, 1993). It is also considered as a non-causality test; the zero impulse responses between two variables simply indicate a lack of causality (Ji & In, 2010). The forecast error variance decomposition analysis within the SVAR framework is another technique I apply to analyse market integration levels during the U.S. QE periods. It can tell us what proportion the forecast error variance of one bond yield can be attributed to the external shocks.

3.5 The U.S. QE Spillover Effects on Global Bond Yields

In order to assess the U.S. QE spillover effects on global bond yields (*second research objective*), I apply the DCC-MGARCH model as suggested by previous research (Guerello, 2016; Kishor & Marfatia, 2013). One merit of the DCC-MGARCH model is that it allows for interaction between different markets. I include both the short- and long-term U.S. QE monetary policy surprises calculated in section 3.4 as the exogenous shock to different bond markets. I examine the short- and long-term U.S. QE policy shocks simultaneously. Our model is developed also in the spirit of Steeley & Matyushkin's (2015) study, adding the stock index variable to control for the broader economic environments both internationally and domestically. The mean equation for each bond yield with short- and long-term U.S. QE policy shocks is given as:

$$\begin{aligned}\Delta Y_t &= C_0 + a_1 R_t^{ds} + a_2 \Delta Y_{t-1} + a_3 R_t^{us} + a_4 R_t^{uk} + a_5 R_t^{jp} + b_1(\mathrm{d}_1 * \Delta r_t^{ST}) + b_2(\mathrm{d}_2 * \Delta r_t^{ST}) \\ &+ b_3(\mathrm{d}_3 * \Delta r_t^{ST}) + b_4(\mathrm{d}_1 * \Delta r_t^{LT}) + b_5(\mathrm{d}_2 * \Delta r_t^{LT}) + b_6(\mathrm{d}_3 * \Delta r_t^{LT}) + \varepsilon_t\end{aligned} \tag{8}$$

Where ΔY_t is the change of yield data at time t for each bond market, R_t^{ds} is the daily stock return data, which stands for the domestic economic changes for each sample economy, R_t^{us}, R_t^{uk} and R_t^{jp} are the change of economic environments from three leading economies (U.S., U.K. and Japan), respectively. The inclusion of domestic economic changes in each equation is due to the important effects that the domestic economic changes have on bond yields. The economic changes from the U.S., the U.K. and Japan represent the international economic changes, since these economies have significant impact on international financial markets. Δr_t^{ST} are the short-term U.S. monetary policy shocks calculated with federal funds futures data (see section 3.3). Δr_t^{LT} are the long-term U.S. monetary policy shocks calculated with ten-year Treasury futures data. d_1, d_2 and d_3 are dummy variables that measure different U.S. QE rounds, respectively (see Table 3.2). Therefore, $\mathrm{d}_1 * \Delta r_t^{ST}$, $\mathrm{d}_2 * \Delta r_t^{ST}$ and $\mathrm{d}_3 * \Delta r_t^{ST}$ are the short-term policy surprises within different QE rounds, respectively. Thus, $\mathrm{d}_1 * \Delta r_t^{LT}$, $\mathrm{d}_2 * \Delta r_t^{LT}$ and $\mathrm{d}_3 * \Delta r_t^{LT}$ are the long-term U.S. QE policy shocks for each U.S. QE period.

The residuals for each individual bond markets calculated in equation (8) are modelled as follows:

$$h_t = C_1 + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 h_{t-1}^2 \tag{9}$$

This is the first step in estimating univariate in the GARCH (1, 1) model. The second step in estimating the conditional correlation will be modelled based on the univariate results and the residual ε_t generated from all three mean equations in a standard GARCH model as:

$$\varepsilon_t = D_t v_t \sim \qquad\qquad) \tag{10}$$

Where ε_t is a k x 1 vector of residual yields of Y, k is the number of sample markets, v_t is a k x 1 vector of standardized residual yields. H_t is a k x k matrix of dynamic variances. Specially,

$$H_t = D_t R_t D_t \tag{11}$$

D_t is a k x k diagonal matrix of dynamic standard deviation of residuals in equation (8), with $D_t = diag\left\{\sqrt{h_t}\right\}$. Where each h_t is calculated from the univariate GARCH (1, 1) model in equation (9).

The framework also consists of a specific DCC structure R_t, which is a k x k matrix of time-varying correlations and can be expressed as:

$$R_t = Q_t^{*-1} Q_t Q_t^{*-1} \tag{12}$$

The dynamic conditional correlation structure is then given by equation (13):

$$Q_t = (1 - \alpha - \beta)\bar{Q} + \alpha v_{t-1} v_{t-1}^{'} + \beta Q_{t-1} \tag{13}$$

Where Q_t is the conditional variance–covariance matrix of residuals with its unconditional variance–covariance matrix $\bar{Q}$ obtained from the GARCH (1, 1) process in equation (9). Q_t^* is a diagonal matrix with the square root of the diagonal elements of Q_t, and $Q_t^* = diag\left\{\sqrt{Q_t}\right\}$. $v_t = \varepsilon_t / \sqrt{h_t}$, the scalars α and β are non-negative which satisfy $\alpha + \beta < 1$.

The parameters estimated in equation (13) represent the dynamic conditional correlation among the global bond markets. Unlike the estimation in univariate GARCH model independently, which ignores the interaction within each markets, the DCC-MGARCH model jointly consider the interdependence among the markets and the exogenous QE shocks, which can better identify the spillover effects triggered by the U.S. QE policies. These parameters are associated with the exponential smoothing process that is used to construct the dynamic conditional correlations. The DCC model is mean reverting as long as the sum of α and β is less than one. In this case, the sum of these two dynamic coefficients is less one which implies that there is a stationary time-varying correlation among the sample markets.

3.6 The U.S. QE Volatility Spillover on Global Bond Markets

As well as assessing the U.S. QE spillover effects on global bond yields, I also apply the DCC-MGARCH framework to determine the U.S. QE volatility spillover effects on global bond yields (*third research objective*). However, I make some modifications to the models when estimating the U.S. QE volatility spillover effects. First, unlike the DCC-MGARCH discussed in section 3.5, which incorporates both the short- and long-term U.S. QE policy shocks in the mean equation, I add the U.S. QE policy shocks (both the short- and long-term U.S. QE policy shocks) and the control variables in the variance equation to test the volatility spillover effects of the U.S. QE policy shocks. Hence, the mean equation is defined as follow:

$$\Delta Y_t = C_n + e_t \tag{14}$$

Y_t is the change of bond yield for each bond market, e_t is the error term.

Another difference from the DCC-MGARCH in section 3.5, is that compared to the ordinary GARCH model, the Threshold GARCH (TGARCH) model includes the asymmetric term in variance equation. Therefore, besides the U.S. QE shocks and the control variables, there is also the asymmetric term to capture the potential leverage effects of the U.S. QE policy shocks on global bond yield volatilities. The variance equation with the short-term U.S. QE policy shocks is defined as follow:

$$\begin{aligned} h_{1t} &= C_2 + \alpha_2 e_{t-1}^2 + \beta_2 h_{1t-1}^2 + a_1^{'} R_t^{ds} + a_2^{'} R_t^{us} + a_3^{'} R_t^{uk} + a_4^{'} R_t^{jp} + b_1^{'}(\mathrm{d}_1 * \Delta r_t^{ST}) + b_2^{'}(\mathrm{d}_2 * \Delta r_t^{ST}) \\ &+ b_3^{'}(\mathrm{d}_3 * \Delta r_t^{ST}) + b_4^{'}(\mathrm{d}_1 * \Delta r_t^{LT}) + b_5^{'}(\mathrm{d}_2 * \Delta r_t^{LT}) + b_6^{'}(\mathrm{d}_3 * \Delta r_t^{LT}) + \lambda e_{t-1}^2 I(\mathrm{e}_{t-1}) \end{aligned} \tag{15}$$

Where h_{1t} is the conditional variance at time t, e_{t-1}^2 is the square of residuals on time t-1, which is the previous period of t, h_{1t-1}^2 is the square of the conditional variance on time t-1, which also stands for the previous t period. Similar to section 3.5, $d_1 * \Delta r_t$, $d_2 * \Delta r$, $d_3 * \Delta r_t$, $d_1 * \Delta r_t^{LT}$, $d_2 * \Delta r_t^{LT}$ and $d_3 * \Delta r_t^{LT}$ are the short-term and long-term U.S. QE policy shocks for each U.S. QE period defined in section 3.4, respectively. Meanwhile, R_t^{ds}, R_t^{us}, R_t^{uk} and R_t^{jp} are the changes in economic environments from the domestic economy as well as the three leading economies (the U.S., the U.K. and Japan), respectively. Term $I(e_{t-1})$ measures the potential leverage effects to which different information may affect bond yield volatility. The whole term is equal to one if $e_{t-1} < 0$ and 0 otherwise. A positive value of λ suggests that negative residuals tend to increase more variance than the positive ones. This can also be interpreted as 'bad news bring more volatility to good news.' The rest of the DCC model is the same as the ones discussed in equations (10) to (13).

3.7 Summary

This chapter describes the models used to investigate the (volatility) spillover effects triggered by the Fed's QE policies to other bond markets from January 2007 to January 2016. The current study examines the U.S. QE spillover effects from both a bond yield perspective and a volatility spillover effects perspective. Our study also assesses bond market integration levels during each U.S. QE period. Unlike previous studies which only use the dummy or event study with a short window to quantify QE shocks, our study adopts the monetary surprise calculated with Federal future funds data as well as ten-year Treasury futures data to represent the QE surprises. These have only been used to estimate the spillover effects in global stock markets and have never been applied to global bond markets. Furthermore, compared to many studies that attempt to quantify QE spillover effects with a fix trend, I apply the DCC-MGARCH framework which allows for dynamic changes of the conditional correlations among global bond markets. The results generated from these models are expected to provide more accurate measures of the global spillover effects initiated by the U.S. QE policies. Next chapter will present the empirical results of each research object of this thesis.

Chapter 4

Empirical Results

4.1 Introduction

Having outlined the methodology in Chapter Three, this chapter discusses the empirical results. It argues that with the increasing integration levels among international bond markets, the U.S. QE policy shocks (in particular the long-term U.S. QE shocks) significantly influenced the bond yields in most developed markets and bond volatilities in most emerging markets. In detail, this chapter first presents both the descriptive statistics of the long-term bond yield data. Next, this chapter reports the time series property and the structural breaks in the data. Then this chapter reports the empirical results of the market integration levels among global bond markets over the three U.S. QE periods. This chapter also reports the regression results of the U.S. QE policy spillover effects on global bond markets from both the bond yield and bond volatility perspectives. This chapter ends with a brief summary of the empirical results

4.2 Descriptive Statistics and Data Properties

This section presents the descriptive statistics on the changes in government bond yield data applied in this study. It describes global bond market movements after the U.S. subprime loan crisis (from 2007 to 2016), and provides evidence of how the bond yields reacted during different U.S. QE periods. Figure 4.1 reveals the general movement of global bond yields after 2007. Figure 4.2 shows the first difference of daily bonds yield data. Table 4.1 summarises the bond yield data from ten long-term (ten-year) bond markets from 2007 to 2016. Tables 4.2 to 4.4 describe the long-term bond yield data during each of the U.S. QE periods, respectively. Tables 4.5 to 4.8 report the unconditional correlation among global bond markets during both the entire sample period and individual U.S. QE rounds, respectively. The time series properties of the data are also discussed in this section along with the unit root test results (see Table 4.9).

4.2.1 Descriptive Statistics

Table 4.1 reveals the characteristics of bond yields from global bond market after 2007. The table shows the highest mean bond yields achieved in the Russian long-term market was 8.55%, while the lowest was the long-term Japanese bond yield, with a mean yield of 1.04%. The average bond yields were higher in emerging markets than in developed markets. One possible explanation could be that the widely-spread economic deterioration originated in the U.S. The long-term bond yield represent investors' expectations of future inflation. Since most of the advanced economies suffered from a recession over that period, investors would have had low or even negative expectations regarding future economic conditions and inflation rates. However, since then (after the 2007 Subprime Loan Crisis), the emerging markets exhibited better economic conditions than developed markets, and investors' future expectations of their economic developments were higher than developed markets, which also indicates higher long-term bond yields. However, bond yield movements are different during each QE period. As Tables 4.2 to 4.4 show, during the U.S. QE1 and QE2 periods, most of the markets had higher mean bond yield than the mean bond yields for the entire sample period. The data shows seven markets exhibiting the highest mean bond yield values during the U.S. QE1 period. This indicates that during both the U.S. QE1 and QE2 periods, especially during the U.S. QE1 period, global bond yields are at a comparative high level. However, during the U.S. QE3 period, only a few markets (China and India) have higher bond yields than the entire sample mean value, which indicates that most bond yields dropped in the QE3 period. This can also be supported by the mean and median difference results shown in Table 4-5. Based on these results, the bond yields from all markets tends to have a pronounced difference in their mean and median values, since all the results reject the null hypothesis of same mean and median across different U.S. QE periods. This indicates that within each of the U.S. QE programs, the Fed's absorbed a large amount of floating long-term Treasury bonds (the majority had a ten-year maturity). This significantly changed the supply and demand relationship of the U.S. Treasury market and may have spread to the rest of the world (see Figure 4.1).

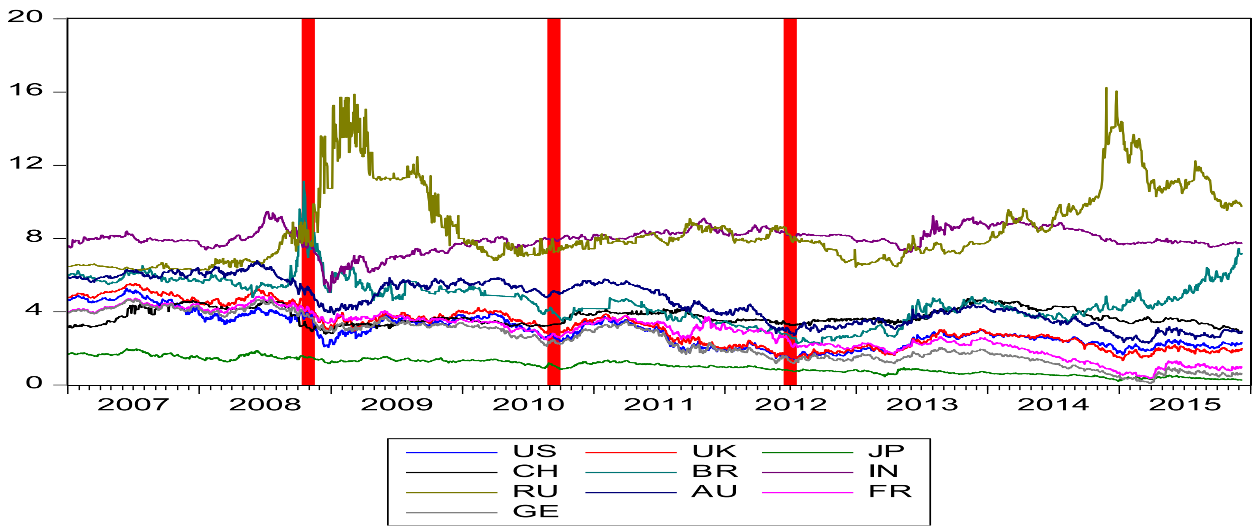

Figure 4-1 Global Bond Yield Movements (2007 to 2016)

Source: Author's Calculations based on data from Bloomberg and DataStream

Table 4-1 Descriptive Statistics for Ten-Year Bond Yields (2007 to 2016)

	US10	UK10	JP10	CH10	BR10	IN10	RU10	AU10	FR10	GE10
Mean	2.92	3.13	1.04	3.72	4.61	7.97	8.55	4.53	2.87	2.43
Median	2.74	2.98	1.03	3.6	4.59	7.98	7.87	4.35	3.02	2.33
Maximum	5.29	5.55	1.97	4.71	11.13	9.48	16.24	6.79	4.84	4.68
Minimum	1.39	1.33	0.2	2.78	2.24	5.08	6.26	2.28	0.35	0.08
Std. Dev.	0.92	1.12	0.43	0.43	1.18	0.62	2.03	1.19	1.14	1.24
Skewness	0.53	0.36	-0.01	0.43	0.41	-1.01	1.27	-0.07	-0.37	0.05
Kurtosis	2.37	1.94	1.92	2.21	4.14	5.43	4.11	1.67	2.15	1.8
Jarque-Bera	141.74	158.87	113.62	133.88	193.24	971.22	749.07	174.98	122.83	140.4
Probability	0	0	0	0	0	0	0	0	0	0
Observations	2333	2333	2333	2333	2333	2333	2333	2333	2333	2333

Source: Author's Calculations

Table 4-2 Descriptive Statistics for Ten-Year Bond Yields (U.S. QE1 Period)

	US10	UK10	JP10	CH10	BR10	IN10	RU10	AU10	FR10	GE10
Mean	3.26	3.66	1.35	3.38	5.39	6.98	10.82	5.1	3.6	3.24
Median	3.41	3.68	1.33	3.38	5.22	7.06	11.26	5.43	3.58	3.24
Maximum	3.95	4.23	1.56	3.71	7.73	8.02	15.88	5.86	4.05	3.72
Minimum	2.05	2.95	1.17	2.78	4.61	5.08	7.02	3.86	3.36	2.89
Std. Dev.	0.45	0.278	0.07	0.21	0.54	0.64	2.27	0.6	0.14	0.16
Skewness	-0.8	-0.49	0.37	-0.68	1.66	-0.6	0.16	-0.65	0.77	0.35
Kurtosis	2.71	2.66	2.85	3.3	6.2	2.89	2.28	1.78	3.25	3.35
Jarque-Bera	38.62	15.42	8.05	28.41	308.55	21.14	9.03	46.2	34.89	9.08
Probability	0	0	0.02	0	0	0	0.01	0	0	0.01
Observations	347	347	347	347	347	347	347	347	347	347

Source: Author's Calculations

Table 4-3 Descriptive Statistics for Ten-Year Bond Yields (U.S. QE2 Period)

	US10	UK10	JP10	CH10	BR10	IN10	RU10	AU10	FR10	GE10
Mean	3.24	3.49	1.2	3.92	4.28	8.11	7.85	5.48	3.44	3.06
Median	3.33	3.51	1.21	3.91	4.17	8.1	7.84	5.5	3.45	3.10
Maximum	3.74	3.88	1.36	4.13	4.76	8.46	8.3	5.78	3.78	3.49
Minimum	2.49	2.95	0.93	3.72	3.54	7.89	7.39	5.02	2.82	2.39
Std. Dev.	0.26	0.2	0.08	0.07	0.25	0.13	0.24	0.17	0.21	0.24
Skewness	-0.72	-0.3	-0.73	0.37	0.02	0.48	-0.07	-0.64	-0.91	-0.92
Kurtosis	2.96	2.63	3.89	3	2.69	2.43	2.26	3	3.74	3.69
Jarque-Bera	14.42	3.5	20.29	3.85	0.68	8.58	3.96	11.41	27	26.97
Probability	0	0.17	0	0.15	0.71	0.01	0.14	0	0	0
Observations	167	167	167	167	167	167	167	167	167	167

Source: Author’s Calculations

Table 4-4 Descriptive Statistics for Ten-Year Bond Yields (U.S. QE3 Period)

	US10	UK10	JP10	CH10	BR10	IN10	RU10	AU10	FR10	GE10
Mean	2.35	2.37	0.67	3.97	3.66	8.36	7.88	3.66	2.04	1.49
Median	2.51	2.48	0.64	4.03	3.8	8.48	7.68	3.61	2.14	1.52
Maximum	3.03	3.07	0.93	4.71	4.84	9.24	10.22	4.39	2.63	2.05
Minimum	1.58	1.62	0.45	3.29	2.24	7.2	6.44	2.87	1.13	0.76
Std. Dev.	0.42	0.4	0.11	0.4	0.72	0.47	0.98	0.38	0.34	0.28
Skewness	-0.44	-0.31	0.22	0.15	-0.38	-0.56	0.53	0.13	-0.84	-0.45
Kurtosis	1.75	1.69	2.08	1.58	1.86	2.41	2.1	1.8	2.92	2.68
Jarque-Bera	53.36	48.5	23.74	48.01	42.69	36.58	44.3	34.47	64.19	21.22
Probability	0	0	0	0	0	0	0	0	0	0
Observations	550	550	550	550	550	550	550	550	550	550

Source: Author’s Calculations

Table 4-5 Mean and Median Difference for Bond Yields across Different U.S. QE Periods

	Mean Difference		Median Difference	
Market	Anova F-test	Welch F-test	Med. Chi-square	Kruskal-Wallis
US	654.1***	729.1***	589.8***	613.3***
UK	1750***	1789***	986.6***	806.9***
JP	6197***	6535.1***	994.4***	852.7***
CH	395.5***	921.6***	422.3***	487.6***
BR	860.1***	896.7***	527.2***	747.8***
IN	842.9***	619.3***	512***	649.8***
RU	461.6***	288.8***	210.4***	388.9***
AU	1700.9***	3884.1***	733.8***	749.2***
FR	4120.6***	4562.9***	994.4***	813.3***
GE	6749.2***	7456.4***	994.4***	811.2***

Source: Author's Calculations

***, ** and * represent significant values at 1%, 5% and 10% levels, respectively.

Table 4-6 Unconditional Correlation among Long-Term Bond Yields (2007 to 2016)

	US10	UK10	JP10	CH10	BR10	IN10	RU10	AU10	FR10	GE10
US10	1.00									
UK10	0.97***	1.00								
JP10	0.83***	0.90***	1.00							
CH10	0.27***	0.29***	0.09***	1.00						
BR10	0.69***	0.67***	0.50***	-0.03	1.00					
IN10	-0.10***	-0.13***	-0.25***	0.59***	-0.38***	1.00				
RU10	-0.36***	-0.39***	-0.38***	-0.36***	0.12***	-0.46***	1.00			
AU10	0.88***	0.94***	0.91***	0.30***	0.50***	-0.07***	-0.47***	1.00		
FR10	0.78***	0.88***	0.97***	0.19***	0.44***	-0.15***	-0.43***	0.91***	1.00	
GE10	0.88***	0.95***	0.97***	0.21***	0.56***	-0.20***	-0.40***	0.95***	0.97***	1.00

Source: Author's Calculations

***, ** and * represent significant values at 1%, 5% and 10% levels, respectively.

Table 4-7 Unconditional Correlation among Long-Term Bond Yields (U.S. QE1 Period)

	US10	UK10	JP10	CH10	BR10	IN10	RU10	AU10	FR10	GE10
US10	1.00									
UK10	0.83***	1.00								
JP10	0.37***	0.27***	1.00							
CH10	0.71***	0.54***	0.04	1.00						
BR10	-0.50***	-0.29***	-0.08	-0.33***	1.00					
IN10	0.80***	0.68***	0.08	0.78***	-0.29***	1.00				
RU10	-0.63***	-0.67***	0.02	-0.51***	0.40***	-0.72***	1.00			
AU10	0.94***	0.75***	0.30***	0.73***	-0.57***	0.81***	-0.70***	1.00		
FR10	0.11**	0.09	0.64***	-0.21***	0.03	-0.29***	0.39***	-0.02	1.00	
GE10	0.63***	0.54***	0.66***	0.27***	-0.29***	0.20***	-0.14***	0.57***	0.76***	1.00

Source: Author's Calculations
***, ** and * represent significant values at 1%, 5% and 10% levels, respectively.

Table 4-8 Unconditional Correlation among Long-Term Bond Yields (U.S. QE2 Period)

	US10	UK10	JP10	CH10	BR10	IN10	RU10	AU10	FR10	GE10
US10	1.00									
UK10	0.94***	1.00								
JP10	0.87***	0.90***	1.00							
CH10	0.37***	0.45***	0.49***	1.00						
BR10	0.61***	0.53***	0.63***	0.17**	1.00					
IN10	-0.24***	-0.31***	-0.20***	0.08	-0.24***	1.00				
RU10	-0.10	-0.11	-0.01	0.35***	-0.03	0.64***	1.00			
AU10	0.74***	0.83***	0.67***	0.23***	0.30***	-0.54***	-0.49***	1.00		
FR10	0.85***	0.79***	0.85***	0.44***	0.76***	-0.04	0.20***	0.43***	1.00	
GE10	0.84***	0.77***	0.84***	0.41***	0.76***	-0.03	0.20***	0.43***	0.99***	1.00

Source: Author's Calculations
***, ** and * represent significant values at 1%, 5% and 10% levels, respectively

Table 4-9 Unconditional Correlation among Long-Term Bond Yields (U.S. QE3 Period)

	US10	UK10	JP10	CH10	BR10	IN10	RU10	AU10	FR10	GE10
US10	1.00									
UK10	0.97***	1.00								
JP10	-0.26***	-0.29***	1.00							
CH10	0.83***	0.87***	-0.51***	1.00						
BR10	0.95***	0.90***	-0.25***	0.77***	1.00					
IN10	0.67***	0.74***	-0.58***	0.87***	0.59***	1.00				
RU10	0.47***	0.46***	-0.62***	0.60***	0.41***	0.57***	1.00			
AU10	0.88***	0.88***	-0.13***	0.79***	0.86***	0.63***	0.19***	1.00		
FR10	0.18***	0.21***	0.64***	0.03	0.19***	-0.03	-0.59***	0.46***	1.00	
GE10	0.40***	0.42***	0.54***	0.20***	0.38***	0.12***	-0.47***	0.63***	0.96***	1.00

Source: Author’s Calculations
***, ** and * represent significant values at 1%, 5% and 10% levels, respectively.

Figure 4.1 reports the daily ten-year generic government bond yield data of the ten bond markets during 2007 to 2016. The vertical bars indicate the date of each individual U.S. QE program was announced by the Federal Reserves. There was a significant decline in most bond yields right after the first announcement of both the U.S. QE1 and QE2 programs. Since then, the global bond yields have gradually decreased. This is consistent with the mean bond yields reported in Tables 4.1, 4.2, 4.3 and 4.4 which show that most of the bond yields are highest during the U.S. QE1 period (seven out of ten markets).

Although mean bond yield values are higher during the U.S. QE1 and QE2 periods, the bond yield volatility (standard deviation) is different. Most of the bond yield volatility values (with the exception of India and Russia in the U.S. QE1 period) are lower than the entire sample values. This suggests that during the U.S. QE periods, the bond yields are less volatile compared to the non-QE period. In other words, for most bond markets, the U.S. QE programs reduce the volatility of the global ten-year bond markets. Conversely, most of the bond volatilities are higher in the QE3 period than the other two QE periods, which suggests that bond yields are more volatile during this period than others.

Apart from the mean and standard deviation values reported, there are other values to discuss. Most of the bond yields are positively skewed during the entire sample period, but the bond yields during each QE period are mostly negatively skewed. This suggests that during the U.S. QE periods, most of the yield change series have long left tails. Most of the kurtosis values are less than 3, which suggests that compared to the normal distribution, the bond yield series have less and fewer extreme outliers and the distribution curves are flatter. Except for some bond yield series during the U.S. QE2 period, none of the series shows any evidence of normal distribution since the Jarque-Bera statistics significantly reject the null hypothesis of normality. Figure 4.2 describes the daily difference data of bond yields (also known as the first difference of the original data), and shows a volatility clustering phenomena in all of the data series. More specifically, the volatility clustering implies large changes on bond yield generally followed by large bond yield changes while small changes on bond yield tend to be followed by small bond yield changes. It is for this reason that I used the GARCH type model in this study. The GARCH model measures the volatility clustering phenomena in financial data (Bollerslev 1986; Bai, Russell & Tiao 2003). Furthermore, the GARCH models allow the bond yield volatility to be dependent on past volatility processes rather than assuming constant volatility.

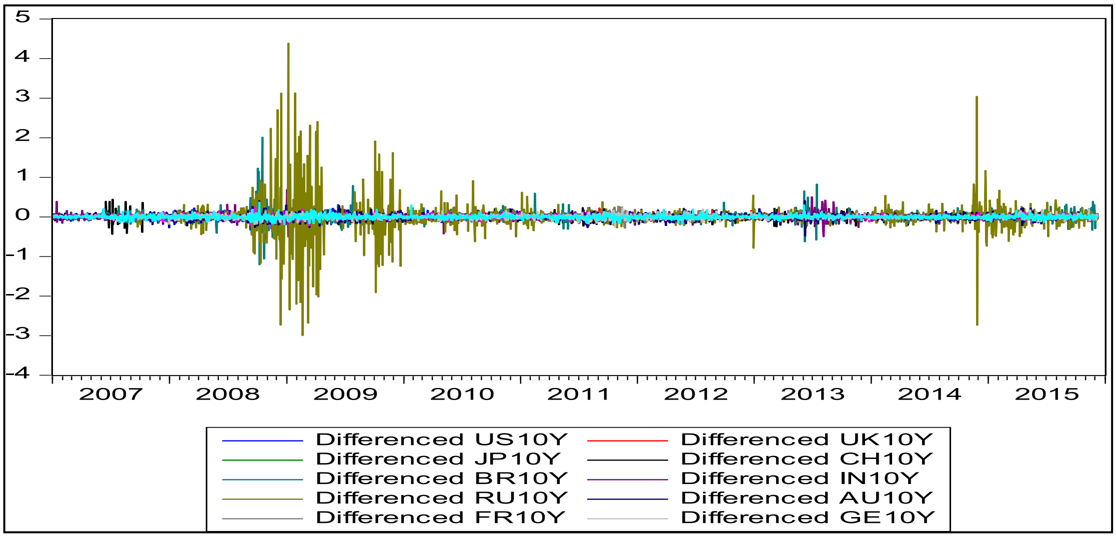

Figure 4-2 Daily Differenced Data of Global Bond Yields (2007 to 2016)

Data Source: Author's Calculations based on Data from Bloomberg and DataStream

In addition to the descriptive statistics presented in Tables 4.1 to 4.4, there are also unconditional correlation values reported in Tables 4.6 to 4.9. As these tables demonstrate, most of the long-term bond markets are significantly correlated during the entire sample period. In advanced markets, the correlation is generally much higher than emerging markets, with the highest (97%), between U.S. ten-year bond yield and the U.K. ten-year bond yield. The correlation between advanced markets is also highly correlated during each of the U.S. QE period. For instance, during the U.S. QE1 period, the correlation between Australia and the U.S. is 94%. During the U.S. QE2 period, the correlation between France and Germany is 99%. In terms of the U.S. QE3 period, the highest correlation is 97% between the U.S. and the U.K. This is no surprise since developed markets have demonstrated higher levels of market integration for many years. However, the situation for emerging markets is different. The correlation within emerging markets is comparatively lower than developed markets, with 87% between China and India during the U.S. QE3 period. Most of the correlation coefficients for emerging markets are less than 50%, some are insignificant. The correlation between emerging and developed markets are negative, which suggests bond yields in advanced and emerging markets move in the opposite direction.

4.2.2 Time Series Property of the Data

Having discussed the descriptive statistics in the previous section, I now describes the unit root test results for the stationary of the data series. Prior to the estimation of either SVAR or DCC-MGARCH models, I apply the unit root test to ensure the data series are statistically stationary, otherwise, there may be spurious regression problems. The spurious regression problem implies that regression results may be statistically meaningless even with high R^2 and the t statistics that appear to be significant (Granger & Newbold, 1974). First of all, based on the visual impression of the bond yield changes, there is a trend and intercept for all of the data series (see Figure 4.1). Therefore, I run the unit root tests with both trend and intercept included for the level. Later on, for the first differenced data, I choose no trend nor intercept (see Figure 4.2). The results in Table 4.10 show that most of the ten-year bond yield series are non-stationary at level (except for JP), while they are all stationary in first differences, which means that the data series are integrated of order 1 (Dickey & Fuller, 1979). Therefore, the first differenced data of all bond yield series are used in the regression model to avoid the spurious regression problem. Another reason of choosing the log differenced data for all bond yield series is the benefit on result discussion and interpretation. Since most financial data is nonstationary and the ranges of value are various from each other, there may be the large value problem when using the level of data. The log differenced data represent the % change of the bond yields rather than the actual changes of the data, which can avoid the too large values in the data analysis. Also based on the various unit root results, most of the data series are I(1) only except for JP. In this case, I choose to adopt I (1) of the data (the log differenced data) for all the data series. This will not provide a large over-differencing problem (only the JP data has been over-differenced).

Table 4-10 Unit Root Results among ADF, DFGLS, PP and Break Point ADF Tests

Markets	ADF	DFGLS	PP	Break Point ADF
US	I(1)	I(1)	I(1)	I(1)
UK	I(1)	I(1)	I(1)	I(1)
JP	I(0)	I(0)	I(0)	I(0)
CH	I(1)	I(1)	I(1)	I(1)
BR	I(1)	I(1)	I(1)	I(1)
IN	I(1)	I(1)	I(1)	I(1)
RU	I(1)	I(1)	I(1)	I(1)
AU	I(1)	I(1)	I(1)	I(1)
FR	I(0)	I(1)	I(0)	I(1)
GE	I(0)	I(1)	I(1)	I(1)

Results based on author's calculation. The null hypothesis for each test is there is a unit root in the data, or in other words, the data series is not stationary.

4.2.3 Tests for Structural Break Points

In order to address the potential structural breaks induced by the U.S. QE policy shocks, I run more tests of the models. First, as stated in section 4.2.2, I run the break point unit root (ADF) tests for all the data series. The tests show similar results with other non-break point unit root tests as stated in Table 4.10.

Regarding the structural breaks in models, first based on the reality and my study design, I test whether the starting and ending dates are the structural break points for all the bond yield data. Based on the joint Chow test results reported in Table 4.11, I reject the null hypothesis of none breaks at these specified breakpoints. This indicates that all of these dates are break points. According to these results, I use different methods to incorporate the structural breaks. In my SVAR models, I not only run the regression on the entire sample, but also divide it into three subsamples. Each subsample measures the global bond yield movements during the different U.S. QE periods. This avoids the potential effects from the structural breaks. In terms of DCC-MGARCH model, I incorporate the dummy variables which represent the individual U.S. QE rounds to control for the potential structural breaks brought by the U.S. QE policies. Besides the structural breaks described in Table 4.11, I also conclude the structural break points suggested by the break point unit root tests in Table 4.12.

Table 4-11 Chow Tests for All Starting and Ending Dates of U.S. QE Policies

Chow Breakpoint Test: 11/25/2008 3/25/2010 11/03/2010 6/27/2011 9/13/2012 10/29/2014

Null Hypothesis: No breaks at specified breakpoints

Varying regressors: All equation variables

Equation Sample: 1/01/2007 12/31/2015

F-statistic	264.9773	Prob. F(60,2269)	0.0000
Log likelihood ratio	4865.828	Prob. Chi-Square(60)	0.0000
Wald Statistic	15898.64	Prob. Chi-Square(60)	0.0000

Author’s calculation.

Table 4-12 Break Point Dates for All Markets from Break Point Unit Root Tests

Market	Level	1st Difference	Log Difference
US	4/27/2012	12/16/2008	11/14/2008
UK	4/11/2012	3/24/2009	10/07/2014
JP	5/25/2007	5/14/2013	11/05/2014
CH	7/23/2014	6/27/2007	9/11/2008

BR	10/24/2012	10/22/2008	4/26/2013
IN	3/28/2014	8/19/2013	11/18/2008
RU	12/04/2012	12/19/2008	11/19/2008
AU	3/21/2007	6/24/2013	3/22/2013
FR	8/14/2013	11/15/2011	12/17/2014
GE	5/15/2012	7/10/2015	1/30/2015

Author's calculation.

I also try to incorporate the log-differenced break point dates (Table 4.12) into the regressions. In case of the SVAR model, I create an individual dummy variables for each markets. The value is zero all before the break point date and then one. I also add the dummy variables which represent the break dates for each series into the DCC-MGARCH models[10].

4.3 Empirical Results and Discussions of Market Integration during the U.S. QE Periods

Having examined the stationarity of the data in previous section, this section presents the empirical results of the market integration level (also known as the market interrelationship) among the international bond markets during different U.S. QE periods. In order to achieve this objective, both the short- and long-term U.S. QE policy shocks are incorporated as exogenous variables within the Structural VAR (SVAR) framework. Before running the SVAR model, I first developed the reduced form VAR model and decided the optimal lag length for each model. Thereafter, I report the contemporaneous coefficients defined in the matrices A and B defined in Chapter 3. I also report the empirical results of both impulse response function and the variance decomposition generated within the SVAR framework.

4.3.1 Optimal Lag Length of Unrestricted VAR Models

As defined in section 4.1, the time series data applied in this study is the change of ten-year bond yield data (also known as the first difference of the ten-year bond yield data), which is all statistically stationary. Prior to using the SVAR model, I developed an unrestricted VAR model that included all of the ten long-term bond yield change data as an endogenous variable. The short-term and long-term U.S. QE policy shocks were also included as exogenous variables. Before estimating the SVAR models, I defined the lag-length of the dependent variables. The value of Akaike information criterion (AIC), Schwarz information criterion (SC) and Hannan-Quinn information criterion (HQ) are

[10] Both the SVAR results and DCC-MGARCH results with different break point dates provide similar findings as the ones without these break points. Since the priority of this study is to examine the impact from U.S. QE periods, and some of the break point dates are not included in the U.S. QE periods. Therefore, I do not include these results in my thesis for the brevity purpose. However, it is available upon requests.

reported in Table 4.13. Table 4.13 shows the AIC, SC and HQ values for both the entire sample period (2007 to 2016) and each U.S. QE period, respectively.

Table 4-13 Information Criteria for Optimal Lag Length

Panel A: Entire Sample Period			
Order	AIC	SC	HQ
0	24.187	24.263	24.215
1	23.438	23.768*	23.558
2	23.32	23.904	23.533*
3	23.21	24.078	23.546
4	23.238*	24.329	23.636
5	23.239	24.585	23.73

Panel B: U.S. QE1 Period			
Order	AIC	SC	HQ
0	21.642	21.989*	21.78
1	20.671*	22.174	21.271*
2	20.812	23.472	21.874
3	20.831	24.648	22.354
4	21.027	26	23.011
5	21.242	27.371	23.687
Panel C: U.S. QE2 Period			
Order	AIC	SC	HQ
0	13.077	13.661*	13.314*
1	12.606*	15.137	13.634
2	12.802	17.28	14.621
3	13.111	19.535	15.72
4	13.404	21.775	16.804
5	13.766	24.083	17.956

Panel D: U.S. QE3 Period			
Order	AIC	SC	HQ
0	19.781	20.024*	19.876
1	19.177	20.228	19.589*
2	19.15*	21.01	19.878
3	19.185	21.853	20.229
4	19.308	22.785	20.669
5	19.382	23.667	21.059

* indicates the optimal lag length selected by each criterion

In line with previous literature (Kang et al., 2016; Kilian 2001; Yang 2005), I decided the optimal lag length for each VAR model based on the AIC criteria, since AIC is of higher accuracy in confidence intervals than other selection criteria in impulse response analysis (Kilian, 2001). Therefore, the lag length is 4 for the SVAR model to estimate the entire sample period, 1 for the U.S. QE1 and QE2 period and 2 for the U.S. QE3 period.

4.3.2 The Contemporaneous Interactions among Global Bond Markets

After deciding the optimal lag length for each SVAR model, for the brevity purpose, I report the coefficients of the structural matrix calculated in each SVAR model shown in Tables 4.6 to 4.9, respectively. In all four tables (Table 4.14 to 4.17), column 1 reports the variance of contemporaneous shocks from each individual bond yield, which is also the coefficients in matrix B defined in Chapter 3. Column 2 reports the contemporaneous influence from the U.S. bond yield to other bond yields. Similarly, columns 3 and 4 represent the contemporaneous influence from the U.K. and Japanese yields to other bond yields, respectively. As defined in Chapter 3, I assumed that the U.S. bond yield could affect others (including the U.K. and Japan). Also I believed that the U.K. bond yield can influence other bond yields (only except for the U.S.). The Japan bond yield could affect bond yields other than the U.S. and the U.K. These assumptions were made not only based on the fact that all three markets (the U.S., the U.K. and Japan) are leading economies, but also because these three economies implemented QE policies during the sample period.

In terms of the contemporaneous effects from the U.S. bond market, most of them (both emerging and developed markets) are significant (see Table 4.14) during the entire sample period and within the U.S. QE1 period (see Table 4.15). However, for the later U.S. QE periods (the U.S. QE2 and QE3 periods), there are less significant contemporaneous effects from the U.S. bond market (see Table 4.16 and 4.17). This suggests that the integration level between the U.S. and other bond markets gradually declined over the U.S. QE periods. Moreover, the negative significant coefficients of the contemporaneous effects from the U.S. indicates a reverse trend between the U.S. bond yields and the bond yield in other markets. When compared to the contemporaneous impact from the U.K. and Japanese bond markets, the U.S. contemporaneous effects are more significant during the U.S. QE1 and QE3 periods (see Table 4.16). The reason may be that both the U.S. QE1 and QE3 policies carried more unexpected shocks to the markets than the U.S. QE2 policy. More specifically, the U.S. QE1 policy was the first unconventional monetary policy implemented after the 2008 financial crisis, which was unanticipated. In terms of the U.S. QE3 policy, although it was less unexpected compared to the U.S. QE1 and QE2 policies, it did contain information about the halt of future U.S. QE policies, which was unanticipated. In general, the contemporaneous effects from the U.S. bond market were larger than the U.K's and Japanese for the most part; this suggests that the market interrelationship between the U.S. and others are higher than those of the U.K. and Japan.

4.3.3 Impulse Response Analysis

Apart from the contemporaneous coefficients estimated in the SVAR models, I also examined market integration levels based upon the impulse response function generated from the SVAR models[11]. Impulse response analysis examines how long it takes for bond yields to return to zero level following one standard deviation shock in other bond markets. The shorter the response time (to return to pre-shock levels), the faster the speed of adjustment, which indicates a higher level of market integration (Phylaktis, 1999). Figures 4.3 to 4.5 show global bond impulse responses towards the U.S., the U.K. and Japanese bond market shocks during the entire sample period (2007 to 2016). Figures 4.6 to 4.8 report global bond impulse responses towards the U.S., the U.K. and Japanese bond shocks during the U.S. QE1 period. Figures 4.9 to 4.11 and Figures 4.12 to 4.14 depict global bond responses towards the U.S., the U.K. and Japan shocks during the U.S. QE2 and QE3 periods, respectively.

Figures 4.3 to 4.5 display the global bond yield impulse responses to the shocks of the U.S., the U.K. and Japanese bond markets during the last decade (2007 to 2016), respectively. Specifically, most bond yields (only except for China and Russia) have a significant and positive response towards the U.S. shocks. This response reduces and then vanishes (becomes insignificant) instantly within three trading dates. In terms of the Chinese bond yields, they seem to be immune from the U.S. shocks. However, for the Russian markets, the bond yields exhibit a negative but gradually increase response to the U.S. shocks. In case of the U.K. and Japanese shocks, they have less pronounced impact on especially the bond yields in emerging markets as well as the U.S. markets. Another interesting finding is that, for the U.S. bond yields, their impulse responses are only significant to their own shocks. During this period, the global bond yields adjust quicker following the U.S. bond yield shocks than following the U.K. and Japanese bond shocks. Following the U.S. bond shocks, the bond yield responses in developed markets generally lasted for one week and then returned to zero level. As for the emerging bond yields, it took less than ten days to go back to zero level. In the case of the U.K. and Japanese bond shocks, the responses from the global bond yields lasted approximately ten days. This indicates that over the last decade (2007 to 2016), the global bond markets adjusted quicker to the U.S. bond shocks than the U.K. and Japanese shocks.

Meanwhile, most of the bond yields showed positive responses following the U.S., U.K. and Japanese bond shocks. Russia was the only market that exhibited negative instant responses to the bond yield shocks from the U.S., the U.K. and Japan. In terms of the magnitude of the responses, the U.S. bond shocks triggered larger responses than the U.K. and Japanese bond yield shocks. Specifically, all of the developed bond yields ranged more than 30% intervals due to the U.S. bond shocks (the widest fluctuating interval was the U.S. bond yield ranges from 80% to -5%), while for the emerging bond yields, they fluctuated within 10% intervals. As for the impulse responses towards the U.K. and

[11] Only the impulse response results from the U.S., the U.K. and Japan shocks are reported in this study.

Japanese bond shocks, most of the bond yields changed within 10% intervals, some within 5% intervals. Based on the speed adjustment of the global bond markets, and the magnitude of the responses following the U.S., U.K. and Japanese bond shocks, it is evident that the global bond markets are more integrated with the U.S. bond markets than with the U.K. and Japanese markets.

Figures 4.6 to 4.8 portray the impulse response results from the global bond markets following the U.S., U.K. and Japanese bond shocks during the U.S. QE1 period. As with the impulse responses for the entire sample period (2007 to 2016), most of the bond yields responded positively to the U.S., U.K. and Japanese bond shocks immediately after the shocks. However, compared to the adjustment speed of the impulse responses from 2007 to 2016, the adjusted speed of the responses during the U.S. QE1 were faster. During the U.S. QE1 period, the impulse responses following the U.S. bond shocks generally lasted for five days, which was considerably shorter than the responses (from 5 to 12 days) from the previous decade (2007 to 2016).

During the U.S. QE1 period, the adjusted speed of the global bond yields in response to the U.K. and Japanese bond shocks also increased. It took approximately 7 days for global bond yields to respond to the U.K. and Japanese bond shocks during the U.S. QE1 period. However, the impulse responses for the global bond yields due to the U.K. and Japan bond shocks generally lasted 10 days. This suggests that during the U.S. QE1 period, market integration levels between all three markets (the U.S., the U.K. and Japan) and global bond markets are increasing. In terms of the magnitude of the impulse responses, the emerging bond yields responded (following the U.S. bond shocks) were more volatile than during the entire sample period. For example, the Brazilian bond yield ranged from 20% to zero level due to the U.S. bond shocks (during the U.S. QE1 period), while the interval ranged from 10% to -1% from 2007 to 2016. Similar to the U.S. bond shocks, the U.K. and Japanese bond yield shocks also triggered more intense emerging bond yield responses during the U.S. QE1 period. For instance, Russian bond yields changed from 5% to -25% in response to the U.K. shock during the U.S. QE1 period. However, for the entire sample period, following the U.K. shocks, Russian bond yields fluctuated from 4% to -4%. In the case of the Japanese shocks, Russian bond yields dropped from 15% to zero level during the U.S. QE1 period. When considering the entire sample period, Russian bond yield fluctuated within intervals of 3% to -1%.

In terms of impulse responses during the U.S. QE2 and QE3 periods, the results are similar to the responses during the U.S. QE1 period (see Figure 4.9 to 4.14). The global bond impulse responses towards all three markets (the U.S., the U.K. and the Japanese) last for a shorter period than the ones during the entire sample period (2007 to 2016). This faster speed of global bond yield adjustment indicates higher levels of integration between these three markets and the global bond markets. The positive responses from most bond markets suggests a positive co-movements of global bond yields. In other words, most of the bond yields tended to move in the same direction during this time. The emerging bond yield fluctuated more following the U.S., U.K. and Japanese shocks during the U.S. QE2 and QE3 periods than during the entire sample period. This is consistent with emerging bond yield responses during the U.S. QE1 period, which suggests a larger response in emerging markets during the U.S. QE periods.

4.3.4 Variance Decomposition Analysis

The variance decomposition analysis tests what proportion the variance of each dependent variable changes in response to the shocks. I use variance decomposition to examine how much of the bond yield variance changes due to the U.S., U.K., Japanese and domestic bond market shocks[12]. Table 4.18 reports the variance decomposition results of global bond yields variance decomposed by the U.S., U.K., Japan, along with the domestic factors. Each bond yield is decomposed and forecasted for 1, 5, 10 and 15 days (Horizon column in Table 4.18). In Table 4.18, there are four columns within each decomposed factor (the U.S., U.K., Japan and domestic factors), which represents the different SVAR results estimated to examine global bond market integration levels during the entire sample period (entire column), and the U.S. QE1, QE2 and QE3 periods, respectively. Most of the bond yield variances are subject to domestic factors. During the entire sample period, the domestic shocks accounted for all of the bond yield variances from the sample markets; the highest, in the U.S. bond yield variance can be fully explained by the initial domestic shocks. Likewise, the lowest, in the German bond market, with around 60% of the bond yield variance, can be explained by the domestic shocks. The effects from the domestic shocks on the most developed bond yield variances gradually reduce over ten 10 days following the initial domestic shocks. Thereafter, the effects of domestic shocks on developed bond yield variances are stable. However, the effects of domestic shocks on emerging bond yield variances are more constant when compared with developed bond yield variances. Emerging bond yield variances (due to domestic shocks) tended to change only 5 days after the initial domestic shocks happened. This suggests that emerging bond yield variances are more subject to domestic shocks rather than external shocks or those from other markets. In the case of developed bond yield variances, these were not only affected by domestic shocks, but also by external shocks as well. This indicates that developed bond markets are more integrated with global bond markets than emerging markets.

[12] Only global bond markets variances decomposed by the U.S., U.K., and Japan (and domestic factors) are reported in this study.

This study found several interesting observations related to the effects of the shocks in the U.S. QE periods. Firstly, compared to the entire sample period, most of the bond yield variances were less affected by their domestic shocks. Only a few bond yield variances were more subject to their domestic shocks during the U.S. QE periods than the entire sample period (the U.K. and Japan during the U.S. QE1 period and India and Australia during the U.S. QE3 period). Most developed bond yield variances were affected less by domestic shocks than the emerging bond yield variances. This indicates that global bond markets, especially the developed bond markets, are more integrated with each other during the U.S. QE periods.

Moreover, compared to the bond yield variances induced by external shocks (from the U.S., the U.K. and Japanese markets) during entire sample period, within the three U.S. QE periods, most of the bond yield variance changes were the result of external shocks, not only from the U.S., but also from the U.K. and Japanese markets. The increasing proportion of the bond yield variance changes explained by external shocks, suggests growing market integration levels for global bond markets, among the U.S., the U.K. and Japanese markets. However, most bond yield variance changes were more affected by the U.S. shocks than by those from the U.K. or Japan; this indicates that global bond markets are much more integrated with U.S. bond markets than with the U.K. and Japanese markets.

In terms of the U.S. shocks, there was an increasing proportion of bond yield variance changes in most developed markets, induced by the U.S. shocks during the U.S. QE2 and QE3 periods. This growing trend indicates that during the U.S. QE2 and QE3 periods, most developed bond yield variance changes were affected by the U.S. shocks than during the U.S. QE1 period. However, the bond yield variance changes in emerging markets were more affected by the U.S. shocks, particularly during the U.S. QE1 period. This means that emerging markets are far more integrated with the U.S. bond market in the U.S. QE1 period, while developed markets are more integrated with the U.S. market in the U.S. QE3 period. .

Table 4-14 Structural Matrix Coefficients for the Entire Sample Period

	Coefficient		Coefficient		Coefficient		Coefficient
C_{US}	0.797***	C_{USUK}	-0.512***	C_{UKJP}	-0.082**	C_{JPCH}	-0.001
C_{UK}	0.709***	C_{USJP}	-0.099***	C_{UKCH}	0.004	C_{JPBR}	-0.027
C_{JP}	1.128***	C_{USCH}	-0.018	C_{UKBR}	-0.004	C_{JPIN}	-0.002
C_{CH}	0.592***	C_{USBR}	-0.111***	C_{UKIN}	0.021*	C_{JPRU}	0.01
C_{BR}	0.934***	C_{USIN}	-0.027**	C_{UKRU}	0.065*	C_{JPAU}	-0.061***
C_{IN}	0.371***	C_{USRU}	0.056	C_{UKAU}	-0.114***	C_{JPFR}	-0.078***
C_{RU}	1.201***	C_{USAU}	-0.055***	C_{UKFR}	-0.598***	C_{JPGE}	-0.089***
C_{AU}	0.574***	C_{USFR}	-0.081***	C_{UKGE}	-1.125***		
C_{FR}	0.893***	C_{USGE}	-0.191***				
C_{GE}	1.323***						

Source: Author’s Calculations

***, ** and * represent significant values at 1%, 5% and 10% levels, respectively

Table 4-15 Structural Matrix Coefficients for the U.S. QE1 Period

	Coefficient		Coefficient		Coefficient		Coefficient
C_{US}	0.865***	C_{USUK}	-0.266***	C_{UKJP}	-0.023	C_{JPCH}	0.044
C_{UK}	0.764***	C_{USJP}	-0.041	C_{UKCH}	-0.025	C_{JPBR}	-0.227**
C_{JP}	0.577***	C_{USCH}	-0.081**	C_{UKBR}	0.08	C_{JPIN}	-0.056
C_{CH}	0.602***	C_{USBR}	-0.217***	C_{UKIN}	0.074	C_{JPRU}	-0.245
C_{BR}	1.009***	C_{USIN}	-0.108**	C_{UKRU}	0.328*	C_{JPAU}	-0.26***
C_{IN}	0.644***	C_{USRU}	-0.057	C_{UKAU}	-0.019	C_{JPFR}	0.007
C_{RU}	2.559***	C_{USAU}	-0.127***	C_{UKFR}	-0.406***	C_{JPGE}	-0.01
C_{AU}	0.537***	C_{USFR}	-0.067***	C_{UKGE}	-0.505***		
C_{FR}	0.381***	C_{USGE}	-0.105***				
C_{GE}	0.437***						

Source: Author’s Calculations

***, ** and * represent significant values at 1%, 5% and 10% levels, respectively

Table 4-16 Structural Matrix Coefficients for the U.S. QE2 Period

	Coefficient		Coefficient		Coefficient		Coefficient
C_{US}	0.709***	C_{USUK}	-0.374***	C_{UKJP}	-0.309**	C_{JPCH}	-0.097*
C_{UK}	0.441***	C_{USJP}	-0.039	C_{UKCH}	0.031	C_{JPBR}	-0.044
C_{JP}	0.765***	C_{USCH}	0.035	C_{UKBR}	0.3**	C_{JPIN}	-0.003
C_{CH}	0.536***	C_{USBR}	-0.305***	C_{UKIN}	0.023	C_{JPRU}	0.114*
C_{BR}	0.784***	C_{USIN}	0.003	C_{UKRU}	-0.196*	C_{JPAU}	-0.133***
C_{IN}	0.2***	C_{USRU}	0.134*	C_{UKAU}	-0.135***	C_{JPFR}	0.011
C_{RU}	0.601***	C_{USAU}	0.027	C_{UKFR}	-0.619***	C_{JPGE}	0.035
C_{AU}	0.286***	C_{USFR}	0.013	C_{UKGE}	-0.81***		
C_{FR}	0.348***	C_{USGE}	-0.041				
C_{GE}	0.423***						

Source: Author’s Calculations
***, ** and * represent significant values at 1%, 5% and 10% levels, respectively

Table 4-17 Structural Matrix Coefficients for the U.S. QE3 Period

	Coefficient		Coefficient		Coefficient		Coefficient
C_{US}	0.672***	C_{USUK}	-0.636***	C_{UKJP}	-0.054	C_{JPCH}	0.006
C_{UK}	0.613***	C_{USJP}	-0.114	C_{UKCH}	-0.035	C_{JPBR}	-0.022
C_{JP}	1.107***	C_{USCH}	-0.032	C_{UKBR}	-0.095	C_{JPIN}	0.005
C_{CH}	0.578***	C_{USBR}	-0.25***	C_{UKIN}	0.01	C_{JPRU}	0.003
C_{BR}	1.014***	C_{USIN}	0.016	C_{UKRU}	0.037	C_{JPAU}	-0.048*
C_{IN}	0.356***	C_{USRU}	0.031	C_{UKAU}	-0.062	C_{JPFR}	-0.047**
C_{RU}	0.54***	C_{USAU}	-0.027	C_{UKFR}	-0.527***	C_{JPGE}	-0.047**
C_{AU}	0.63***	C_{USFR}	-0.077*	C_{UKGE}	-0.883***		
C_{FR}	0.579***	C_{USGE}	-0.169***				
C_{GE}	0.546***						

Source: Author’s Calculations
***, ** and * represent significant values at 1%, 5% and 10% levels, respectively

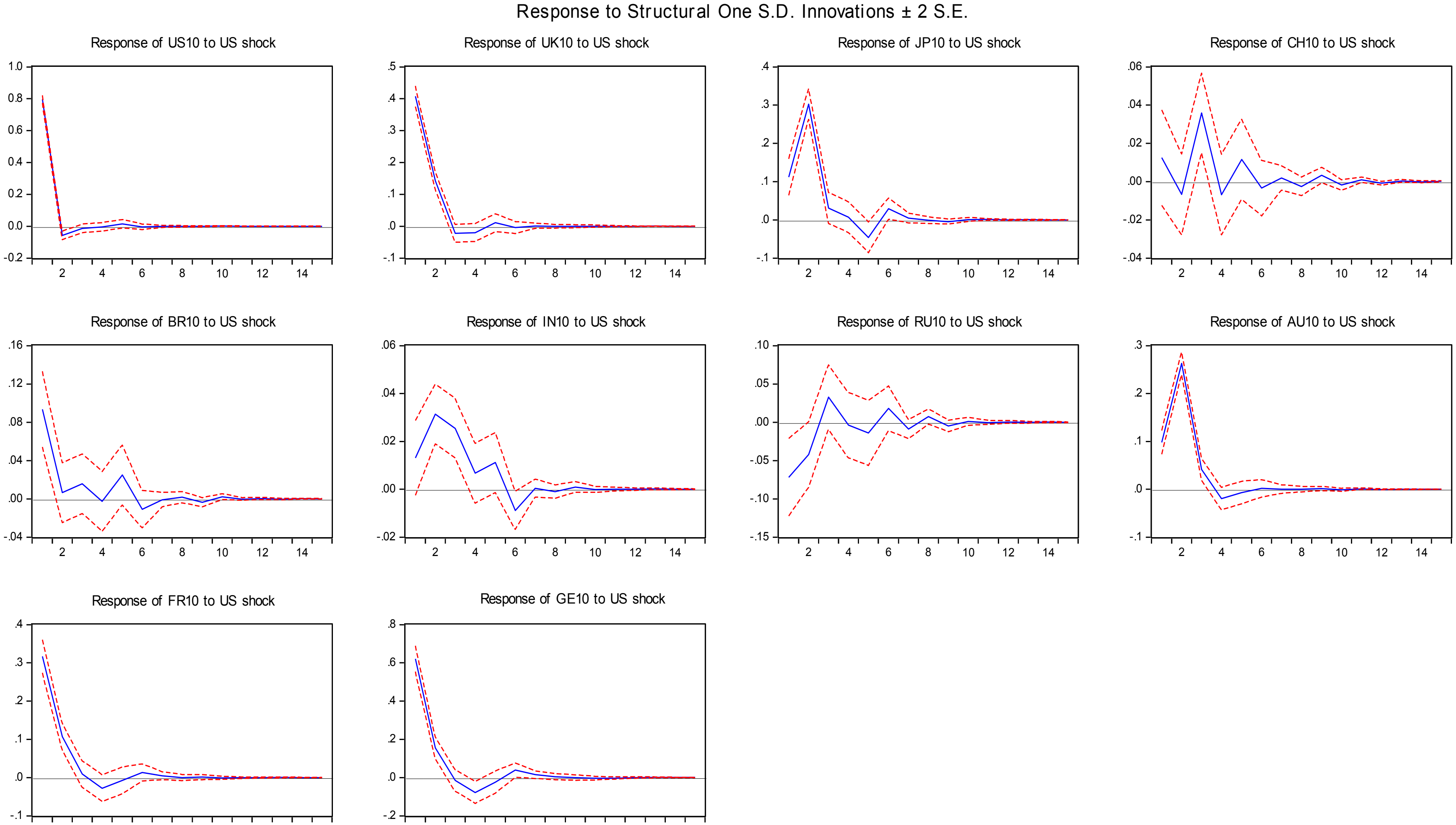

Figure 4-3 Impulse Responses to U.S. Bond Shocks (2007 to 2016)

Source: Author's Calculations

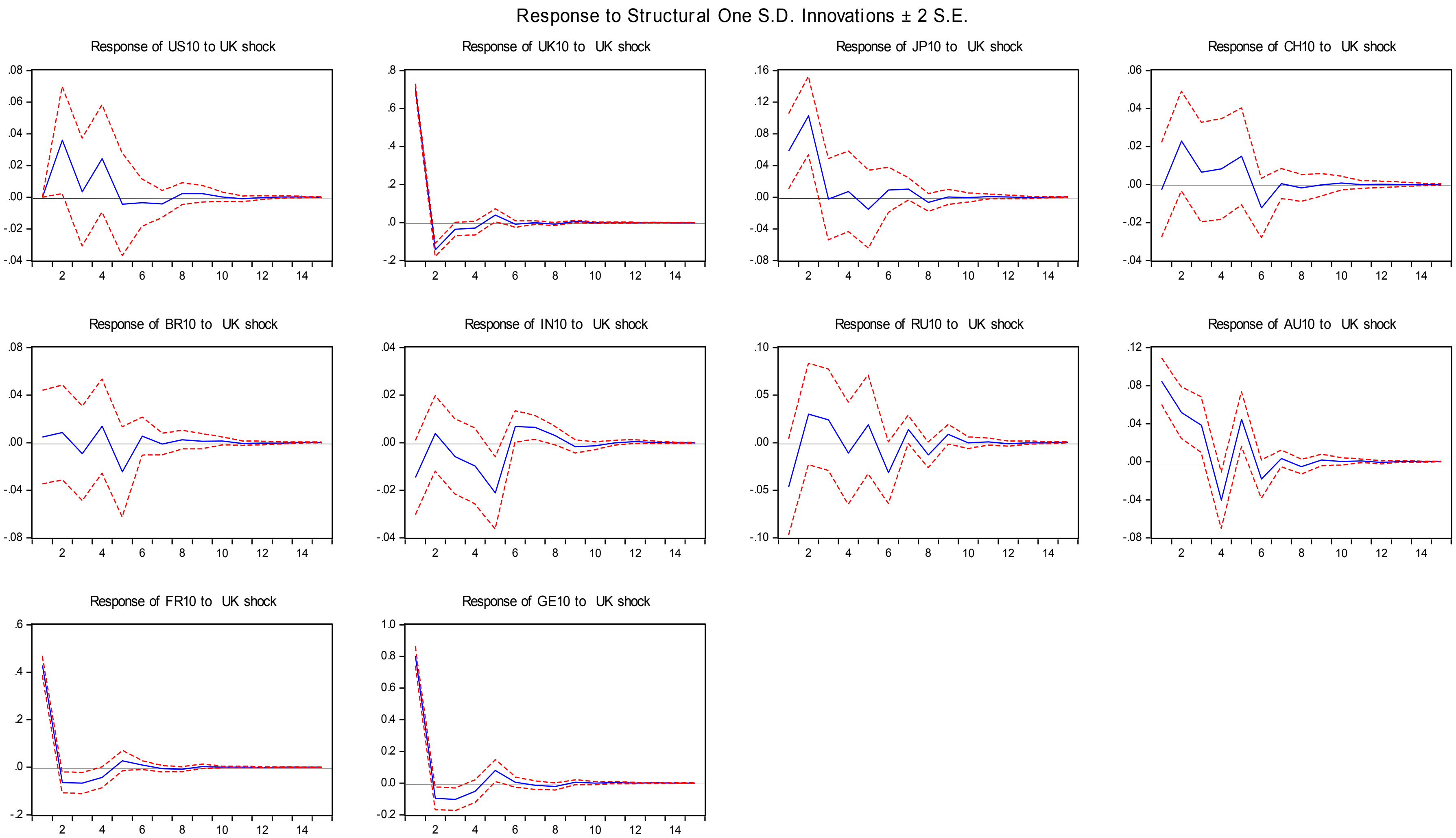

Figure 4-4 Impulse Responses to the U.K. Bond Shocks (2007 to 2016)

Source: Author's Calculations

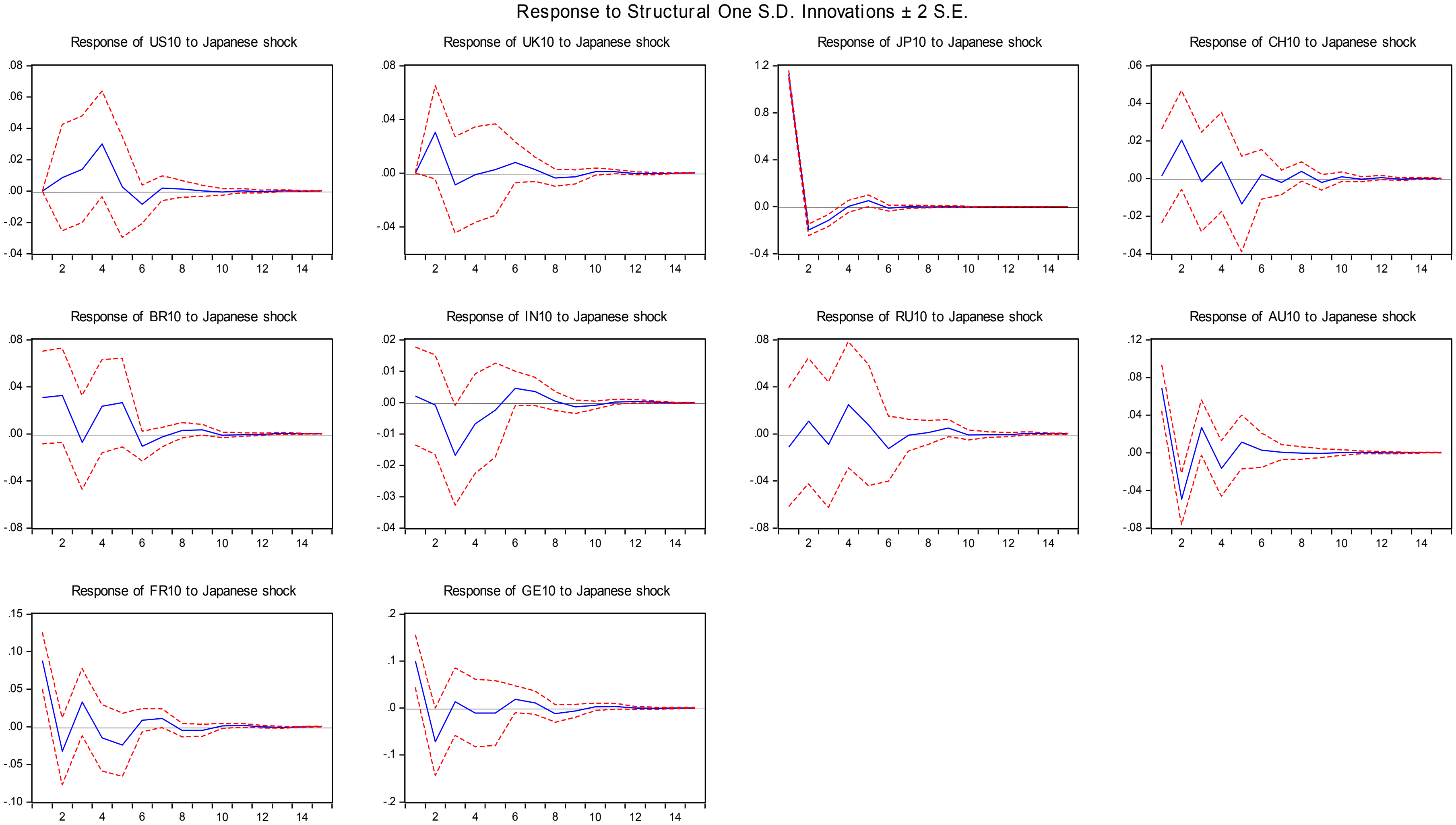

Figure 4-5 Impulse Responses to Japanese Bond Shocks (2007 to 2016)

Source: Author's Calculations

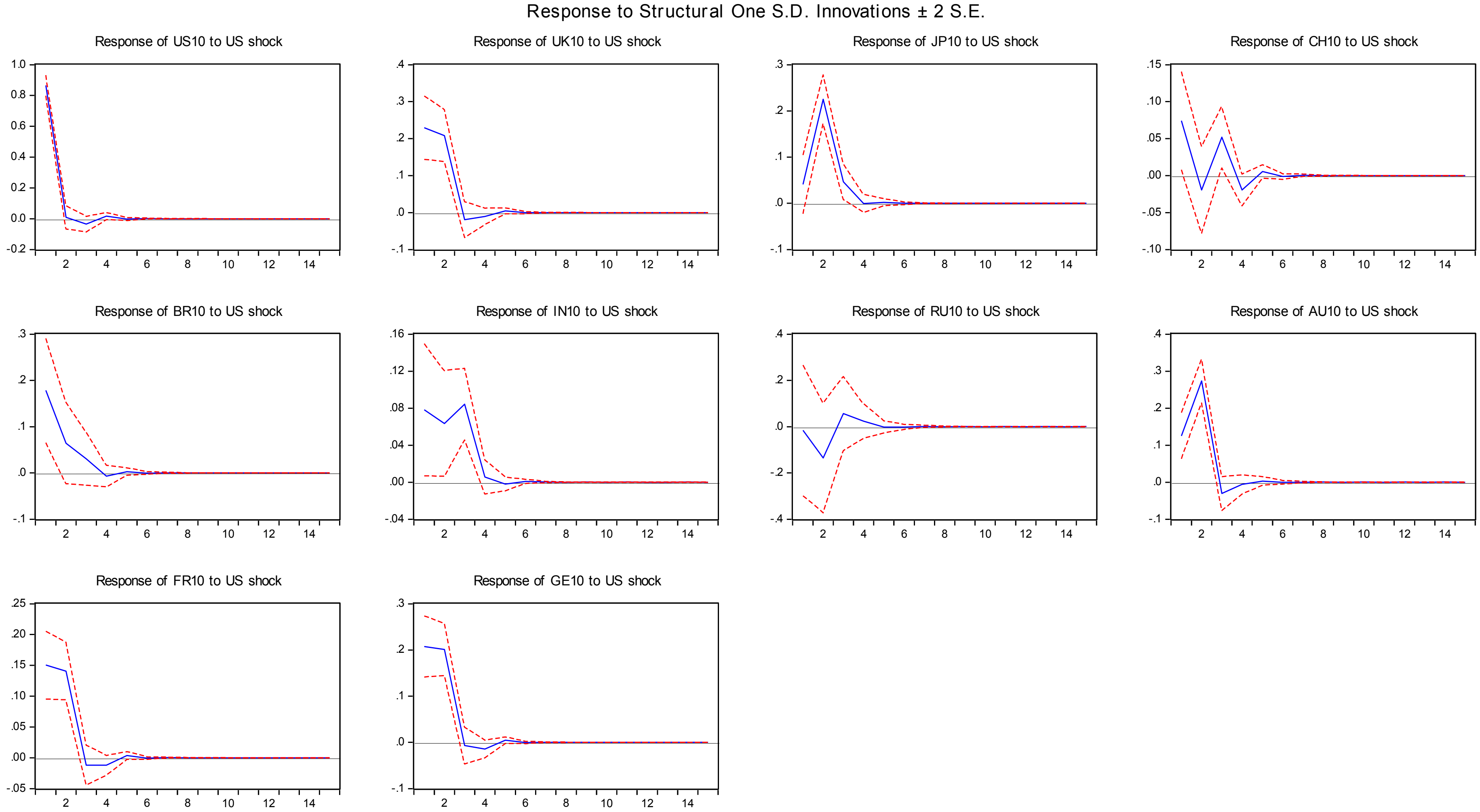

Figure 4-6 Impulse Response to U.S. Bond Shocks during the U.S. QE1 Period

Source: Author's Calculations

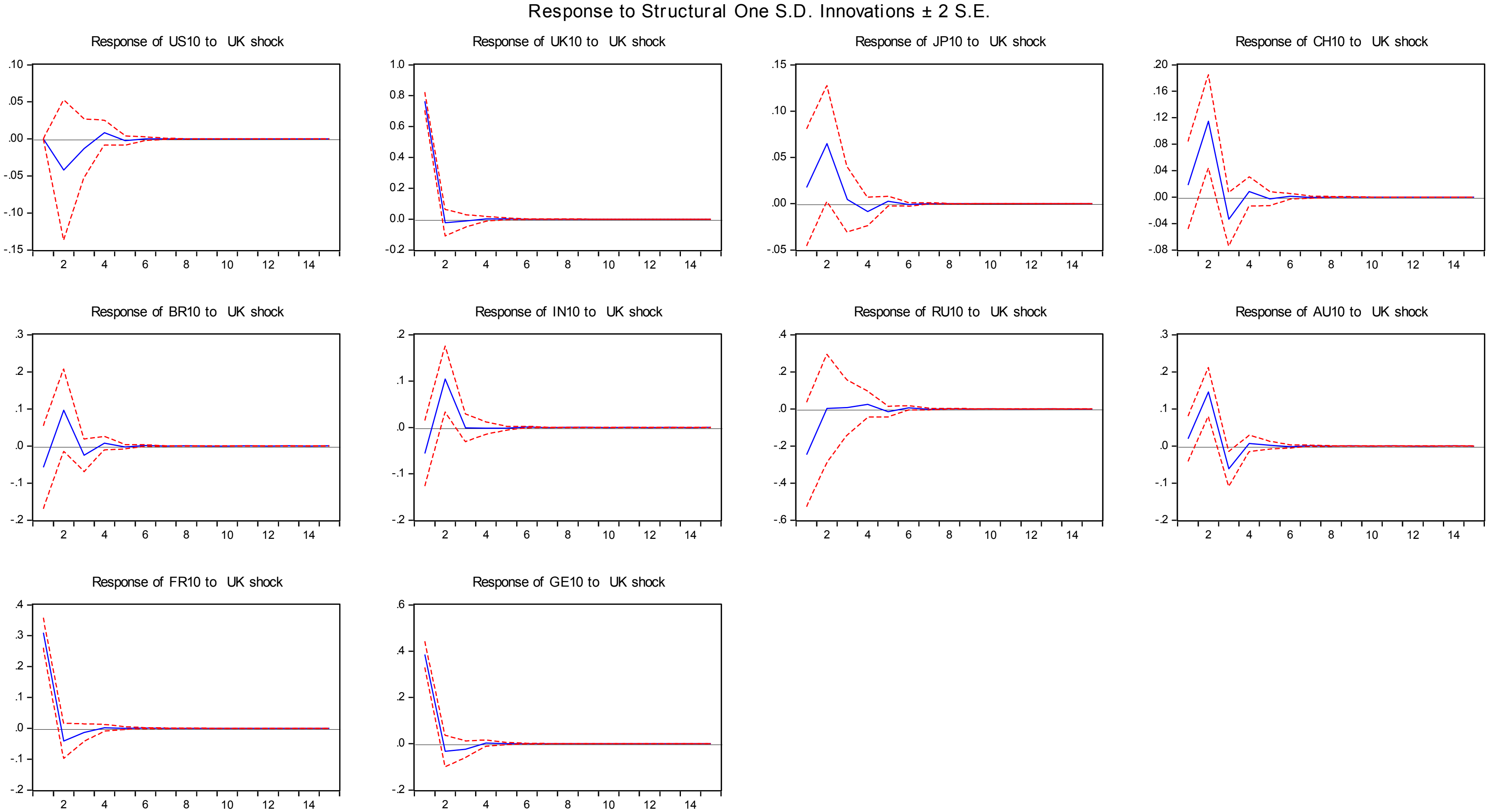

Figure 4-7 Impulse Responses to the U.K. Bond Shocks during the U.S. QE1 Period

Source: Author's Calculations

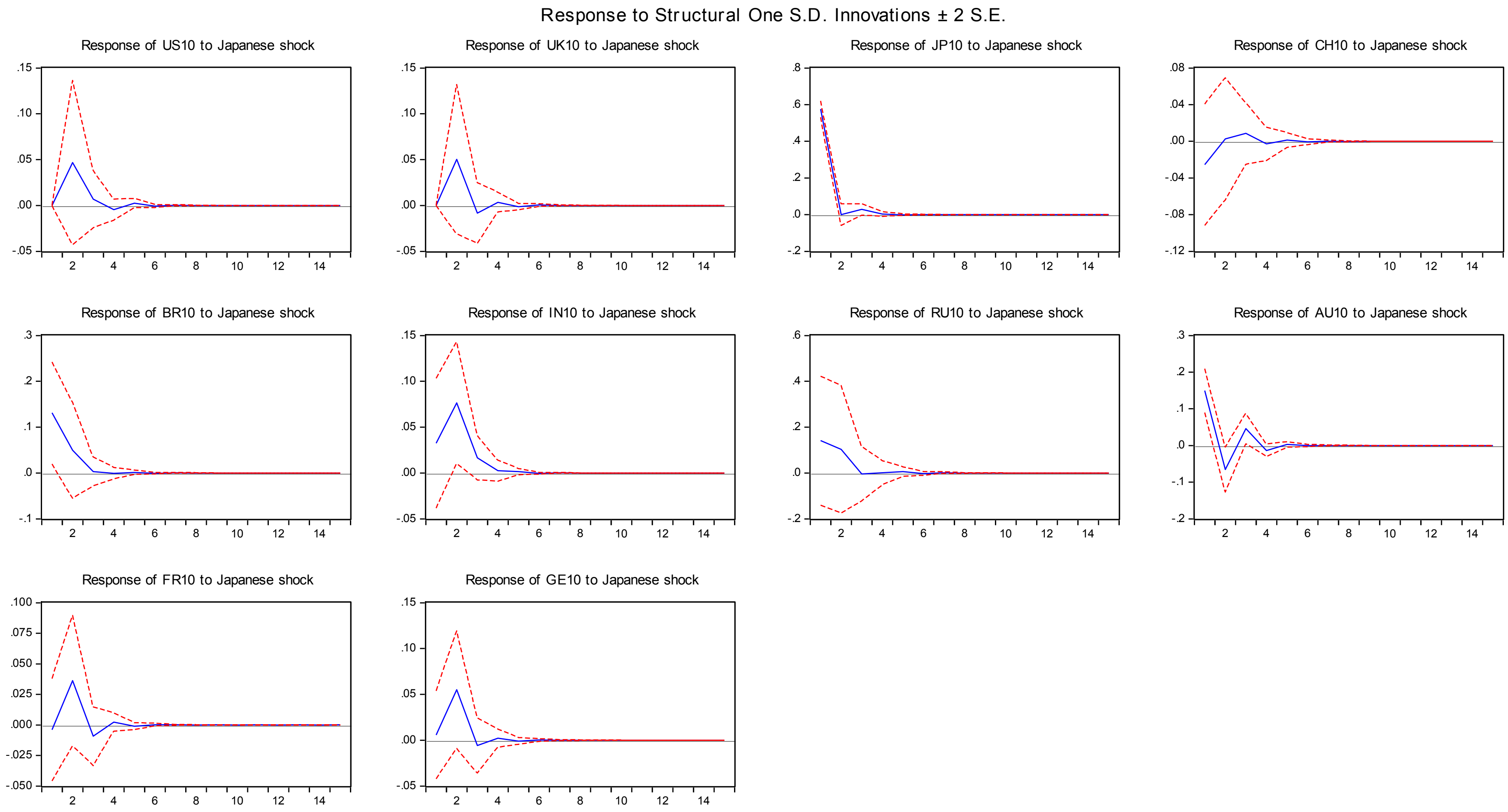

Figure 4-8 Impulse Responses to Japanese Bond Shocks during the U.S. QE1 Period

Source: Author's Calculations

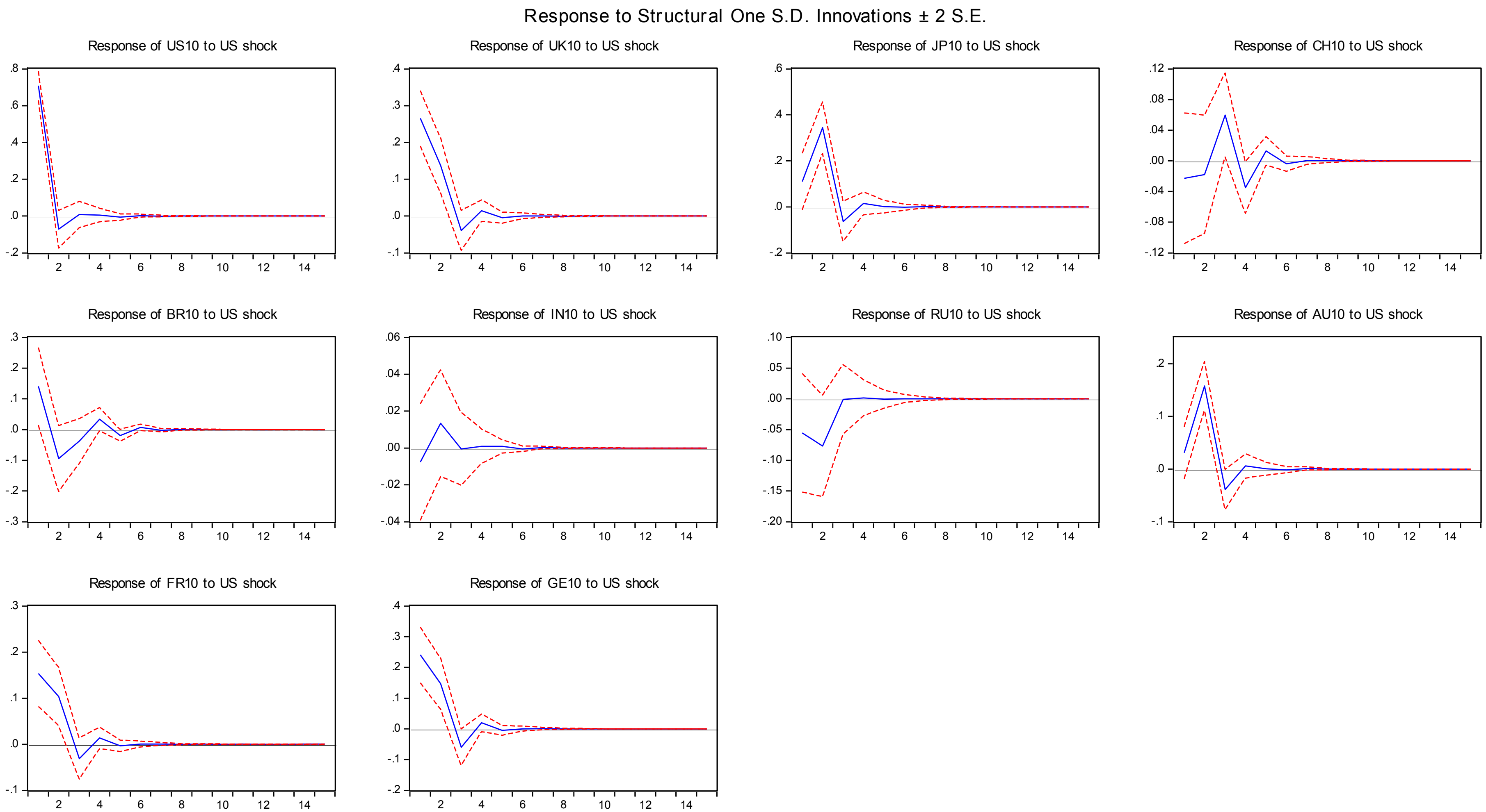

Figure 4-9 Impulse Response to U.S. Bond Shocks during the U.S. QE2 Period

Source: Author’s Calculations

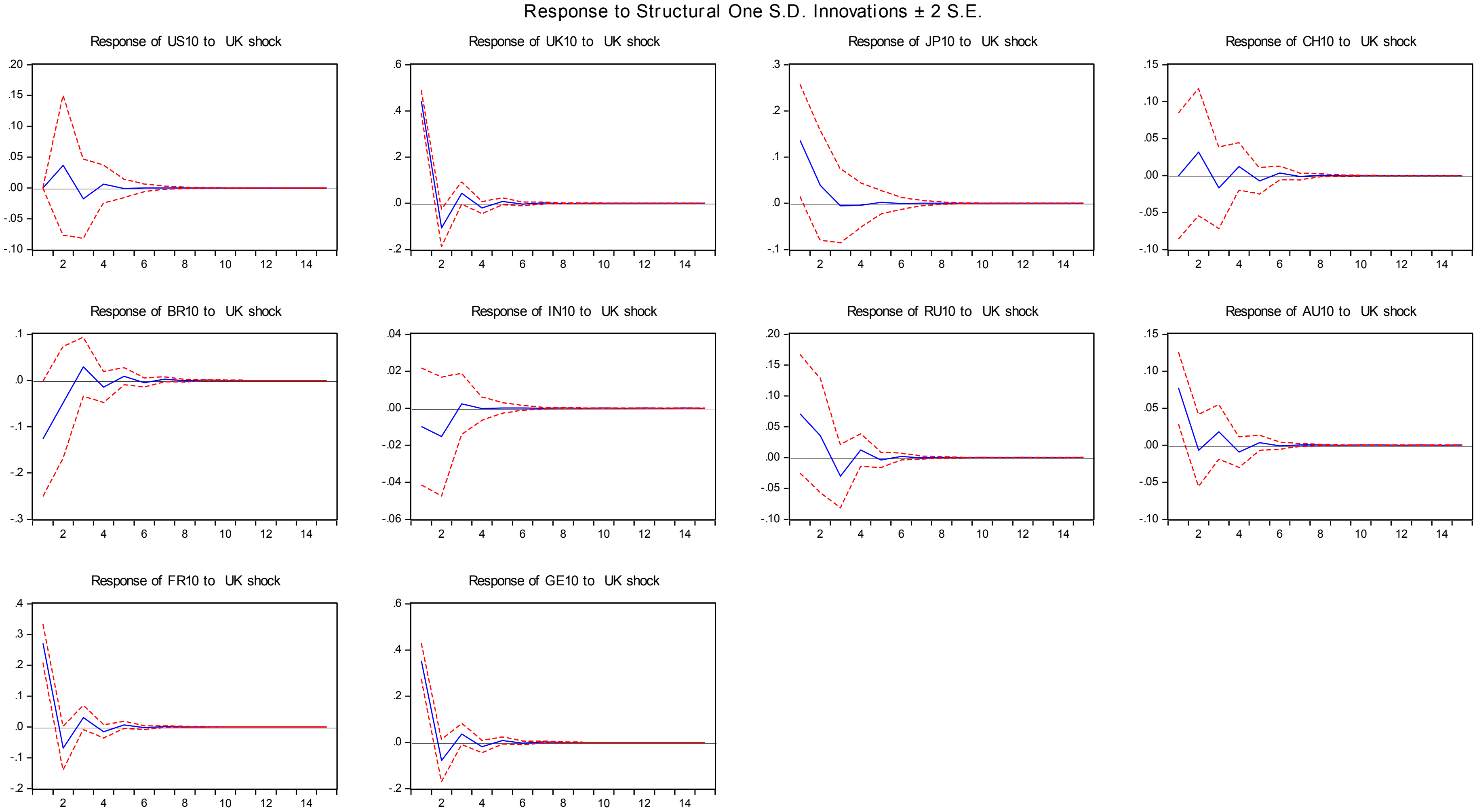

Figure 4-10 Impulse Response to U.K. Bond Shocks during the U.S. QE2 Period

Source: Author's Calculations

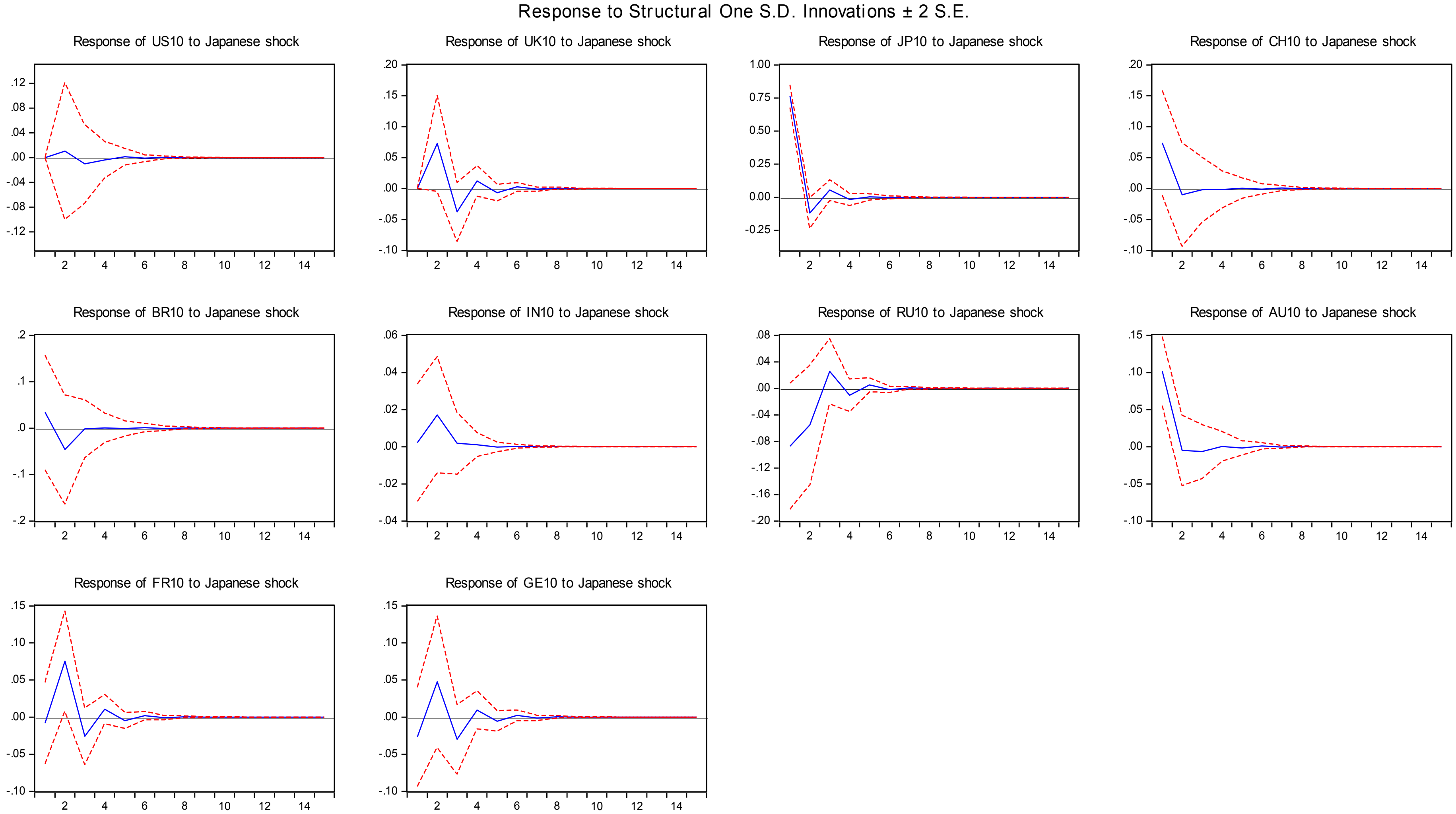

Figure 4-11 Impulse Response to Japanese Bond Shocks during the U.S. QE2 Period

Source: Author's Calculations

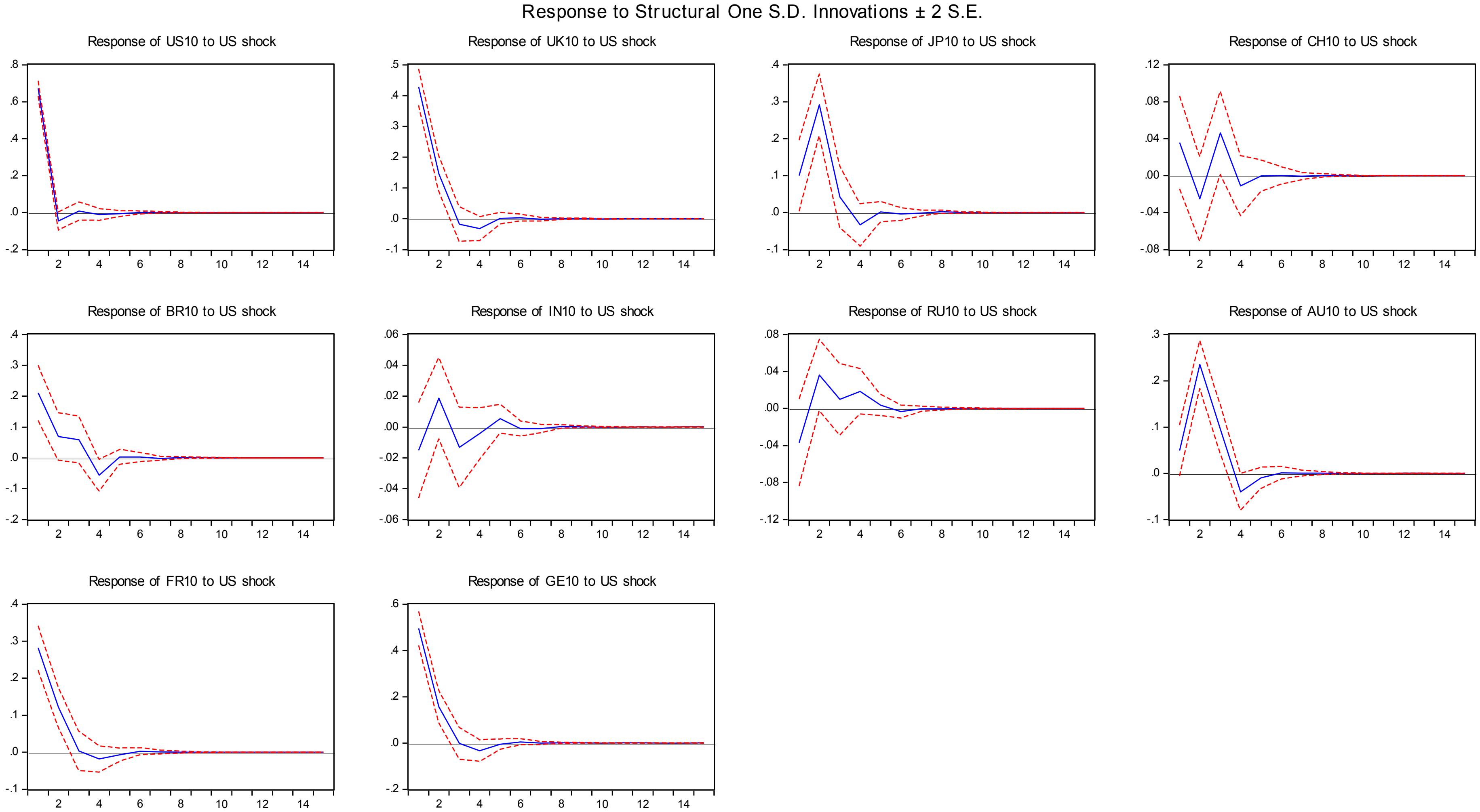

Figure 4-12 Impulse Responses to U.S. Bond Shocks during the U.S. QE3 Period

Source: Author's Calculations

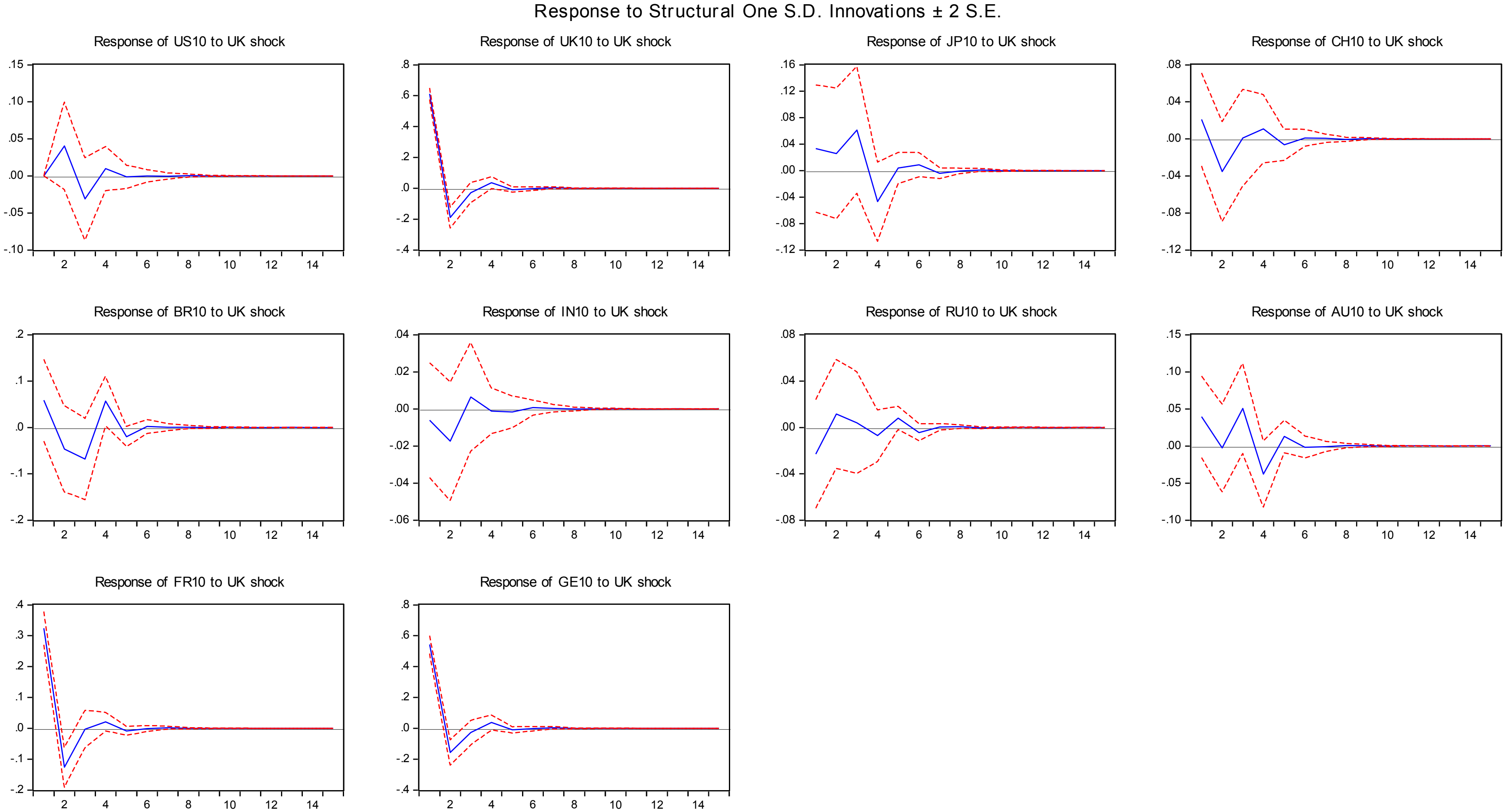

Figure 4-13 Impulse Responses to U.K. Bond Shocks during the U.S. QE3 Period

Source: Author's Calculations

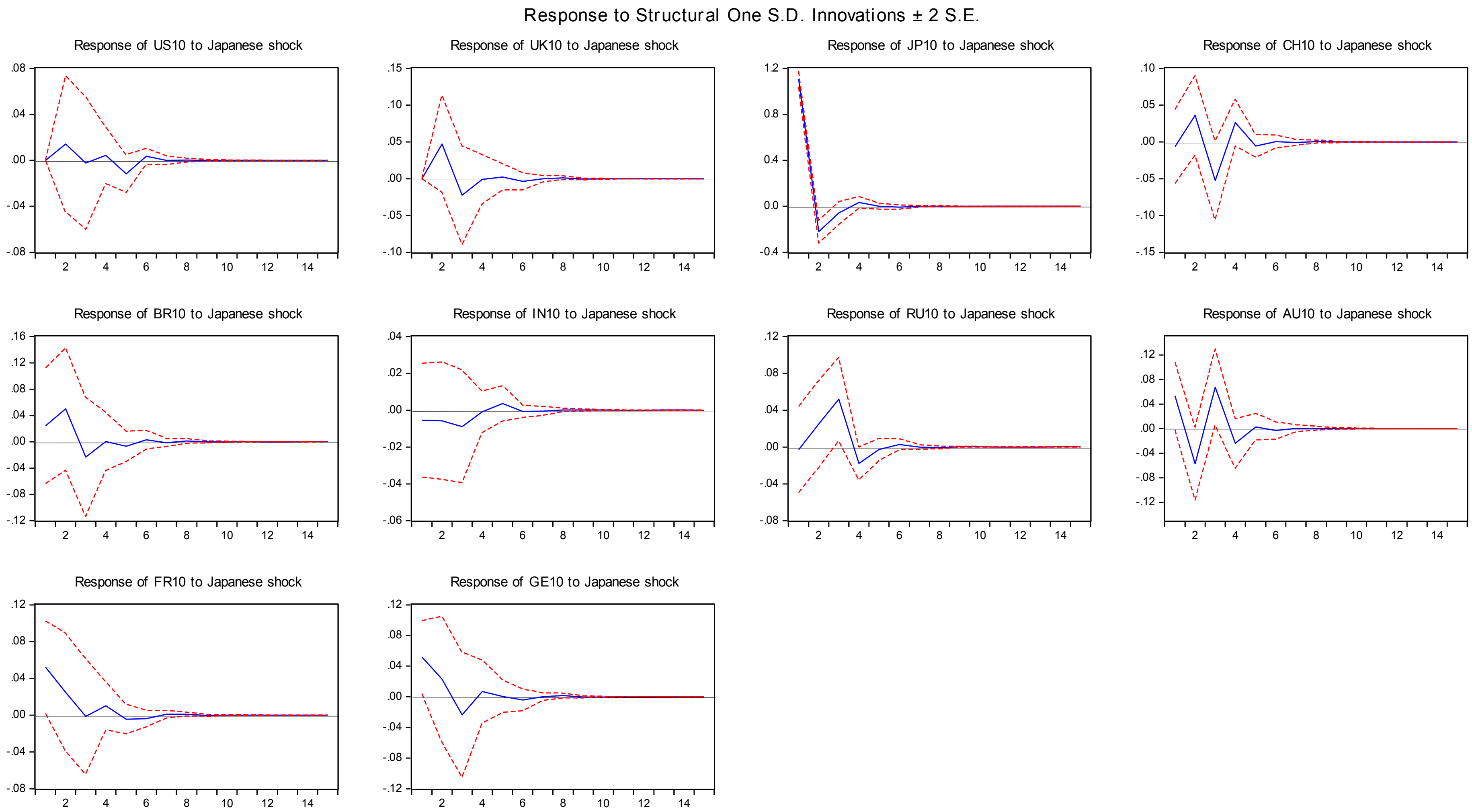

Figure 4-14 Impulse Responses to Japanese Bond Shocks during the U.S. QE3 Period

Source: Author's Calculations

Table 4-18 Variance Decomposition with the U.S., U.K., Japanese and Domestic Yields (%)

Markets	Horizon	US				UK				JP				Domestic			
		Entire	USQE1	USQE2	USQE3	Entire	USQE1	USQE2	USQE3	Entire	USQE1	USQE2	USQE3	Entire	USQE1	USQE2	USQE3
US	1	100	100	100	100	0	0	0	0	0	0	0	0	100	100	100	100
	5	98.849	92.574	82.704	92.744	0.291	0.248	0.276	0.551	0.178	0.28	0.037	0.074	98.849	92.574	82.704	92.744
	10	96.387	92.574	82.702	92.728	0.296	0.248	0.276	0.551	0.189	0.28	0.038	0.077	96.387	92.574	82.702	92.728
	15	96.274	92.574	82.702	92.728	0.297	0.248	0.276	0.551	0.189	0.28	0.038	0.077	96.274	92.574	82.702	92.728
UK	1	24.862	8.283	26.609	32.754	75.138	91.717	73.391	67.246	0	0	0	0	75.138	91.717	73.391	67.246
	5	25.465	13.462	26.596	31.486	71.442	81.685	60.741	63.374	0.137	0.367	2.018	0.421	71.442	81.685	60.741	63.374
	10	25.422	13.462	26.593	31.479	71.34	81.684	60.735	63.359	0.15	0.367	2.021	0.423	71.34	81.684	60.735	63.359
	15	25.422	13.462	26.593	31.479	71.34	81.684	60.735	63.359	0.15	0.367	2.021	0.423	71.34	81.684	60.735	63.359
JP	1	0.978	0.5	1.949	0.808	0.263	0.094	3.017	0.09	98.759	99.406	95.033	99.102	98.759	99.406	95.033	99.102
	5	7.142	13.234	16.257	6.855	0.95	1.125	2.433	0.545	88.122	80.718	72.723	89.546	88.122	80.718	72.723	89.546
	10	7.176	13.234	16.257	6.854	0.962	1.125	2.433	0.551	87.819	80.717	72.72	89.521	87.819	80.717	72.72	89.521
	15	7.166	13.234	16.257	6.854	0.962	1.125	2.433	0.551	87.818	80.717	72.72	89.521	87.818	80.717	72.72	89.521
CH	1	0.045	1.495	0.177	0.383	0.002	0.088	0.001	0.132	0.001	0.176	1.871	0.012	99.952	98.242	97.951	99.473
	5	0.416	1.92	1.602	1.015	0.214	3.123	0.411	0.448	0.172	0.158	1.55	1.171	96.624	93.22	89.136	95.059
	10	0.423	1.92	1.605	1.014	0.251	3.123	0.415	0.448	0.178	0.158	1.55	1.171	96.332	93.217	89.12	95.05
	15	0.424	1.92	1.605	1.014	0.251	3.123	0.415	0.448	0.178	0.158	1.55	1.171	96.33	93.217	89.12	95.05
BR	1	0.993	2.971	3.054	4.116	0.002	0.308	2.454	0.322	0.108	1.603	0.175	0.054	98.896	95.118	94.317	95.508
	5	1.063	3.296	4.378	4.672	0.107	1.187	2.693	1.164	0.366	1.751	0.45	0.306	96.156	92.007	86.777	91.641
	10	1.077	3.296	4.386	4.671	0.112	1.187	2.697	1.164	0.381	1.751	0.45	0.307	96.035	92.007	86.753	91.617
	15	1.077	3.296	4.386	4.671	0.112	1.187	2.697	1.164	0.381	1.751	0.45	0.307	96.035	92.07	86.753	91.617
IN	1	0.124	1.44	0.146	0.18	0.156	0.736	0.242	0.03	0.003	0.246	0.011	0.024	99.717	97.578	99.601	99.767
	5	1.341	3.674	0.494	0.564	0.55	3	0.697	0.274	0.23	1.529	0.62	0.112	95.916	89.14	82.426	95.954
	10	1.391	3.674	0.494	0.565	0.616	3	0.697	0.274	0.253	1.529	0.62	0.112	95.694	89.14	82.425	95.945
	15	1.391	3.674	0.494	0.565	0.616	3	0.697	0.274	0.253	1.529	0.62	0.112	95.692	89.14	82.425	95.945
RU	1	0.357	0.004	0.809	0.463	0.149	0.916	1.329	0.179	0.009	0.3	2.02	0.003	99.485	98.78	95.843	99.354
	5	0.497	0.289	2.113	1.018	0.248	0.799	1.745	0.258	0.06	0.396	2.719	1.187	96.564	94.767	89.659	95.209
	10	0.525	0.289	2.112	1.022	0.333	0.799	1.746	0.264	0.071	0.397	2.72	1.19	96.322	94.765	89.656	95.185
	15	0.525	0.289	2.112	1.022	0.333	0.799	1.746	0.264	0.071	0.397	2.72	1.19	96.321	94.765	89.656	95.185

AU	1	2.718	4.812	0.959	0.603	2.043	0.116	6.068	0.383	1.355	6.873	10.45	0.693	93.884	88.199	82.523	98.321
	5	16.036	18.668	18.64	12.095	2.965	5.191	4.412	1.005	1.65	5.942	7.094	1.981	76.517	63.491	58.666	78.295
	10	15.959	18.667	18.64	12.093	3.025	5.191	4.412	1.005	1.644	5.942	7.094	1.982	76.153	63.488	58.66	78.288
	15	15.959	18.667	18.64	12.093	3.026	5.191	4.412	1.005	1.644	5.942	7.094	1.982	76.152	63.488	58.66	78.288
FR	1	9.244	8.574	10.808	15.214	16.864	36.39	33.737	20.171	0.713	0.006	0.03	0.52	73.178	55.03	55.425	64.095
	5	9.809	13.79	13.93	16.038	16.911	31.625	31.223	20.642	0.93	0.459	2.58	0.586	71.087	47.961	48.905	57.547
	10	9.808	13.79	13.93	16.035	16.899	31.624	31.221	20.637	0.95	0.459	2.582	0.589	70.998	47.96	48.901	57.536
	15	9.808	13.79	13.93.	16.035	16.898	31.624	31.221	20.637	0.95	0.459	2.582	0.589	70.998	47.96	48.901	57.536
GE	1	13.833	11.232	15.986	29.245	23.103	38.918	34.349	35.018	0.357	0.009	0.198	0.318	62.707	49.841	49.468	35.418
	5	13.433	18.364	19.16	28.101	21.69	33.101	30.312	33.246	0.5	0.684	0.919	0.393	60.864	43.189	41.782	35.878
	10	13.404	18.364	19.158	28.096	21.578	33.101	30.31	33.239	0.518	0.684	0.921	0.395	60.74	43.189	41.776	35.87
	15	13.404	18.364	19.158	28.096	21.576	33.101	30.31	33.239	0.518	0.684	0.921	0.395	60.74	43.189	41.776	35.87

Source: Author's Calculations

Table 4-19 Short-Term and Long-Term QE Shocks on Global Bond Yields

Market	Domestic	US	UK	Japan	QE1	QE2	QE3	QEL1	QEL2	QEL3	Lag	θ_1	θ_2
CH	-0.013	0.073***	-0.064***	0.016	1.366	1.325	0.877	-0.034*	0.018	-0.006	-0.218***	0.009***	0.956***
BR	-0.172***	-0.046	-0.125***	0.005	3.397**	-14.316**	-3.404	-0.094***	-0.268***	-0.179***	-0.026	0.007**	0.965***
IN	-0.054***	-0.002	0.006	0.029***	-0.669	-0.869	-2.246	-0.007	0.001	0.003	0.076***	0.012	0.909***
RU	-0.032***	-0.036*	-0.074***	-0.074***	15.372***	18.365***	27.65***	-0.029	0.042**	-0.003	-0.203***	0.006**	0.975***
AU	0.031*	0.055**	0.086***	0.279***	-1.924	-1.206	4.119	-0.04**	-0.02	-0.11***	-0.171***	0.014***	0.92***
FR	0.116***	0.11***	0.171***	-0.022	-0.832	3.857	-2.497	-0.084***	-0.085***	-0.214***	0.032	0.01***	0.983***
GE	0.275***	0.115***	0.189***	-0.013	-1.024	3	5.318	-0.108***	-0.115***	-0.354***	0.003	0.012***	0.965***
US	0.669***	0.669***	0.108***	-0.006	-1.978**	-2.138	-10.657	-0.282***	-0.293***	-0.353***	-0.042*	0.008**	0.978***
UK	0.326***	0.15***	0.326***	0.02	-1.06	5.308	2.447	-0.107***	-0.106***	-0.268***	-0.031	0.008**	0.978***
JP	0.444***	-0.011	0.037	0.444***	0.405	18.689**	-27.021***	0.006	0.041	-0.06*	-0.04*	0.008**	0.978***

Source: Author's Calculations

***, ** and * represent significant values at 1%, 5% and 10% levels, respectively

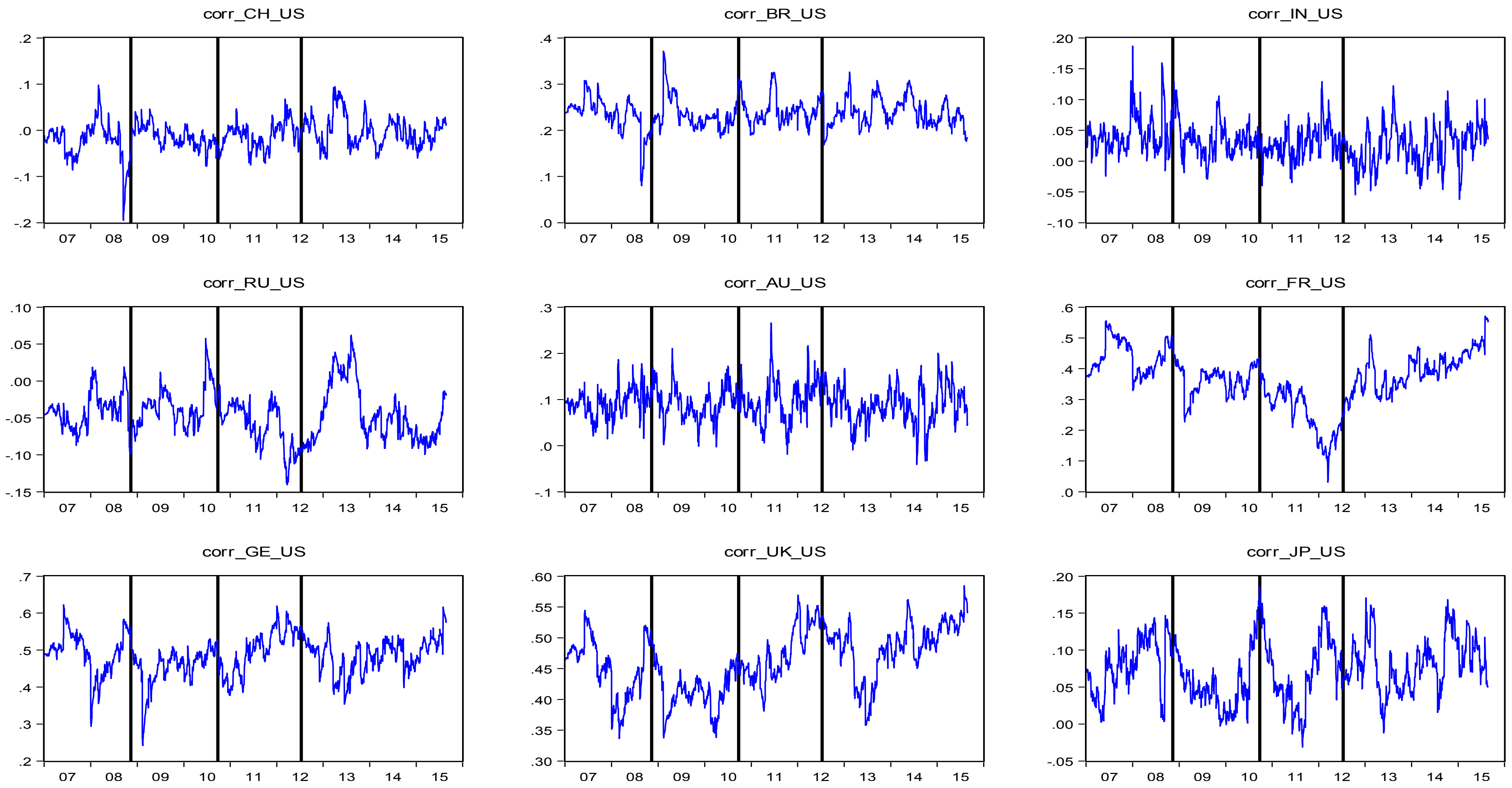

Figure 4-15 Dynamic Conditional Correlation among Markets with Short-and Long-Term QE Shocks (DCC-GARCH)

Source: Author’s Calculations

Table 4-20 Short- and Long-Term QE Shocks on Global Bond Yield Volatility

Market	ARCH	GARCH	Leverage	Domestic	US	UK	Japan	QE1	QE2	QE3	QEL1	QEL2	QEL3	θ_1	θ_2
CH	0.102***	0.582***	0.021	-0.007	-0.24***	-0.031	-0.022	-0.448	-8.464	-3.649	0.028**	0.034	-0.021	0.039***	0.729***
BR	0.161***	0.471***	0.07*	-0.035	0.081	-0.239***	0.038	7.701***	-6.523	-18.591*	0.1***	0.125***	-0.081***	0.008**	0.985***
IN	0.121***	0.577***	-0.016	-0.024***	-0.028*	-0.012	-0.024***	2.53***	-6.795***	13.708***	0.009	0.017	-0.027***	0.039***	0.62***
RU	0.152***	0.568***	0.034	0.202***	-1.554***	-0.034	-0.187***	1.524	-75.336***	-117.74***	0.264***	0.202***	-0.298***	0.027**	0.451
AU	0.263***	0.451***	-0.084**	0.001	-0.015	-0.036	-0.056***	0.389	-7.558***	0.844	-0.007	0.049***	-0.028***	0.043***	0.693***
FR	0.018***	0.95***	0.065***	-0.016	-0.024*	-0.001	0.022***	0.05	-0.526	3.664***	0.001	0.006	0.001	0.014***	0.981***
GE	0.185***	0.699***	0.295***	-0.072***	-0.142***	0.198***	0.026	-3.062***	-9.038***	1.626	0.038***	-0.001	-0.02	0.006***	0.993***
US	0.023***	0.952***	0.039***	-0.136***	-0.136***	0.016	0.05***	-0.019	-2.073	3.838**	-0.002	-8.79E-05	-0.005	0.061***	0.636***
UK	0.306***	0.649***	0.058	0.16***	-0.251***	0.16***	-0.019***	2.563*	-6.984*	0.939	-0.053**	0.021	0.005	0.061***	0.636***
JP	0.116***	0.567***	-0.077**	-0.087	-0.154	-0.109	-0.087	-5.807	-74.804***	115.586***	0.108	0.072	-0.283***	0.061***	0.636***

Source: Author's Calculations

***, ** and * represent significant values at 1%, 5% and 10% levels, respectively

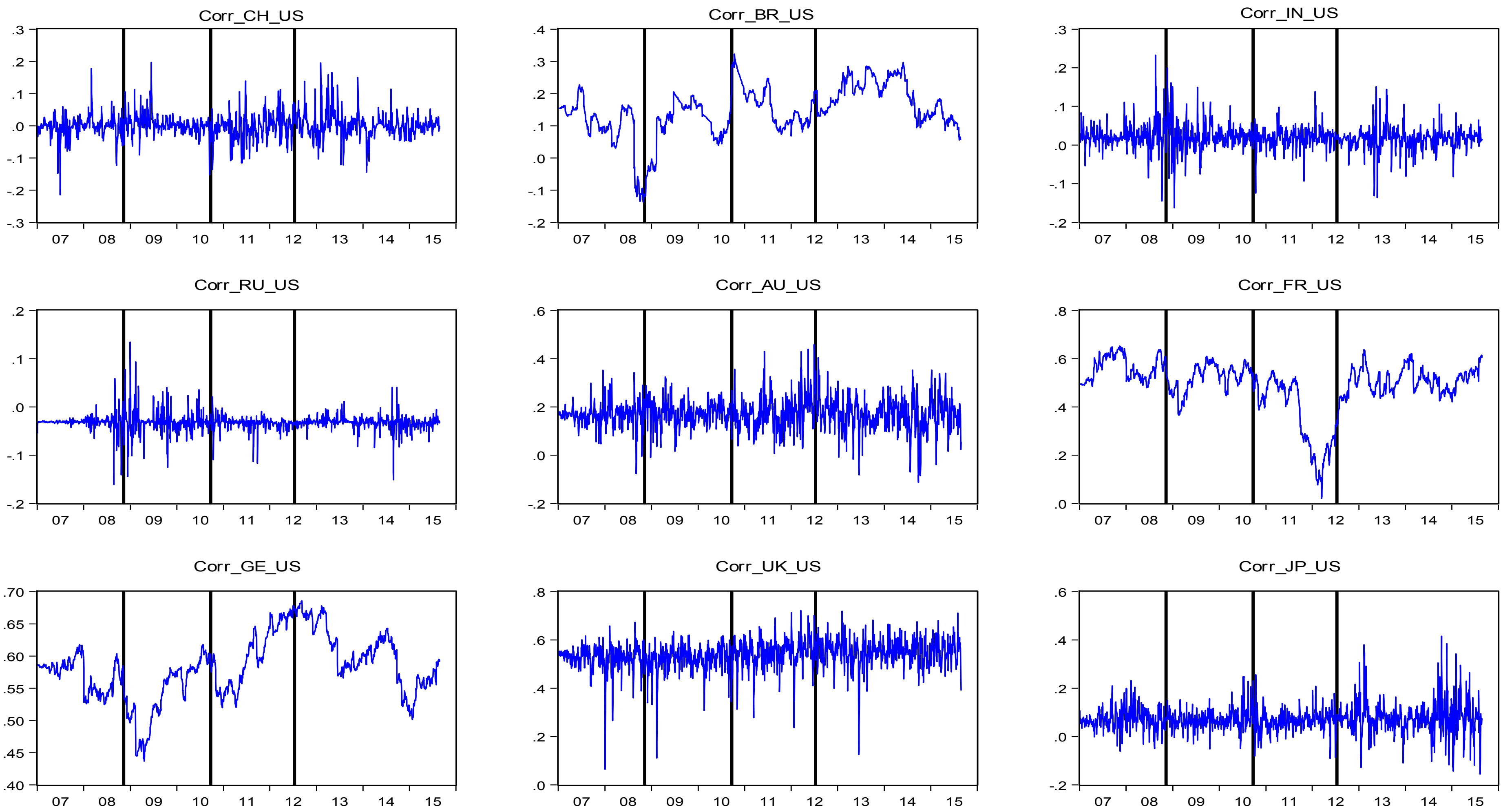

Figure 4-16 Dynamic Conditional Correlation among Markets with Short- and Long-Term QE Shocks (DCC-TGARCH)

Source: Author’s Calculations

4.4 Empirical Results and QE Spillover Effects on Global Bond Yields

This section describes the regression results calculated using the Dynamic Conditional Correlation (DCC)-MGARCH model. The model enable researchers to investigate how the U.S. QE spillover effects influence both the bond yields and volatilities on long-term bond markets globally. In order to measure the spillover effects of different U.S. QE policies on global bond yields (see research objective 2), I incorporated the DCC-MGARCH (1, 1) models with both short-term and long-term U.S. QE policy shocks. Table 4.19 reports both the short- and long-term U.S. QE policy shocks that measure the U.S. QE spillover effects on global bond yields. Figure 4.15 depicts the dynamic conditional correlation plots between the U.S. bond market and global bond markets, with both the short- and long-term U.S. QE policy shocks.

4.4.1 Effects of Domestic and International Economic Factors on Bond Yields

Before estimating the U.S. QE spillover effects on global bond markets, I first provide a control for changes in both the domestic and international economic environment and their impact on global bond yields. Column 1 in Table 4.19 shows the impact of the changes in domestic economic environments on global bond yields, calculated using daily domestic stock returns from each market. A significant and positive coefficient for this column means that the bond yield will increase when domestic economic environments improve; in short, domestic economic prosperity increases bond yields. While, a significant and negative coefficient in column 1 means changes in domestic economic environments will have a negative impact on bond yields. More specifically, bond yields will increase when the domestic economy is in recession. As Table 4.19 shows, changes in domestic economic environments have a significant and positive impact on bond yields in developed markets; conversely, in most emerging markets (with the exception of China), changes in domestic economic environments have a significant, but negative, impact on bond yields. One possible explanation for positive coefficients in developed market is that bad economic environments push investors towards safer investments. Therefore, when the economy is depressed, as it was during the 2007 subprime loan crisis, market participants tend to invest in less risky securities such as government bonds. Moreover, central banks such as the Federal reserves launched large-asset purchasing programs during that period, causing the demand for government bond such as Treasury to rapidly increase. This rapid increase in the ten-year bond demand led to a dramatic increase in the bond price and a decrease in bond yields. However, sluggish economic environments can also reduce investors' future expectations about inflation, which leads to a drop in bond yields. During the sample period (around the 2007 subprime loan crisis), most emerging markets had better economic growth than their developed counterparts; in short, emerging bond markets attracted investment interest from developed markets and bond prices increased while bond yields subsequently decreased.

Column 2, 3 and 4 in Table 4.19 report coefficients for changing conditions of leading economies (the U.S., the U.K. and Japan) on bond yields, respectively. As with changes in domestic economic environments, stock return data is used to represent the changes in the economic environments of the three leading economies (the U.S., the U.K. and Japan). I selected data from these countries because they are the leading economies in the word. Additionally, these three economies launched quantitative easing policies after the 2008 global financial crisis. This enlarges the potential spillover effects from these economies into global markets. According to Table 4.19 (Column 2), the changes in U.S. economic environments were positive significant impact upon most ten-year bond yields, especially in advanced markets. This indicates that economic prosperity in the U.S. can lead to an increase in most developed bond yields. Meanwhile, unlike the impact on developed bond markets, changes in the U.S. economic environment had negative effects on most emerging bond markets, with the exception of China. The impact was much smaller than the impact on advanced markets and most of the results were statistically insignificant. This fact suggests that for most emerging markets, bond yields tend to be less affected by changes in the U.S. economic environment.

The impact from U.K. stock returns on global bond yields is similar with the U.S. Column 3 in Table 4.19 shows a significant and positive impact on all advanced bond yields due to changes in the U.K. economic environments. Unlike the U.S., the changes in the U.K. economic environment significantly lowered long-term bond yields in most emerging markets (except for India). This suggests that when the U.K. economy is in recession, investors tend to invest in emerging bond markets. Similarly, changes in the Japanese economic environment has a significant and positive impact on global bond yields. However, compared to the impact from the U.S. and U.K. economies, changes in the Japanese economic environment had less notable impact on developed bond yields. This finding is consistent with the empirical results, discussed in section 4.2, which demonstrate that there is a lack of market integration between Japanese and other bond markets as compared with the U.S. and U.K.

Meanwhile, the impact of domestic and international economic changes on bond yields are different. Most long-term bond yields were affected more by the changes in the domestic economic environments (including the U.S., the U.K. and Japan) than the spillover effects from the changes in economic environments in other markets. The changes in international economic environments played a less significant role on bond yield changes, than domestic economic changes. When comparing the impact triggered by the changes in the economic environments of the U.S., U.K. and Japan, it seems changes in the U.S. economy have less impact on global bond yields than the U.K. This is because the changes triggered by the U.S. QE policies shocks are examined individually in this study, rather than overall changes in the economy, which reduces the spillover effects caused by changes to the U.S. economy. In other words, the changes in the U.K. and Japanese economies also include part of the QE shocks from these two countries.

Apart from the impact of changes in economic environments domestically and externally, there is also the dynamic impact of bond yield changes. The dynamic coefficients in Table 4.19 (column 11) show that in most markets, the bond yield from last period has a significant impact on the current period. This suggests that for most long-term bond markets, the current bond yield changes are significantly affected by previous yield changes and there is a significant dynamic relationship in bond markets.

4.4.2 The U.S. QE Spillover Effects on Global Bond Yields

Besides changes to domestic and international economic environments and the dynamic effects of bond yields discussed in Section 4.4.1, the U.S. QE spillover effects on global bond yields are also included. In order to assess the potential U.S. QE policy shocks, from both short- and long-term perspectives, in this study, I examined both the short- and long-term U.S. QE policy shocks defined in section 3.3. Specifically, Table 4.19 shows the spillover effects of both the short-term U.S. QE (column 5, 6 and 7) and long-term U.S. QE policy shocks (column 8, 9 and 10) on global bond yields.

In terms of the short-term U.S. QE policy shock, as suggested by some previous studies, these had limited significant spillover effects on most bond markets (with the exception of Russia). As has been argued in to previous literature, during the U.S. QE periods, the short-term interest rate is limited to zero lower bound and cannot drop any further; therefore, the monetary policy of keeping lower future short-term interest rates ceases to be effective. Table 4.19 also shows that the short-term U.S. QE policy shocks significantly lowered the U.S. domestic government bond yields in the early phase of the U.S. QE period (the U.S. QE1 period). In contrast, for Russia bond yields, the short-term U.S. QE policy shocks significantly raised bond yields throughout all three U.S. QE periods. Moreover, though the short-term U.S. QE spillover effects on most developed bond markets were insignificant, they lowered bond yields in most developed markets during U.S. QE1 and QE3 periods. In terms of bond yields in emerging markets, there is no common response to the U.S. QE spillover effects.

Unlike the short-term U.S. QE spillover effects, which only affected limited bond yields, the long-term U.S. QE policy shocks have pronounced spillover effects on most bond yields, especially in developed markets. According to Table 4.19 (column 8, 9 and 10), the long-term U.S. QE policy shocks significantly lowered bond yields in most developed markets throughout all three U.S. QE periods (with the exception of Japan). In emerging markets, bond yields significantly dropped in respond to the long-term U.S. QE policy shocks, although this was limited to certain emerging markets like Brazil. This indicates that the U.S. QE policy shocks (through continuous long-term assets purchase programs), had persistent spillover effects such as lowering most long-term bond yields.

The persistent negative spillover effects on most developed bond yields during all three U.S. QE periods can also explain capital flows in global bond markets during the U.S. QE periods. Based on previous studies, the U.S. QE policies affected financial assets through the portfolio rebalancing channel. Through this channel, the purchase of long-term U.S. domestic assets, especially the long-term U.S. government bonds, resulted in changes to the supply and demand of certain financial assets (which related to long-term U.S. securities) in global financial markets. In particular, since the Federal Reserves absorbed large scale, long-term U.S. Treasuries after the 2008 financial crisis, the supply of long-term U.S. Treasuries reduced. In order to rebalance their investment portfolios, market participants had to purchase assets which were close substitutes for long-term U.S. Treasuries. Therefore, the wide-spread spillover effects of the U.S. QE policy shocks on developed markets also meant that, market participants' chose securities with similar maturities to the long-term U.S. assets, in developed markets, as a substitute to rebalance their investment portfolios in global financial markets. The negative long-term U.S. QE spillover effects on developed markets can be explained in the following manner: the long-term U.S. Treasury purchase policies (the U.S. QE policies) which continuously reduced the amount of long-term U.S. securities on the market. This practice led to an increased demand for long-term securities in other developed markets, which in turn decreased most developed bond yields. Hence, a pronounced amount of capital flowed from the U.S. bond market flows into developed bond markets throughout all three U.S. QE periods. At the same time, only limited capital flowed into emerging bond markets, since there were less significant spillover effects from the U.S. QE policies on emerging bond yields.

In terms of the magnitude of the long-term U.S. QE spillover effects on global bond yields, the largest effects created by the U.S. QE policy shocks were on the U.S. Treasury yields in general. The magnitude of the long-term U.S. QE spillover effects on developed bond markets were generally larger than the ones on emerging bond markets (with the exception of Brazil). Moreover, when comparing different U.S. QE policies on developed bond yields, the spillover effects from the U.S. QE3 policies are generally more significant than the ones from previous U.S. QE policies.

4.4.3 Dynamic Correlations (Modelling Spillover Effects on Bond Yields)

The time-varying conditional correlation coefficients reported in Table 4.19 (column 12, 13) were significant for most of markets, with the exception of India. Meanwhile, the sum of these two dynamic conditional correlation coefficients for each market have a total value of less than one, which suggests all of the dynamic correlation series are stationary. Since in this study, the interaction from three leading bond markets (the U.S., the U.K. and Japan) are also included in the model, the dynamic correlation coefficients in Table 4.19 and 4.20 are the correlation coefficients not just between the U.S. and other bond markets, but also the correlations between each bond market and the three leading bond markets. Hence, the coefficients for each bond market suggest that after the 2008 global financial crisis, there was a significant dynamic and time-varying correlation between global bond markets and leading bond markets[13]. In other words, the policy shocks generated from these three leading markets spread to all of the sample markets. Moreover, the plots of the dynamic conditional correlation among global bond markets with both short- and long-term U.S. QE policy shocks are also displayed in Figure 4.15[14]. The dynamic correlation plots reveal the relationship between each bond market and the U.S. bond market.

In Figure 4.15, the three vertical bars in each figure represent the initial announcement date of each U.S. QE policy. Generally, the correlations between the U.S. bond market and emerging markets are weaker (no more than 0.5) compared to developed markets; sometimes the emerging bond markets are negatively correlated with the U.S. bond markets (less than 0). This indicates that the emerging bond yields are weakly correlated with the U.S. bond market; therefore the U.S. QE policy shocks tended to have a lesser impact on emerging markets than developed markets. Moreover, most of the developed bond markets have a positive correlation with the U.S. bond market (except for Australia and Japan). This suggests that developed bond yields change in the same direction as the U.S. bond yields. The positive correlation between the U.S. bond market and other developed bond markets implies that as the U.S. bond yield drops, other developed bond yields drop as well. This phenomenon indicates that developed bond markets are affected more by the U.S. QE policy shocks compared to emerging bond markets. In terms of the magnitude of the correlation, the dynamic correlations between emerging bond markets and the U.S. bond market fluctuated within a narrow range during the U.S. QE periods. In terms of developed bond markets, the dynamic correlations with the U.S. tended had a wider range of change than emerging markets. Increasing volatile correlations with the U.S. market suggests that developed bond markets were more affected the U.S. QE policy shocks. When considering each individual U.S. QE policy in relation to various bond markets, correlations with the U.S. bond market tended to decline right after each initial U.S. QE announcement, and then the dynamic correlations gradually increased to around the same with the pre-announcement level for most bond markets. This can be attributed to the spillover effects of the initial U.S. QE policy shocks on global bond markets. The return to pre-announcement levels of time-varying correlation movements with the U.S. bond market can be considered a result of a reduction of spillover effects of the initial U.S. QE policy shock.

[13] In this case, the coefficients calculated for the U.S., the U.K. and Japan are the same, since the coefficients all report the dynamic correlations among these three bond markets.

[14] In the interest of brevity, only the dynamic conditional correlation between the U.S. market and other markets are reported in this study.

4.5 Empirical Results and QE Spillover Effects on Global Bond Volatilities

This section presents the U.S. QE volatility spillover effect on global bond markets (see research objective 3). In order to measure the U.S. QE spillover effects on global bond yield volatilities, I use the DCC-TGARCH model to examine the U.S. QE volatility spillover effects. The model also includes control variables such as changes to domestic economic environments and changes to the U.S., U.K. and Japan's economic environments. Furthermore, the TGARCH model tests for asymmetric terms in the variance equation, which examines the potential leverage effects on global bond yield volatilities. As with the U.S. QE policy spillover effects on global bond yields, both the short- and long-term U.S. QE policy shocks are jointly included. Table 4.20 shows the results of both the short-and long-term U.S. QE policy spillover effects on the bond yield volatilities. More specifically, column 1 in Table 4.20 reports the ARCH term, which measures the impact of short-term shock on bond volatility. Similarly, column 2 in Table 4.20 shows the coefficient of the GARCH term that measures the impact of persistent long-term shocks. Column 3 reports the asymmetric terms, calculated using the TGARCH model, to examine the potential leverage effects of bond volatilities. Column 4 represents the impact of changes in domestic economic environments on bond yield volatilities. Columns 5, 6, and 7 report the impact of changes in the U.S., U.K and Japanese economic environments on global bond yield volatilities. Columns 8, 9, and 10 in Table 4.20 report the volatility spillover effects from short-term U.S. QE policy shocks while columns 11, 12 and 13 report volatility spillover effects from long-term U.S. QE policy shocks. The last two columns in Table 4.20 report the time-varying conditional correlation coefficients between global bond market and the three leading bond markets. The dynamic conditional correlation plots between the U.S. and global bond markets incorporated with both short-and long-term U.S. QE policy shocks are depicted in Figure 4.16.

4.5.1 ARCH, GARCH and Asymmetric Terms on Global Bond Yield Volatilities

The ARCH and GARCH coefficients in Table 4.20 are significant at 1% levels, which indicate that all of the long-term bond volatilities are influenced by previous short-term shocks as well as long-term shocks. Moreover, the GARCH term coefficients are far higher than the ARCH term coefficients. This indicates that in long-term bond markets, the long-term volatility impact is more persistent than the short-term. These significant coefficients for both ARCH and GARCH terms provide evidence for the volatility clustering phenomena of the bond yield data.

The coefficients of asymmetric terms vary between emerging and developed market (see Table 4.20). In most emerging bond markets, asymmetric terms are insignificant. This indicates that for emerging bond yield volatilities, there is no significant leverage effects. More specifically, the emerging bond yield volatilities show no difference in relation to either good or bad news. In short, bad news did not trigger more bond volatility than good news in most emerging bond markets. However, the developed bond yield volatilities show significant leverage effects towards different policy news. Moreover, the pronounced leverage effects on developed bond yield volatilities are mostly positive. This positive leverage effect on developed bond yield volatilities means that negative residuals tended to increase the conditional volatility more than positive shocks. In other words, developed bond yields were more volatile when faced with bad news than good news.

4.5.2 Effects of Domestic and International Economic Factors on Bond Yield Volatilities

Changes to domestic economic environments greatly affect most emerging bond yield volatilities; however, the same is not true for developed bond yield volatilities (see Table 4.20). This indicates that for most emerging bond markets, bond yield volatilities are subject to changes in the domestic economic environment. However, for most developed bond markets, changes in domestic economic environments have no significant effects on bond yield volatility, with the exception of the U.S. The negative and significant impact of the U.S. domestic economic changes indicate that when the U.S. economy is in recession, the U.S. bond yield volatility tends to increase. This is particularly true in the case of the subprime loan crisis which erupted in 2007. The U.S. economy fell into a recession and the Federal Reserve launched the QE policies, which significantly pushed down long-term bond yields and increased market volatility.

Most bond yield volatilities were significantly influenced by changes in the U.S. and Japanese economies, while in the U.K., a limited number of bond yield volatilities were significantly affected. In particular, changes in the U.S. economic environment had a negative impact upon global bond yield volatilities. This indicates that when the U.S. economy is in recession, bond yield volatilities will increase. This can be attributed to the U.S. QE policies, since the Federal Reserves launched large scale assets purchase policies, which reduced the supply of the U.S. long-term assets and thereafter, pushed private investors to purchase other securities or assets in other markets. This, in turn, which increased global market liquidity levels as well as volatility levels.

4.5.3 Volatility Spillover Effects of the U.S. QE Policies on Global Bond Yields

Bond yield volatilities across markets have different responses towards the U.S. QE policy shocks during different U.S. QE phases. Generally, most emerging bond volatilities were significantly affected by both the short- and long-term U.S. QE policy shocks. However, for developed bond yield volatilities, the volatility spillover effects from the U.S. QE policies, especially long-term U.S. QE policy shocks were less significant.

In terms of the short-term U.S. QE policy shocks, they increased bond yield volatilities in most emerging markets in the early U.S. QE period (the U.S. QE1 period), though some changes were insignificant (see Russia). During later U.S. QE phases, the short-term U.S. QE policy shocks continuously reduced bond yield volatilities in most emerging markets. The only exception was China; although the short-term U.S. QE policy shocks lowered the Chinese bond yield volatilities during all three U.S. QE periods, the spillover effects are insignificant. In terms of for bond yield volatilities, there were only a few developed markets influenced by the short-term U.S. QE policy shocks (see Table 4.20). The increase in emerging bond volatilities can be explained by the U.S. QE spillover effects through the liquidity channel. During this period, major economies suffered from severe economic recession. Most central banks injected massive liquidity to stimulate their economies; the rapid increase in liquidity generated market uncertainty. Investors tended to purchase assets with lower risk, such as government bonds. Increasing levels of market liquidity level and the need for safer assets jointly contributed to growing demand for government bonds. The increase in demand for government bonds bought more uncertainty and increased volatility levels in government bond markets. In other words, the U.S. QE policies increased the global systematic risks (Yang & Zhou, 2016).

Since emerging markets are less developed than advanced markets, they are more vulnerable to systematic risk. Emerging bond yield volatilities were thus more volatile during the U.S. QE periods. During the later U.S. QE phases (the U.S. QE2 and QE3 periods), especially the U.S. QE3 period, bond yield volatilities in most emerging markets tended to decline. The decrease in emerging bond volatilities during the U.S. QE3 period may due to the announcement of exiting QE policies by the Federal Reserves (Ghosh and Saggar, 2016). This was an unpredicted shock for market participants, which suggested that the U.S. QE policies were no longer effective and there would be no more QE policies after the U.S. QE3 period. This signalled the reduction of market liquidity at a global level. Reduced liquidity levels in the market led to a decline bond yield volatilities. Less pronounced short-term U.S. QE spillover effects on developed bond yield volatilities can be attributed to the adaptability of developed markets. Developed markets were less affected by to external shocks than emerging markets.

The long-term U.S. QE policy shocks also had pronounced spillover effects on bond yield volatilities in most emerging markets (across all three U.S. QE periods). This was not the case for most developed markets. Like the short-term U.S. QE policy shocks, the long-term U.S. QE policy shocks also increased emerging bond yield volatilities in the U.S. QE1 phase and decreased them in the U.S. QE3 period. The explanation for these volatility spillover effects induced by the long-term U.S. QE policy shocks are the same as the short-term ones.

Overall, the results for both short- and long-term U.S. QE policy spillover effects on global bond yield volatilities suggest that bond yield volatilities in developed markets were less likely to be affected by the U.S. QE policy shocks (either short- or long-term). In terms of bond yield volatilities in most emerging markets, the introduction of the U.S. QE policies significantly increased volatility levels in emerging bond markets. This increase in emerging bond volatility level can be explained by the nature of emerging markets, which are less developed, and increased liquidity levels resulting from the implementation of the U.S. QE1 policy. The significant reduction in emerging bond volatility during the U.S. QE3 policy phase can be attributed to the exit announcement, which represented the gradual reduction of asset purchases and signalled a decrease in global liquidity levels[15]. All these signals lead to a decrease in emerging bond volatility. However, when compared to developed bond volatilities, emerging bond volatilities were more vulnerable to the U.S. QE policy shocks since most emerging bond yield volatilities are significantly influenced by both short- and long-term U.S. QE policy shocks. This indicates that emerging markets are less able to protect themselves from external shocks.

4.5.4 Dynamic Correlations (Modelling Spillover Effects on Bond Yield Volatilities)

Similar to the dynamic conditional correlation coefficients estimated in section (4.3), most of the coefficients are positive and significant (see the last two columns in Table 4.20). Furthermore, the sum of the two coefficients for all markets are less than one, which indicates that there is a stationary and significant dynamic correlation between each bond market and the three leading bond markets. Moreover, since the sum of the two coefficients are less than one, this time-varying conditional correlations are mean reverting. Figure 4.16 shows the DCC coefficient plots of the U.S. market and global bond markets, with both the short-and long-term U.S. QE policy shocks included in the variance equations. The three vertical bars represent the announcements date of each of the U.S. QE policies. Unlike the DCC plots in Figure 4.15, which were generated using different U.S. QE policy shocks in the DCC-GARCH model, the DCC plots in Figure 4.16 were estimated with the U.S. QE policy shocks included in the variance equation of the DCC-TGARCH models. Most of the dynamic conditions correlations are persistent during this period (2007 to 2016), with no clear upward or downward trends. Only the dynamic conditional correlations between the U.S. market and the French and German bond market decline after the U.S. QE policy announcements. The dynamic correlation between the U.S. market and Brazilian bond market is another exception in which the correlation increases when faced with the U.S. QE policy announcements. Although there is no clear trend for the dynamic conditional correlations between the U.S. bond market and other bond markets , when the different U.S. QE policy are announced, most of the dynamic correlations were more volatile than before the U.S. QE announcements. Developed bond markets tended to have higher dynamic correlations with the U.S. bond markets than emerging markets. This is consistent

[15] In this study, the announcement of tapering talk of the U.S. QE policy are included in the U.S. QE3 policy.

with the results of unconditional correlation reported in section (4.1.1) (see Tables 4.6 to 4.9). Similar to the dynamic conditional correlation discussed in section (4.3.3), the high correlation between the U.S. market and other developed bond markets suggests that these markets are affected more by policy shocks from the U.S. market. This means that developed bond markets are more integrated the U.S. bond market (this is demonstrated in the SVAR results in section 4.3).

In terms of the emerging bond markets, most of the dynamic correlation with the U.S. bond market is lower than developed bond markets. On the one hand, this lower correlations with the U.S. market hand indicates that emerging bond markets are less affected by the U.S. QE policy shocks, which means the markets are more segmented. On the other hand, the low or even negative dynamic correlations with the U.S. bond market indicates that emerging bond yields are less likely to move along with U.S. bond yields, which provides potential diversification benefits for investors when compared with developed bond yields.

4.6 Summary

This chapter reports the empirical results of the U.S. QE impact on the global bond markets. Based on the SVAR results, the global bond markets are increasingly integrated with the U.S. bond market during each U.S. QE phase. This increasing integration level among global bond markets indicates the strong spillover effects from the U.S. QE policy shocks. In terms of the U.S. QE spillover effects on the global bond yields, the long-term U.S. QE policy shocks significantly lower the bond yields in most developed markets across different U.S. QE periods. While for short-term U.S. QE policy shocks and the U.S. QE spillover effects on bond yields in emerging markets, there is little evidence of pronounced impact. When considering the U.S. QE spillover effects on bond yield volatilities, most emerging markets show pronounced effects while not for the developed markets. In specific, the long-term U.S. QE policy shocks tend to increase the volatility level in emerging markets at the early phase of U.S. QE policy. Later when the Fed exited their QE policies, bond yield volatilities in most emerging markets tend to decline in response. Next chapter will conclude the entire thesis. There are also some practical suggestions for both policy makers and market participants.

Chapter 5

Conclusion

5.1 Introduction

Having discussed the research results in the previous chapter, this chapter concludes the thesis. This chapter first summarizes the main empirical findings against each of the research objectives and then presents the practical implications for policy makers as well as market participants. This chapter also includes the contributions and the limitations of this study. This chapter then ends with recommendations for future studies.

5.2 Summary of the Empirical Findings

5.2.1 Research Objective One

The first objective of this research was to test integration levels among the global bond markets over the three U.S. QE periods. When faced with a shock (either external or internal), the market is forced to respond. In terms of this study, bond yields are affected by both internal and external (also known as domestic and international) shocks. Changes to bond yields can last for a short period or significantly longer. The quicker the speed of adjustment of bond yields or returns to pre-shock levels, the higher the market integration level. Higher integration levels between specific markets, means that those markets have higher levels of convergence and unexpected changes in one market can spillover in the others. This is less likely in those which have lower levels of integration.

This study has shown that there were significant contemporaneous effects from U.S. bond markets on global bond yields during the U.S. QE1 period. In terms of the later U.S. QE periods (the U.S. QE2 and QE3 period), the contemporaneous effect was less significant; however, when compared with effects caused by the British and Japanese markets on global bond yields, the U. S. effects were larger. The U.S. central position in global markets, means that any announcements (including the U.S. QE policy shocks) almost immediate affect bond yields.

In this study, market integration levels were assessed using both the impulse response function and forecasted variance decomposition analysis generated within the SVAR framework. The impulse response results showed that overall, global bond yields had shorter adjustment periods following the U.S. bond shocks during all three U.S. QE periods than the responses during the entire sample period (2007 to 2016). This result means that global bond markets were more integrated with U.S. bond markets during the U.S. QE periods than other period (the entire sample period). Additionally, the speed of adjustment for bond yields in developed economies were much shorter than those from emerging economies. Moreover, when considering the response to external shocks (the U.S., U.K. and Japan bond shocks), most bond yields spent less time digesting U.S. bond shocks than the British and Japanese shocks. These results indicate that, the majority of bond markets are more integrated with U.S. bond markets than with the British and Japanese markets

In particular, this study found that developed bond markets are more integrated with the U.S. bond market compared with emerging bond markets. On the one hand, higher integration levels between global bond markets suggests that bond yields follow U.S. trends and are affected by policy changes. On the other hand, higher integration levels indicate that bond yields are correlated with U.S. bond yields. In other words, the U.S. spillover effects on bond yields (developed bond markets) are more significant than on those with lower levels of integration with the US bond market (emerging bond markets). All bond markets were found to be more integrated with the U.S. bond market during the U.S. QE periods than over the entire sample period (2007 to 2016). This indicates that the U.S. QE policies can increase market integration levels for global bond markets. More importantly, this increase in the global bond market integration level in turn enhanced the spillover effects of the U.S. QE policies on the global bond markets.

This study also employed forecast error variance decomposition to assess market integration levels. Variance decomposition analysis was used to quantify the forecast error of each variable which can be explained by other variables. The higher the proportion, the higher the market integration levels are. Although most of the forecast errors are due mainly to domestic shocks, during the U.S. QE periods, external shocks (such as the U.S., U.K. and Japanese bond shocks), can explain more proportion of the forecast errors. This is particularly true when the results are compared with the entire sample period (2007 to 2016). Moreover, the proportion of forecast errors for developed bond yields that can be explained by the U.S. bond shocks, increases during the latter U.S. QE periods (the U.S. QE2 and QE3 periods). When compared with the effects triggered by the U.S., U.K. and Japanese bond shocks, the U.S. bond shocks affected more of the bond yield forecast errors. Like the impulse response results, the variance decomposition results suggest increasing levels of market integration between developed economies during the during the U.S. QE periods. The results also show that the U.S. bond markets are more integrated with global bond markets than the British and Japanese markets. As with the previous results, these findings indicate high levels of convergence between global bond markets and the U.S. one. Therefore it is no surprise that the U.S. QE policy shocks had a significant impact on global bond markets during the U.S. QE periods.

5.2.2 Research Objective Two

Research objective two examined the spillover effects of both short- and long-term U.S. QE policy shocks on global bond yields. The empirical results suggest that the long-term U.S. QE policy shocks persistently lowered long-term bond yields, especially in developed bond markets across all three U.S. QE periods (QE1, QE2 and QE3 periods). In terms of emerging bond yields, long-term U.S. QE policy shocks had less noticeable effects. The persistent significant results of long-term U.S. QE policy shocks revealed that as long as the Feds kept purchasing long-term float securities, investors' global portfolio rebalancing activities will continue. This continuous global portfolio rebalancing activities increased demand and lowered yields (or returns) of securities with similar maturities in other markets. Reductions to developed bond yields also indicates the main direction of global portfolio rebalancing movements; investors looking for substitutes to U.S. long-term securities tended to purchase assets with similar maturities available in other developed markets.

Short-term U.S. QE spillover effects differ from the long-term ones. This study found that short-term U.S. QE policy shocks had limited significant spillover effects on most bond yields. This suggests that U.S. QE policies which signal future short-term interest rates did not significantly affect global bond yields during the U.S. QE periods. This is consistent with previous research (Wright, 2012; Glick & Leduc, 2015) which indicated that short-term U.S. monetary policy shocks would have little impact on financial variables since during periods of liquidity trap, the short-term interest rate cannot be lowered any further and would therefore have little or no impact upon market participants' expectations.

When compared with the short-term U.S. QE policy shocks (announcements about lower future policy rates), the long-term U.S. QE policy shocks, generated by persistent long-term asset purchasing activities, lowered global bond yields (especially developed bond yields) throughout all three U.S. QE phases. The continual lowering of developed long-term bond yields was a result of U.S. QE policy. As long as the Feds keep absorbing domestic long-term securities, market participants will keep their rebalancing their assets and global long-term bond yields, especially long-term bond yields in developed markets will drop in response to U.S. QE policy shocks.

In terms of the short-term U.S. QE policy shocks, the spillover effects on global bond yields were less pronounced. This is due to the reality that short-term policy rates were already very low at the onset of the U.S. QE period. Based on the fact that the developed bond markets were more impacted than emerging ones, it is fair to conclude that global portfolio rebalancing activities mainly occurred within developed markets. More specifically, since the long-term U.S. QE policy shocks significantly reduced bond yields primarily in developed markets, investors tended to substitute securities in developed markets as a way to rebalance their asset portfolios. In terms of emerging bond yields, this study found limited evidence to support significant U.S. QE spillover effects. As noted earlier, emerging bond yields are more vulnerable to internal shocks or are more likely to be affected by domestic financial factors than external ones.

5.2.3 Research Objective Three

In addition to examining the U.S. QE spillover effects on long-term bond yields globally, our study also reports the empirical results of the U.S. QE volatility spillover effects on global bond markets (research objective three). In order to examine the U.S. QE volatility spillover effects on global bond markets, this study applied the DCC-TGARCH model to capture both U.S. QE volatility spillover effects and leverage effects of the policy shocks. The empirical results demonstrate that both short- and long-term U.S. QE policy shocks significantly affected bond yield volatilities, especially in the emerging markets. In contrast, most developed bond yield volatilities (including U.S. bond yield volatilities), the U.S. QE policy shocks had a much more limited impact.

The U.S. QE policy shocks vary within each period. Volatility spillover effects from the short-term U.S. QE policy shocks, significantly increased volatility levels in emerging bond markets during the U.S. QE1 phases, but lowered them in later U.S. QE periods (the U.S. QE 2 and QE3 periods). This finding was hardly surprising given that the U.S. QE policies introduced large-scale assets purchase programs which, in turn, increased liquidity levels in the markets. Increasing liquidity levels increased market uncertainty or market volatility levels. Unlike developed markets, emerging markets are less developed (both in terms of fundamentals and market liquidity levels) and therefore are more vulnerable to external shocks (Chen et al., 2014). Bond volatility levels in most emerging markets significantly increased in response to the U.S. QE1 policy shocks. Later U.S. QE policies, especially the U.S. QE3 policy, which included the “taper talking” period, signalled the Feds intention to exit QE policies and lower market liquidity levels. Bond volatility levels in emerging markets reduced during the U.S. QE3 period. In contrast to some previous studies (Steeley & Matyushkin, 2015; Tan & Kohli 2011), which found significant reductions in equity volatilities as a result of QE policies (both the U.S. and U.K. QE policies), our study found negative but insignificant bond yield volatility changes in most developed markets.

Long-term U.S. QE volatility spillover effects are similar to short-term U.S. QE policy shocks. The long-term U.S. QE policy shocks significantly increased emerging bond yield volatilities during the U.S. QE1 period and lowered emerging bond yield volatilities during the U.S. QE3 period. The explanation are the same as the volatility spillover effects from the short-term U.S. QE policies. The introduction of U.S. QE policies led to uncertainty and hence increasing bond yield volatilities in emerging markets, especially during the U.S. QE1 period.

The end of this unconventional monetary policy (during the U.S. QE3 period) signalled a reduction in global liquidity levels and accounted for the decreasing uncertainty levels in emerging markets. Lower emerging bond volatilities can also be explained by the fact that the U.S QE3 policy shocks were “positive shock”. Policy shocks which increase volatility are seen as “negative shocks,” while those which decrease volatility are “positive shock” (Asai & McAleer, 2011). In short, the U.S. QE3 shocks which led to declining bond yield volatility in emerging bond were largely positive.

In terms of developed bond yield volatilities, most were less affected by U.S. QE policy shocks. As with some previous studies (Chen et al., 2014; Neely, 2015; Park & Um, 2016) we believe that different volatility responses between developed and emerging markets to the U.S. QE policy shocks can be explained by the characteristics of the recipient markets, or financial and economic fundamentals (such as the soundness of banking systems, real GDP growth and exchange rate regimes). Since most emerging markets have weaker banking systems and less developed economic fundamentals compared to the developed markets, they are typically more sensitive to external shocks. Hence, the U.S. QE policy shocks had pronounced volatility spillover effects (both positive and negative) on emerging markets.

Another explanation for the more significant volatility spillover effects in most emerging markets is related to increasing global liquidity levels. As suggested by some studies (Eichengreen & Gupta., 2014; Chen et al., 2014), the liquidity created by the U.S. QE policies increased global liquidity levels and the resulting market uncertainty; thereafter, emerging markets appeared to be more volatile than developed markets. Our results on the dynamic correlations between the U.S. and global bond markets also support this idea. During the U.S. QE periods, there is no evidence of significant growth in the dynamic correlations between the U.S. bond market and the emerging markets; the correlations are still much lower than the ones between the U.S. market and other developed markets. Therefore, the U.S. QE volatility spillover effects on emerging markets cannot pass through increasing market interactions between the U.S. and emerging markets. Hence, the pronounced volatility spillover effects of the U.S. QE policy shocks may be attribute to growing uncertainty levels in global markets.

5.3 Practical Implications for Policy Makers and Market Participants

Based on the empirical results of the three research objectives (discussed in section 5.1), there are several implications for both the policy makers and the market participants. The implications for policy makers are discussed in section 5.2.1 and the implications for market participants are presented in section 5.2.2.

5.3.1 Implications for Policy Makers

Since global bond markets (both developed and emerging markets) are more integrated with the U.S. bond market, U.S. spillover effects to other markets were more pronounced than during non-QE periods. Therefore, policy makers in host markets (markets which were subject to the U.S. QE spillover effects) should strengthen prudential regulations to mitigate future risks. Moreover, also due to the pronounced effects on other markets (either from bond yield or bond volatility perspectives), it is essential to consider external macroeconomic and policy shocks when designing domestic economic policies. More specifically, it is necessary to construct financial stabilization mechanisms to protect from potential negative spillover effects from other markets. Equally, the enhancement of the cross-border policy coordination would also help lower the global systematic risks induced by asymmetric information.

The pronounced U.S. QE spillover effects on emerging bond volatilities (but not bond yields), indicates that bond yield volatilities in emerging markets are more vulnerable to external shocks than those in developed markets. The dynamic correlations between the U.S. bond market and most emerging markets are much lower than the correlations between the U.S. market and other developed markets. These results indicate that the significant volatility spillover effects of the U.S. QE policies on emerging markets may not be transferred through market interactions (since the correlations are very low) but from growing global market liquidity levels. The results also imply that for markets with better economic and financial fundamentals (such as the developed markets), the U.S. QE volatility spillover effects tend to be minimized. In terms of emerging markets, it is necessary to improve both their economic and financial fundamentals and develop their liquidity markets to dampen market volatility triggered by external policy shocks. These would be more effective than distortion-creating implements such as capital controls and foreign exchange interventions.

5.3.2 Suggestions for Market Participants

In addition to policy implications, there are some suggestions for market participants as well. The U.S. QE spillover effects on both bond yield changes and bond yield volatilities can significantly affect investors' portfolio decisions and increase uncertainty in global government bond markets, even for markets which are less affected by the 2008 financial crisis. Australia is one such example, it had a relatively strong economy and good market performance even after the 2008 crisis (Allen et al., 2017). Nevertheless, based on our empirical results, Australian long-term government bond markets were still significantly reduced by the U.S. QE policy shocks. The pronounced U.S. QE spillover effects on global bond markets acts as a reminder for investors to pay special attention, even if they are investing outside the U.S. Brazil is another example. According to the results in this study, the dynamic correlations between the U.S. bond market and the Brazil bond markets are much lower than with other developed markets. This means that the interaction between the Brazilian bond market and U.S. bond market are fairly limited, when compared with developed markets. However, the U.S. QE policy shocks have had pronounced spillover effects on Brazilian bond yield volatilities. This suggests that it is necessary for investors in emerging markets to track policy implementations in leading economies, especially the U.S.

Although government bonds have traditionally been considered as safe investments[16], the U.S. QE spillover effects have increased the stakes for investors. Based on our empirical results, the U.S. QE volatility spillover effects on emerging bond markets increased bond yield volatilities, which increased the risks for bond investors. Hence, it is better for investors to diversify their investment portfolios and buy other assets, such as gold or real estate. Moreover, there is an upward trend in global bond market integration levels (with the U.S. bond market) during the U.S. QE periods. This trend indicates increasing co-movements in global bond markets, which results in decreasing diversification benefits for bond investors. This also supports the decision to invest outside bond markets.

5.4 Contributions of this Study

This study contributes to the extant literature in several aspects. First, most of the previous studies have focused on the U.S. QE impacts on cross financial variables (such as international stock returns and exchange rates) within the same markets. There is limited research on cross-bond markets, especially long-term government bond markets. This study has examined the U.S. QE spillover effects on both bond yields and bond volatilities, both from developed and emerging markets. Since long-term government bonds are not only the main source of government spending, but also one of the most actively traded markets across the world, the results of this study provides essential advice for policy makers and investors who are interested in bond markets.

The majority of studies on the U.S. QE policies have focused primarily on the U.S. QE1 and QE2 periods, with only a few on the entire U.S. QE period. This study has covered a ten year period (2007 to 2016), and not only covers the time period before the 2008 financial crisis, but also includes all three different U.S. QE periods. The empirical results suggest that within each individual U.S. QE period (including the U.S. QE3 period), the U.S. QE spillover effects on global bond markets are different.

Unlike most existing literature which either applies the event study method with intraday data right after the U.S. QE announcements or defines it using VAR models, this study has calculated both short-and-long-term U.S. policy shocks independently to ensure that the impact of the U.S QE policies is measured correctly.

This method is free of data length (compared to the event study method) and can explicitly measure unexpected changes of U.S. QE policies (compared to the shocks calculated in VAR models). The

[16] Short-term government bonds are considered 'safe investments.' Long-term government bonds carry an inflation risk but are still seen as safe investments when compared to company bonds issued in developed markets. Hence, the U.S. QE policy shocks bring additional external risks for government bonds in most emerging markets.

application of the DCC-MGARCH model and control variables in this study also allows for potential interactions across markets, especially potential interactions from the leading markets (the U.S., U.K. and Japan) to be considered. This provides less biased results of the U.S. QE spillover effects than the univariate models.

Another advantage of this study is the application of daily data. It addresses the transient responses to the U.S. QE policy shocks. This transient responses may be obscured when using weekly or monthly data. In terms of different bond markets, the trading hours vary from each other. While compared with intraday data, daily data can better capture simultaneous responses from international bond markets. Hence, I chose daily data which captures the transient U.S. QE policy shocks and also reduces difference in trading hours across markets.

5.5 Limitations of the Study

This study has several limitations. Firstly, I did not separate the "tapering talk" period from the U.S. QE3 period. In this study, the U.S. QE3 period includes the "tapering talk" period, as the announcement of exiting future U.S. QE policies was made within the U.S. QE3 period. Although the "tapering talk" provides important signals to the markets as suggested in some previous studies (Eichengreen & Gupta 2015; Ghosh & Saggar 2016), the Feds was still purchasing long-term U.S. Treasuries, albeit at a slower rate. Hence, I chose not to split the data into two periods.

Another limitation was due to data availability. Although both developed and emerging bond markets were included in our study, there was no sample for frontier markets. The emerging markets examined in this study were BRIC markets. In short, our results may not be generalized to other developing markets.

The study also only used ten-year government bond yield data. I have not included any discussion on government bond yield data with other maturities and I did not include private bonds. Hence, the results are limited to ten-year government bond markets and may not be applied to government bonds with different maturities or to private bonds.

5.6 Suggestions for Future Studies

This study provides some insights for future studies. First, as discussed in section 5.4, future study could divide the U.S. QE3 period into two; the "tapering talk" period and the remainder of the U.S. QE3 period. It may provide more explicit results relating to the U.S. unconventional monetary policy spillover effects on global markets. Also, the method of defining U.S. QE policy shocks could be applied to measure the unconventional monetary policy shocks in other leading economies such as the U.K. and Japan. It may help to better capture the spillover effects of the British and Japanese unconventional monetary policy shocks on other markets. Further study could also extend the scope of this study to address the U.S. QE spillover effects on other markets. For example, the method could be applied to other developing markets which are also less likely to be correlated with the U.S. bond market (such as the frontier markets), since the results of this study suggest that the U.S. QE policy shocks can affect markets which have limited levels of correlation and integration with the U.S. market.

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